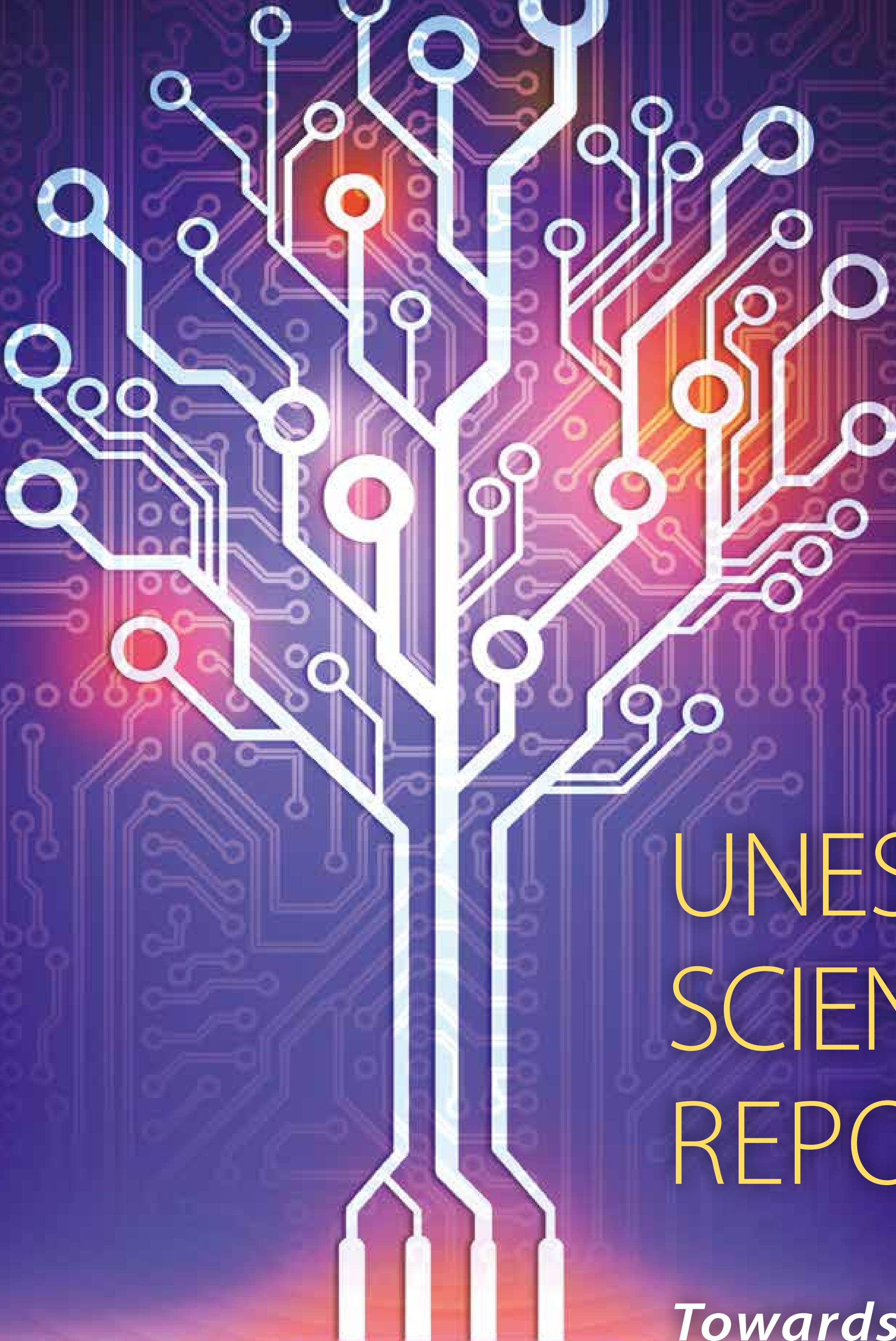

UNESCO SCIENCE REPORT

Towards 2030

UNESCO
United Nations
Educational, Scientific and
Cultural Organization

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Towards 2030

Published in 2015 by the United Nations Educational,
Scientific and Cultural Organization
7, place de Fontenoy, 75352 Paris 07 SP, France

Revised edition 2016

ISBN 978-92-3-100129-1

Original title: *UNESCO Science Report: towards 2030*

Design, typeset, data visualization and pre-press production:
Baseline Arts Ltd, Oxford, United Kingdom

Cover design: Corinne Hayworth
Cover photo: © Bygermina/Shutterstock.com

Printed in Luxembourg by Imprimerie Centrale

UNESCO
Publishing

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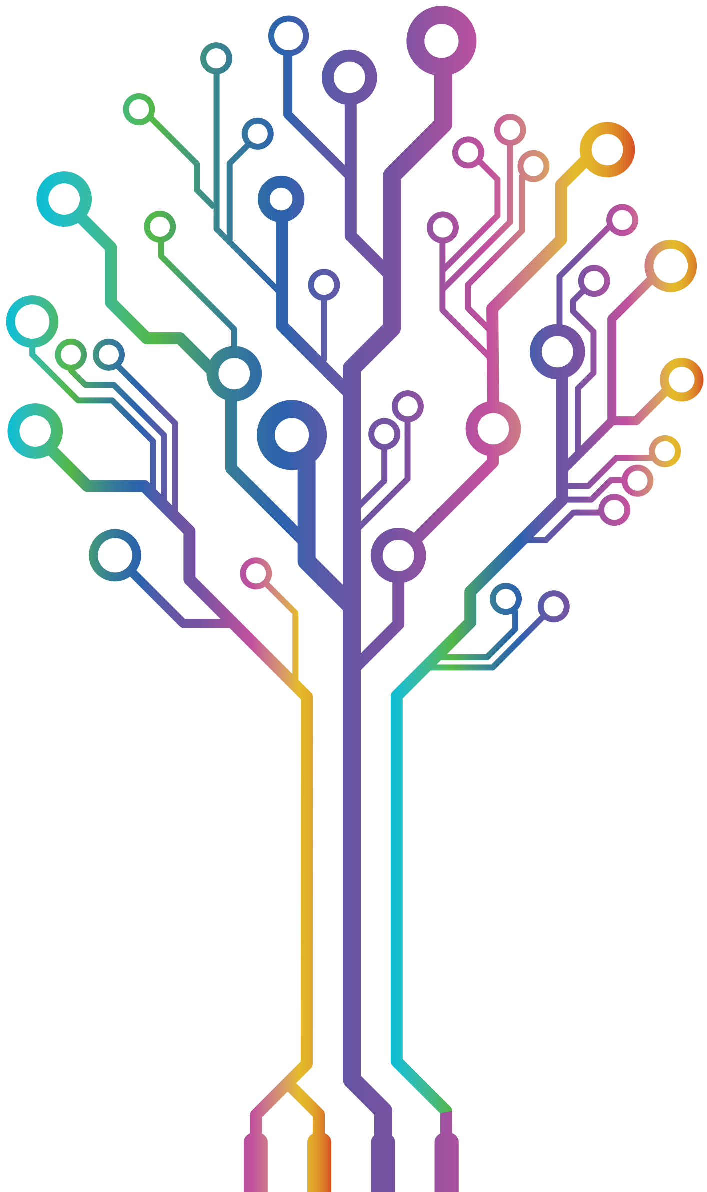

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Thanks go also to:
Sonia Bahri, Alessandro Bello, Anathea Brooks, Isabelle Brugnon, Andrea Gisselle Burbano Fuertes, Anne Candau, Alison Clayson, Natasha Lazic, Bassam Safeiddine, Natalia Tolochko, Carl Vannetelbosch and Rebecca Vella Muskat

Acknowledgments

UNESCO wishes to express its gratitude to Thomson Reuters for providing the data on publications used throughout the *UNESCO Science Report,* in the interests of stimulating a global debate on relevant policy issues. UNESCO also wishes to thank the Organization of Petroleum Exporting Countries' Fund for International Development and the Swiss Federal University of Lausanne for their financial support. UNESCO also wishes to extend its thanks to the L'Oréal Foundation for sponsoring the chapter in the report entitled 'Is the gender gap narrowing in science and engineering?'

A number of partners have also contributed to the dissemination of the report's findings by sponsoring and/or translating other language editions of the executive summary of the report. Thanks go to the Government of Flanders (French, Russian and Spanish editions), the Egyptian Academy of Scientific Research and Technology (Arabic edition), the China Association for Science and Technology (Chinese edition), the National Commissions for UNESCO of Austria, Germany, Luxembourg and Switzerland (German edition) and the National Commission for UNESCO of Andorra (Catalan edition).

UNESCO also takes this opportunity to thank the partners who have committed to producing editions of the full report in the official languages of the United Nations.

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Foreword

Irina Bokova, *Director-General of UNESCO*

In 2015, the United Nations General Assembly took a historic and visionary step with the adoption of the *2030 Agenda for Sustainable Development*. For the first time at this level, the role of science, technology and innovation has been explicitly recognized as a vital driver of sustainability. Sustainability depends on the capacity of states to put science at the heart of their national strategies for development, strengthening their capacities and investment to tackle challenges, some of which are still unknown. This commitment resonates at the heart of UNESCO's mandate and I see this as a call for action, as we celebrate the 70th anniversary of the Organization.

I see this edition of the *UNESCO Science Report* as a springboard to take the *2030 Agenda for Sustainable Development* forward, providing precious insights into the concerns and priorities of member states and sharing critical information to harness the power of science for sustainability.

The *UNESCO Science Report* draws a comprehensive picture of the many facets of science in an increasingly complex world – including trends in innovation and mobility, issues relating to big data and the contribution of indigenous and local knowledge to addressing global challenges.

Since the *UNESCO Science Report 2010*, clear trends have emerged. Firstly, despite the financial crisis, global expenditure on research and development has grown faster than the global economy, showing confidence that investment in science will bring future benefits. Much of this investment is in the applied sciences and is being spearheaded by the private sector. This points to an important shift in the landscape, with high-income countries cutting back public spending, while private sector funding has been maintained or increased, and with lower income countries increasing public investment in R&D. The debate between quick scientific gains and long-term public investment in basic and high-risk research to enlarge the scope of scientific discoveries has never been so relevant.

Secondly, the North–South divide in research and innovation is narrowing, as a large number of countries are incorporating science, technology and innovation in their national development agendas, in order to be less reliant on raw materials and move towards knowledge economies. Broad-based North–South and South–South collaboration is also increasing, in order to solve pressing sustainable developmental challenges, including climate change.

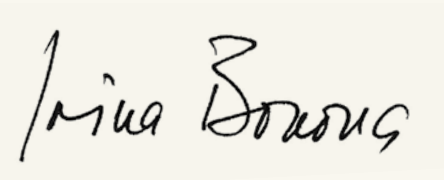
Thirdly, there are ever more scientists in the world and they are becoming more mobile. The number of researchers and publications worldwide increased by over 20% during the period from 2007 and 2014. A growing number of countries are putting policies in place to increase the number of women researchers; at the same time, scientists are not only publishing more in international scientific journals but also co-authoring more with foreign partners, with more articles becoming freely available through open access. At different income levels, countries across the world are striving to attract and retain scientific talent, upgrading their higher education and research infrastructure and developing new scholarships and scientific visas. Private firms are relocating research laboratories and some universities are setting up campuses abroad to tap into a bigger talent pool.

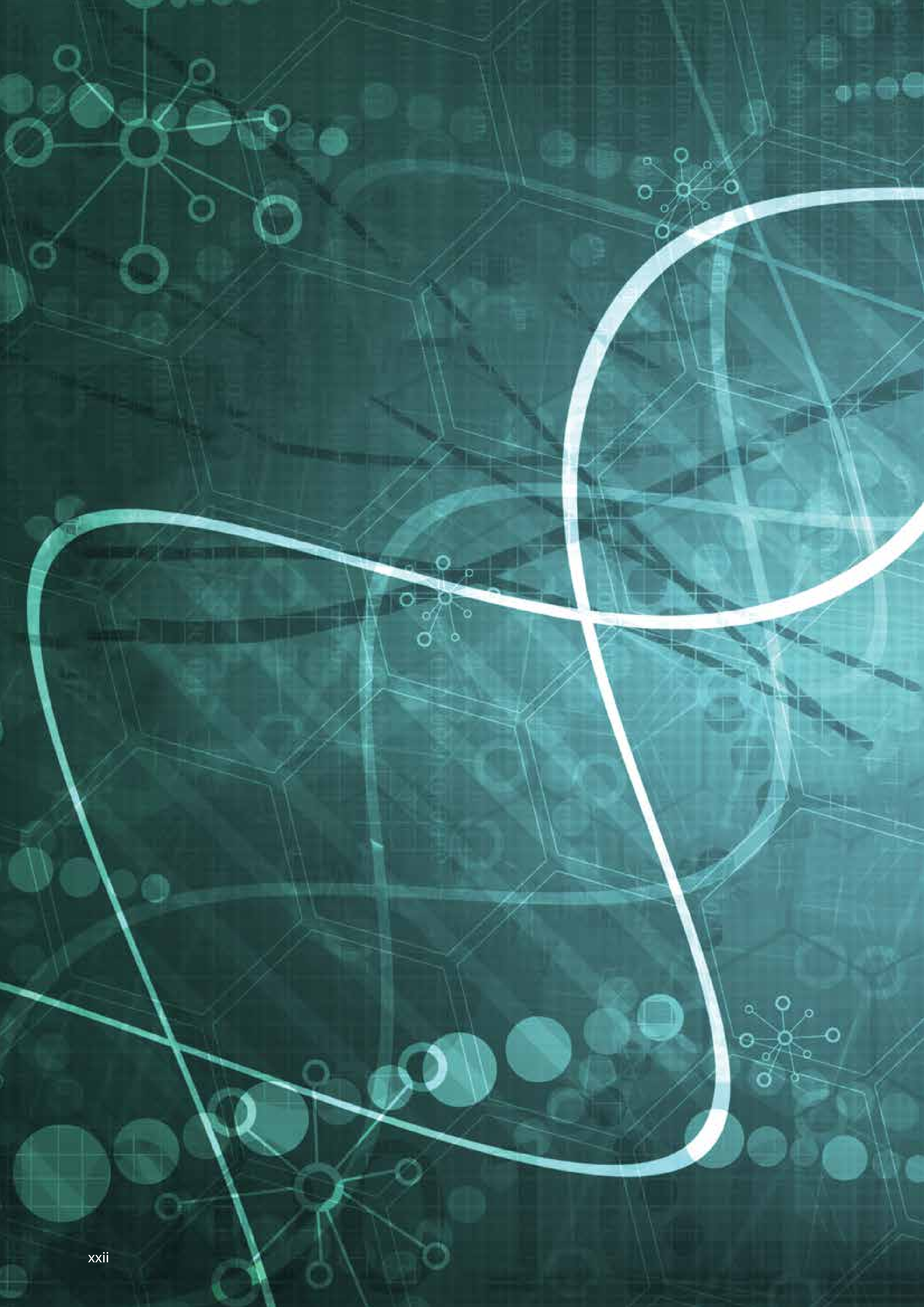
With all this, we face the challenge of mobilizing these accelerating trends of scientific enterprise, knowledge, mobility and international co-operation to inform policy and take the world on a more sustainable path.

This calls for a stronger science–policy interface and for the relentless drive towards innovation. Achieving many of the Sustainable Development Goals will depend not only on the diffusion of technology but also on how well countries partner with one another in the pursuit of science.

I see this as the key challenge of 'science diplomacy' in the years ahead and UNESCO will bring the full force of its scientific mandate to bear to support member states, strengthen capacities and share critical information ranging from sustainable water management to technology and innovation policies.

This report is unique in providing such a clear vision of the global scientific landscape, reflecting the contributions of more than 50 experts from across the world. I am convinced that the analysis here will help clear the path towards more sustainable development, laying the foundations for more inclusive knowledge societies across the world.





Perspectives on emerging issues

International students studying alongside Indian students on the Bangalore campus of the Indian Institute of Management. *Photo: © Atul Loke*

Universities: increasingly global players

Patrick Aebischer, *President, Ecole polytechnique fédérale de Lausanne, Switzerland*

Global competition but also a global family

As I am writing this essay in June 2015, 9.5 million students are simultaneously taking the *gaokao* (高考), the Chinese National College Entrance Examination giving access to university. What better illustration of the formidable importance of higher education at the beginning of the 21st century? More than ever, people are convinced today that knowledge and skills obtained at universities are crucial to personal well-being, as well as to the social and economic health of cities, nations and regions.

Universities have become institutions of a global world, in addition to assuming their traditional local and national roles. The answers to global challenges (energy, water and food security, urbanization, climate change, etc.) are increasingly dependent on technological innovation and the sound scientific advice brokered to decision-makers. The findings contributed by research institutes and universities to the reports of the Intergovernmental Panel on Climate Change and the Consensus for Action[1] statement illustrate the decisive role these institutions are playing in world affairs. Research universities also attract innovative industries. The Googles and Tatas of this world only thrive in proximity to great research institutions and it is this winning combination that fosters the emergence of dynamic entrepreneurial ecosystems such as Silicon Valley in the USA and Bangalore in India which are at the root of innovation and prosperity.

Universities themselves have become global players. Increasingly, they are competing with one another to attract funds, professors and talented students[2]. The reputation of a university is made at the global level. This trend will accelerate with the digital revolution, which is giving world-class universities an even greater global presence through their online courses.

As testimony to this evolution, global university rankings have appeared in the last ten years. They reflect both the existence of global competition and a global family of universities. The annual Academic Ranking of World Universities (ARWU) was first published in June 2003 by the Center for World-Class Universities of Shanghai Jiao Tong University, China. Quickly, other international rankings followed: the QS World University and the Times Higher Education rankings. International university rankings may often be debated but they never go unnoticed.

What makes a university world class? A world-class university has a critical mass of talent (both faculty and students), self-governance and administrative autonomy; academic freedom for faculty and research, which includes the right to critical thought; the empowering of young researchers to head their own laboratories; and sufficient resources to provide a comprehensive environment for learning and cutting-edge research. Some of the top-ranked institutions are seasoned Western universities, from which younger universities might learn a few things. Most universities do not feature in these world-class rankings but they nevertheless fulfil important educational roles at the local level.

In the past ten years, many new universities – most notably from Asia– have entered ARWU's top 500, even though US universities still dominate the top positions. The past decade has seen the advent of an increasingly multi-polar academic world, as noted already in the *UNESCO Science Report 2010*.

If competition between universities is one hallmark of this new league, co-operation and collaboration between scientists is another. In recent years, long-distance scientific collaboration has become the rule: scientists now live in a hyper-connected world. One way to measure this is by examining the co-authorship of scientific papers. The 2015 European Leyden ranking of universities for their capacity to engage in long-distance collaboration shows that six of the top ten universities come from Africa and Latin America, with the University of Hawaii (USA) in the lead.

Explosive growth in brain circulation

Student numbers are exploding around the world, as there has never been a greater need for a good tertiary education. Emerging economies will have around 63 million more university students in 2025 than today and the number worldwide is expected to more than double to 262 million by the same year. Nearly all of this growth will take place in the newly industrializing world, more than half of it in China and India alone. Student migration, brain circulation and the internationalization of universities has never been higher. There were 4.1 million students enrolled at universities abroad in 2013, 2% of all university students[3]. This number could double to eight million by 2025. Given this small percentage, brain drain should generally not represent a threat to the development of national innovation systems, so brain circulation should remain as unencumbered as possible in higher education. Universities will remain in high demand around the world, at a time when public financial support is

1. A message of scientific consensus addressed to world leaders on the need to maintain humanity's life support systems; the project is hosted by Stanford University (USA). See: http://consensusforaction.stanford.edu

2. Malaysia, for instance, hopes to become the sixth-largest global destination for international university students by 2020; between 2007 and 2012, the number of its international students almost doubled to more than 56 000. See Chapter 26.

3. This global figure masks strong variations from one region to another. See Figure 2.12.

strained in most countries. Gains in productivity will therefore be unavoidable, despite the very competitive nature of science; in particular, the emergence of university networks to enable institutions to share their faculty, courses and projects is a way forward.

Be relevant: close the innovation gap

The creation and transfer of scientific knowledge are critical to building and sustaining socio-economic welfare and integration in the global economy. In the long run, no region or nation can remain a simple 'user' of new knowledge but must also become a 'creator' of new knowledge. Closing the innovation gap is a necessary role of universities; innovation (or technology transfer) must become as important a mission as teaching and research.

Unfortunately, many countries in Africa and Asia mainly are producing fewer inventions today than they did in the early 1990s, despite healthy rates of economic growth. An analysis of patents signed between 1990 and 2010 shows that 2 billion people live in regions that are falling behind in innovation. This decline is overshadowed by the extraordinary development in India and China:[4] almost one-third of the 2.6 million patents filed worldwide in 2013 came from China alone.

Youth need to know their (IP) rights and engage in reverse innovation

This deficit in new patents in many countries is not due to a lack of entrepreneurial spirit, as many examples show, such as the re-invention of mobile banking in Africa. Rather, the gap is due to the fact that universities cannot bear the cost of research and technology transfer for lack of financial resources. According to Bloom (2006), responsibility for this relative neglect of higher education lies partly at the door of the international development community, which in the past failed to encourage African governments to prioritize higher education. An estimated 11 million young Africans are set to enter the job market each year over the next decade; efforts must be made to support their ideas, says Boateng (2015). For young people to find good jobs in the global economy, they will need skills, knowledge and will to innovate, as well as greater awareness of the value of intellectual property (IP).

One way to create the best conditions collectively for collaborative and 'reverse innovation' is for universities to work on appropriate (or essential) technology. These technologies aim to be economically, socially and environmentally sustainable; they are both high-tech (and therefore appealing to researchers) and low-cost (and therefore suited to innovators and entrepreneurs).

At the Ecole polytechnique fédérale de Lausanne, we have set up one such initiative, EssentialTech. This programme implements essential technologies in the context of a comprehensive value chain: from understanding needs to monitoring the real impact of these technologies and contributing to their long-term viability. For technology to have a significant and sustainable impact, scientific, economic, societal, environmental and institutional factors all have to be considered. This programme requires an interdisciplinary and multicultural, collaborative approach, as well as partnerships between the private sector, public authorities and civil society, particularly with stakeholders from low- and middle-income countries. Across the globe, many universities have set up such initiatives, or are in the process of doing so.

Digital disruption: a way of going global

The digital revolution is one new and disruptive way for universities to 'go global' beyond their single campuses to reach a global audience. Cloud computing and supercomputing, as well as the handling of big data, have already transformed research. They have given rise to global collaborative projects such as the Human Genome Project in the 1990s and the more recent Human Brain Project.[5] They allow for crowd-based networked science where researchers, patients and citizens can work together. In education, this revolution is increasingly taking the form of massive open online courses (MOOCs). Some world-class universities have realized what MOOCs can do for their visibility and reputation and begun offering such courses.

Two factors have contributed to the rapid rise of MOOCs (Escher *et al.*, 2014). Firstly, digital technology has come of age, with widespread use of laptops, tablets and smartphones in many countries and growing broadband penetration on all continents. Secondly, the 'digital native' generation has now reached university age and is totally at ease with the all-pervasive use of digital social networks for personal communication. The number of world-class universities committed to this digital innovation is steadily growing, as is the number of students – one MOOCs provider, Coursera, has seen the number of students almost double from 7 million in April 2014 to 12 million today. Unlike their online educational predecessors, the costs of MOOCs are borne not by students but by the institution producing the courses, which adds to their attractiveness. MOOCs allow a single university to extend its teaching to a global audience: the Ecole polytechnique fédérale de Lausanne counts 10 000 students on campus but has close to 1 million registrations worldwide for its MOOCs.

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4. See Chapters 22 (India) and 23 (China).

5. This is one of the European Commission's Future and Emerging Technologies Flagship projects to 2023. See : https://www.humanbrainproject.eu

MOOCs could also alleviate the textbook gap

In the coming years, MOOCs will allow affordable, quality courses to be disseminated everywhere. On-campus education will remain fundamental to student life but universities will have to adapt to global competition and increasing demand from students for quality lectures dispensed by top universities. Universities that share their lectures, complemented by seminars and exercises unique to each location, are certain to be part of the landscape in 2020. MOOCS will foster the co-design and co-production of these courses by partner universities. One could also imagine providing a set of high-quality introductory lectures online to a network of partner institutions. MOOCs could also alleviate the textbook gap by providing freely accessible modules of knowledge produced by the best experts and stored in a Wikipedia-like repository.

The momentum created by MOOCs may also result in new educational packages. Up until now, MOOCs have been delivered as individual courses. However, they may aggregate into accredited programmes, in future. Universities – sometimes as networks – will decide on certification and perhaps even revenue-sharing. Certified courses are of great importance for professional education because employers are increasingly focusing on the potential employee's skill set rather than on a formal degree. Through MOOCs, the lifelong learning that is so crucial to knowledge societies is becoming a globally feasible target.

At first, universities feared that a few fast-moving world-class universities would take over the MOOC business to install domination and homogeneity. What we are actually seeing is that MOOCs are becoming a tool for co-operation, co-production and diversity. Competition to produce the best courses, yes, but monolithic domination, no.

The partnering of universities will happen

For many years, and understandably so, primary education was the main challenge in education. Now has come the time to recognize, in parallel, the crucial importance of the research experience and skills that only universities can deliver to students and lifelong learners.

The partnering of universities to co-produce, re-appropriate, integrate, blend and certify classes will happen across the world. The university of tomorrow will be a global and multilevel enterprise, with a lively campus, several antennae located with strategic partners and a global virtual online presence. The Ecole polytechnique fédérale de Lausanne is among those universities that have already embarked on this path.

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Physics students from Iran, Senegal, Spain, Venezuela and Viet Nam enjoying an impromptu study session on the terrace of UNESCO's Abdus Salam International Centre for Theoretical Physics in Italy in 2012. There were 4.1 million international students worldwide in 2013.

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A more developmental approach to science

Bhanu Neupane, *Programme Specialist, Communication Sector, UNESCO*

Science 2.0: the data revolution

Science is not only created using data; the principle output of any scientific investigation is also data. The science-led data revolution has allowed Web 2.0 and Science 2.0 to co-evolve. The second-generation World Wide Web (Web 2.0) has made it easier for people to share information and collaborate and, in turn, the second-generation open science movement (Science 2.0) has used these new web-based technologies to share research more rapidly with a greater range of collaborators. This growth in interconnectedness, information-sharing and data-reuse has helped to develop a modern approach to science. As Science 2.0 is maturing, it has gradually begun replacing existing methods of teaching and learning science. Primarily characterized by the exponential generation and utilization of data for scientific purposes, this paradigm shift has both assisted and benefited from this data revolution (IEAG, 2014).

Increasingly collaborative science

Researchers and academics are now sharing their data and research results across web-based platforms, so that the global scientific community can utilize them and further build upon these raw scientific datasets, through collaboration. One example of this type of collaborative science can be seen in the big data generated for climate change projections developed by using global-scale models (Cooney, 2012). Research such as this provides a case for the utilization of large datasets assimilated and compiled in different parts of the world to solve local problems. This type of big data 'downscaling' can bridge the gap between global and local effects by layering larger-scale data with local-level data. Another example is the recently digitized and openly accessible rice breeding project 3K RGP, 2014 which now provides virtual access to the genomic sequence data of 3 000 rice cultivars from 89 countries. Local researchers can use such information to breed improved rice varieties that are locally customized for distribution at farmer level, resulting in higher annual rice yields that nurture national economic growth.

The combined impact of online tools and advocacy for a culture of open science at the institutional and national levels has fueled the accumulation and sharing of big data in virtual knowledge banks. Such sharing of metadata will, for example, allow for the generation of locally relevant projections of weather patterns and the development of cultivars that can best adapt to a particular climatic condition. In this way, studies in various scientific disciplines have become increasingly interconnected and data-heavy. This has made science more dynamic and given rise to two dimensions of scientific practices.

A shift from basic research towards big science

The focus of scientific discovery has shifted from basic research to 'relevant' or big science, in order to solve pressing developmental challenges, many of which have been identified as Sustainable Development Goals by the United Nations. However, basic research is extremely important for any future scientific discovery; one classic example is the discovery of the double helical structure of DNA by Watson and Crick in 1953, which laid the foundations for the subsequent work done in the fields of genetics and genomics. A more recent example is the sequencing of the human genome, which was completed in 2003 within the Human Genome Project. Whereas the identification of the 25 000 genes in human DNA was purely a quest for knowledge, the sequencing of corresponding base pairs within the same project was undertaken to unravel the mysteries of genetic variation, in order to improve the treatment of genetic diseases.

Computer networks and online interactions which facilitate the sharing of scientific information in real time across the global research community have gradually encouraged researchers to access and build upon these results in locally customized ways to solve social challenges. The global research community is no longer pegged on searching for a new element to add to the periodic table or for a molecular base triplet that encodes an amino acid. Rather, its focus is now on the bigger picture and how research can be applied to address challenges that could ultimately threaten human existence, such as global pandemics, water, food and energy insecurity or climate change. This shift in research priorities towards a big science agenda is evident in the amount of research funds allocated to applied science. Researchers are investing more than before in turning a discovery in basic research into a commercially viable and sustainable product or technology with a potentially beneficial socio-economic impact.

Without citizen engagement, no social good can come of open data

Another shift in the focus of science from basic research to an applied and developmental approach fuelled by Science 2.0 technologies is underscored by scientists' easier access than before to big data. Access can be defined firstly in the context of inclusiveness. If basic research is to be used for the betterment of human lives, there is no better way to identify a citizen's needs and challenges and to serve the interests of that person's wider community than to involve citizens themselves in the associated developmental processes. Science can only be inclusive if all parties at all levels (government, academic and general public) are duly involved. Thus, access can be defined secondly in the context of openness. Citizens cannot participate if science is not open and transparent. Without citizen engagement, no social good can come of open data, since there will be no recognition of local needs for subsequent data downscaling and data mainstreaming. For example, a regional scientific project aiming to identify the local impact of an increase in pollution levels can only be successful if citizens are able to report on the state of their health in real time to the scientific surveyors through a virtual platform that makes them active, yet informal participants in the project. Increasingly, discoveries that support early disaster warning – such as three-dimensional simulation models – are being considered more important that those that improve the capability to handle the post-disaster recovery.

Today's interconnected and futuristic approach to science has therefore redefined open and inclusive scientific practices. What used to be a teacher–student interaction in a research laboratory has now become a virtual interaction. These days, there are many scientific experiments in which ordinary citizens are both able to access and contribute to scientific big data in real time across virtual platforms to influence scientific processes – and sometimes, government decision-making processes that affect their daily lives. Engaging citizens in this way enables the general public to take part informally in the collection and analysis of big data and to influence, for example, the local customization of a developmental technology from the West, so that it is adapted to the local needs of a community in the developing world. This kind of public participation will gradually build an educated citizenry and augment the role played by citizens in solving applied scientific problems. The term ciitizen science refers to the public engagement of citizens who actively contribute to science, such as by providing experimental data and facilities for researchers. This fosters greater interaction between science, policy and society and thus more open, transdisciplinary and democratic research.

One example of citizen science is the project on ecosystem services management being implemented by UNESCO and its partners, which has evident linkages to poverty alleviation. The project blends cutting-edge concepts of adaptive governance with technological breakthroughs in citizen science and knowledge co-generation. A set of environmental virtual observatories enable marginalized and vulnerable communities to participate in solving various local environmental problems (Buytaert *et al.,* 2014).

While fostering a culture of open science through the provision of access to big data underpins scientific reproducibility, it also inevitably raises the question of how this type of openness and inclusiveness can maintain accountability for the actions that result from, and affect, these openly accessible data and how the full integration of science and wide participation at all levels can go hand-in hand with respect for intellectual property rights and the avoidance of research duplication or the misuse of data, such as when citation or restrictions on commercial use are ignored.

Researchers are awash with information

With rapidly evolving technologies that range 'from genome sequencing machines capable of reading a human's chromosomal DNA (*circa* 1.5 gigabytes of data) in half an hour to particle accelerators like the Large Hadron Collider at the European Organization for Nuclear Research (CERN), which generates close to 100 terabytes of data a day), researchers are awash with information' (Hannay, 2014).

A recent survey of the research community undertaken by the DataONE project showed that 80% of scientists were willing to share their data with others in the research and education community (Tenopir *et al.,* 2011). Increasingly though, researchers working in data-intensive scientific fields, in particular, are wondering how best to manage and control the sharing of their data and where to draw the line between data transparency for the social good and the risks of an uncontrollable 'data explosion'.

Avoiding the uncontrolled explosion of big data

Global spending on scientific research amounted to PPP$ 1.48 trillion in 2013 (see Chapter 1); the investment made in publishing this research is in the order of billions (Hannay, 2014). Given that interdisciplinary and highly collaborative research fields such as bionanotechnology, astronomy or geophysics are data-intensive and require frequent data-sharing and access, in order to interpret, compare and collaboratively build upon previous research results, resources should be similarly allocated for defining, implementing and communicating about big data governance and for establishing big-data sharing protocols and data governance policies at higher levels of formal scientific collaboration. Even at the level of citizens, the possible implications of 'sharing without control' in an attempt to make science more citizen-friendly could result in citizens being bombarded with an overwhelming amount of scientific information that they can neither make sense of, nor utilize. The creation of scientific big data must therefore go hand-in-hand with big data security and control, in order to ensure that an open and inclusive scientific culture can function properly.

A workshop on data governance organized by the international Creative Commons community in the State of Virginia (USA) in 2011 defined data governance in big science as being 'the system of decisions, rights and responsibilities that describe the custodians of big data and the methods used to govern it. It includes laws and policies associated with data, as well as strategies for data quality control and management in the context of an organization'.[1] Data governance can happen both at the traditional level (universities) and at the virtual level (across scientific disciplines or within large international collaborative research projects).

A code of conduct for digital science?

Big data governance applies to all stakeholders involved in the research enterprise, including research institutions, governments and funders, commercial industries and the general public. Different stakeholders can contribute at different levels. For example, at the more formal levels, governments could create data governance policies in association with affiliated research institutes at both national and international levels. At the level of citizens, people could be provided with tailored educational resources and courses in virtual classrooms to educate them about big data governance. The beneficiaries would be students, researchers, librarians, data archivists, university administrators, publishers and so on. The recent data governance workshop also describes how this type of training could be integrated into the creation of a code of conduct for digital science describing best practices for citizen science, such as data citation and appropriate data description.

By imposing this type of data usage agreement, terms of use clauses and policies targeting funders on open knowledge banks, the way in which these data are globally searched, viewed and downloaded by those interacting with the data archive could be controlled. This would, in turn, shape and differentiate how e-discovery of scientific data takes place both at the formal levels of scientific collaboration and scientific communities, as well at the informal level of citizens.

Big data and openness for sustainable development

With evolving scientific practices nurturing a gradual shift towards virtual science, there is a lot of potential for using and processing openly accessible big data generated from scientific research to help achieve the Sustainable Development Goals adopted in 2015. For the United Nations, 'data is the lifeblood of decision-making and the raw material for accountability. Without high-quality data providing the right information on the right things at the right time, designing, monitoring and evaluating effective policies becomes almost impossible.' The analysis, monitoring and making of such policies will be vital to taking up the challenges facing humanity, as defined by the 17 Sustainable Development Goals and 169 targets comprising *Agenda 2030*.

As a specialized agency, UNESCO is, itself, committed to making open access and open data one of the central supporting agendas for achieving the Sustainable Development Goals.

A mapping exercise[2] undertaken in May 2015 gives a clear understanding of how open science and openness in scientific big data link to the Sustainable Development Goals; this exercise recalls the interconnectedness between the action line on access to knowledge adopted by the World Summit on the Information Society in 2005 and the sustainable delivery of social goods and services to improve lives and alleviate poverty – an interconnectedness that has been the guiding light for the formulation of the Sustainable Development Goals.

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2. See: www.itu.int/net4/wsis/sdg/Content/wsis-sdg_matrix_document.pdf

Science will play a key role in realizing *Agenda 2030*

The* 2030 Agenda for Sustainable Development *was adopted on 25 September 2015 at the United Nations Summit on Sustainable Development. This new agenda comprises 17 agreed Sustainable Development Goals which replace the Millennium Development Goals adopted in 2000. What role will science[1] play in realizing Agenda 2030? What are the related challenges and opportunities? The following opinion piece[2] attempts to answer these questions.

There can be no sustainable development without science

Since governments have agreed that *Agenda 2030* should reflect an integrated vision of sustainable development, science cuts across virtually all 17 of the Sustainable Development Goals within this agenda. Provisions related to science are also to be found in the *Declaration*, in many of the targets accompanying the Sustainable Development Goals and in the *Means of Implementation*, including as regards national investment in science, technology and innovation, the promotion of basic science, science education and literacy, and, lastly, in the parts of *Agenda 2030* on monitoring and evaluation.

Science will be critical to meeting the challenge of sustainable development, as it lays the foundations for new approaches, solutions and technologies that enable us to identify, clarify and tackle local and global problems. Science provides answers that are testable and reproducible and, thus, provides the basis for informed decision-making and effective impact assessments. Both in its scope of study and its applications, science spans the understanding of natural processes and the human impact thereon, the organization of social systems, the contribution of science to health and well-being and to better subsistence and livelihood strategies, enabling us to meet the overriding goal of reducing poverty.

Faced with the challenge of climate change, science has already provided some solutions for a secure and sustainable energy supply; yet, there is room for further innovation, such as with regard to the deployment and storage of energy or energy efficiency. This is directly relevant to SDG 7 on affordable and clean energy and to SDG 13 on climate action.

The transition to sustainable development cannot rely solely on engineering or technological sciences, though. The social sciences and humanities play a vital role in the adoption of sustainable lifestyles. They also identify and analyse the underlying reasons behind decisions made at the personal, sectorial and societal levels, as reflected in SDG 12 on responsible consumption and production. They also offer a platform for critical discourse about societal concerns and aspirations and for discussion on the priorities and values that determine political processes, the focus of SDG 16 on peace, justice and strong institutions.

The greater accuracy of weather forecasts is one example of a scientific success story, with current five-day forecasts being about as reliable as 24-hour forecasts four decades ago. There is, nevertheless, still a need for longer forecasts and more regional applications, as well as the dissemination of forecasts of extreme weather events such as heavy rain, flash floods and storm surges, which particularly affect the most underdeveloped countries in Africa and Asia. This need relates to SDG 13 on climate action.

Although infectious diseases have been largely contained in recent decades by vaccination and antibiotics, the world still faces an inevitable rise in pathogenic resistance to antimicrobial drugs (WHO, 2014; NAS, 2013). In addition, new pathogens are emerging or mutating. New methods of treatment based on basic research into the origin of antibiotic resistance and applied research devoted to developing new antibiotics and alternatives are of critical importance to furthering human health and well-being. These issues are relevant to SDG 3 on good health and well-being.

Basic and applied science: two sides of the same coin

Basic science and applied science are two sides of the same coin, being interconnected and interdependent (ICSU, 2004). As Max Planck (1925)put it, 'Knowledge must precede application and the more detailed our knowledge […], the richer and more lasting will be the results we can draw from that knowledge' (ICSU, 2004). Basic research is driven by curiosity about the unknown, rather than being oriented towards any direct practical application. Basic science entails thinking out of the box; it leads to new knowledge and offers new approaches which, in turn, may lead to practical applications. This takes patience and time and, thus, constitutes a long-term investment but basic research is the prerequisite for any scientific breakthrough. In turn, new knowledge can lead to practical scientific applications and big leaps forward for humanity. Basic science and applied science thus complement each other in providing innovative solutions to the challenges humanity faces on the pathway to sustainable development.

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1. Science should be understood here in the broader sense of science, technology and innovation (STI), ranging from the natural sciences to technologies, social sciences and the humanities

2. This opinion piece is based on the policy brief entitled *The Crucial Role of Science for Sustainable Development and the Post-2015 Development Agenda: Preliminary Reflection and Comments by the Scientific Advisory Board of the UN Secretary-General.* This policy brief was presented to the high-level session of the United Nations' Economic and Social Council devoted to the sustainable development goals and related processes in New York on 4 July 2014 and has since been updated

There are countless examples of such transformational ideas. In medical history, the discovery of the bacterial origin of diseases allowed for the development of immunization methods, thus saving countless lives. Electricity-based light did not simply evolve from a candle; this transition occurred in steps, through new concepts and sporadic leaps forward. Accelerator-based particle physics is another example of how one invention can have unanticipated beneficial spin-offs: initially developed solely as a tool for basic research, particle accelerators are common nowadays in major medical centres, where they produce X-rays, protons, neutrons or heavy ions for the diagnosis and treatment of diseases such as cancer, thus benefiting millions of patients.

There is, thus, no dichotomy between basic and applied science, nor competition but only opportunities for synergies. These considerations are central to SDG 9 on industry, innovation and infrastructure.

Science, like music, is universal

Science, like music, is universal. It is a language that we can share across cultural and political borders. For example, more than 10 000 physicists from 60 countries work together at the European Laboratory for Particle Physics (CERN) in Switzerland, inspired by the same passion and driven by shared goals. In universities around the world, new graduate and undergraduate programmes are being designed to teach tomorrow's global problem-solvers how to work across disciplines, scales and geographies. Here, science acts as a leverage for research collaboration, science diplomacy and peace, which is also relevant to SDG 16.

Science plays a key educational role. The critical thinking that comes with science education is vital to train the mind to understand the world in which we live, make choices and solve problems. Science literacy supplies the basis for solutions to everyday problems, reducing the likelihood of misunderstandings by furthering a common understanding. Science literacy and capacity-building should be promoted in low- and middle-income countries, particularly in cases where a widespread appreciation of the benefits of science and the resources for science are often lacking. This situation creates dependence on countries that are more scientifically literate and more industrialized. Hence, science has a role to play in the realization of SDG 4 on quality education.

Science is a public good

Public good science not only brings about transformative change on the road to sustainable development. It is also a way of crossing political, cultural and psychological borders and, thus, helps lay the foundation for a sustainable world. Science may further democratic practices when results are freely disseminated and shared, and made accessible to all. For example, the World Wide Web was invented to facilitate the exchange of information among scientists working in the laboratories of the European Organization for Nuclear Research (CERN) in Switzerland. Since then, the Web has radically changed the way in which the world accesses information. CERN being a publicly funded research centre, it preferred to make the Web freely available to everybody, rather than patent its invention.

The need for an integrated approach

For the post-2015 development agenda to be truly transformative, it will be vital to respect the interrelatedness of the development issues addressed by the Sustainable Development Goals. This point was acknowledged by the Open Working Group on the on the Sustainable Development Goals convened by the United Nations' General Assembly during the formal negotiations which led to the formulation of *Agenda 2030*. The artificial division of *Agenda 2030's* goals, based on disciplinary approaches, may be necessary for comprehension, resource mobilization, communication and public awareness-raising. Nevertheless, one cannot insist enough on the complexity and strong interdependence of the three economic, environmental and social dimensions of sustainable development.

To illustrate the strong interrelation between these three dimensions, let us consider the following: nutrition, health, gender equality, education and agriculture are all relevant to several Sustainable Development Goals and all interrelated. It is impossible to be healthy without adequate nutrition. Adequate nutrition, in turn, is closely linked to agriculture as a provider of nutritious food (SDG 2 on zero hunger). Agriculture, however, affects the environment and, thus, biodiversity (the focus on SDGs 14 and 15 on life below water and life on land, respectively); agriculture is estimated to be the main driver of deforestation when mismanaged. Women are at the nexus of health, nutrition and agriculture. In rural areas, they are responsible for the daily production of food and for childcare. Deprived of education and thus of access to knowledge, some women are unfamiliar with the interlinkages portrayed above. Moreover, their cultural background often discriminates against their well-being when they are treated like second-class citizens. Promoting gender equality and empowering rural women will, thus, be of paramount importance to making progress in all the aforementioned areas and to curb unsustainable population growth. Science is well-placed to build bridges permitting such interlinkages, in the context of SDG 5 on gender equality.

Another example of the close interlinkages among agricultural practices, health and environment is the concept of 'one health.' This concept advocates the idea that human and animal health are closely linked. This is demonstrated, for instance, by the fact that viruses originating in animals can spread to humans, as seen in the case of Ebola or influenza (Avian flu, for instance).

Perspectives on emerging issues

Given the interdisciplinary nature of science for sustainable development, the Scientific Advisory Board to the Secretary-General of the United Nations has stressed the importance of intensifying co-operation among the different scientific fields and portraying science clearly and forcefully as a key ingredient in the future success of *Agenda 2030*. Governments should acknowledge the potential of science to federate different knowledge systems, disciplines and findings and its potential to contribute to a strong knowledge base in the pursuit of the Sustainable Development Goals.

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Science for a sustainable and just world: a new framework for global science policy?

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The challenge of global change

The magnitude and implications of human exploitation of the Earth system are becoming clearer each year to the scientists who study them and to the wider public who attempt to grasp them. The Earth's natural capital yields an annual dividend of resources that form the bedrock of the human economy and the life support system for the planet's inhabitants. However, as the world's population grows, its cumulative consumption is increasingly biting into that productive capital. Two human activities stand out, in this regard: the historical development of ever more abundant energy sources to power society and the over-extraction and over–consumption of both non-renewable and, crucially, renewable resources. These activities are not only unsustainable but have also created novel hazards. Their consequences are severe and, for future generations, potentially disastrous. We live in an era in which human society has become a defining geological force, one informally termed the Anthropocene (Zalasiewicz *et al.*, 2008; ISSC and UNESCO, 2013).

The local impact of human activity is transmitted globally through the global ocean, the global atmosphere and global cultural, economic, trade and travel networks. Conversely, these global transmission systems have a local impact that varies in magnitude according to geographic location. This results in a complex coupling between social and biogeophysical processes that has re-configured the global ecology to produce one which is novel to the Earth and to which poverty, inequality and conflict are integral. On account of multiple interdependences and non-linear, chaotic relationships that unfold differently depending on context, this coupling means that attempts to address a problem affecting one aspect of this ecology necessarily have implications for others. Society, therefore, is confronted by a global set of major converging environmental, socio-economic, political and cultural problems that must be understood as parts of a whole in providing guidance for the way in which each can be effectively addressed.

However, this is the set of problems – exemplified by the United Nations Sustainable Development Goals – that society now expects science to help solve, urgently and in ways that are both sustainable and just. Meeting this challenge will require the engagement of peoples from diverse cultures and their leaders; it will demand global responses for which neither the scientific community, nor the policy world, nor the general public is well-prepared. Whereas many sectors of society will need to become involved in this process, the scientific community will have a special role to play.

Central to the challenge is the need to de-couple growth, or even economic stasis, from environmental impact. It is becoming clearer how this might best be done through the widespread adoption of a range of proven or achievable technologies at increasingly competitive costs and of operational systems and business models operating through an enabling economic and regulatory frame. Closely tied to such necessary technological transitions, there is a need for society not only to adapt but to find appropriate ways of fundamentally transforming socio-economic systems, the values and beliefs that underpin them and the behaviour, social practices and lifestyles they perpetuate.

These complex global realities provide a powerful imperative to promote profound changes in the way that science contributes to public policy and practice.

Challenging and changing science

In the past two decades, there has been an increasing realization of the need to create public dialogue and engagement as two-way processes, if effective and equitable public policies are to be developed and implemented. However, the scale and international scope of the challenge described above require an altogether more profound approach (see, for example, Tàbara, 2013). These approaches typically cross boundaries between different disciplines (physical, social, human, engineering, medical, life sciences) to achieve greater interdisciplinarity; foster truly global collaboration embracing the full diversity of scientific voices from around the world; advance new research methods for the analysis of complex, multidisciplinary problems; and combine different types or subcultures of knowledge: specialized scientific, political/strategic, indigenous/local, community-based, individual, and holistic (see, for example, Brown *et al.*, 2010). Open knowledge systems facilitate solutions-oriented research, bringing academics and non-academics together as knowledge partners in networks of collaborative learning and problem-solving and making traditional dichotomies between, for example, basic and applied research irrelevant.

A major example of the open knowledge systems approach at the international level is Future Earth, established in 2012 by an international alliance of partners, including the International

Council for Science, International Social Science Council, UNESCO, the United Nations Environment Programme, World Meteorological Organization, United Nations University and the Belmont Forum, a group of national scientific funding agencies. Future Earth[1] provides a platform for global change and sustainability research. Through this platform, researchers from many disciplines are learning to work with non-academic partners in subject matter-based networks combining knowledge and action on oceans, health, the water– energy–food nexus, social transformations and global finance. Central to the work of Future Earth is the promotion of inter- and transdisciplinary scientific practices.

While the ultimate consequences of the runaway unsustainability of the social–ecological system are, as yet, unfathomed, there are intensified efforts to understand the system by drawing on the perspectives of all disciplines, ensuring their joint, reciprocal framing of the issues and the collaborative design, execution and application of research. At the same time, there has been a shift in emphasis beyond interdisciplinarity towards transdisciplinarity as a fundamental enabling process. Transdisciplinary research engages decision-makers, policy-shapers and practitioners, as well as actors from civil society and the private sector as partners in the codesign and coproduction of solutions-oriented knowledge, policy, and practice. It recognizes that there are multiple sources of relevant knowledge and expertise to be harnessed such that all involved actors are both producers and users of knowledge at one time or another. In this way, transdisciplinarity becomes more than a new way of infusing scientific knowledge into policy and practice, more than merely a strategic reframing of the one-way science-to-action paradigm. It is conceived as a social process of creating actionable knowledge and promoting mutual learning in ways that foster scientific credibility, practical relevance and socio-political legitimacy. It is an effort to link and integrate the perspectives of different knowledge subcultures in addressing social complexity and supporting collective problem-solving. In transdisciplinary research, scientific knowledge 'producers' cease to think of knowledge 'users' as passive information receivers, or at best as contributors of data to analyses framed by scientists. Instead, scientists integrate the concerns, values, and worldviews of policymakers and practitioners, of entrepreneurs, activists and citizens, giving them a voice in developing research that is compatible with their needs and aspirations (Mauser *et al.*, 2013).

A fundamental and, indeed, necessary underpinning for the further development of open knowledge systems is currently being created by national and international initiatives for 'open science' and 'open data' (The Royal Society, 2012). The moves towards wider public engagement in recent years have led naturally to the aspiration that science should become an overtly public enterprise rather than one conducted behind closed laboratory and library doors, that publicly funded science should be done openly, that its data should be open to scrutiny, that its results should be available freely or at minimal cost, that scientific results and their implications should be communicated more effectively to a wide range of stakeholders, and that scientists should engage publicly in the transdisciplinary mode. Open science is also a crucial counterbalance to business models built on the capture and privatization of socially produced knowledge through the monopoly and protection of data. If the scientific enterprise is not to founder under such pressures, an assertive commitment to open data, open information and open knowledge is required from the scientific community.

Challenging science policy

Do the discourses about open knowledge systems and, more broadly, of open science, amount to a new science policy paradigm or framework – one that moves away from seeing the value of science through the (often national) lens of the knowledge economy towards valuing science as a public enterprise working for a sustainable and just world?

In theory, yes. Narratives about basic concepts of science policy have indeed shifted in that direction. For example, within large parts of the scientific community, notions of scientific relevance now focus less on the language of national economic growth and competitiveness, more on the need for transformative research oriented towards finding solutions to the global challenges we face.

We have also seen changes in how the science–policy interface or nexus is understood: from a one-way delivery system based on a linear model of knowledge transfer, with its language of impact and uptake and its dualistic mechanisms of knowledge production and use (e.g. via policy briefs, assessments and some advisory systems), towards a multidirectional model of iterative interaction, with feedback loops and acknowledgement of the messy decision-making processes on both sides.

Last but not least, we are seeing shifts in the geopolitics of science and, particularly, in how we formulate attempts to overcome global knowledge divides. Capacity-building has become capacity development but both have essentially remained locked into the idea of support as a form of catch-up aid for the global South. That thinking is changing towards notions of capacity mobilization, recognizing excellence and the need to support regional science systems in order to foster truly global integration and collaboration. Has a shift towards a new science policy framework been realized in practice? There are encouraging signs of change in this direction. At the international level, Future Earth

1. see: www.futureearth.org

provides a new institutional framework for the promotion of integrated, transdisciplinary scientific practice. More importantly, perhaps, financial support for a such practice has been committed through the multilateral funding initiatives of the Belmont Forum and, more recently, through the International Social Science Council's Transformations to Sustainability Programme.[2]

At the same time, a critical reality check of prevailing science policy practices suggests the opposite. Universities, globally, have a vital role to play here. They are unique among human institutions in the range of knowledge they enfold, in sustaining and reinvigorating inherited knowledge, creating and communicating new knowledge. Only too often, though, that knowledge is still contained and communicated in disciplinary siloes, reinforced by exclusive disciplinary approaches to academic training, funding priorities and incentive mechanisms. Old ways of producing scientific knowledge are perpetuated by traditional forms of evaluation based on unyielding and inappropriate metrics, as well as enduring reward and career advancement systems. Researchers are rarely encouraged (let alone rewarded) to acquire the socio-cultural competencies and engagement skills needed to manage cross-cultural, inter- and transdisciplinary processes.

Creating the conditions of possibility

Science policy is not yet 'walking the talk' of an open knowledge, open science policy framework. The onus lies not only with universities but also with those national science policy bodies that set research priorities, allocate funding and devise incentive systems to recognize and respond to the broader imperative that such a framework entails. In particular, we need creative and co-ordinated solutions from them for a better integration of the natural, social and human sciences in fields such as global change and sustainability research. We also need dedicated support for open, inclusive processes of producing solutions-oriented knowledge in partnership with societal stakeholders. We also need science policy-makers to be critical and reflexive. Theme-focused research must not crowd out creative explorations of unregarded territory to which we owe many of the insights and technologies upon which the modern world is built and where creative solutions for a future world are likely to arise. It is, therefore, vital for there to be careful monitoring and evaluation of the difference the codesign and coproduction of knowledge between academics and non-academics makes to the practice and effectiveness of policy.

Why is this so important? Committed support for integrated, solutions-oriented, transdisciplinary science has real implications for what it means to be a scientist in the Anthropocene – for how they practice their art, how we train them, evaluate and reward them, for the kinds of career systems we put in place. This has implications for how we fund research and whether and how science can respond to current demands for it to contribute solutions to critical global challenges and to support transformations to sustainability. It will determine the role that science plays in shaping the future path of humanity on planet Earth.

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Local and indigenous knowledge at the science–policy interface

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Towards global recognition

In recent years, local and indigenous knowledge has emerged as a new and increasingly influential contribution to the global science–policy interface. Of particular note is the recognition provided by the Intergovernmental Panel on Climate Change (IPCC) in its *Fifth Assessment Report* (2014). In analysing characteristics of adaptation pathways in the Summary for Policy-makers on *Climate Change 2014: Synthesis Report*, the IPCC concludes:

> *Indigenous, local, and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge with existing practices increases the effectiveness of adaptation.*

This acknowledgement of the importance of local and indigenous knowledge is echoed by IPCC's 'sister' global assessment body. The Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES) established in 2012 has retained indigenous and local knowledge as an 'operating principle' that translates into the following scientific and technical function of the IPBES Multidisciplinary Expert Panel: *explore ways and means of bringing different knowledge systems, including indigenous knowledge systems, to the science–policy interface.*

Other prestigious scientific bodies with global mandates in science and policy are bringing local and indigenous knowledge to the fore. The Scientific Advisory Board to the Secretary-General of the United Nations decided at its Third Session in May 2015 *'to prepare a policy brief for the attention of the Secretary-General recognizing the important role of indigenous and local knowledge for sustainable development and providing recommendations for enhancing the synergies between ILK and science'.*

Understanding local and indigenous knowledge systems

Before going any further, it may be useful to clarify what is meant by 'local and indigenous knowledge systems.' The term makes reference to knowledge and know-how that have been accumulated across generations, which guide human societies in their innumerable interactions with their environment; they contribute to the well-being of people around the globe by ensuring food security from hunting, fishing, gathering, pastoralism or small-scale agriculture, as well as by providing health care, clothing, shelter and strategies for coping with environmental fluctuations and change (Nakashima and Roué, 2002). These knowledge systems are dynamic, and are transmitted and renewed by each succeeding generation.

Several terms co-exist in the published literature. They include indigenous knowledge, traditional ecological knowledge, local knowledge, farmers' knowledge and indigenous science. Although each term may have somewhat different connotations, they share sufficient meaning to be used interchangeably.

Berkes (2012) defines traditional ecological knowledge as 'a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment.'

Recognition as 'knowing again'

Local and indigenous knowledge is not something new. Indeed, it is as old as humanity itself. What is new, however, is its growing recognition by scientists and policy-makers around the world, on all scales and in a rapidly growing number of domains.

Recognition is the key word, not in the sense of 'discovering' what was previously unknown but rather as revealed by the word's etymology: 're' (again) + 'cognoscere' (know), meaning 'to know again, recall or recover the knowledge of …. something formerly known or felt.'[1] Indeed, today's efforts to 'know again' indigenous knowledge acknowledge the divide put in place by positivist science centuries ago.

This separation, and even opposition, of science, on the one hand, and local and indigenous knowledge, on the other, was not a malevolent act. It might best be understood as a historical necessity without which science could not have emerged as a distinct body of understanding with defined methods and an identifiable group of thinkers and practitioners. Just as Western philosophy has ignored continuities and emphasized discontinuities when constructing 'nature' in opposition to 'culture', so, too, has positivist science chosen to ignore innumerable traits shared with other knowledge systems in order to set itself apart, first as different then as 'unique' and ultimately as 'superior.'

Still today, young scientists are trained to value the scientific traits of being empirical, rational and objective, which suggest by opposition that other knowledge systems suffer from

1. See: www.etymonline.com/index.php?term=recognize subjectivity, the anecdotal and irrationality. Of course, no one can deny the impressive track record of positivist science in advancing understandings of our biophysical environment with an astounding suite of technical advances that have transformed and continue to transform, for better and for worse, the world in which we live. The division and opposition of science to other knowledge systems, and among disciplines within science itself, are no doubt important keys to the global success of positivist science.

However, compartmentalization, reductionism and specialization also have their limitations and blind spots. Have the advantages of opposing nature and culture, or science and other knowledge systems, been increasingly outweighed in recent decades by their disadvantages? Might the growing understanding and appreciation of these shortcomings be contributing to the emergence of local and indigenous knowledge in the global arena?

Local and indigenous knowledge emerging in global arena

The emergence of local and indigenous knowledge at the global science–policy interface suggests that a long period of separation between science and local and indigenous knowledge systems is coming to an end. This said, separation may not be the right term. In actual fact, the interconnections of science with other knowledge systems may never have been severed, only obscured. Science grew from local observations and understanding of how nature works. In the early days of colonial science, for example, ethnobotany and ethnozoology relied on the knowledge and know-how of local people to identify 'useful' plants and animals. Local and indigenous systems of nomenclature and classification, adopted wholesale, were often disguised as 'scientific' taxonomies. European understanding of Asian botany, for example, *'ironically, depended upon a set of diagnostic and classificatory practices, which though represented as Western science, had been derived from earlier codifications of indigenous knowledge'* (Ellen and Harris, 2000, p.182).

Not until the mid-20th century do we observe a shift in the attitude of Western scientists towards local and indigenous knowledge. This was triggered by Harold Conklin's iconoclastic work in the Philippines on *The Relations of Hanunoo Culture to the Plant World* (1954). Conklin revealed the extensive botanical knowledge of the Hanunoo which covers *'hundreds of characteristics which differentiate plant types and often indicate significant features of medicinal or nutritional value.'* In another realm and another region, Bob Johannes worked with Pacific Island fishers to record their intimate knowledge of *'the months and periods as well as the precise locations of spawning aggregations of some 55 species of fish that followed the moon as a cue for spawning'* (Berkes, 2012). This indigenous knowledge more than doubled the number of fish species known to science that exhibit lunar spawning periodicity (Johannes, 1981). In northern North America, land use mapping for indigenous land claims paved the way for advocating a role for indigenous knowledge in wildlife management and environmental impact assessment (Nakashima, 1990).

Efforts to better understand the vast stores of knowledge possessed by indigenous peoples and local communities expanded in the years to come, with a particular focus on biological diversity. The now well-known article 8(j) of the Convention on Biological Diversity (1992) contributed to building international awareness by requiring Parties to '*respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity.*'

But local and indigenous knowledge was also gaining recognition in other domains. Orlove *et al.* (2002) unveiled that Andean farmers, through their observations of the Pleiades constellation, could predict the advent of an El Niño year with an accuracy equivalent to that of contemporary meteorological science:

> *The apparent size and brightness of the Pleiades varies with the amount of thin, high cloud at the top of the troposphere, which in turn reflects the severity of El Niño conditions over the Pacific. Because rainfall in this region is generally sparse in El Niño years, this simple method (developed by Andean farmers) provides a valuable forecast, one that is as good or better than any long-term prediction based on computer modelling of the ocean and atmosphere.*

Recognition of the veracity of local and indigenous knowledge has also emerged in another domain: that of natural disaster preparedness and response. One of the most striking examples relates to the Indian Ocean tsunami that tragically took over 200 000 lives in December 2004. In the midst of this immense disaster, accounts began to emerge of how local and indigenous knowledge had saved lives. UNESCO had its own direct source of understanding, as a project had been running for many years with the Moken peoples of the Surin Islands in Thailand. The 2004 tsunami completely destroyed their small seaside village, but no lives were lost. After the tsunami, the Moken explained that the entire village, adults and children, had known that the unusual withdrawal of the ocean from the island shore was a sign that they should abandon the village and move rapidly to high ground. None of the Moken present on the Surin Islands had themselves witnessed *laboon*, their term for tsunami but, from the knowledge passed down through generations, they knew the signs and how to respond (Rungmanee and Cruz, 2005).

Biodiversity, climate and natural disasters are but a few of the many domains in which the competence of local and indigenous knowledge has been demonstrated. Others could be mentioned, such as knowledge of the genetic diversity of animal breeds and plant varieties, including pollination and pollinators (Lyver *et al*., 2014; Roué *et al*., 2015), knowledge of ocean currents, swells, winds and stars that is at the heart of traditional open ocean navigation (Gladwin, 1970) and, of course, traditional medicine, including women's in-depth knowledge of childbirth and reproductive health (Pourchez, 2011). That human populations around the world have developed expertise in a multitude of domains related to their everyday lives seems self-evident, yet this fount of knowledge has been obscured by the rise of scientific knowledge, as if science needed to marginalize others ways of knowing in order to ensure its own global growth in recognition and influence.

Where to from here?

The emergence of local and indigenous knowledge at the global level brings with it many challenges. One relates to maintaining the vitality and dynamism of local and indigenous knowledge and practices in the local communities from which they originate. These other knowledge systems are confronted with a multitude of threats, including mainstream education systems that ignore the vital importance of a childhood education anchored in indigenous languages, knowledge and worldviews. Recognizing the risks of an education centred only on positivist ontologies, UNESCO's programme on Local and Indigenous Knowledge Systems is developing education resources rooted in local languages and knowledge with the Mayangna of Nicaragua, the people of Marovo Lagoon in the Solomon Islands and for Pacific youth.[2]

Of a different nature is the challenge of meeting expectations raised by the recognition, in multiple domains, of the importance of local and indigenous knowledge. How, for example, might local knowledge and knowledge-holders contribute to assessments of biodiversity and ecosystems services, or to understanding the impact of climate change and opportunities for adaptation? Moving beyond recognition to address the 'how' has become a major focus in science–policy fora. Having reinforced recognition of the importance of local and indigenous knowledge for climate change adaptation in the IPCC's *Fifth Assessment Report* (Nakashima *et al*., 2012), UNESCO is now collaborating with the United Nations' Framework Convention on Climate Change to identify tools for, and methods of, bringing indigenous and traditional knowledge, alongside science, into the response to climate change. Last but not least, a Task Force on Indigenous and Local Knowledge has been established to provide IPBES with appropriate 'approaches and procedures' for bringing indigenous and local knowledge into global and regional assessments of biodiversity and ecosystem services. UNESCO is assisting in that effort through its role as the technical support unit for the task force.

2. See: www.unesco.org/links, www.en.marovo.org and www.canoeisthepeople.org

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Global overview

Many dilemmas appear increasingly common to a wide range of countries, such as that of trying to find a balance between local and international engagement in research, or between basic and applied science, the generation of new knowledge and marketable knowledge, or public good science versus science to drive commerce.

Luc Soete, Susan Schneegans, Deniz Eröcal, Baskaran Angathevar and **Rajah Rasiah**

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1 · A world in search of an effective growth strategy

Luc Soete, Susan Schneegans, Deniz Eröcal, Baskaran Angathevar and Rajah Rasiah

INTRODUCTION

For two decades now, the *UNESCO Science Report* series has been mapping science, technology and innovation (STI) around the world on a regular basis. Since STI do not evolve in a vacuum, this latest edition summarizes the evolution since 2010 against the backdrop of socio-economic, geopolitical and environmental trends that have helped to shape contemporary STI policy and governance.

More than 50 experts have contributed to the present report, each of them covering the region or country from which they hail. A quinquennial report has the advantage of being able to focus on longer-term trends, rather than becoming entrenched in descriptions of short-term annual fluctuations which, with respect to policy and science and technology indicators, rarely add much value.

KEY INFLUENCES ON STI POLICY AND GOVERNANCE

Geopolitical events have reshaped science in many regions

The past five years have witnessed major geopolitical changes with significant implications for science and technology. To name just a few: the Arab Spring in 2011; the nuclear deal with Iran in 2015; and the creation of the Association of Southeast Asian Nations (ASEAN) Economic Community in 2015.

At first sight, many of these developments have little to do with science and technology but their indirect impact has often been significant. In Egypt, for instance, there has been a radical change in STI policy since the Arab Spring. The new government considers the pursuit of a knowledge economy as being the best way to harness an effective growth engine. The Constitution adopted in 2014 mandates the state to allocate 1% of GDP to research and development (R&D) and stipulates that the 'state guarantees the freedom of scientific research and encourages its institutions as a means towards achieving national sovereignty and building a knowledge economy that supports researchers and inventors' (Chapter 17).

In Tunisia, there has been greater academic freedom in the past year and scientists have been developing closer international ties; Libya, on the other hand, is confronted with a militant insurgency, offering little hope of a rapid revival of science and technology. Syria is in the throes of a civil war. Porous political borders resulting from the political upheaval of the Arab Spring have, meanwhile, allowed opportunistic terrorist groups to prosper. These hyper-violent militias not only pose a threat to political stability; they also undermine national aspirations towards a knowledge economy, for they are inherently hostile to enlightenment, in general, and the education of girls and women, in particular. The tentacles of this obscurantism now stretch as far south as Nigeria and Kenya (Chapters 18 and 19).

Meanwhile, countries emerging from armed conflict are modernizing infrastructure (railways, ports, etc) and fostering industrial development, environmental sustainability and education to facilitate national reconciliation and revive the economy, as in Côte d'Ivoire and Sri Lanka (Chapters 18 and 21).

The nuclear deal concluded in 2015 could be a turning point for science in Iran but, as Chapter 15 observes, international sanctions have already incited the regime to accelerate the transition to a knowledge economy, in order to compensate for lost oil revenue and international isolation by developing local products and processes. The flow of revenue from the lifting of sanctions should give the government an opportunity to boost investment in R&D, which accounted for just 0.31% of GDP in 2010.

Meanwhile, the Association of South East Asian Nations (ASEAN) intends to transform this vast region into a common market and production base with the creation of the ASEAN Economic Community by the end of 2015. The planned removal of restrictions to the cross-border movement of people and services is expected to spur co-operation in science and technology and thereby reinforce the emerging Asia–Pacific knowledge hub. The greater mobility of skilled personnel should be a boon for the region and enhance the role of the ASEAN University Network, which already counts 30 members. As part of the negotiating process for the ASEAN Economic Community, each member state may express its preference for a specific research focus. The Laotian government, for instance, hopes to prioritize agriculture and renewable energy (Chapter 27).

In sub-Saharan Africa, too, regional economic communities are playing a growing role in the region's scientific integration, as the continent prepares the groundwork for its own African Economic Community by 2028. Both the Economic Community of West African States and the Southern African Development Community (SADC) have adopted regional strategies for STI in recent years that complement the continent's decadal plans.[1] The East African Community (EAC) has entrusted the Inter-University Council for East Africa with the mission of developing a Common Higher Education Area. The ongoing development of networks of centres of excellence across the continent should foster greater scientific mobility and information-sharing, as long as obstacles to the mobility of scientists can be removed. The decision by Kenya, Rwanda and Uganda in 2014 to adopt a single tourist visa is a step in the right direction.

It will be interesting to see the extent to which the new Union of South American Nations (UNASUR) fosters regional scientific integration in the years to come. Modelled on the European Union (EU), UNASUR plans to establish a common parliament and currency for its 12 members and to foster the free movement of goods, services, capital and people around the subcontinent (Chapter 7).

Environmental crises raising expectations of science

Environmental crises, be they natural or human-made, have also influenced STI policy and governance in the past five years. The shockwaves from the Fukushima nuclear disaster in March 2011 carried far beyond Japan's shores. The disaster prompted Germany to commit to phasing out nuclear energy by 2020 and fostered debate in other countries on the risks of nuclear energy. In Japan itself, the triple catastrophe[2] made a tremendous impact on Japanese society. Official statistics show that the tragedy of 2011 has shaken the public's trust not only in nuclear technology but in science and technology more broadly (Chapter 24).

It doesn't tend to make the headlines but growing concern over recurrent drought, flooding and other natural phenomena have led governments to adopt coping strategies in the past five years. Cambodia, for instance, has adopted a *Climate Change Strategy* (2014–2023) with the assistance of European development partners to protect its agriculture. In 2013, the Philippines was hit by possibly the strongest tropical cyclone ever to make landfall. The country has been investing heavily in tools to mitigate disaster risk, such as 3D disaster-simulation models, and building local capability to apply, replicate and produce many of these technologies (Chapter 27). The biggest single US economy, the State of California, has been experiencing drought for years; in April 2015, the state governor announced a 40% carbon emissions reduction target by 2030 over 1990 levels (Chapter 5).

Angola, Malawi and Namibia have all experienced below-normal rainfall in recent years that has affected food security. In 2013, ministers from the SADC approved the development of a Regional Climate Change programme. In addition, the Common Market for Eastern and Southern Africa (COMESA), EAC and SADC have been implementing a joint five-year initiative since 2010 known as the Tripartite Programme on Climate Change Adaptation and Mitigation (Chapter 20).

In Africa, agriculture continues to suffer from poor land management and low investment. Despite the continent's commitment, in the *Maputo Declaration* (2003), to devoting at least 10% of GDP to agriculture, only a handful of countries have since reached this target (see Table 19.2). Agricultural R&D suffers as a consequence. There have been moves, however, to reinforce R&D. For instance, Botswana established an innovative hub in 2008 to foster the commercialization and diversification of agriculture and Zimbabwe is planning to establish two new universities of agricultural science and technology (Chapter 20).

Energy has become a major preoccupation

The EU, USA, China, Japan, the Republic of Korea and others have all toughened national legislation in recent years to reduce their own carbon emissions, develop alternative energy sources and promote greater energy efficiency. Energy has become a major preoccupation of governments everywhere, including oil-rent economies like Algeria and Saudi Arabia that are now investing in solar energy to diversify their energy mix.

This trend was evident even before Brent crude oil prices began their downward spiral in mid-2014. Algeria's Renewable Energy and Energy Efficiency Programme was adopted in March 2011, for instance, and has since approved more than 60 wind and solar energy projects. Gabon's *Strategic Plan* to 2025 (2012) states that setting the country on the path to sustainable development 'is at the heart of the new executive's policy'. The plan identifies the need to diversify an economy dominated by oil (84% of exports in 2012), foresees a national climate plan and fixes the target of raising the share of hydropower in Gabon's electricity matrix from 40% in 2010 to 80% by 2020 (Chapter 19).

A number of countries are developing futuristic, hyper-connected 'smart' cities (such as China) or 'green' cities which use the latest technology to improve efficiency in water and energy use, construction, transportation and so on, examples being Gabon, Morocco and the United Arab Emirates (Chapter 17).

If sustainability is a primary concern for most governments, some are swimming against the tide. The Australian government, for instance, has shelved the country's carbon

1. Namely, *Africa's Science and Technology Consolidated Plan of Action* (2005–2014) and its successor, the *Science, Technology and Innovation Strategy for Africa* (STISA–2024)

2. A subterranean earthquake generated a tsunami that swamped the Fukushima nuclear plant, cutting off the power supply to its cooling system, causing the nuclear rods to overheat and sparking multiple explosions which released radioactive particles into the air and water.

tax and announced plans to abolish institutions instigated by the previous government[3] to stimulate technological development in the renewable energy sector (Chapter 27).

The quest for a growth strategy that works

Overall, the years 2009–2014 have been a difficult transition period. Ushered in by the global financial crisis of 2008, this transition has been marked by a severe debt crisis in the wealthier countries, uncertainty over the strength of the ensuing recovery and the quest for an effective growth strategy. Many high-income countries are faced with similar challenges, such as an ageing society (USA, EU, Japan, etc.) and chronic low growth (Table 1.1); all are confronted with tough international competition. Even those countries that are doing well, such as Israel and the Republic of Korea, fret over how to maintain their edge in a rapidly evolving world.

In the USA, the Obama administration has made investment in climate change research, energy and health a priority but much of its growth strategy has been contraried by the congressional priority of reducing the federal budget deficit. Most federal research budgets have remained flat or declined in inflation-adjusted dollars over the past five years (Chapter 5).

In 2010, the EU adopted its own growth strategy, *Europe 2020*, to help the region emerge from the crisis by embracing smart, sustainable and inclusive growth. The strategy observed that 'the crisis has wiped out years of economic and social progress and exposed structural weaknesses in Europe's economy'. These structural weaknesses include low R&D spending, market barriers and insufficient use of information and communication technologies (ICTs). *Horizon 2020*, the EU's current seven-year framework programme for research and innovation, has received the biggest budget ever in order to drive this agenda between 2014 and 2020. The *2020 Strategy* adopted by Southeast Europe mirrors that of its EU namesake but, in this case, the primary aim of this growth strategy is to prepare countries for their future accession to the EU.

Japan is one of the world's big spenders on R&D (Figure 1.1) but its self-confidence has been shaken in recent years, not only by the triple catastrophe in 2011 but also by the failure to shake off the deflation that has stifled the economy for the past 20 years. Japan's current growth strategy, Abenomics, dates from 2013 and has not yet delivered on its promise of faster growth. The effects of a low-growth equilibrium on investor confidence are visible in the reluctance of Japanese firms to raise R&D spending or staff salaries and in their aversion to the necessary risk-taking to launch a new growth cycle.

The Republic of Korea is seeking its own growth strategy. Although it came through the global financial crisis remarkably unscathed, it has outgrown its 'catch-up model.' Competition with China and Japan is intense, exports are slipping and global demand is evolving towards green growth. Like Japan, it is faced with a rapidly ageing population and declining birthrates that challenge its long-term economic development prospects. The Park Geun-hye administration is pursuing her predecessor's goal of 'low carbon, green growth' but also emphasizing the 'creative economy,' in an effort to revitalize the manufacturing sector through the emergence of new creative industries. Up until now, the Republic of Korea has relied on large conglomerates such as Hyundai (vehicles) and Samsung (electronics) to drive growth and export earnings. Now, it is striving to become more entrepreneurial and creative, a process that will entail changing the very structure of the economy – and the very bases of science education.

Among the BRICS (Brazil, Russian Federation, India, China and South Africa), China has managed to dodge the fallout from the 2008 global financial and economic crisis but its economy was showing signs of strain[4] in mid-2015. Up until now, China has relied upon public expenditure to drive growth but, with investor confidence faltering in August 2015, China's desired switch from export-orientation to more consumption-driven growth has been thrown into doubt. There is also some concern among the political leadership that the massive investment in R&D over the past decade is not being matched by scientific output. China, too, is in search of an effective growth strategy.

By maintaining a strong demand for commodities to fuel its rapid growth, China has buffeted resource-exporting economies since 2008 from the drop in demand from North America and the EU. Ultimately, however, the cyclical boom in commodities has come to an end, revealing structural weaknesses in Brazil and the Russian Federation, in particular.

In the past year, Brazil has entered into recession. Although the country has expanded access to higher education in recent years and raised social spending, labour productivity remains low. This suggests that Brazil has, so far, not managed to harness innovation to economic growth, a problem shared by the Russian Federation.

The Russian Federation is searching for its own growth strategy. In May 2014, President Putin called for a widening of Russian import substitution programmes to reduce the country's dependence on technological imports. Action plans have since been launched in various industrial sectors to produce cutting-edge technologies. However, the government's plans to stimulate business innovation may be

3. namely the Australian Renewable Energy Agency and the Clean Energy Finance Corporation

4. The Chinese economy grew by 7.4% in 2014 and is projected to grow by 6.8% in 2015 but there is growing uncertainty as to whether it will achieve this target.

contraried by the current recession, following the downturn in Brent crude oil prices, the imposition of sanctions and a deteriorating business climate.

Meanwhile, in India, growth has remained at the respectable level of about 5% in the past few years but there are concerns that economic growth is not creating enough jobs. Today, India's economy is dominated by the services sector (57% of GDP). The Modi government elected in 2014 has argued for a new economic model based on export-oriented manufacturing to foster job creation. India is already becoming a hub for frugal innovation, thanks to the large domestic market for pro-poor products and services such as low-cost medical devices and cheap cars.

With the end of the commodities boom, Latin America is, itself, in search of a new growth strategy. Over the past decade, the region has reduced its exceptionally high levels of economic inequality but, as global demand for raw materials has fallen, Latin America's own growth rates have begun stagnating or even contracting in some cases. Latin American countries are not lacking in policy initiatives or in the sophistication of institutional structures to promote science and research (Chapter 7). Countries have made great strides in terms of access to higher education, scientific mobility and output. Few, however, appear to have used the commodities boom to embrace technology-driven competitiveness. Looking ahead, the region may be well placed to develop the type of scientific excellence that can underpin green growth by combining its natural advantages in biological diversity and its strengths with regard to indigenous (traditional) knowledge systems.

The long-term planning documents to 2020 or 2030 of many low- and middle-income countries also reflect the quest for a growth strategy able to carry them into a higher income bracket. These 'vision' documents tend to have a triple focus: better governance, in order to improve the business environment and attract foreign investment to develop a dynamic private sector; more inclusive growth, to reduce poverty levels and inequality; and environmental sustainability, to protect the natural resources on which most of these economies depend for foreign exchange.

GLOBAL TRENDS IN R&D EXPENDITURE

How has the crisis affected R&D investment?

The *UNESCO Science Report 2010* was written in the immediate aftermath of the global financial crisis. Its coverage encompassed a period of historically unmatched global economic growth between 2002 and 2007. It was also forward-looking. One question it addressed was the extent to which the global crisis might be bad for global knowledge creation. The conclusion that global investment in R&D would not be that strongly affected by t he crisis appears, with hindsight, to have been spot on.

In 2013, world GERD amounted to PPP$ 1 478 billion, compared to only PPP$ 1 132 billion in 2007[5]. This was less than the 47% increase recorded over the previous period (2002–2007) but a significant increase nevertheless. Moreover, this rise took place during a time of crisis. As GERD progressed much faster than global GDP, this caused global R&D intensity to climb from 1.57% (2007) to 1.70% (2013) of GDP (Tables 1.1 and 1.2).

As argued in the *UNESCO Science Report 2010*, Asia, in general, and China, in particular, were the first to recover from the crisis, pulling global R&D investment relatively quickly to higher levels.[6] In other emerging economies such as Brazil and India, the rise in R&D intensity took longer to kick in.

Similarly, the prediction that both the USA and EU would be able to maintain their own R&D intensity at pre-crisis levels was not only correct but even too conservative a prediction. The Triad (EU, Japan and USA) have all seen GERD rise over the past five years to levels well above those of 2007, unlike Canada.

Public research budgets: a converging, yet contrasting picture

The past five years have seen a converging trend: disengagement in R&D by the public sector in many high-income countries (Australia, Canada, USA, etc.) and a growing investment in R&D on the part of lower income countries. In Africa, for instance, Ethiopia has used some of the fastest growth rates on the continent to raise GERD from 0.24% (2009) to 0.61% (2013) of GDP. Malawi has raised its own ratio to 1.06% and Uganda to 0.48% (2010), up from 0.33% in 2008. There is a growing recognition in Africa and beyond that the development of modern infrastructure (hospitals, roads, railways, etc.) and the achievement of economic diversification and industrialization will necessitate greater investment in STI, including the constitution of a critical mass of skilled workers.

Spending on R&D is on the rise in many East and Central African countries with innovation hubs (Cameroon, Kenya, Rwanda, Uganda, etc.), driven by greater investment by both the public and private sectors (Chapter 19). The sources of Africa's heightened interest in STI are multiple but the global financial crisis of 2008–2009 certainly played a role. It boosted commodity prices and focused attention on beneficiation policies in Africa.

5. PPP stands for purchasing power parity.

6. China's R&D intensity more than doubled between 2007 and 2013 to 2.08. This is above the EU average and means that China is on track to achieve its target of a 2.5% GERD/GDP ratio by 2020.

Table 1.1: **World trends in population and GDP**

	Population (in millions)		Share of global population (%)		GDP in constant 2005 PPP$ billions				Share of global GDP (%)			
	2007	2013	2007	2013	2007	2009	2011	2013	2007	2009	2011	2013
World	**6 673.1**	**7 162.1**	**100.0**	**100.0**	**72 198.1**	**74 176.0**	**81 166.9**	**86 674.3**	**100.0**	**100.0**	**100.0**	**100.0**
High-income economies	1 264.1	1 309.2	18.9	18.3	41 684.3	40 622.2	42 868.1	44 234.6	57.7	54.8	52.8	51.0
Upper-middle-income economies	2 322.0	2 442.1	34.8	34.1	19 929.7	21 904.3	25 098.5	27 792.6	27.6	29.5	30.9	32.1
Lower-middle-income economies	2 340.7	2 560.4	35.1	35.7	9 564.7	10 524.5	11 926.1	13 206.4	13.2	14.2	14.7	15.2
Low-income economies	746.3	850.3	11.2	11.9	1 019.4	1 125.0	1 274.2	1 440.7	1.4	1.5	1.6	1.7
Americas	**913.0**	**971.9**	**13.7**	**13.6**	**21 381.6**	**21 110.0**	**22 416.8**	**23 501.5**	**29.6**	**28.5**	**27.6**	**27.1**
North America	336.8	355.3	5.0	5.0	14 901.4	14 464.1	15 088.7	15 770.5	20.6	19.5	18.6	18.2
Latin America	535.4	574.1	8.0	8.0	6 011.0	6 170.4	6 838.5	7 224.7	8.3	8.3	8.4	8.3
Caribbean	40.8	42.5	0.6	0.6	469.2	475.5	489.6	506.4	0.6	0.6	0.6	0.6
Europe	**806.5**	**818.6**	**12.1**	**11.4**	**18 747.3**	**18 075.1**	**19 024.5**	**19 177.9**	**26.0**	**24.4**	**23.4**	**22.1**
European Union	500.8	509.5	7.5	7.1	14 700.7	14 156.7	14 703.8	14 659.5	20.4	19.1	18.1	16.9
Southeast Europe	19.6	19.2	0.3	0.3	145.7	151.0	155.9	158.8	0.2	0.2	0.2	0.2
European Free Trade Association	12.6	13.5	0.2	0.2	558.8	555.0	574.3	593.2	0.8	0.7	0.7	0.7
Other Europe	273.6	276.4	4.1	3.9	3 342.0	3 212.3	3 590.5	3 766.4	4.6	4.3	4.4	4.3
Africa	**957.3**	**1 110.6**	**14.3**	**15.5**	**3 555.7**	**3 861.4**	**4 109.8**	**4 458.4**	**4.9**	**5.2**	**5.1**	**5.1**
Sub-Saharan Africa	764.7	897.3	11.5	12.5	2 020.0	2 194.3	2 441.8	2 678.5	2.8	3.0	3.0	3.1
Arab States in Africa	192.6	213.3	2.9	3.0	1 535.8	1 667.1	1 668.0	1 779.9	2.1	2.2	2.1	2.1
Asia	**3 961.5**	**4 222.6**	**59.4**	**59.0**	**27 672.8**	**30 248.0**	**34 695.7**	**38 558.5**	**38.3**	**40.8**	**42.7**	**44.5**
Central Asia	61.8	67.2	0.9	0.9	408.9	446.5	521.2	595.4	0.6	0.6	0.6	0.7
Arab States in Asia	122.0	145.2	1.8	2.0	2 450.0	2 664.0	3 005.2	3 308.3	3.4	3.6	3.7	3.8
West Asia	94.9	101.9	1.4	1.4	1 274.2	1 347.0	1 467.0	1 464.1	1.8	1.8	1.8	1.7
South Asia	1 543.1	1 671.6	23.1	23.3	5 016.1	5 599.2	6 476.8	7 251.4	6.9	7.5	8.0	8.4
Southeast Asia	2 139.7	2 236.8	32.1	31.2	18 523.6	20 191.3	23 225.4	25 939.3	25.7	27.2	28.6	29.9
Oceania	**34.8**	**38.3**	**0.5**	**0.5**	**840.7**	**881.5**	**920.2**	**978.0**	**1.2**	**1.2**	**1.1**	**1.1**
Other groupings												
Least developed countries	783.4	898.2	11.7	12.5	1 327.2	1 474.1	1 617.9	1 783.6	1.8	2.0	2.0	2.1
Arab States all	314.6	358.5	4.7	5.0	3 985.7	4 331.1	4 673.2	5 088.2	5.5	5.8	5.8	5.9
OECD	1 216.3	1 265.2	18.2	17.7	38 521.2	37 306.1	39 155.4	40 245.7	53.4	50.3	48.2	46.4
G20	4 389.5	4 615.5	65.8	64.4	57 908.7	59 135.1	64 714.6	68 896.8	80.2	79.7	79.7	79.5
Selected countries												
Argentina	39.3	41.4	0.6	0.6	631.8	651.7	772.1	802.2	0.9	0.9	1.0	0.9
Brazil	190.0	200.4	2.8	2.8	2 165.3	2 269.8	2 507.5	2 596.5	3.0	3.1	3.1	3.0
Canada	33.0	35.2	0.5	0.5	1 216.8	1 197.7	1 269.4	1 317.2	1.7	1.6	1.6	1.5
China	1 334.3	1 385.6	20.0	19.3	8 313.0	9 953.6	12 015.9	13 927.7	11.5	13.4	14.8	16.1
Egypt	74.2	82.1	1.1	1.1	626.0	702.1	751.3	784.2	0.9	0.9	0.9	0.9
France	62.2	64.3	0.9	0.9	2 011.1	1 955.7	2 035.6	2 048.3	2.8	2.6	2.5	2.4
Germany	83.6	82.7	1.3	1.2	2 838.9	2 707.0	2 918.9	2 933.0	3.9	3.6	3.6	3.4
India	1 159.1	1 252.1	17.4	17.5	3 927.4	4 426.2	5 204.3	5 846.1	5.4	6.0	6.4	6.7
Iran	71.8	77.4	1.1	1.1	940.5	983.3	1 072.4	1 040.5	1.3	1.3	1.3	1.2
Israel	6.9	7.7	0.1	0.1	191.7	202.2	222.7	236.9	0.3	0.3	0.3	0.3
Japan	127.2	127.1	1.9	1.8	4 042.1	3 779.0	3 936.8	4 070.5	5.6	5.1	4.9	4.7
Malaysia	26.8	29.7	0.4	0.4	463.0	478.0	540.2	597.7	0.6	0.6	0.7	0.7
Mexico	113.5	122.3	1.7	1.7	1 434.8	1 386.5	1 516.3	1 593.6	2.0	1.9	1.9	1.8
Republic of Korea	47.6	49.3	0.7	0.7	1 293.2	1 339.2	1 478.8	1 557.6	1.8	1.8	1.8	1.8
Russian Federation	143.7	142.8	2.2	2.0	1 991.7	1 932.3	2 105.4	2 206.5	2.8	2.6	2.6	2.5
South Africa	49.6	52.8	0.7	0.7	522.1	530.5	564.2	589.4	0.7	0.7	0.7	0.7
Turkey	69.5	74.9	1.0	1.0	874.1	837.4	994.3	1 057.3	1.2	1.1	1.2	1.2
United Kingdom	61.0	63.1	0.9	0.9	2 203.7	2 101.7	2 177.1	2 229.4	3.1	2.8	2.7	2.6
United States of America	303.8	320.1	4.6	4.5	13 681.1	13 263.0	13 816.1	14 450.3	18.9	17.9	17.0	16.7

Source: World Bank's World Development Indicators, April 2015; and estimations by UNESCO Institute for Statistics; United Nations Department of Economic and Social Affairs, Population Division (2013) *World Population Prospects: the 2012 Revision*

Table 1.2: **World shares of expenditure on R&D, 2007, 2009, 2011 and 2013**

	GERD (in PPP$ billions)				Share of world GERD (%)			
	2007	2009	2011	2013	2007	2009	2011	2013
World	**1 132.3**	**1 225.5**	**1 340.2**	**1 477.7**	**100.0**	**100.0**	**100.0**	**100.0**
High-income economies	902.4	926.7	972.8	1 024.0	79.7	75.6	72.6	69.3
Upper middle-income economies	181.8	243.9	303.9	381.8	16.1	19.9	22.7	25.8
Lower middle-income economies	46.2	52.5	60.2	68.0	4.1	4.3	4.5	4.6
Low-income economies	1.9	2.5	3.2	3.9	0.2	0.2	0.2	0.3
Americas	**419.8**	**438.3**	**451.6**	**478.8**	**37.1**	**35.8**	**33.7**	**32.4**
North America	382.7	396.5	404.8	427.0	33.8	32.4	30.2	28.9
Latin America	35.5	39.8	45.6	50.1	3.1	3.3	3.4	3.4
Caribbean	1.6	2.0	1.3	1.7	0.1	0.2	0.1	0.1
Europe	**297.1**	**311.6**	**327.5**	**335.7**	**26.2**	**25.4**	**24.4**	**22.7**
European Union	251.3	262.8	278.0	282.0	22.2	21.4	20.7	19.1
Southeast Europe	0.5	0.8	0.7	0.8	0.0	0.1	0.1	0.1
European Free Trade Association	12.6	13.1	13.7	14.5	1.1	1.1	1.0	1.0
Other Europe	32.7	34.8	35.0	38.5	2.9	2.8	2.6	2.6
Africa	**12.9**	**15.5**	**17.1**	**19.9**	**1.1**	**1.3**	**1.3**	**1.3**
Sub-Saharan Africa	8.4	9.2	10.0	11.1	0.7	0.7	0.7	0.8
Arab States in Africa	4.5	6.4	7.1	8.8	0.4	0.5	0.5	0.6
Asia	**384.9**	**440.7**	**524.8**	**622.9**	**34.0**	**36.0**	**39.2**	**42.2**
Central Asia	0.8	1.1	1.0	1.4	0.1	0.1	0.1	0.1
Arab States in Asia	4.3	5.0	5.6	6.7	0.4	0.4	0.4	0.5
West Asia	15.5	16.1	17.5	18.1	1.4	1.3	1.3	1.2
South Asia	35.4	39.6	45.7	50.9	3.1	3.2	3.4	3.4
Southeast Asia	328.8	378.8	455.1	545.8	29.0	30.9	34.0	36.9
Oceania	**17.6**	**19.4**	**19.1**	**20.3**	**1.6**	**1.6**	**1.4**	**1.4**
Other groupings								
Least developed countries	2.7	3.1	3.7	4.4	0.2	0.3	0.3	0.3
Arab States all	8.8	11.4	12.7	15.4	0.8	0.9	0.9	1.0
OECD	860.8	882.2	926.1	975.6	76.0	72.0	69.1	66.0
G20	1 042.6	1 127.0	1 231.1	1 358.5	92.1	92.0	91.9	91.9
Selected countries								
Argentina	2.5	3.1	4.0	4.6^{-1}	0.2	0.3	0.3	0.3^{-1}
Brazil	23.9	26.1	30.2	31.3^{-1}	2.1	2.1	2.3	2.2^{-1}
Canada	23.3	23.0	22.7	21.5	2.1	1.9	1.7	1.5
China	116.0	169.4^{b}	220.6	290.1	10.2	13.8^{b}	16.5	19.6
Egypt	1.6	3.0^{b}	4.0	5.3	0.1	0.2^{b}	0.3	0.4
France	40.6	43.2	44.6^{b}	45.7	3.6	3.5	3.3^{b}	3.1
Germany	69.5	73.8	81.7	83.7	6.1	6.0	6.1	5.7
India	31.1	36.2	42.8	–	2.7	3.0	3.2	–
Iran	7.1^{+1}	3.1^{b}	3.2^{-1}	–	0.6^{+1}	0.3^{b}	0.3^{-1}	–
Israel	8.6	8.4	9.1	10.0	0.8	0.7	0.7	0.7
Japan	139.9	126.9^{b}	133.2	141.4	12.4	10.4^{b}	9.9	9.6
Malaysia	2.7^{-1}	4.8^{b}	5.7	6.4^{-1}	0.3^{+1}	0.4^{b}	0.4	0.5^{-1}
Mexico	5.3	6.0	6.4	7.9	0.5	0.5	0.5	0.5
Republic of Korea	38.8	44.1	55.4	64.7	3.4	3.6	4.1	4.4
Russian Federation	22.2	24.2	23.0	24.8	2.0	2.0	1.7	1.7
South Africa	4.6	4.4	4.1	4.2^{-1}	0.4	0.4	0.3	0.3^{-1}
Turkey	6.3	7.1	8.5	10.0	0.6	0.6	0.6	0.7
United Kingdom	37.2	36.7	36.8	36.2	3.3	3.0	2.7	2.5
United States of America	359.4	373.5	382.1	396.7^{-1}	31.7	30.5	28.5	28.1^{-1}

-n/+n = data are for n years before or after reference year

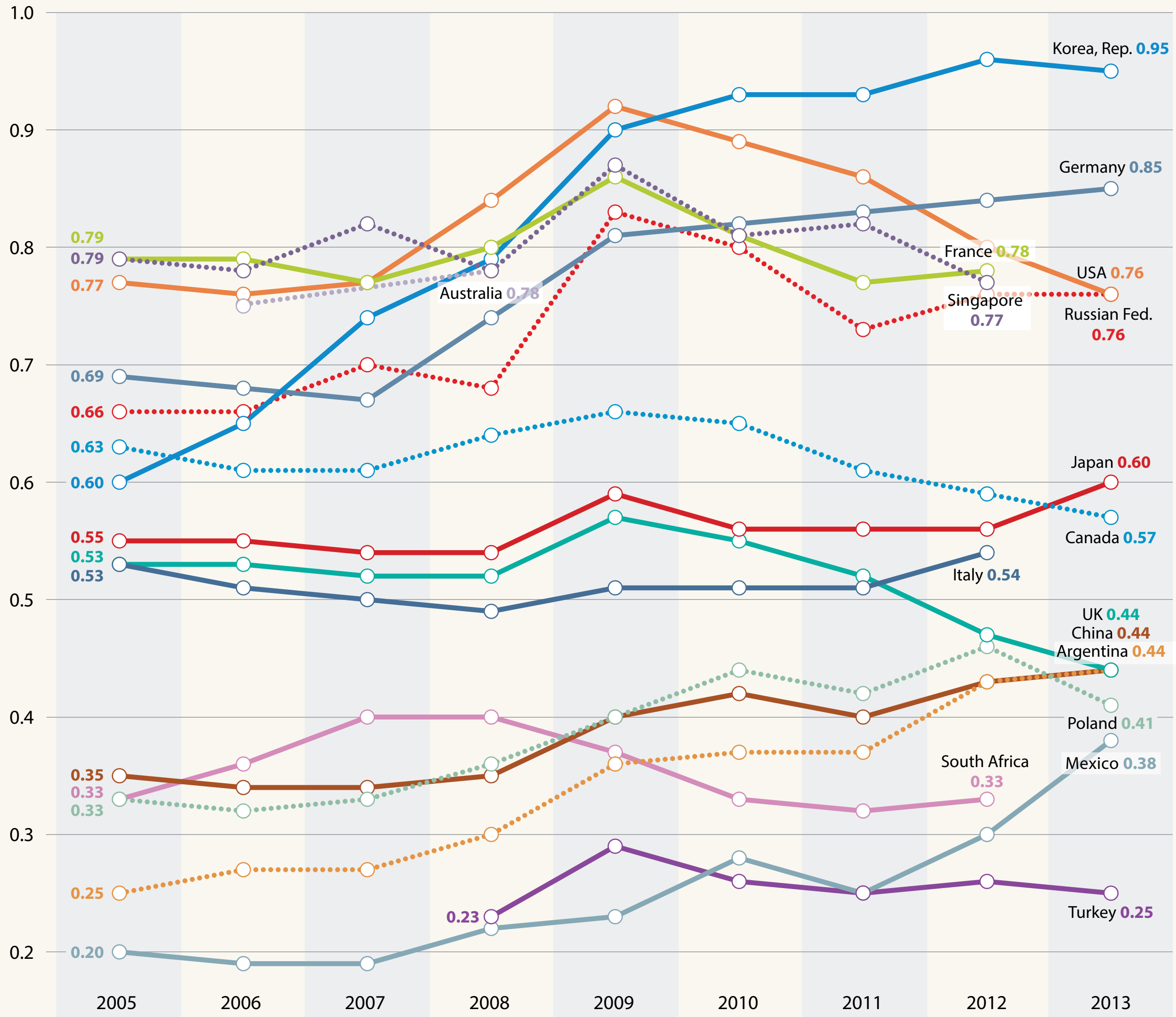
b: break in series with previous year for which data are shown

Note: GERD figures are in PPP$ (constant prices – 2005). Many of the underlying data are estimated by the UNESCO Institute for Statistics for developing countries, in particular. Furthermore in a substantial number of developing countries data do not cover all sectors of the economy.

	GERD as share of GDP (%)				GERD per capita (in PPP$)				GERD per researcher (PPP$ thousands)			
	2007	2009	2011	2013	2007	2009	2011	2013	2007	2009	2011	2013
	1.57	**1.65**	**1.65**	**1.70**	**169.7**	**179.3**	**191.5**	**206.3**	**176.9**	**177.6**	**182.3**	**190.4**
	2.16	2.28	2.27	2.31	713.8	723.2	750.4	782.1	203.0	199.1	201.7	205.1
	0.91	1.11	1.21	1.37	78.3	103.3	126.6	156.4	126.1	142.7	155.7	176.1
	0.48	0.50	0.50	0.51	19.7	21.8	24.2	26.6	105.0	115.9	126.0	137.7
	0.19	0.22	0.25	0.27	2.6	3.1	3.9	4.5	26.2	28.7	32.9	37.6
	1.96	**2.08**	**2.01**	**2.04**	**459.8**	**469.9**	**474.2**	**492.7**	**276.8**	**264.6**	**266.3**	**278.1**
	2.57	2.74	2.68	2.71	1 136.2	1 154.9	1 158.3	1 201.8	297.9	283.0	285.9	297.9
	0.59	0.65	0.67	0.69	66.3	72.7	81.2	87.2	159.5	162.1	168.2	178.9
	0.33	0.41	0.26	0.34	38.5	47.6	30.5	40.8	172.9	202.0	138.4	203.1
	1.58	**1.72**	**1.72**	**1.75**	**368.3**	**384.0**	**401.6**	**410.1**	**139.8**	**141.3**	**142.6**	**139.4**
	1.71	1.86	1.89	1.92	501.9	521.3	548.2	553.5	172.4	169.1	171.2	163.4
	0.31	0.56	0.47	0.51	23.0	43.5	38.2	42.4	40.0	65.9	52.0	54.9
	2.25	2.36	2.39	2.44	995.1	1 014.4	1 038.8	1 072.0	242.0	231.0	218.4	215.2
	0.98	1.08	0.98	1.02	119.5	126.6	127.0	139.2	54.1	59.8	58.8	64.1
	0.36	**0.40**	**0.42**	**0.45**	**13.5**	**15.5**	**16.2**	**17.9**	**86.2**	**101.8**	**98.6**	**106.1**
	0.42	0.42	0.41	0.41	11.0	11.4	11.7	12.4	143.5	132.2	129.4	135.6
	0.29	0.38	0.43	0.49	23.4	32.0	34.5	41.2	49.3	76.5	73.8	83.3
	1.39	**1.46**	**1.51**	**1.62**	**97.2**	**108.8**	**126.9**	**147.5**	**154.1**	**159.0**	**171.3**	**187.7**
	0.20	0.24	0.20	0.23	13.4	16.9	15.7	20.7	38.2	42.7	39.2	41.5
	0.18	0.19	0.18	0.20	35.5	38.5	40.2	45.9	137.2	141.3	136.4	151.3
	1.22	1.20	1.19	1.24	163.3	166.2	176.1	178.1	133.4	135.4	141.0	132.6
	0.71	0.71	0.70	0.70	23.0	25.0	28.0	30.5	171.8	177.3	195.9	210.0
	1.78	1.88	1.96	2.10	153.7	174.4	206.5	244.0	154.9	160.0	172.4	190.8
	2.09	**2.20**	**2.07**	**2.07**	**505.7**	**537.5**	**512.0**	**528.7**	**159.3**	**166.1**	**158.7**	**164.3**
	0.20	0.21	0.23	0.24	3.4	3.8	4.3	4.8	59.0	61.4	66.4	74.1
	0.22	0.26	0.27	0.30	28.1	34.6	36.8	43.1	71.9	95.9	92.4	103.3
	2.23	2.36	2.37	2.42	707.7	715.1	740.8	771.2	220.8	213.7	215.7	217.7
	1.80	1.91	1.90	1.97	237.5	252.3	271.1	294.3	186.0	186.5	192.5	201.5
	0.40	0.48	0.52	0.58^{-1}	64.5	78.6	98.1	110.7^{-1}	65.6	72.0	79.4	88.2^{-1}
	1.11	1.15	1.20	1.15^{-1}	126.0	135.0	153.3	157.5^{-1}	205.8	202.4	210.5^{-1}	–
	1.92	1.92	1.79	1.63	707.5	682.3	658.5	612.0	154.2	153.3	139.2	141.9^{-1}
	1.40	1.70^{b}	1.84	2.08	87.0	125.4^{b}	161.2	209.3	–*	147.0^{b}	167.4	195.4
	0.26	0.43^{b}	0.53	0.68	21.5	39.6^{b}	50.3	64.8	32.4	86.5^{b}	96.1	111.6
	2.02	2.21	2.19^{b}	2.23	653.0	687.0	701.4	710.8	183.1	184.3	178.9^{b}	172.3
	2.45	2.73	2.80	2.85	832.0	887.7	985.0	1 011.7	239.1	232.7	241.1	232.3
	0.79	0.82	0.82	–	26.8	30.5	35.0	–	171.4^{-2}	–	201.8^{-1}	–
	0.75^{+1}	0.31^{b}	0.31^{-1}	–	97.5^{+1}	41.8^{b}	43.0	–	130.5^{+1}	58.9^{b}	58.4^{-1}	–
	4.48	4.15	4.10	4.21	1 238.9	1 154.1	1 211.4	1 290.5	–	–	165.6	152.9^{-1}
	3.46	3.36^{b}	3.38	3.47	1 099.5	996.2^{b}	1 046.1	1 112.2	204.5	193.5^{b}	202.8	214.1
	0.61^{-1}	1.01^{b}	1.06	1.13^{-1}	101.1^{1}	173.7^{b}	199.9	219.9^{-1}	274.6^{-1}	163.1^{b}	121.7	123.5^{-1}
	0.37	0.43	0.42	0.50	46.6	51.3	54.0	65.0	139.3	138.9	139.7	–
	3.00	3.29	3.74	4.15	815.6	915.7	1 136.0	1 312.7	174.8	180.7	191.6	200.9
	1.12	1.25	1.09	1.12	154.7	168.4	160.1	173.5	47.4	54.7	51.3	56.3
	0.88	0.84	0.73	0.73^{-1}	92.9	87.1	79.7	80.5^{-1}	238.6	224.0	205.9	197.3^{-1}
	0.72	0.85	0.86	0.95	90.9	99.8	117.0	133.5	127.1	123.1	118.5	112.3
	1.69	1.75	1.69	1.63	610.1	594.4	590.3	573.8	147.2	143.2	146.6	139.7
	2.63	2.82	2.77	2.81^{-1}	1 183.0	1 206.7	1 213.3	$1 249.3^{-1}$	317.0	298.5	304.9	313.6^{-1}

Source: estimations by UNESCO Institute for Statistics, July 2015; for Brazilian GERD/GDP ratio in 2012: Brazilian Ministry of Science, Technology and Innovation

Figure 1.1: **GERD financed by government as a share of GDP, 2005–2013 (%)**



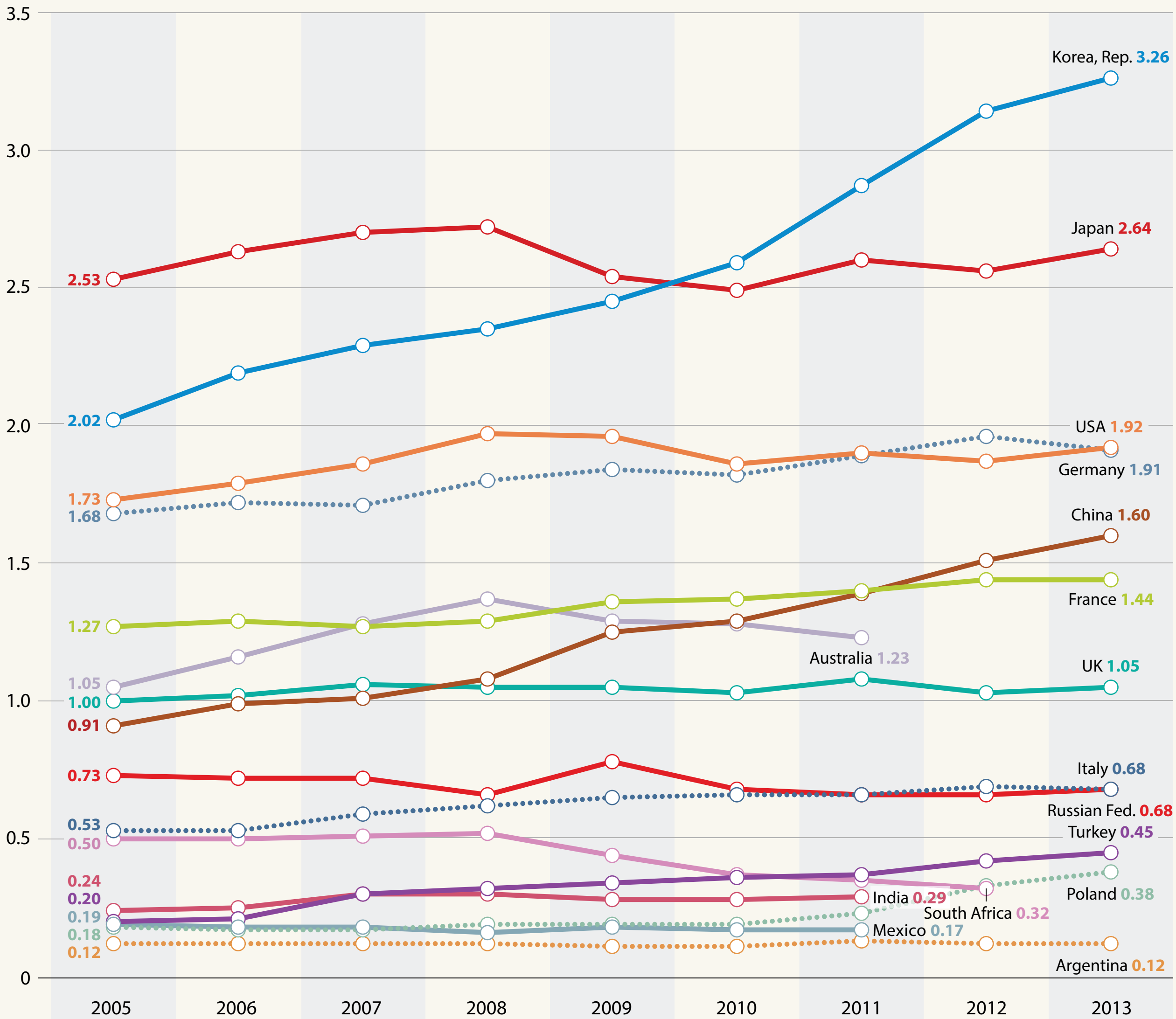
Source: OECD's Main Science and Technology Indicators, September 2015

The global crisis also provoked a reversal in brain drain in some parts of Africa, as visions of Europe and North America struggling with low growth rates and high unemployment discouraged emigration and encouraged some to return home. Returnees are today playing a key role in STI policy formulation, economic development and innovation. Even those who remain abroad are contributing: remittances are now overtaking FDI inflows to Africa (Chapter 19).

The heightened interest in STI is clearly visible in the *Vision 2020* or *2030* planning documents adopted by African countries in recent years. In Kenya, for instance, the Science, Technology and Innovation Act passed in 2013 contributes to the realization of *Kenya Vision 2030*, which foresees the country's transformation into an upper middle-income economy with a skilled labour force by 2030. The act may be a 'game-changer' for Kenya, which has not only created a National Research Fund but also, critically, made provisions for the fund to receive 2% of Kenya's GDP each financial year. This substantial commitment of funds should help Kenya raise its GERD/GDP ratio well above 0.79% (2010).

The BRICS countries present a contrasting picture. In China, public and business funding of R&D have risen in tandem. In India, business R&D has progressed faster than government commitment to R&D. In Brazil, public commitment to R&D has remained more or less stable since 2008, whereas the business enterprise sector has slightly augmented its own effort. Since all firms surveyed in 2013 reported a drop in innovation activity since 2008, this trend will most likely affect spending if the Brazilian economic

Figure 1.2: **GERD performed by business enterprises as a share of GDP, 2005–2013 (%)**



Source: OECD's Main Science and Technology Indicators, September 2015

slowdown persists. In South Africa, there has been a sharp drop in private-sector R&D since the global financial crisis, in spite of rising public spending on R&D. This partly explains why the GERD/GDP ratio shrank from a high of 0.89% in 2008 to 0.73% in 2012.

The high-income countries have been particularly hard hit by the crisis which swept the world in 2008 and 2009. Whereas the US economy is back on an even keel, Japan and the EU are finding recovery an uphill struggle. In Europe, slow economic growth since the financial crisis of 2008 and the ensuing pressures of fiscal consolidation within Eurozone countries have put pressure on public investment in knowledge (Chapter 9), despite the hike in the Horizon 2020 budget. Among EU countries, only Germany was actually in a position to increase its commitment to public R&D over the past five years. France and the UK saw it decline. As in Canada, budgetary pressures on national research budgets have led to significant reductions in government-funded R&D intensity (Figure 1.1). With the notable exception of Canada, this trend is not perceptible in overall R&D expenditure, since the private sector has maintained its own level of spending throughout the crisis (Figures 1.1 and 1.2 and Table 1.2).

In search of an optimal balance between basic and applied science

The great majority of countries now acknowledge the importance of STI for sustaining growth over the longer term. Low and lower-middle income countries hope to use it to raise income levels, wealthier countries to hold their own in an increasingly competitive global marketplace.

The danger is that, in the race to improve national competitiveness, countries may lose sight of the old adage that 'without basic science, there would be no science to apply'. Basic research generates the new knowledge that gives rise to applications, commercial or otherwise. As the author of the chapter on Canada puts it (Chapter 4), 'science powers commerce – but not only.' The question is: what is the optimal balance between basic and applied research?

The Chinese leadership has become dissatisfied with the return on its wider investment in R&D. At the same time, China has opted to devote just 4–6% of research expenditure to basic research over the past decade. In India, universities perform just 4% of GERD. Although India has created an impressive number of universities in recent years, industry has complained about the 'employability' of science and engineering graduates. Basic research not only generates new knowledge; it also contributes to the quality of university education.

In the USA, the federal government specializes in supporting basic research, leaving industry to take the lead in applied research and technological development. There is a risk that the current austerity drive, combined with changing priorities, may affect the USA's long-term capacity to generate new knowledge.

Meanwhile, the USA's northern neighbour is cutting back on federal funding of government science but investing in venture capital, in order to develop business innovation and woo new trading partners. In January 2013, the Canadian government announced its *Venture Capital Action Plan*, a strategy for deploying CAN$ 400 million in new capital over the next 7–10 years to leverage private sector-led investment in the form of venture capital funds.

The Russian Federation has traditionally devoted a large share of GERD to basic research (like South Africa: 24% in 2010). Since the government adopted an innovation-led growth strategy in 2012, a greater share of its appropriation for R&D has been oriented towards the needs of industry. Since funding is finite, this readjustment has occurred to the detriment of basic research, which dropped from 26% to 17% of the total between 2008 and 2013.

The EU has made the opposite calculation. Despite the chronic debt crisis, the European Commission has maintained its commitment to basic research. The European Research Council (est. 2007), the first pan-European funding body for frontier research in basic sciences, has been endowed with € 13.1 billion for the period 2014–2020, equivalent to 17% of Horizon 2020's overall budget.

The Republic of Korea increased its own commitment to basic research from 13% to 18% of GERD between 2001 and 2011 and Malaysia has followed a similar path (from 11% in 2006 to 17% in 2011). These two countries now devote a comparable share to that of the USA: 16.5% in 2012. In the Republic of Korea, the government is investing heavily in basic research to correct the impression that the country made the transition from a poor agricultural country to an industrial giant through imitation alone, without developing an endogenous capacity in basic sciences. The government also plans to foster linkages between basic sciences and the business world: in 2011, the National Institute for Basic Science opened on the site of the future International Science Business Belt in Daejeon.

The gap in R&D expenditure is narrowing

Geographically, the distribution of investment in knowledge remains unequal (Table 1.2). The USA still dominates, with 28% of global investment in R&D. China has moved into second place (20%), ahead of the EU (19%) and Japan (10%). The rest of the world represents 67% of the global population but just 23% of global investment in R&D.

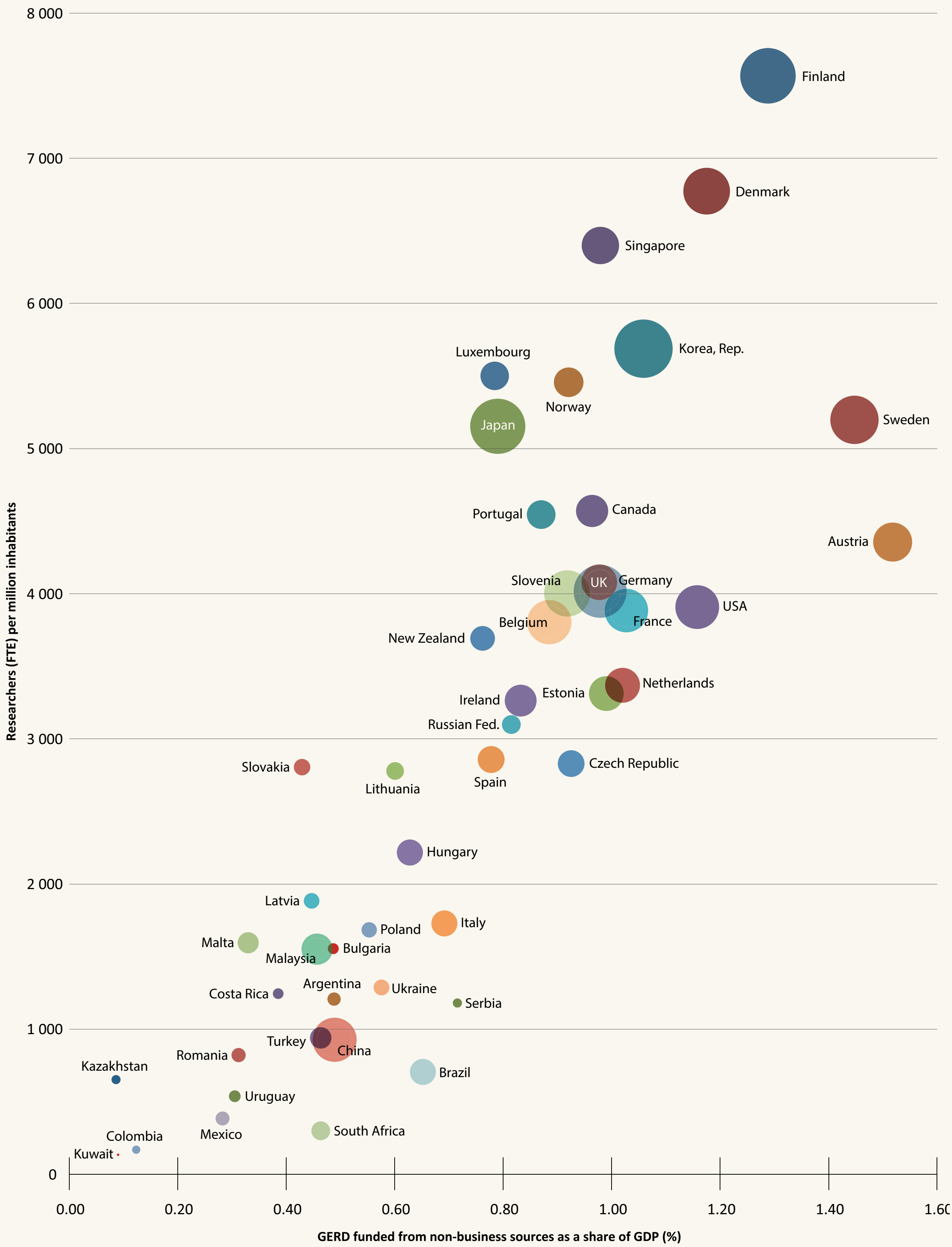
GERD encompasses both public and private investment in R&D. The share of GERD performed by the business enterprise sector (BERD) tends to be higher in economies with a greater focus on technology-based competitiveness in manufacturing, as reflected in their higher BERD/GDP ratio (Chapter 2). Among the larger economies for which adequate data are available, the BERD/GDP intensity has risen appreciably in only a few countries such as the Republic of Korea and China and, to a lesser extent, in Germany, the USA, Turkey and Poland (Figure 1.2). At best, it has remained stable in Japan and the UK and receded in Canada and South Africa.

Given the fact that almost one in five human beings is Chinese, the rapid progression in BERD in China has had a knock-on effect of massive proportions: between 2001 and 2011, China and India's combined global share of BERD quadrupled from 5% to 20%, largely to the detriment of Western Europe and North America (see Figure 2.1).

Figure 1.3 highlights the continuing concentration of R&D resources in a handful of highly developed or dynamic economies. Several of these advanced economies fall in the middle of the figure (Canada and UK), reflecting their similar density of researchers with the leaders (such as Germany or the USA), yet lower levels of R&D intensity. The R&D or human capital intensities of Brazil, China, India and Turkey might still be low but their contribution to the global stock of knowledge is rapidly rising, thanks to the sheer size of their financial investment in R&D.

Figure 1.3: **Mutually reinforcing effect of strong government investment in R&D and researchers, 2010–2011**

The size of the bubbles is proportionate to GERD funded by business as a share of GDP (%)



Source: UNESCO Institute for Statistics, August 2015

Table 1.3: **World shares of researchers, 2007, 2009, 2011 and 2013**

	Researchers ('000s)				Share of global researchers (%)			
	2007	2009	2011	2013	2007	2009	2011	2013
World	**6 400.9**	**6 901.9**	**7 350.4**	**7 758.9**	**100.0**	**100.0**	**100.0**	**100.0**
High-income economies	4 445.9	4 653.9	4 823.1	4 993.6	69.5	67.4	65.6	64.4
Upper middle-income economies	1 441.8	1 709.4	1 952.3	2 168.8	22.5	24.8	26.6	28.0
Lower middle-income economies	439.6	453.2	478.0	493.8	6.9	6.6	6.5	6.4
Low-income economies	73.6	85.4	96.9	102.6	1.2	1.2	1.3	1.3
Americas	**1 516.6**	**1 656.7**	**1 696.1**	**1 721.9**	**23.7**	**24.0**	**23.1**	**22.2**
North America	1 284.9	1 401.2	1 416.1	1 433.3	20.1	20.3	19.3	18.5
Latin America	222.6	245.7	270.8	280.0	3.5	3.6	3.7	3.6
Caribbean	9.1	9.7	9.2	8.5	0.1	0.1	0.1	0.1
Europe	**2 125.6**	**2 205.0**	**2 296.8**	**2 408.1**	**33.2**	**31.9**	**31.2**	**31.0**
European Union	1 458.1	1 554.0	1 623.9	1 726.3	22.8	22.5	22.1	22.2
Southeast Europe	11.3	12.8	14.2	14.9	0.2	0.2	0.2	0.2
European Free Trade Association	51.9	56.8	62.9	67.2	0.8	0.8	0.9	0.9
Other Europe	604.3	581.4	595.8	599.9	9.4	8.4	8.1	7.7
Africa	**150.1**	**152.7**	**173.4**	**187.5**	**2.3**	**2.2**	**2.4**	**2.4**
Sub-Saharan Africa	58.8	69.4	77.1	82.0	0.9	1.0	1.0	1.1
Arab States in Africa	91.3	83.3	96.3	105.5	1.4	1.2	1.3	1.4
Asia	**2 498.1**	**2 770.8**	**3 063.9**	**3 318.0**	**39.0**	**40.1**	**41.7**	**42.8**
Central Asia	21.7	25.1	26.1	33.6	0.3	0.4	0.4	0.4
Arab States in Asia	31.6	35.6	40.7	44.0	0.5	0.5	0.6	0.6
West Asia	116.2	119.2	124.3	136.9	1.8	1.7	1.7	1.8
South Asia	206.2	223.6	233.0	242.4	3.2	3.2	3.2	3.1
Southeast Asia	2 122.4	2 367.4	2 639.8	2 861.1	33.2	34.3	35.9	36.9
Oceania	**110.5**	**116.7**	**120.1**	**123.3**	**1.7**	**1.7**	**1.6**	**1.6**
Other groupings								
Least developed countries	45.2	51.0	55.8	58.8	0.7	0.7	0.8	0.8
Arab States all	122.9	118.9	137.0	149.5	1.9	1.7	1.9	1.9
OECD	3 899.2	4 128.9	4 292.5	4 481.6	60.9	59.8	58.4	57.8
G20	5 605.1	6 044.0	6 395.0	6 742.1	87.6	87.6	87.0	86.9
Selected countries								
Argentina	38.7	43.7	50.3	51.6^{-1}	0.6	0.6	0.7	0.7^{-1}
Brazil	116.3	129.1	138.7^{-1}	–	1.8	1.9	2.0^{-1}	–
Canada	151.3	150.2	163.1	156.6^{-1}	2.4	2.2	2.2	2.1^{-1}
China	–*	1 152.3^{b}	1 318.1	1 484.0	–*	16.7^{b}	17.9	19.1
Egypt	49.4	35.2	41.6	47.7	0.8	0.5	0.6	0.6
France	221.9	234.4	249.2^{b}	265.2	3.5	3.4	3.4^{b}	3.4
Germany	290.9	317.3	338.7	360.3	4.5	4.6	4.6	4.6
India	154.8^{-2}	–	192.8^{-1}	–	2.6^{-2}	–	2.7^{-1}	–
Iran	54.3^{+1}	52.3^{b}	54.8^{-1}	–	0.8^{+1}	0.8^{b}	0.8^{-1}	–
Israel	–	–	55.2	63.7^{-1}	–	–	0.8	0.8^{-1}
Japan	684.3	655.5^{b}	656.7	660.5	10.7	9.5^{b}	8.9	8.5
Malaysia	9.7^{-1}	29.6^{b}	47.2	52.1^{-1}	0.2^{-1}	0.4^{b}	0.6	0.7^{-1}
Mexico	37.9	43.0	46.1	–	0.6	0.6	0.6	–
Republic of Korea	221.9	244.1	288.9	321.8	3.5	3.5	3.9	4.1
Russian Federation	469.1	442.3	447.6	440.6	7.3	6.4	6.1	5.7
South Africa	19.3	19.8	20.1	21.4^{-1}	0.3	0.3	0.3	0.3^{-1}
Turkey	49.7	57.8	72.1	89.1	0.8	0.8	1.0	1.1
United Kingdom	252.7	256.1	251.4	259.3	3.9	3.7	3.4	3.3
United States of America	1 133.6	1 251.0	1 252.9	1 265.1^{-1}	17.7	18.1	17.0	16.7^{-1}

-n/+n = data are for n years before or after reference year

b: break in series with previous year for which data are shown

	Researchers per million inhabitants			
	2007	2009	2011	2013
	959.2	**1 009.8**	**1 050.4**	**1 083.3**
	3 517.0	3 632.3	3 720.4	3 814.1
	620.9	723.9	813.0	888.1
	187.8	187.8	192.2	192.9
	98.7	109.6	119.1	120.7
	1 661.2	**1 776.1**	**1 780.8**	**1 771.6**
	3 814.6	4 081.5	4 052.0	4 034.1
	415.8	448.3	482.7	487.7
	223.0	235.4	220.2	200.8
	2 635.4	**2 717.4**	**2 816.4**	**2 941.9**
	2 911.8	3 081.9	3 202.0	3 388.3
	575.4	659.9	734.8	772.0
	4 112.4	4 390.4	4 757.0	4 980.8
	2 208.8	2 115.3	2 160.2	2 170.4
	156.8	**151.8**	**164.1**	**168.8**
	77.0	86.0	90.6	91.4
	474.0	418.1	467.2	494.5
	630.6	**684.4**	**740.8**	**785.8**
	351.6	395.0	399.7	500.0
	259.2	272.5	294.4	303.1
	1 224.1	1 226.9	1 249.1	1 343.2
	133.7	141.0	143.1	145.0
	991.9	1 090.1	1 197.6	1 279.1
	3 173.8	**3 235.7**	**3 226.8**	**3 218.9**
	57.7	62.2	65.0	65.5
	390.7	360.5	397.8	417.0
	3 205.9	3 346.7	3 433.7	3 542.3
	1 276.9	1 353.2	1 408.0	1 460.7
	983.5	1 092.3	1 236.0	1 255.8[-1]
	612.0	667.2	710.3[-1]	–
	4 587.7	4 450.6	4 729.0	4 493.7[-1]
	–[*]	852.8[b]	963.2	1 071.1
	665.0	457.9	523.6	580.7
	3 566.1	3 726.7	3 920.1[b]	4 124.6
	3 480.0	3 814.6	4 085.9	4 355.4
	137.4[-2]	–	159.9[-1]	–
	746.9[+1]	710.6[b]	736.1[-1]	–
	–	–	7 316.6	8 337.1[-1]
	5 377.7	5 147.4[b]	5 157.5	5 194.8
	368.2[-1]	1 065.4[b]	1 642.7	1 780.2[-1]
	334.1	369.1	386.4	–
	4 665.0	5 067.5	5 928.3	6 533.2
	3 265.4	3 077.9	3 120.4	3 084.6
	389.5	388.9	387.2	408.2[-1]
	714.7	810.7	987.0	1 188.7
	4 143.8	4 151.1	4 026.4	4 107.7
	3 731.4	4 042.1	3 978.7	3 984.4[-1]

Note: Researchers are in full-time equivalents.

Source: estimations by UNESCO Institute for Statistics, July 2015

GLOBAL TRENDS IN HUMAN CAPITAL

Widespread growth in researchers, little change in the global balance

Today, there are some 7.8 million researchers worldwide (Table 1.3). Since 2007, the number of researchers has risen by 21%. This remarkable growth is also reflected in the explosion of scientific publications.

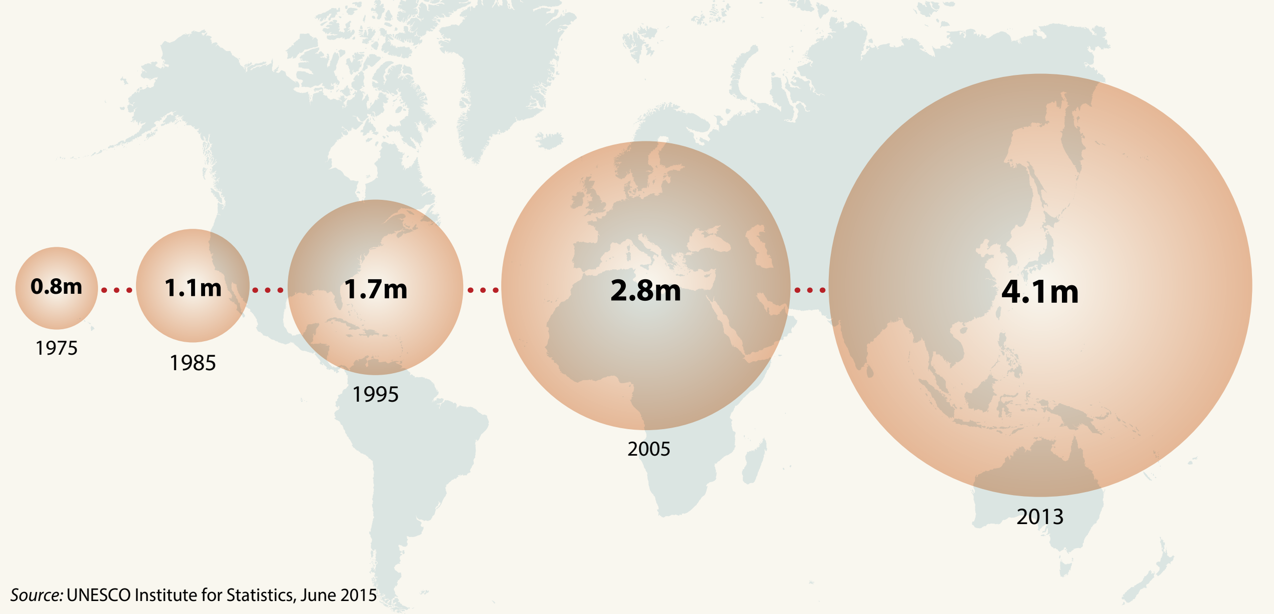
The EU remains the world leader for the number of researchers, with a 22.2% share. Since 2011, China (19.1%) has overtaken the USA (16.7%), as predicted by the *UNESCO Science Report 2010*, despite a downward readjustment of the Chinese figures since this publication's release. Japan's world share has shrunk from 10.7% (2007) to 8.5% (2013) and the Russian Federation's share from 7.3% to 5.7%.

The Big Five thus still account for 72% of all researchers, even if there has been a reshuffle in their respective shares. Of note is that the high-income countries have ceded some ground to the upper middle-income countries, including China; the latter accounted for 22.5% of researchers in 2007 but 28.0% in 2013 (Table 1.3).

As Figure 1.3 highlights, once countries are prepared to invest more in research personnel and in publicly funded research, the propensity of businesses to invest in R&D also increases (the size of the bubbles). Public and privately funded research have different aims, of course, but their contribution to national growth and welfare depends on how well they complement one another. This holds for countries of all income levels but it is clear that the relationship becomes powerful above a certain threshold in researcher density and publicly funded R&D intensity. Whereas one can find a few countries with a relatively high intensity of business-funded R&D in the lower left-hand quadrant of the graphic, none in the upper right-hand quadrant have a low intensity of business R&D.

Researchers from lower income countries are still pursuing career opportunities abroad but their destination of choice is widening. This may be partly because the 2008 crisis has somewhat tarnished the image of Europe and North America as an Eldorado. Even countries suffering from brain drain are also attracting researchers. For instance, Sudan lost more than 3 000 junior and senior researchers to migration between 2002 and 2014, according to the National Research Centre. Researchers were drawn to neighbouring countries such as Eritrea and Ethiopia by the better pay, which is more than double that offered to university staff in Sudan. In turn, Sudan has become a refuge for students from the Arab world, particularly since the turmoil of the Arab Spring. Sudan is also attracting a growing number of students from Africa (Chapter 19).

Figure 1.4: **Long-term growth of tertiary-level international students worldwide, 1975–2013**



Source: UNESCO Institute for Statistics, June 2015

In the coming years, competition for skilled workers from the global pool will most likely intensify (Chapter 2). This trend will depend in part on levels of investment in science and technology around the world and demographic trends, such as low birth rates and ageing populations in some countries (Japan, EU, etc). Countries are already formulating broader policies to attract and retain highly skilled migrants and international students, in order to establish an innovative environment or maintain it, as in Malaysia (Chapter 26).

The number of international students is growing rapidly (Figure 1.4). Chapter 2 highlights the increasing mobility at doctoral level, which, in turn, is driving the mobility of scientists. This is perhaps one of the most important trends of recent times. A study conducted recently by the UNESCO Institute for Statistics found that students from the Arab States, Central Asia, sub-Saharan African and Western Europe were more likely to study abroad than their peers from other regions. Central Asia has even overtaken Africa for the share of tertiary students studying abroad (see Figure 2.10).

National and regional schemes in Europe and Asia are actively encouraging doctoral students to study abroad. The Vietnamese government, for instance, sponsors the doctoral training of its citizens overseas, in order to add 20 000 doctorate-holders to the faculty of Vietnamese universities by 2020. Saudi Arabia is taking a similar approach. Malaysia, meanwhile, plans to become the sixth-largest global destination for international university students by 2020. Between 2007 and 2012, the number of international students in Malaysia almost doubled to more than 56 000 (Chapter 26). South Africa hosted about 61 000 international students in 2009, two-thirds of whom came from other SADC nations (Chapter 20). Cuba is a popular destination for Latin American students (Chapter 7).

The other half of human capital still a minority

As countries grapple with the need to establish a pool of scientists or researchers that is commensurate with their ambitions for development, their attitudes to gender issues are changing. Some Arab States now have more women than men studying natural sciences, health and agriculture at university (Chapter 17). Saudi Arabia plans to create 500 vocational training schools to reduce its dependence on foreign workers, half of which will train teenage girls (Chapter 17). Some 37% of researchers in the Arab world are women, more than in the EU (33%).

On the whole, women constitute a minority in the research world. They also tend to have more limited access to funding than men and to be less represented in prestigious universities and among senior faculty, which puts them at a further disadvantage in high-impact publishing (Chapter 3). The regions with the highest shares of women researchers are Southeast Europe (49%), the Caribbean, Central Asia and Latin America (44%). Sub-Saharan Africa counts 30% women and South Asia 17%. Southeast Asia presents a contrasting picture, with women representing 52% of researchers in the Philippines and Thailand, for instance, but only 14% in Japan and 18% in the Republic of Korea (Chapter 3).

Globally, women have achieved parity (45–55%) at the bachelor's and master's levels, where they represent 53% of graduates. At the PhD level, they slip beneath parity to 43%.

The gap widens at the researcher level, where they now only account for 28.4% of researchers, before becoming a gulf at the higher echelons of decision-making (Chapter 3).

A number of countries have put policies in place to foster gender equality. Three examples are Germany, where the coalition agreement of 2013 introduced a 30% quota for women on company boards of directors, Japan, where the selection criteria for most large university grants now take into account the proportion of women among teaching staff and researchers, and the Republic of Congo, which established a Ministry for the Promotion of Women and Integration of Women in National Development in 2012.

TRENDS IN KNOWLEDGE GENERATION

The EU still leads the world for publications

The EU still leads the world for publications (34%), followed by the USA on 25% (Table 1.4). Despite these impressive figures, the world shares of both the EU and the USA have fallen over the past five years, as China has pursued its meteoric rise: Chinese publications have nearly doubled over the past five years to 20% of the world total. Ten years ago, China accounted for just 5% of global publications. This rapid growth reflects the coming of age of the Chinese research system, be it in terms of investment, the number of researchers or publications.

In terms of the relative specializations of countries in scientific disciplines, Figure 1.5 points to the large differences in specialization among countries. The traditionally dominant scientific countries seem to be relatively strong in astronomy and relatively weak in agricultural sciences. This is particularly the case for the UK, which is strong in social sciences. France's scientific strength still seems to lie in mathematics. The USA and UK focus more on life sciences and medicine and Japan on chemistry.

Among the BRICS countries, there are some striking differences. The Russian Federation shows a strong specialization in physics, astronomy, geosciences, mathematics and chemistry. By contrast, China's scientific output shows a fairly well-balanced pattern, with the exception of psychology, social and life sciences, where China's scientific output is well below the average. Brazil's relative strengths lie in agriculture and life sciences. Malaysia, not surprisingly, specializes in engineering and computer sciences.

Over the past five years, several new trends have emerged in terms of national research priorities. Some of the data on scientific publications reflect these priorities but often the classification across disciplines is not detailed enough. For instance, energy has become an overriding preoccupation but related research is spread across several disciplines.

Innovation occurring in countries of all income levels

As Chapter 2 highlights, and contrary to some received wisdom, innovative behaviour is occurring in countries spanning all income levels. The significant differences in innovation rate and typologies observed among developing countries that otherwise have comparable levels of income are of distinct policy interest. According to a survey of innovation conducted by the UNESCO Institute for Statistics (Chapter 2), firms' innovative behaviour tends to be clustered in research hotspots, such as in coastal regions of China or in the Brazilian State of São Paolo. The survey suggests that, over time, FDI flows related to R&D are spreading innovation more evenly around the world.

Whereas much high-level policy focuses on fostering investment in R&D, the innovation survey underscores the potential importance for firms of acquiring external knowledge or pursuing non-technological innovation (Chapter 2). The survey confirms the weakness of interaction between firms, on the one hand, and universities and public laboratories, on the other. This worrying trend is highlighted in many chapters of the present report, including those on Brazil (Chapter 8), the Black Sea basin (Chapter 12), Russian Federation (Chapter 13), Arab States (Chapter 17) and India (Chapter 22).

Patenting behaviour provides insights into the impact of innovation. Triadic patents – a term referring to the same invention being patented by the same inventor with the patenting offices of the USA, EU and Japan – provide an indicator of a country's propensity to pursue technology-based competitiveness at the global level. The overall dominance of high-income economies in this regard is striking (Table 1.5 and Figure 1.6). The Republic of Korea and China are the only countries that have made a significant dent in the dominance of the Triad for this indicator. Although the global share of the non-G20 countries tripled in the ten years to 2012, it remains a trifling 1.2%. Table 1.5 likewise illustrates the extreme concentration of patent applications in North America, Asia and Europe: the rest of the world barely counts for 2% of the world stock.

The United Nations is currently discussing how to operationalize the proposed technology bank for least developed countries.[7] The purpose of the technology bank will be to enhance the ability of these countries to access technologies developed elsewhere and to increase their capacity to patent. In September 2015, the United Nations adopted a Technology Facilitation Mechanism for clean and environmentally sound technologies at a Summit on Sustainable Development in New York (USA); this mechanism will contribute to the implementation of the Sustainable Development Goals (*Agenda 2030*) adopted the same month.

7. See: http://unohrlls.org/technologybank

Table 1.4: **World shares of scientific publications, 2008 and 2014**

	Total publications		Change (%) 2008–2014	World share of publications (%)		Publications per million inhabitants		Publications with international co-authors (%)	
	2008	2014		2008	2014	2008	2014	2008	2014
World	**1 029 471**	**1 270 425**	**23.4**	**100.0**	**100.0**	**153**	**176**	**20.9**	**24.9**
High-income economies	812 863	908 960	11.8	79.0	71.5	653	707	26.0	33.8
Upper middle-income economies	212 814	413 779	94.4	20.7	32.6	91	168	28.0	28.4
Lower middle-income economies	58 843	86 139	46.4	5.7	6.8	25	33	29.2	37.6
Low-income economies	4 574	7 660	67.5	0.4	0.6	6	9	80.1	85.8
Americas	**369 414**	**417 372**	**13.0**	**35.9**	**32.9**	**403**	**428**	**29.7**	**38.2**
North America	325 942	362 806	11.3	31.7	28.6	959	1 013	30.5	39.6
Latin America	50 182	65 239	30.0	4.9	5.1	93	112	34.5	41.1
Caribbean	1 289	1 375	6.7	0.1	0.1	36	36	64.6	82.4
Europe	**438 450**	**498 817**	**13.8**	**42.6**	**39.3**	**542**	**609**	**34.8**	**42.1**
European Union	379 154	432 195	14.0	36.8	34.0	754	847	37.7	45.5
Southeast Europe	3 314	5 505	66.1	0.3	0.4	170	287	37.7	43.3
European Free Trade Association	26 958	35 559	31.9	2.6	2.8	2 110	2 611	62.5	70.1
Other Europe	51 485	57 208	11.1	5.0	4.5	188	207	27.2	30.3
Africa	**20 786**	**33 282**	**60.1**	**2.0**	**2.6**	**21**	**29**	**52.3**	**64.6**
Sub-Saharan Africa	11 933	18 014	51.0	1.2	1.4	15	20	57.4	68.7
Arab States in Africa	8 956	15 579	74.0	0.9	1.2	46	72	46.0	60.5
Asia	**292 230**	**501 798**	**71.7**	**28.4**	**39.5**	**73**	**118**	**23.7**	**26.1**
Central Asia	744	1 249	67.9	0.1	0.1	12	18	64.0	71.3
Arab States in Asia	5 842	17 461	198.9	0.6	1.4	46	118	50.3	76.8
West Asia	22 981	37 946	65.1	2.2	3.0	239	368	33.0	33.3
South Asia	41 646	62 468	50.0	4.0	4.9	27	37	21.2	27.8
Southeast Asia	224 875	395 897	76.1	21.8	31.2	105	178	23.7	25.2
Oceania	**35 882**	**52 782**	**47.1**	**3.5**	**4.2**	**1 036**	**1 389**	**46.8**	**55.7**
Other groupings									
Least developed countries	4 191	7 447	77.7	0.4	0.6	5	8	79.7	86.8
Arab States all	14 288	29 944	109.6	1.4	2.4	44	82	45.8	65.9
OECD	801 151	899 810	12.3	77.8	70.8	654	707	25.8	33.3
G20	949 949	1 189 605	25.2	92.3	93.6	215	256	22.4	26.2
Selected countries									
Argentina	6 406	7 885	23.1	0.6	0.6	161	189	44.9	49.3
Brazil	28 244	37 228	31.8	2.7	2.9	147	184	25.6	33.5
Canada	46 829	54 631	16.7	4.5	4.3	1 403	1 538	46.6	54.5
China	102 368	256 834	150.9	9.9	20.2	76	184	23.4	23.6
Egypt	4 147	8 428	103.2	0.4	0.7	55	101	38.0	60.1
France	59 304	65 086	9.7	5.8	5.1	948	1 007	49.3	59.1
Germany	79 402	91 631	15.4	7.7	7.2	952	1 109	48.6	56.1
India	37 228	53 733	44.3	3.6	4.2	32	42	18.5	23.3
Iran	11 244	25 588	127.6	1.1	2.0	155	326	20.5	23.5
Israel	10 576	11 196	5.9	1.0	0.9	1 488	1 431	44.6	53.1
Japan	76 244	73 128	-4.1	7.4	5.8	599	576	24.5	29.8
Malaysia	2 852	9 998	250.6	0.3	0.8	104	331	42.3	51.6
Mexico	8 559	11 147	30.2	0.8	0.9	74	90	44.7	45.9
Republic of Korea	33 431	50 258	50.3	3.2	4.0	698	1 015	26.6	28.8
Russian Federation	27 418	29 099	6.1	2.7	2.3	191	204	32.5	35.7
South Africa	5 611	9 309	65.9	0.5	0.7	112	175	51.9	60.5
Turkey	18 493	23 596	27.6	1.8	1.9	263	311	16.3	21.6
United Kingdom	77 116	87 948	14.0	7.5	6.9	1 257	1 385	50.4	62.0
United States of America	289 769	321 846	11.1	28.1	25.3	945	998	30.5	39.6

Note: The sum of the numbers for the various regions exceeds the total number because papers with multiple authors from different regions contribute fully to each of these regions.

Source: Data from Thomson Reuters' Web of Science Science Citation Index Expanded compiled for UNESCO by Science-Metrix, May 2015

Figure 1.5: **Trends in scientific publications worldwide, 2008 and 2014**

13.8%
Growth in publications with authors from Europe between 2008 and 2014

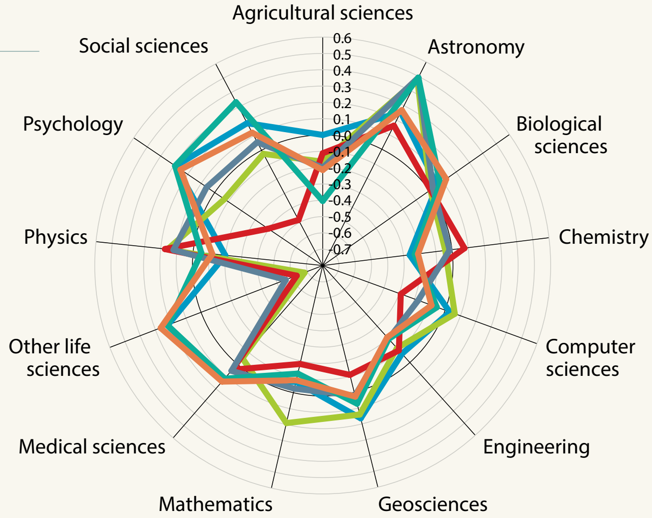
60.1%
Growth in publications with authors from Africa between 2008 and 2014

109.6%
Growth in publications with authors from Arab states between 2008 and 2014

Scientific specialization in large advanced economies

France tops G7 counties for its specialization in mathematics

G7 countries diverge the most in their specialization in psychology and social sciences



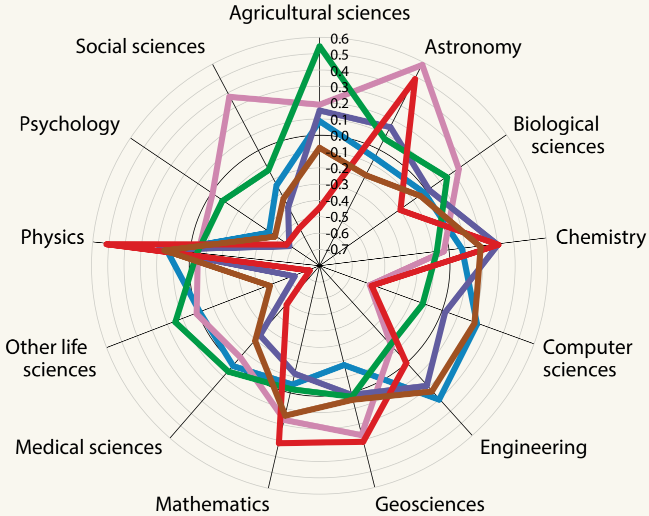
USA — UK — Germany — France — Canada — Japan

Scientific specialization in large emerging economies

The Russian Federation tops large emerging economies in geosciences, physics and mathematics but trails them in life sciences

The Republic of Korea, China and India dominate engineering and chemistry

Brazil specializes in agricultural sciences, South Africa in astronomy

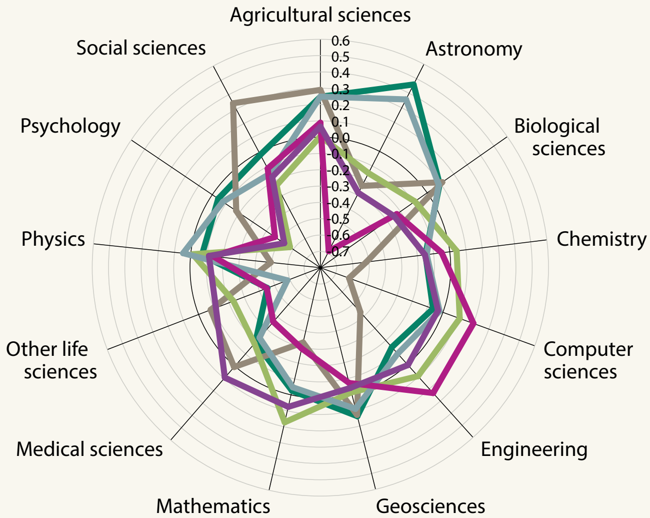


China — India — Brazil — Korea, Rep. — Russian Fed. — South Africa

Scientific specialization in other emerging national and regional economies

Sub-Saharan Africa and Latin America have a similar concentration in agriculture and geosciences

The Arab States focus most on mathematics and least on psychology



Turkey — Arab States — Malaysia — Latin America (minus Brazil) — Mexico — Sub-Saharan Africa (minus S. Africa)

Source: UNU-MERIT, based on the Web of Science (Thomson Reuters); data treatment by Science–Metrix

Table 1.5: **Patents submitted to USPTO, 2008 and 2013**

By region or country of inventor

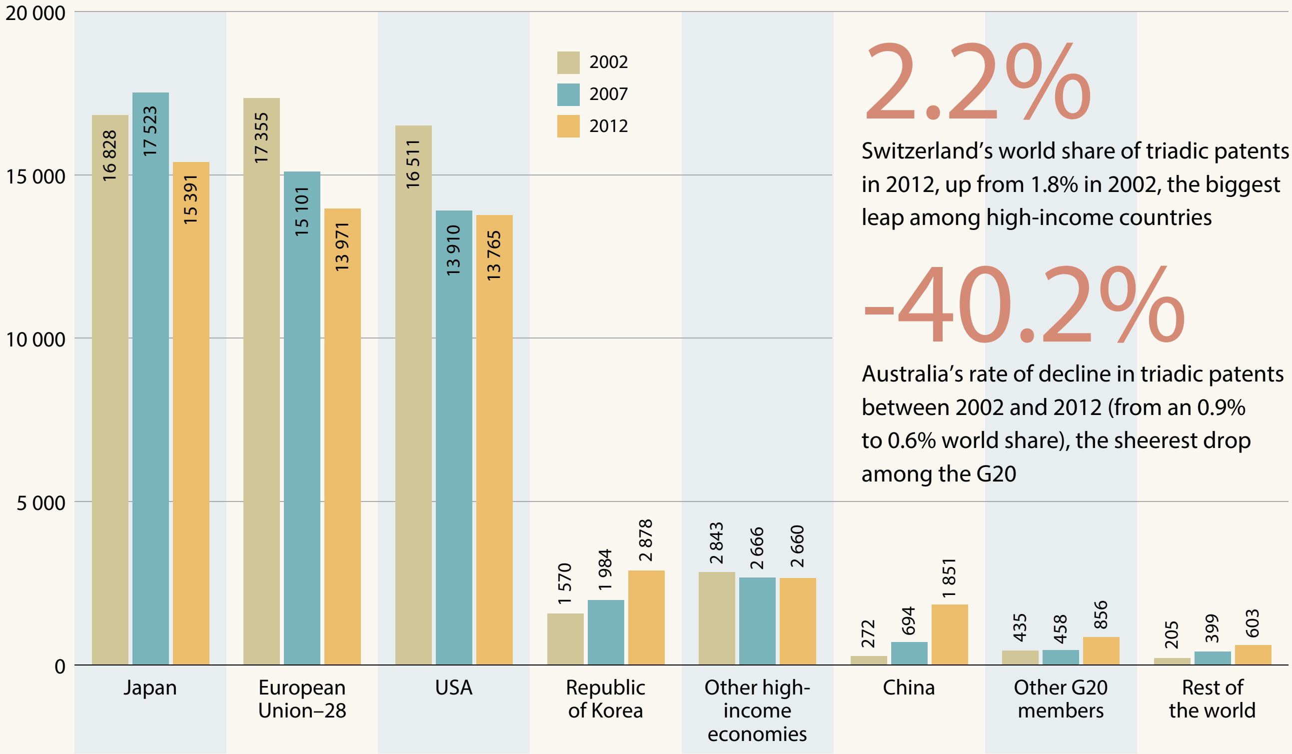
	USPTO patents			
	Total		World share (%)	
	2008	2013	2008	2013
World	**157 768**	**277 832**	**100.0**	**100.0**
High-income economies	149 290	258 411	94.6	93.0
Upper middle-income economies	2 640	9 529	1.7	3.4
Lower middle-income economies	973	3 586	0.6	1.3
Low-income economies	15	59	0.0	0.0
Americas	83 339	145 741	52.8	52.5
North America	83 097	145 114	52.7	52.2
Latin America	342	829	0.2	0.3
Caribbean	21	61	0.0	0.0
Europe	**25 780**	**48 737**	**16.3**	**17.5**
European Union	24 121	45 401	15.3	16.3
Southeast Europe	4	21	0.0	0.0
European Free Trade Association	1 831	3 772	1.2	1.4
Other Europe	362	773	0.2	0.3
Africa	**137**	**303**	**0.1**	**0.1**
Sub-Saharan Africa	119	233	0.1	0.1
Arab States in Africa	18	70	0.0	0.0
Asia	**46 773**	**83 904**	**29.6**	**30.2**
Central Asia	3	8	0.0	0.0
Arab States in Asia	81	426	0.1	0.2
West Asia	1 350	3 464	0.9	1.2
South Asia	855	3 350	0.5	1.2
Southeast Asia	44 515	76 796	28.2	27.6
Oceania	**1 565**	**2 245**	**1.0**	**0.8**
Other groupings				
Least developed countries	7	23	0.0	0.0
Arab States all	99	492	0.1	0.2
OECD	148 658	257 066	94.2	92.5
G20	148 608	260 904	94.2	93.9
Selected countries				
Argentina	45	114	0.0	0.0
Brazil	142	341	0.1	0.1
Canada	3 936	7 761	2.5	2.8
China	1 757	7 568	1.1	2.7
Egypt	10	52	0.0	0.0
France	3 683	7 287	2.3	2.6
Germany	9 901	17 586	6.3	6.3
India	848	3 317	0.5	1.2
Iran	3	43	0.0	0.0
Israel	1 337	3 405	0.8	1.2
Japan	34 198	52 835	21.7	19.0
Malaysia	200	288	0.1	0.1
Mexico	90	217	0.1	0.1
Republic of Korea	7 677	14 839	4.9	5.3
Russian Federation	281	591	0.2	0.2
South Africa	102	190	0.1	0.1
Turkey	35	113	0.0	0.0
United Kingdom	3 828	7 476	2.4	2.7
United States of America	79 968	139 139	50.7	50.1

Note: The sum of the numbers and percentages for the various regions exceeds the total because patents with multiple inventors from different regions contribute fully to each of these regions.

Source: Data from United States Patents and Trademark Office (USPTO) PATSTAT, database compiled for UNESCO by Science-Metrix, June 2015

Figure 1.6: **Trends in triadic patents worldwide, 2002, 2007 and 2012**

Number of triadic patents, 2002, 2007 and 2012

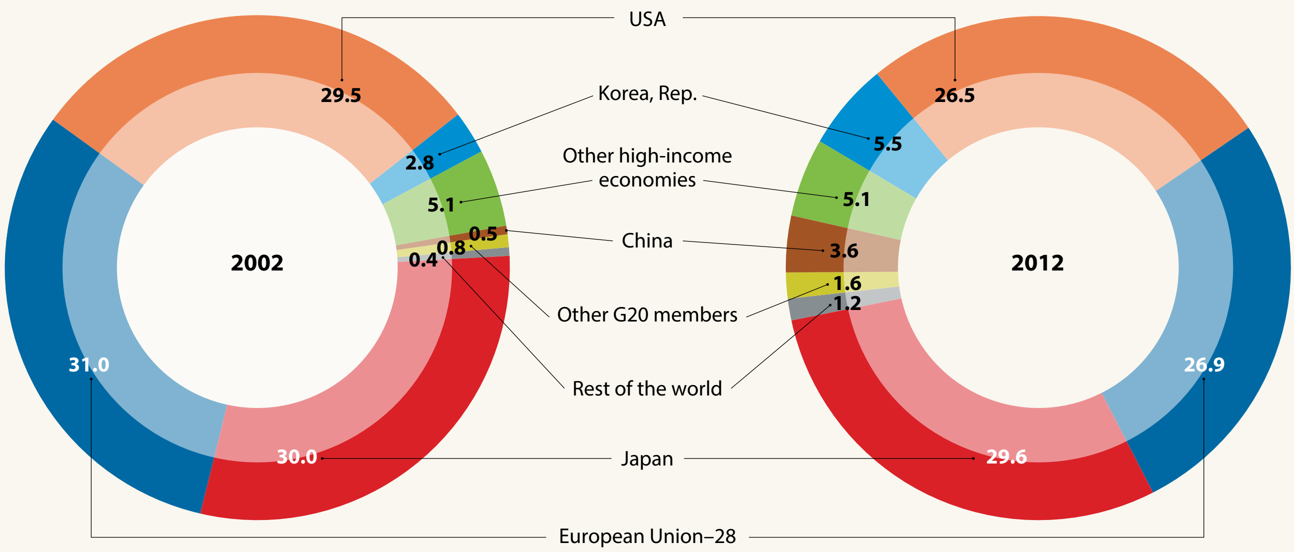


Among the Triad, the European Union and USA showed the greatest contraction in their world share of triadic patents between 2002 and 2012

The Republic of Korea's share of triadic patents almost doubled to 5.5% between 2002 and 2012

China's share of triadic patents grew from 0.5% to 3.6% and the other G20 members doubled their world share to 1.6%, on average

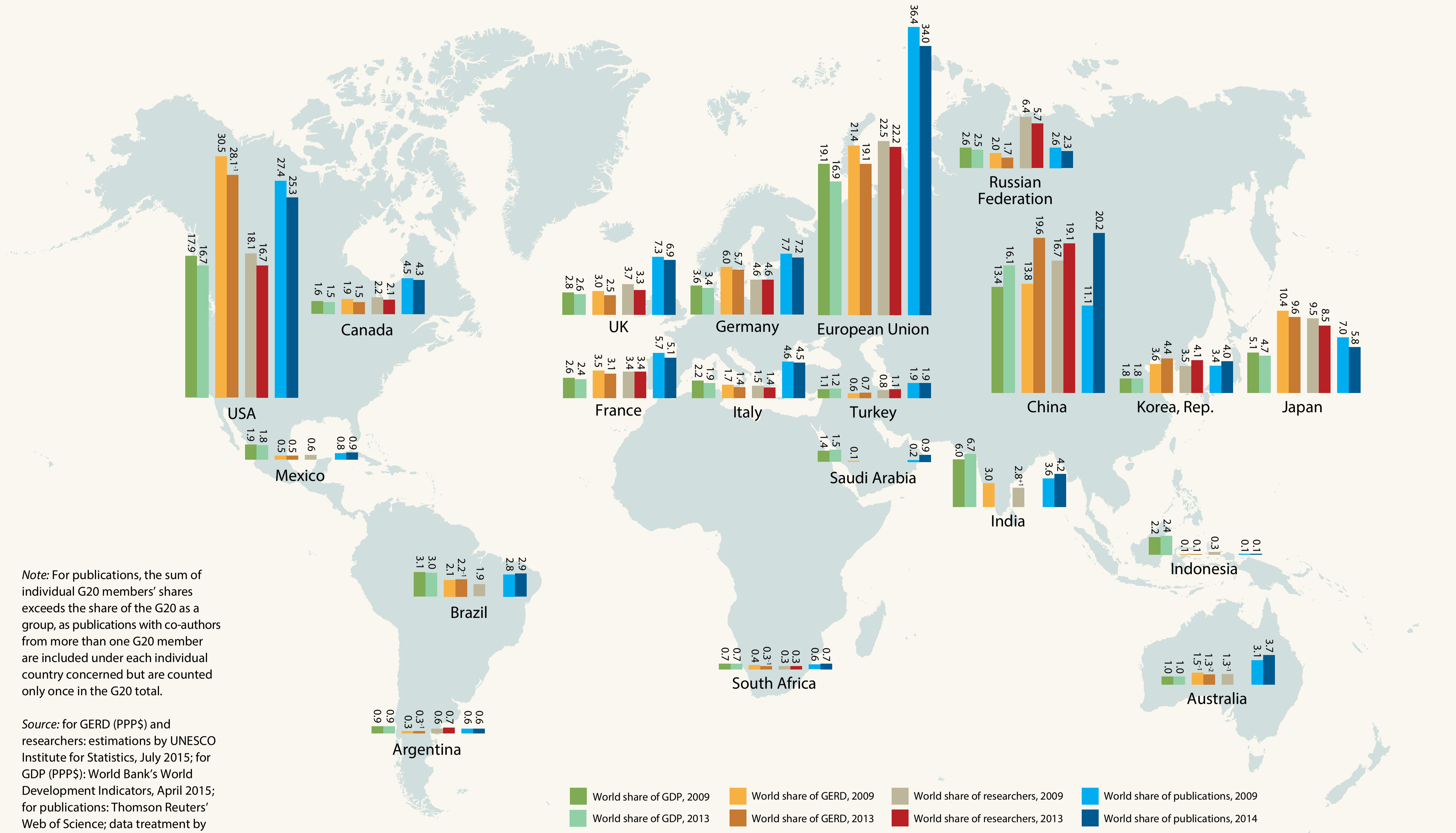
Global shares of triadic patents, 2002 and 2012 (%)



Note: Nowcasting triadic patents of countries in the USPTO database, 2002, 2007 and 2012; triadic patents are a series of corresponding patents filed at the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO) for the same invention, by the same applicant or inventor.

Source: UNESCO Institute for Statistics based on OECD online database (OECD.Stat), August 2015

Figure 1.7: **World shares of GDP, GERD, researchers and publications for the G20, 2009 and 2013 (%)**



Note: For publications, the sum of individual G20 members' shares exceeds the share of the G20 as a group, as publications with co-authors from more than one G20 member are included under each individual country concerned but are counted only once in the G20 total.

Source: for GERD (PPP$) and researchers: estimations by UNESCO Institute for Statistics, July 2015; for GDP (PPP$): World Bank's World Development Indicators, April 2015; for publications: Thomson Reuters' Web of Science; data treatment by Science–Metrix

A CLOSER LOOK AT COUNTRIES AND REGIONS

More countries are covered by the *UNESCO Science Report* this time than ever before. This reflects the growing acceptance worldwide of STI as a driver of development. The following section summarizes the most insightful trends and developments emerging from Chapters 4 to 27.

Canada (Chapter 4) has managed to dodge the worst shockwaves from the US financial crisis of 2008, thanks to a robust banking industry and strong energy and natural resource sectors, but this is now changing with the decline in global oil prices since 2014.

Two important weaknesses highlighted by the *UNESCO Science Report 2010* persist: a tepid private-sector commitment to innovation and the lack of a strong national agenda for talent and training in scientific and engineering fields. Academic research remains relatively strong, overall, with publications outperforming the OECD average in terms of average citation rate, but Canada is slipping in higher education rankings. An additional vulnerability has emerged: a policy agenda focused almost exclusively on using science to power commerce, often to the detriment of critical 'public good' science, alongside the downsizing of government science agencies and departments.

A recent government review has identified a possible disconnect between Canada's strengths in science and technology, on the one hand, and industrial R&D and economic competitiveness, on the other. Although overall industrial R&D remains weak, four industries display considerable strength: aerospace products and parts manufacturing; ICTs; oil and gas extraction; and pharmaceutical manufacturing.

Between 2010 and 2013, Canada's GERD/GDP fell to its lowest level in a decade (1.63%). In parallel, the share of business funding of R&D receded from 51.2% (2006) to 46.4%. The pharmaceutical, chemical, primary and fabricated metals industries have all experienced an erosion in R&D spending. Consequently, the number of personnel employed in industrial R&D shrank by 23.5% between 2008 and 2012.

Notable developments since 2010 include a renewed focus on polar research and knowledge, enhanced support for universities, growing applications of genomics through Genome Canada, a *Venture Capital Action Plan* (2013), a Canadian partnership with the EU's Eureka programme and an *International Education Strategy* to attract more foreign students to Canada's shores and maximize opportunities for global partnerships.

In the **United States of America** (Chapter 5), GDP has been on the upswing since 2010. However, the recovery from the 2008–2009 recession remains fragile. Despite the decline in unemployment levels, wages have stagnated. There is evidence that the economic stimulus package of 2009, formally known as the American Recovery and Reinvestment Act, may have buffered immediate job losses for those working in science and technology, since a significant portion of this stimulus package went to R&D.

Since 2010, federal investment in R&D has stagnated in the wake of the recession. Despite this, industry has largely maintained its commitment to R&D, particularly in growing, high-opportunity sectors. As a result, total R&D spending has dipped only slightly and the balance of spending has shifted further towards industrial sources since 2010. GERD is now rising and the business sector's investment in innovation appears to be accelerating.

Most of the 11 agencies that conduct the bulk of federally funded R&D have seen flat R&D budgets for the past five years. The Department of Defense has even experienced a steep decline, reflecting the winding down of the intervention in Afghanistan and Iraq and the lesser need for related technologies. The decline in non-defence R&D appears to be due to a combination of decreasing federal budgets for specific research and the budget sequester instigated by Congress in 2013, which has enacted US$1 trillion in automatic cuts to the federal budget to reduce the deficit.

This trend is having the greatest impact on basic research and public-interest science in such areas as life sciences, energy and climate, which happen to be priority areas for the executive branch of government. In order to take up the 'grand challenges' in priority areas announced by the president in 2013, the executive is fostering tripartite industry–non–profit–government partnerships. Some milestones built on this collaborative model are the BRAIN Initiative, the Advanced Manufacturing Partnership and the American Business Act on Climate Pledge that received a US$140 billion commitment from its industrial partners in 2015.

While business R&D has been thriving, budget restrictions have resulted in deep cuts to universities' research budgets. Universities have responded by seeking new sources of funding from industry and relying heavily on temporary contract or adjunct workers. This is affecting the morale of both young and established scientists and inciting some to change career course or emigrate. In parallel, the rate of return migration among foreign students based in the USA is rising as levels of development in their country of origin improve.

The countries of the Caribbean Common Market (CARICOM) (Chapter 6) have been hit by the post-2008 economic slowdown in developed countries, on which they are highly dependent for trade. After meeting their debt obligations, there is little left over for the state to spend on socio-economic development. Many countries also rely heavily on volatile earnings from tourism and remittances.

The region is vulnerable to natural disasters. A costly and ageing fossil-fuel-based energy infrastructure and acute vulnerability to climate change make renewable energy an obvious focus for future research. The *Caribbean Community Climate Change Centre Plan* (2011–2021) for climate change mitigation and resilient development is a key step in this direction.

Health is another key priority, the region boasting several centres of excellence in this field. One of these, St George's University, produces 94% of Grenada's refereed publications. Thanks to the impressive growth in output from this university in recent years, Grenada is now only surpassed by the larger Jamaica and Trinidad and Tobago for the volume of internationally catalogued publications.

One of the region's greatest challenges will be to develop a more vibrant research culture. Even the more affluent Trinidad and Tobago spends just 0.05% of GDP (2012) on R&D. Poor data hamper evidence-based STI policy-making in most countries. Existing pockets of research excellence in academia and business tend to owe more to dynamic individuals than to any particular policy framework.

The *Strategic Plan for the Caribbean Community* (2015–2019) is a first for the region. This planning document advocates nurturing innovation and creativity, entrepreneurship, digital literacy and inclusiveness. CARICOM countries stand to gain a lot from a genuinely regional approach to STI by reducing duplication and promoting synergies in research. There are already some bases to build upon, including the regional University of the West Indies and the Caribbean Science Foundation.

Socio-economic development in **Latin America** (Chapter 7) has slowed after a buoyant decade, especially for the region's commodity exporters, but high-tech production and exports remain marginal for most Latin American countries.

There is, however, a growing public policy focus on research and innovation. Several countries now have sophisticated STI policy instruments in place. The region is also leading efforts to understand and promote the role of indigenous knowledge systems for development.

However, with the exception of Brazil (Chapter 8), no Latin American country has an R&D intensity comparable to that of dynamic emerging market economies. To narrow this gap, countries need to start by augmenting the number of researchers. It is, thus, encouraging that investment in higher education is on the rise; so, too, are scientific production and international scientific collaboration.

Latin America's modest performance in patenting reveals a lack of zeal for technology-driven competitiveness. There is a trend towards greater patenting in natural resource-related sectors such as mining and agriculture, however, largely through public research institutions.

In order to harness STI to development more effectively, some Latin American countries have adopted measures to support strategic sectors such as agriculture, energy and ICTs, including a focus on biotechnologies and nanotechnologies. Examples are Argentina, Brazil, Chile, Mexico and Uruguay. Other countries are targeting science and research funding to expand endogenous innovation, such as Panama, Paraguay and Peru, or promoting broad-based strategies to foster competitiveness, as in the Dominican Republic and El Salvador.

Technologies fostering sustainable development are an emerging priority throughout Latin America, especially in the area of renewable energy, but the region needs to do much more to close the gap with dynamic emerging markets in technology-focused manufacturing. A first step will be to instil greater stability in long-term STI policy-making and to prevent a proliferation of strategies and initiatives.

Brazil (Chapter 8) has faced an economic slowdown since 2011 that has affected its capacity to push on with socially inclusive growth. The slowdown has been triggered by weaker international commodities markets, coupled with the perverse effects of economic policies designed to fuel consumption. In early 2015, Brazil entered into recession for the first time in six years.

Labour productivity has stagnated, despite a range of policies to revive it. Since productivity levels are an indication of the rate of absorption and generation of innovation, this trend suggests that Brazil has not managed to harness innovation to economic growth. The Brazilian experience is akin to that of the Russian Federation and South Africa, where labour productivity has stagnated since 1980, unlike in China and India.

Brazil's R&D intensity in both the government and business enterprise sectors has grown but the GERD/GDP ratio failed to reach the government target of 1.50% by 2010 (1.15% in 2012) and business stands no chance of contributing the

Table 1.6: **Internet users per 100 population, 2008 and 2013**

	2008	2013
World	**23.13**	**37.97**
High-income economies	64.22	78.20
Upper middle-income economies	23.27	44.80
Lower middle-income economies	7.84	21.20
Low-income economies	2.39	7.13
Americas	**44.15**	**60.45**
North America	74.26	84.36
Latin America	27.09	47.59
Caribbean	16.14	30.65
Europe	**50.82**	**67.95**
European Union	64.19	75.50
Southeast Europe	34.55	57.42
European Free Trade Association	83.71	90.08
Other Europe	25.90	53.67
Africa	**8.18**	**20.78**
Sub-Saharan Africa	5.88	16.71
Arab States in Africa	17.33	37.65
Asia	**15.99**	**31.18**
Central Asia	9.53	35.04
Arab States in Asia	19.38	38.59
West Asia	14.37	37.84
South Asia	4.42	13.74
Southeast Asia	24.63	43.58
Oceania	**54.50**	**64.38**
Other groupings		
Least developed countries	2.51	7.00
Arab States all	18.14	38.03
OECD	63.91	75.39
G20	28.82	44.75
Selected countries		
Argentina	28.11	59.90
Brazil	33.83	51.60
Canada	76.70	85.80
China	22.60	45.80
Egypt	18.01	49.56
France	70.68	81.92
Germany	78.00	83.96
India	4.38	15.10
Iran	10.24	31.40
Israel	59.39	70.80
Japan	75.40	86.25
Malaysia	55.80	66.97
Mexico	21.71	43.46
Republic of Korea	81.00	84.77
Russian Federation	26.83	61.40
South Africa	8.43	48.90
Turkey	34.37	46.25
United Kingdom	78.39	89.84
United States of America	74.00	84.20

Source: for data on internet users: International Telecommunications Union/ICT Indicators database, June 2015, and estimations by UNESCO Institute for Statistics; for population, United Nations Department of Economic and Social Affairs, Population Division (2013) *World Population Prospects: the 2012 Revision*

desired 0.90% of GDP by 2014 (0.52% in 2012). Public and private firms have actually reported a drop in innovation activity since 2008. Among the targets set by the four-year plan *Brasil Maior* (Larger Brazil), only that for expanding access to fixed broadband internet has seen tangible progress. Brazil's share of world exports has actually receded (see also Table 1.6).

The government's efforts to overcome rigidities in the public research system by instituting a category of autonomous research bodies ('social organizations') to pave the way for research institutions to apply modern management methods and develop closer ties with industry has produced some success stories in fields such as applied mathematics or sustainable development. Research excellence nevertheless remains concentrated in a handful of institutions situated mainly in the south.

The volume of Brazilian publications has swelled in recent years but patenting by Brazilians in key global markets remains low. Technology transfer from public research institutions to the private sector remains a major component of innovation in fields ranging from medicine to ceramics, agriculture and deep-sea oil drilling. Two national laboratories have been set up since 2008 to foster the development of nanotechnology. Universities now have the capacity to develop nanoscale materials for drug delivery but, since domestic pharmaceutical companies don't have internal R&D capabilities, universities have to work with them to push new products and processes out to market.

Since 2008, the **European Union** (Chapter 9) has been in a protracted debt crisis. Unemployment rates have soared, especially for the young. As it strives to shore up its macroeconomic governance, the world's most advanced project for economic and political union between sovereign states is searching for a growth strategy that works.

Europe 2020, the ten-year strategy adopted in 2010 for smart, sustainable and inclusive growth, is striving to reposition the EU to reach the unfulfilled goals of its earlier Lisbon Strategy by raising investment in R&D (1.92% of GDP in 2013), completing the internal market (especially in services) and promoting the use of ICTs. Additional programmes have been launched since 2010, including the ambitious *Innovation Union*. In July 2015, the Juncker Commission added a European Fund for Strategic Investment to the EU's growth policy arsenal, a small public budget (€ 21 billion) being used to leverage 14 times more (€ 294 billion) in private investment.

Europe remains a pole of excellence and international co-operation in basic research. The first pan-European funding body for frontier research was set up in 2008: the European

Research Council (ERC). Between 2008 and 2013, one-third of all ERC grantees co-authored articles listed among the top 1% most highly cited publications worldwide. The Horizon 2020 programme for research and innovation, which has been endowed with by far the biggest budget yet of any EU framework programme (nearly € 80 billion), is expected to boost EU scientific output further.

Although the R&D intensity of the ten countries which joined the EU in 2004 remains lower than that of the older members, the gap is narrowing. The same cannot be said of Bulgaria, Croatia and Romania, which contributed less to EU GERD in 2013 than in 2007.

Several member states are promoting technology-intensive manufacturing, including France and Germany, or seeking ways to give SMEs greater access to finance. Of some concern is the fact that the innovation performance of 13 countries out of 28 has slipped, owing to a declining share of innovative companies, fewer public–private scientific partnerships and a lesser availability of risk capital.

Southeast European (Chapter 10) economies are at different stages of EU integration, which remains a common goal: whereas Slovenia has been part of the Eurozone since 2007, Bosnia and Herzegovina's Stabilisation and Association Agreement with the EU only entered into force in June 2015. In July 2014, all non-EU countries in the region announced their decision to join the EU's Horizon 2020 programme.

Slovenia is often considered a leader in the region. Its GERD/GDP ratio rose from 1.63% to 2.59% between 2008 and 2013, albeit within a contracting GDP. Slovenia is also the only country in Southeast Europe where business enterprises fund and perform the majority of R&D. Although business R&D has stagnated in most other countries, R&D intensity has risen in Bosnia and Herzegovina, the Former Yugoslav Republic of Macedonia and Serbia; as of 2012, it was close to 1% in Serbia (0.91), which was also performing better in innovation surveys. However, even the more industrialized countries of Croatia and Serbia suffer from weak university–industry linkages. Strong growth in the number of doctorate-holders has enabled researcher density to grow in most countries.

In 2013, governments adopted the *SEE 2020 Strategy* mirroring its EU namesake, in which they commit to raising their R&D intensity and boosting the size of their highly skilled labour force. This strategy is complemented by the *Western Balkans Regional Research and Development Strategy for Innovation* (2013) promoting technology transfer from public research organizations to the private sector and greater collaboration with industry; it advocates smart specialization in high-opportunity areas, such as 'green' innovation and energy, and includes a component promoted by the UNESCO Institute for Statistics of bringing the region's statistics up to EU standards by 2018.

The **European Free Trade Association** (Chapter 11) encompasses four wealthy countries which remain strongly integrated with the EU, yet distinct from it. The European Economic Area agreement signed two decades ago gives Iceland, Liechtenstein and Norway fully associated partner status in EU research programmes. Switzerland's involvement in the latter, while traditionally strong, has recently been confined to temporary arrangements limiting participation in key programmes like Excellent Science, pending the resolution of a dispute with the EU over the implications of the February 2014 Swiss referendum for the free movement of EU researchers in Switzerland.

Switzerland figures in the top three OECD countries for innovation. It has a research-intensive private sector, even though the share of Swiss firms investing in innovation has recently fallen. Switzerland owes its success partly to its ability to attract international talent to private industry and the university sector.

At 1.7 (2013), Norway's GERD/GDP ratio remains below the EU28 average and the level of Iceland (1.9 in 2013) and Switzerland (3.0 in 2012). Norway's share of the adult population with tertiary qualifications and/or engaged in the STI sector is one of the highest in Europe. Unlike Switzerland, Norway struggles to attract international talent and to transform scientific knowledge into innovative products; it also counts a small proportion of high-tech companies conducting R&D. These trends may reflect weak incentives to compete in an oil-rich welfare state.

Iceland was severely hit by the global financial crisis of 2008. Its R&D intensity declined from 2.6 to 1.9 between 2007 and 2013. Despite being confronted with brain drain, Iceland has an excellent publication record, largely due to a highly mobile younger generation of scientists. Most spend at least part of their career abroad and half of all doctorates are awarded in the USA.

Despite Liechtenstein's tiny size, some of its internationally competitive companies in machinery, construction and medical technology conduct a high level of R&D.

Seldom viewed as a region, the countries of the **Black Sea basin** (Chapter 12) are middle-income economies that face similar challenges with regard to STI. Although they have followed different trajectories, most Black Sea countries appear to be converging in terms of educational attainment and, for the larger ones (such as Turkey and Ukraine), in terms of their level of industrialization. Most are feeling the gravitational pull of the EU in international scientific collaboration.

In their strategic documents, all seven Black Sea countries acknowledge the importance of science-based innovation for long-term productivity growth, including Azerbaijan where R&D intensity had struggled to keep up with oil-driven growth in the 2000s. In the historically more industrialized post-Soviet states of Belarus and Ukraine, GERD is no longer as high as in the heady days of the 1980s but remains on a par (0.7–0.8% of GDP) with less ambitious middle-income economies.

In the other, less populous post-Soviet states (Armenia, Georgia and Moldova), post-transition instability and long-term policy and funding neglect have rendered much of the Soviet-era research infrastructure obsolete and severed modern industry–science linkages. These countries do have exploitable assets, though. Armenia, for instance, can boast of scientific excellence in ICTs.

All six post-Soviet states suffer from severe lacunae when it comes to the availability or comparability of data on R&D and personnel, partly because this aspect of their transition to advanced economies remains incomplete.

Coming from a lower starting point, Turkey has been surpassing the other Black Sea countries for many quantitative measures of STI input. Its equally impressive socio-economic transformation over the past decade appears to have been mostly driven by medium-tech production. Turkey could still learn from the other shores of the Black Sea why an early emphasis on strong educational attainment is so important for building technological excellence. In turn, its neighbours could learn from Turkey that a highly educated labour force and R&D alone do not lead to innovation; you also need a business-friendly economic environment and contestable markets.

Economic growth has slowed in the **Russian Federation** (Chapter 13) since the global financial crisis (2008) and the country has been in recession since the third-quarter of 2014, following the sharp drop in global oil prices and the imposition of sanctions by the EU and USA in reaction to the events in Ukraine.

Reforms implemented since 2012 as part of an innovation-led growth strategy have failed to overcome the structural weaknesses which hamper growth in the Russian Federation, including limited market competition and persistent barriers to entrepreneurship. These reforms include an attempt to attract researchers to 'research deserts' by raising their salaries and providing incentives for state-owned enterprises to innovate. Government appropriations for R&D in 2013 reflected a greater orientation towards the needs of industry than five years earlier, to the detriment of basic research, which was down from 26% to 17% of the total.

Despite government efforts, the financial contribution of industry to GERD in the Russian Federation fell from 33% to 28% between 2000 and 2013, even though industry performs 60% of GERD. Generally speaking, a low proportion of industrial investment goes towards acquiring new technologies and technology-based start-ups remain uncommon. The modest investment so far in sustainable technologies can largely be explained by the business sector's tepid interest in green growth. Only one in four (26%) innovative enterprises are producing inventions in the environmental field. The government has high hopes for the Skolkovo Innovation Centre, a high-tech business complex being built near Moscow to attract innovative companies and nurture start-ups in five priority areas: energy efficiency and energy saving; nuclear technologies; space technologies; biomedicine; and strategic computer technologies and software. A law adopted in 2010 provides residents with generous tax benefits for 10 years and makes provision for the establishment of the Skolkovo Fund to support development of a university on site. One of the centre's biggest partners is the Massachusetts Institute of Technology (USA).

Low business patenting illustrates the weak synergies between a relatively determined government effort to promote economically relevant research and a business sector unfocused on innovation. For example, since the government made nanotechnology a priority growth area in 2007, production and exports have grown but the patenting intensity of related research has been very low.

Scientific production has shown modest growth but is making a relatively low impact. A recent government initiative has shaken up university research by establishing a Federal Agency for Research Organizations to take over the role of financing and managing the property of research institutes from the Russian Academy of Sciences. In 2013, the government set up the Russian Science Foundation to expand the spectrum of competitive funding mechanisms for research.

The countries of **Central Asia** (Chapter 14) are gradually moving from a state-controlled to a market economy. Although both exports and imports grew impressively during the commodities boom of the past decade, these countries remain vulnerable to economic shocks, owing to their reliance on exports of raw materials, a restricted circle of trading partners and a negligible manufacturing capacity.

All but Uzbekistan halved the number of its national research institutions between 2009 and 2013. These centres established during the Soviet period have since become obsolete with the development of new technologies and changing national priorities. As part of a drive modernize infrastructure, Kazakhstan and Turkmenistan are both building technology parks and grouping existing institutions to create research hubs. Bolstered by strong economic growth in all but Kyrgyzstan, national development strategies are fostering new high-tech industries, pooling resources and orienting the economy towards export markets.

Three universities have been set up in Central Asia in recent years to foster competence in strategic economic areas: Nazarbayev University in Kazakhstan, Inha University in Uzbekistan, specializing in ICTs, and the International Oil and Gas University in Turkmenistan. Countries are not only bent on augmenting the efficiency of traditional extractive sectors but also wish to make greater use of ICTs and other modern technologies to develop the business sector, education and research.

This ambition is hampered by chronic low investment in R&D. Over the past decade, the region's GERD/GDP ratio has hovered around 0.2–0.3%. Uzbekistan broke with this trend in 2013 by raising its own R&D intensity to 0.41%. Kazakhstan is the only country where the business enterprise and private non-profit sectors make any significant contribution to R&D – but R&D intensity overall is very low in Kazakhstan: just 0.17 in 2013. Nevertheless, spending on scientific and technological services has risen strongly in this country, suggesting a growing demand for R&D products. This trend is also revealing of enterprises' preference for purchasing embodied technological solutions in imported machinery and equipment. The government has adopted a strategy for modernizing enterprises through technology transfer and the development of business acumen; the focus is on developing project finance, including through joint ventures.

Between 2005 and 2014, Kazakhstan's share of scientific papers from the region grew from 35% to 56%. Although two-thirds of papers from the region have a foreign co-author, the main partners tend to come from beyond Central Asia.

In **Iran** (Chapter 15), international sanctions have slowed industrial and economic growth, limited foreign investment and oil and gas exports and triggered national currency devaluation and hyperinflation. The sanctions also appear to have accelerated the shift from a resource-based economy to a knowledge economy by challenging policy-makers to look beyond extractive industries to the country's human capital for wealth creation, including a large pool of young university graduates. Between 2006 and 2011, the number of firms declaring R&D activities more than doubled. However, even though one-third of GERD came from the business sector in 2008, this contribution (0.08% of GDP) remains too small to nurture innovation effectively. GERD amounted to just 0.31% of GDP in 2010. The easing of sanctions following the conclusion of the nuclear deal in July 2015 may help the government to reach its target of raising GERD to 3% of GDP.

As economic sanctions have tightened their grip, the government has sought to boost endogenous innovation. The Innovation and Prosperity Fund was established by law in 2010 to support investment in R&D by knowledge-based firms and the commercialization of research results, as well as to help SMEs acquire technology. Between 2012 and late 2014, it planned to allocate 4 600 billion Iranian rials (*circa* US$ 171.4 million) to 100 knowledge-based companies.

Although sanctions have caused a shift in Iran's trading partners from West to East, scientific collaboration has remained largely oriented towards the West. Between 2008 and 2014, the top foreign partners for scientific co-authorship were the USA, Canada, the UK, Germany and Malaysia. Ties with Malaysia are growing: one in seven foreign students in Malaysia is now of Iranian origin (see Chapter 26).

Over the past decade, several research centres and 143 companies have been established in nanotechnology. By 2014, Iran ranked seventh worldwide for the volume of papers related to nanotechnology, even if few patents are being granted to inventors, as yet.

Israel (Chapter 16) has the world's most R&D-intensive business sector, in addition to being the world's most venture capital-intensive economy. The country has achieved a qualitative edge in a range of technologies in electronics, avionics and related systems, initially propelled by spin-offs from the defence industry. The development of these systems has given Israeli high-tech industries a qualitative edge in civilian spin-offs in the software, communications and internet sectors. In 2012, the high-tech sector accounted for an exceptional 46% of Israel's exports.

Such success, combined with an acute sense of vulnerability in a country largely isolated from its immediate neighbourhood, has given rise to introspection. There is debate, for instance, on how Israel should promote its technological edge in the largely non-defence-driven disciplines that are considered to be tomorrow's drivers of growth, including biotechnology and pharmaceuticals, nanotechnology and material sciences. Since excellence in these areas tends to be rooted in the basic research laboratories of universities, Israel's decentralized university research system will need to manage the necessary transition to these growth areas – but is it equipped to do so? In the absence of a national policy for universities, it is not clear how they will manage to supply the knowledge, skills and human resources needed for these new science-based industries.

There is a visible ageing of scientists and engineers in some fields, including physical sciences and practical engineering. The shortage of professional staff will be a major handicap for the national innovation system, as the growing demand for engineers and technical professionals begins to outpace supply. The *Sixth Higher Education Plan* (2011–2015) foresees the recruitment of 1 600 senior faculty, about half of whom will occupy new positions (a net increase of more than 15%). It also foresees an investment of NIS 300 million (*circa* US$ 76 million) over six years in upgrading and renovating academic infrastructure and research facilities. Some argue that the plan pays insufficient attention to the funding of university research, which in the past relied heavily on Jewish philanthropic contributions from abroad.

Israel's broader problem of a binary economic structure persists, with a small high-tech sector serving as the locomotive of the economy co-existing with much larger but less efficient traditional industrial and services sectors with lower productivity levels. This binary economic structure has led to a well-paid labour force living at the 'core' of the country and a poorly paid labour force living primarily on the periphery. Israeli decision-makers need to reflect on how to address such systemic issues in the absence of an umbrella organization for STI policy, without sacrificing the flexibility of the decentralized education and research systems that has served the country so well, so far.

Most **Arab States** (Chapter 17) devote more than 1% of GDP to higher education and many have high gross tertiary enrolment rates for both sexes. Generally speaking, though, they have failed to create economic opportunities on a sufficient scale to absorb the growing pool of youth.

With the exception of the capital-surplus oil-exporting countries, Arab economies have not experienced rapid, sustained expansion. Low economic participation rates (especially among women) and high unemployment rates (especially among youth) have been exacerbated in most countries since 2008. Events that have erupted since 2011 (the so-called Arab Spring) were as much a reaction to economic frustration as poor public governance. Military spending was already high in the Middle East but political turmoil in recent years and the concomitant rise of opportunist terrorist groups have led many governments to divert additional resources towards military spending.

The democratic transition in Tunisia is one of the Arab Spring's success stories. It has brought greater academic freedom that will be a boon for Tunisian research and should make it easier for universities to develop ties with industry. Tunisia already counts several technoparks.

R&D intensity has remained low in most Arab states, especially in the oil-rent economies where high GDP makes it hard to increase intensity. The GERD/GDP ratio in Morocco and Tunisia (around 0.7%) is close to the average for upper middle-income economies. Moreover, this ratio has risen in the most populous Arab country, Egypt: from 0.43% (2009) to 0.68% of GDP (2013); the government has opted to engage Egypt on the path to a knowledge economy, with the prospect of more diversified sources of income.

Governments dependent on both oil exports (Gulf States and Algeria) and oil imports (Morocco and Tunisia) are also fostering the development of knowledge economies. A wide range of recent initiatives harness STI to socio-economic development, often in the field of energy. Examples are the revival of the Zewail City of Science and Technology project in Egypt and the establishment of the Emirates Institution for Advanced Science and Technology to operate Earth observation satellites. Morocco inaugurated Africa's biggest wind farm in 2014 and is developing what may turn out to be Africa's biggest solar farm. In 2015, Saudi Arabia announced a programme to develop solar energy.

Both Qatar and Saudi Arabia have seen phenomenal growth in the volume of scientific publications over the past decade. Saudi Arabia now counts two universities among the world's top 500. It plans to reduce its dependence on foreign workers by developing technical and vocational education, including for girls.

West Africa (Chapter 18) has experienced strong economic growth in recent years, despite the Ebola epidemic and other crises. However, this growth masks structural weaknesses: the members of the Economic Community of West African States (ECOWAS) remain dependent on revenue from commodities and have, so far, failed to diversify their economies. The main obstacle is the shortage of skilled personnel, including technicians. Only three West African countries devote more than 1% of GDP to higher education (Ghana, Mali and Senegal) and illiteracy remains a major hurdle to expanding vocational training.

Africa's Science and Technology Consolidated Plan of Action (2005–2014) called for the establishment of regional networks of centres of excellence and for a greater mobility of scientists across the continent. In 2012, the West African Economic and Monetary Union designated 14 centres of excellence, a label which earned them funding for the next two years. The World Bank launched a similar project in 2014 but in the form of loans.

ECOWAS' *Vision 2020* (2011) provides a road map for improving governance, accelerating economic and monetary integration and fostering public–private partnerships. The *ECOWAS Policy on Science and Technology* (2011) is an integral part of *Vision 2020* and espouses the ambitions of the continental plan of action for STI.

So far, the research sector has had little impact in West Africa, owing to a lack of national research and innovation strategies, low investment in R&D, little private-sector involvement and little intraregional collaboration among West African researchers. The government remains by far the biggest source of GERD. West African output remains low, with only Gambia and Cabo Verde publishing 50 scientific articles or more per million inhabitants.

In **East and Central Africa** (Chapter 19), there has been a considerable gain in interest in STI since 2009. Most countries have based their long-term planning ('vision') documents on harnessing STI to development. These planning documents tend to reflect the common vision for the future that they share with West and Southern Africa: a prosperous middle-income country (or higher) characterized by good governance, inclusive growth and sustainable development.

Governments are increasingly looking for investors rather than donors and devising schemes to support local businesses: a fund developed by Rwanda to foster a green economy provides competitive funds to successful public and private applicants; in Kenya, the Nairobi Industrial and Technology Park is being developed within a joint venture with a public university. The first technology incubators in Kenya have been incredibly successful in helping start-ups capture markets in information technology (IT), in particular. Many governments are now investing in this dynamic sector, including those of Cameroon, Rwanda and Uganda.

Spending on R&D is on the rise in most countries with innovation hubs. Kenya now has one of Africa's highest R&D intensities (0.79% of GDP in 2010), followed by Ethiopia (0.61% in 2013), Gabon (0.58% of GDP in 2009) and Uganda (0.48% in 2010). The government tends to be the main source of R&D spending but business contributes 29% in Gabon (2009) and 14% in Uganda (2010). Foreign sources account for at least 40% of R&D in Kenya, Uganda and Tanzania.

East and Central African countries participated in *Africa's Science and Technology Consolidated Plan of Action* (CPA, 2005–2014) and have embraced its successor, the *Science, Technology and Innovation Strategy for Africa* (STISA-2024). Implementation of the CPA suffered from the failure to set up the African Science and Technology Fund to ensure sustainable funding but several networks of centres of excellence in biosciences were nevertheless established, including a research hub for East Africa in Kenya and two complementary networks, Bio-Innovate and the African Biosafety Network of Expertise. Five African Institutes of Mathematical Sciences have been established in Cameroon, Ghana, Senegal, South Africa and Tanzania. Since 2011, the African Observatory of Science, Technology and Innovation – another product of the CPA – has been helping to improve African data.

The East African Community (EAC) and Common Market for Southern and Eastern Africa consider STI to be a key component of economic integration. For instance, the EAC *Common Market Protocol* (2010) makes provisions for market-led research, technological development and the adaptation of technologies in the community, in order to support the sustainable production of goods and services and enhance international competitiveness. The EAC has entrusted the Inter-University Council for East Africa with the mission of developing a Common Higher Education Area by 2015.

Southern Africa (Chapter 20) is characterized by a common desire to harness STI to sustainable development. As elsewhere in the subcontinent, the economies of the Southern African Development Community (SADC) are highly dependent on natural resources. The drop in government funding for agricultural R&D by SADC countries is, thus, a cause for concern.

There is a wide disparity in R&D intensity, from a low of 0.01% in Lesotho to a high of 1.06% in Malawi, which is trying to attract FDI to develop its private sector. South Africa attracted about 45% of the FDI flowing to the SADC in 2013 and is establishing itself as a leading investor in the region: between 2008 and 2013, its outward flows of FDI almost doubled to US$ 5.6 billion, powered by investment in telecommunications, mining and retail in mostly neighbouring countries.

The contraction in South Africa's GERD/GDP ratio between 2008 and 2012 from 0.89% to 0.73% is mostly due to a drop in private-sector funding that could not be offset by the concomitant rise in public spending on R&D. South Africa generates about one-quarter of African GDP and has a fairly solid innovation system: it filed 96% of SADC patents between 2008 and 2013.

In most SADC countries, STI policies remain firmly linked to the state apparatus, with little participation by the private sector. STI policy documents are rarely accompanied by implementation plans and allocated budgets. A lack of human and financial resources has also hampered progress towards regional STI policy targets. Other obstacles to the development of national innovation systems include a poorly developed manufacturing sector, few incentives for private-sector investment in R&D, a serious shortage of scientific and technological skills at all levels, ongoing brain drain, poor science education at school for want of qualified teachers and an appropriate curricula, poor legal protection of intellectual property rights, and lack of co-operation in science and technology.

Intra-African trade remains dismally low, at approximately 12% of total African trade. Regional integration is high on the list of the African Union, the New Partnership for Africa's

Development and regional economic communities like the SADC, COMESA and EAC, which formally launched a Free Trade Area in June 2015. The development of regional STI programmes is also high on their list of priorities. The most formidable obstacle of all to regional integration is probably the resistance of individual governments to relinquishing any national sovereignty.

In **South Asia** (Chapter 21), political instability has been a barrier to development but the resolution of crises in the region, including the return to peace in Sri Lanka and the democratic transition in Afghanistan offer hope for the future. Sri Lanka is investing heavily in infrastructure development and Afghanistan in education at all levels.

All economies have grown in the past decade, with GDP per capita progressing fastest in Sri Lanka (excluding India, see Chapter 22). South Asia nevertheless remains one of the world's least economically integrated regions, intraregional trade accounting for just 5% of the total.

Although South Asian countries have made a strong drive to achieve universal primary education by 2015, this effort has eaten into investment in higher education (just 0.2–0.8% of GDP). Most countries have formulated policies and programmes to foster the use of ICTs in schools, research and economic sectors but these efforts are hampered by an unreliable electricity supply in rural areas, in particular, and the lack of broadband internet infrastructure. Mobile phone technology is widely used in the region but still underutilized for information- and knowledge-sharing, as well as for the development of commercial and financial services.

Pakistan's R&D effort slid from 0.63% to 0.29% of GDP between 2007 and 2013, whereas Sri Lanka maintained a low 0.16% of GDP. Pakistan plans to hoist its investment in R&D to 1% of GDP by 2018 and Sri Lanka to 1.5% by 2016. The challenge will be to put effective mechanisms in place to achieve these targets. Afghanistan has surpassed its own target by doubling university enrolment between 2011 and 2014.

The country to watch may be Nepal, which has improved several indicators in just a few years: its R&D effort has risen from 0.05% (2008) to 0.30% (2010) of GDP, it now has more technicians per million inhabitants than either Pakistan or Sri Lanka and is just a whisker behind Sri Lanka for researcher intensity. Reconstruction needs after the tragic earthquake of 2015 may oblige the government to review some of its investment priorities.

To realize their ambition of becoming knowledge economies, many South Asian countries will need to boost the uptake into secondary education and adopt credible funding and prioritization mechanisms. Tax incentives for innovation and a more business-friendly economic environment could help to make public–private partnerships a driver of economic development.

In **India** (Chapter 22), economic growth has slowed to about 5% per year since the 2008 crisis; there is concern that this respectable growth rate is not creating sufficient jobs. This has led Prime Minister Modi to argue for a new economic model based on export-oriented manufacturing, as opposed to the current model weighted towards services (57% of GDP).

Despite slower economic growth, all indicators of R&D output have progressed rapidly in recent years, be they for the share of high-tech exports among Indian exports or the number of scientific publications. The business enterprise sector has become increasingly dynamic: it performed nearly 36% of all R&D in 2011, compared to 29% in 2005. The only key indicator which has stagnated is the measure of India's R&D effort: 0.82% of GDP in 2011. The government had planned to raise GERD to 2% of GDP by 2007 but has since had to set back the target date to 2018.

Innovation is concentrated in nine industrial sectors, with more than half of business R&D expenditure concerning just three industries: pharmaceuticals, automotive and computer software. Innovative firms are also largely circumscribed to just six of India's 29 states. Despite India having one of the most generous tax regimes for R&D in the world, this regime has failed to spread an innovation culture across firms and industries.

There has been strong growth in patents, six out of ten of which were in IT and one out of ten in pharmaceuticals in 2012. The majority of pharmaceutical patents are held by domestic firms, whereas foreign firms tend to hold most IT patents. This is because Indian companies have traditionally had less success in manufacturing products which require engineering skills than in science-based industries like pharmaceuticals.

The majority of patents granted to Indians are for high-tech inventions. In order to sustain this capacity, the government is investing in new areas such as aircraft design, nanotechnology and green energy sources. It is also using India's capabilities in ICTs to narrow the urban–rural divide and setting up centres of excellence in agricultural sciences to reverse the worrying drop in yields of some staple food crops. India is also evolving into a hub for 'frugal innovation,' with a growing local market for pro-poor inventions, such as low-cost medical devices or Tata's latest micro-car, the Nano Twist.

The employability of scientists and engineers has been a nagging worry for policy-makers for years and, indeed, for prospective employers. The government has introduced a number of remedial measures to improve the quality of higher education and academic research. Researcher density in the private sector is now rising, underpinned by spectacular growth in the number of engineering students. Nevertheless, the government still needs to invest more heavily in university research, which performs just 4% of R&D, to enable universities to fulfil their role better as generators of new knowledge and providers of quality education.

In **China** (Chapter 23), scientists and engineers have clocked up some remarkable achievements since 2011. These span a wide range of areas from fundamental discoveries in condensed matter physics to landing a probe on the moon in 2013 and China's first large passenger aircraft. China is on track to become the world's largest scientific publisher by 2016. Meanwhile, at home, seven out of ten (69%) of the patents granted by China's State Intellectual Property Office in 2013 went to domestic inventors.

There is nevertheless some dissatisfaction among the political leadership with the return so far on the government's investment in R&D. Despite a massive injection of funds (2.09% of GDP in 2014), better trained researchers and sophisticated equipment, Chinese scientists have yet to produce cutting-edge breakthroughs. Few research results have been turned into innovative and competitive products and China faces a US$ 10 billion deficit (2009) in its intellectual property balance of payments. Many Chinese enterprises still depend on foreign sources for core technologies. Just 4.7% of GERD goes on basic research, compared to 84.6% on experimental development (up from 73.7% in 2004).

These problems have forced China to put its ambition on hold of embarking on a truly innovation-driven development trajectory while the leadership pushes ahead with a comprehensive reform agenda to address perceived weaknesses. The Chinese Academy of Sciences, for instance, has come under pressure to raise the quality of academic research and collaborate more with other innovation actors. To foster technology transfer, an expert group has been set up under Vice-Premier Ma Kai to identify industrial champions capable of concluding strategic partnerships with foreign multinationals. This resulted in Intel acquiring 20% of the shares in Tsinghua Unigroup, a state company, in September 2014.

The 'new normal' of slower economic growth highlights the urgency for China to transform its economic development model from one that is labour-, investment-, energy- and resource-intensive to one that is increasingly dependent upon technology and innovation. A number of policies are moving in this direction. For instance, the *Twelfth Five-Year Plan* (2011–2015) specifically calls for the development of smart city technologies.

China has already managed to reach many of the quantitative targets set by its *Medium and Long-term Plan for the Development of Science and Technology* (2006–2020) and is on track to reach that of a 2.5% GERD/GDP ratio by 2020. This plan is currently undergoing a mid-term review. The findings may determine the extent to which the country preserves elements of the open, bottom-up development strategy that has served it so well for the past three decades. One risk is that a more politicized, interventionist strategy might deter foreign capital and slow down China's brain gain, which has recently accelerated: nearly half of the 1.4 million students who have returned home since the early 1990s have done so since 2010.

Japan (Chapter 24) has been pursuing extraordinarily active fiscal and economic policies to shake itself out of the economic lethargy that has plagued it since the 1990s. This policy reform package has come to be known as Abenomics, in reference to the prime minister. The third 'arrow' of this package in the area of pro-growth policies is yet to show results, however.

Japan nevertheless remains one of the most R&D-intensive economies in the world (3.5% of GDP in 2013). The most remarkable trend in industrial spending on R&D in recent years has been the substantial cutback in ICTs. Most other industries maintained more or less the same level of R&D expenditure between 2008 and 2013.The challenge for Japanese industry will be to combine its traditional strengths with a future-oriented vision.

Japan faces a number of challenges. Its ageing population, coupled with a waning interest among the young for an academic career and the drop in scientific publications, reflect a need for a far-reaching reform of the national innovation system.

For the academic sector, university reform has been a challenge for years. Regular funding of national universities has declined consistently for more than a decade by roughly 1% a year. In parallel, the amount of competitive grants and project funding have increased. In particular, there has been a proliferation recently of multipurpose, large-scale grants that do not target individual researchers but rather the universities themselves; these grants do not purely fund university research and/or education *per se;* they also mandate universities to conduct systemic reforms, such as the revision of curricula, promotion of female researchers and internationalization of education and research. The drop in regular funding has been accompanied by increasing demands on academics, who now have less time for research. This has translated into a drop in scientific publications, a trend almost unique to Japan.

The Fukushima disaster in March 2011 has had a profound impact on science. The disaster has not only shaken the public's confidence in nuclear technology but also in science and technology more broadly. The government has reacted by trying to restore public confidence. Debates have been organized and, for the first time, the importance of scientific advice in decision-making has come to the fore. Since the Fukushima disaster, the government has decided to reinvigorate the development and use of renewable energy.

Published just months after the Fukushima disaster, the *Fourth Basic Plan for Science and Technology* (2011) was a radical departure from its predecessors. It no longer identified priority areas for R&D but rather put forward three key areas to be addressed: recovery and reconstruction from the Fukushima disaster, 'green innovation' and 'life innovation.'

The **Republic of Korea** (Chapter 25) is the only nation to have transformed itself from a major recipient of foreign aid into a major donor – and in just two generations. Today, it is in search of a new development model. The government recognizes that the remarkable growth of the past is no longer sustainable. Competition with China and Japan is intense, exports are slipping and global demand for green growth has altered the balance. In addition, a rapidly ageing population and declining birthrates threaten Korea's long-term economic prospects.

The Park government is pursuing the low carbon, green growth policy adopted by its predecessor but has added the creative economy to this mix. Seed money has been allocated to fostering the emergence of a creative economy over the five years to 2018.

The government has come to realize that developing national capabilities for innovation will require nurturing creativity among the young. Ministries have jointly introduced measures to attenuate the focus on academic backgrounds and promote a new culture whereby people encourage and respect the creativity of individuals. One example of these measures is the Da Vinci Project being experimented in selected primary and secondary schools to develop a new type of class which encourages students to exercise their imagination and revitalizes hands-on research and experience-based education.

The process of making the country more entrepreneurial and creative will entail changing the very structure of the economy. Up until now, it has relied on large conglomerates to drive growth and export earnings. These still represented three-quarters of private investment in R&D in 2012. The challenge will be for the country to produce its own high-tech start-ups and to foster a creative culture in SMEs. Another challenge will be to turn the regions into hubs for creative industries by providing the right financial infrastructure and management to improve their autonomy. The new Innovation Center for the Creative Economy in Daejeon serves as a business incubator.

In parallel, the government is building the International Science Business Belt in Daejeon. The aim is to correct the impression that the Republic of Korea made the transition from a poor agricultural country to an industrial giant through imitation alone, without developing an endogenous capacity in basic sciences. A National Institute for Basic Science opened on the site in 2011 and a heavy ion accelerator is currently under construction to support basic research and provide linkages to the business world.

Malaysia (Chapter 26) has recovered from the global financial crisis to register healthy average annual GDP growth of 5.8% over 2010–2014. This, coupled with strong high-tech exports, has helped sustain government efforts to finance innovation, such as through the provision of R&D grants to universities and firms. This has helped to raise the GERD/GDP ratio from 1.06% in 2011 to 1.13% in 2012. The rise in R&D funding has translated into more patents, scientific publications and foreign students.

It was in 2005 that Malaysia adopted the target of becoming the sixth-largest global destination for international university students by 2020. Between 2007 and 2012, the number of international students almost doubled to more than 56 000, the target being to attract 200 000 by 2020. Malaysia is attracting a lot of students from the region but was also one of the top ten destinations for Arab students by 2012.

A number of bodies have helped to strengthen the participation of business in R&D in strategic sectors. One example is the Malaysian Palm Oil Board. In 2012, a group of multinational corporations created their own platform for Collaborative Research in Engineering, Science and Technology (CREST). This trilateral partnership involving industry, academia and the government strives to satisfy the research needs of electrical and electronics industries in Malaysia that employ nearly 5 000 research scientists and engineers.

While the government has done remarkably well in supporting R&D, a number of issues have undermined Malaysia's capacity to support frontier technologies. Firstly, collaboration between the principal actors of innovation still needs strengthening. Secondly, science and mathematics teaching needs upgrading, as 15 year-old Malaysian students have been performing less well in the triennial assessments conducted by the OECD's Programme for International Student Assessment. Thirdly, the share of full-time equivalent researchers per million inhabitants has grown steadily but remains fairly low for a dynamic Asian economy like Malaysia: 1 780 in 2012. Malaysia is also still a net technology importer, as its royalties from technological licensing and services have remained negative.

Southeast Asia and Oceania (Chapter 27) has successfully navigated through the global financial crisis of 2008, with many countries managing to avoid recession. The creation of the Association of Southeast Asian Nations (ASEAN) Economic Community in late 2015 is likely to boost economic growth in the region and spur both the cross-border movement of researchers and greater specialization. Meanwhile, democratic reforms in Myanmar have led to the easing of international sanctions, offering prospects for growth, particularly since the government is fostering export-oriented industries.

The Asia–Pacific Economic Cooperation completed a study in 2014 of skills shortages in the region, with a view to setting up a monitoring system to address training needs. For its part, the *ASEAN Plan of Action on Science, Technology and Innovation* (2016–2020) emphasizes social inclusion and sustainable development, including in such areas as green technology, energy, water resources and innovation for life. Government priorities in Australia, on the other hand, are shifting away from renewable energy and low carbon strategies.

Countries from the region are increasingly collaborating with one another, as reflected by trends in international scientific co-authorship. For the less developed economies, co-authorship even accounts for 90–100% of output; the challenge for them will be to steer international scientific collaboration in the direction envisaged by national S&T policies.

A comparatively high share of R&D is performed by the business sector in four countries: Singapore, Australia, the Philippines and Malaysia. In the case of the latter two, this is most likely a product of the strong presence of multinational companies in these countries. Innovation performance is generally weak in the region, which produces 6.5% of the world's scientific publications (2013) but only 1.4% of global patents (2012); moreover, four countries accounted for 95% of those patents: Australia, Singapore, Malaysia and New Zealand. The challenge for economies such as Viet Nam and Cambodia will be to draw on the knowledge and skills embedded in the large foreign firms that they host, in order to develop the same level of professionalism among local suppliers and firms.

Since 2008, many countries have boosted their R&D effort, including in the business enterprise sector. In some cases, though, business expenditure on R&D is highly concentrated in the natural resource sector, such as mining and minerals in Australia. The challenge for many countries will be to deepen and diversify business sector involvement across a wider range of industrial sectors, especially since the onset of a cycle of declining prices for raw materials adds a sense of urgency to the task of developing innovation-driven growth policies.

CONCLUSION

An evolving public commitment to science and research

This latest edition of the *UNESCO Science Report* covers more countries and regions than ever before. This reflects the growing acceptance worldwide and, in particular, in the non-OECD world, of STI as a driver of development. At the same time, the statistical data on basic STI indicators remain patchy, especially in non-OECD countries. Nevertheless, there is a growing awareness of the need for reliable data to enable monitoring of national science and innovation systems and inform policy. This realization has given rise to the African Science and Technology Indicators Initiative, which has spawned an observatory based in Equatorial Guinea. A number of Arab economies are also establishing observatories of STI, including Egypt, Jordan, Lebanon, Palestine and Tunisia.

Another striking trend observed in the *UNESCO Science Report* is the decline in public commitment to R&D observed in many developed countries (Canada, UK, USA, etc), as opposed to a growing belief in the importance of public investment in R&D for knowledge creation and technology adoption in emerging and lower income countries. STI has, of course, been mainstreamed in many emerging economies for some time, including Brazil, China and the Republic of Korea. What we are seeing now is the adhesion of many middle- and low-income countries to this philosophy, with many incorporating STI in their 'vision' or other planning documents. Of course, these countries have benefited from much higher economic growth rates than OECD countries in recent years, so the jury is still out, to some extent, as to whether they will be able to pursue this public commitment in years of lower or even negative growth. Brazil and the Russian Federation will be test cases, as both have now entered recession following the end of a cyclical boom in raw materials.

However, as Chapter 2 highlights, it is not just the diverging public commitment to investment in R&D between the highly developed and emerging and middle-income world that is narrowing. While most R&D (and patenting) is taking place in high-income countries, innovation is occurring in countries across the full spectrum of income levels. Much innovation is occurring without any R&D activity at all; in the majority of countries surveyed by the UNESCO Institute for Statistics in 2013, innovation unrelated to R&D implicated more than 50% of firms. Policy-makers should take note of this phenomenon and, accordingly, focus not just on designing incentives for firms to engage in R&D. They also need to facilitate non-research-related innovation, particularly in relation to technology transfer, since the acquisition of machinery, equipment and software is generally the most important activity tied to innovation.

Innovation spreading but policy hard to get right

Formulating a successful national science and innovation policy remains a very difficult task. Reaping the full benefit from science- and innovation-driven economic development requires moving in the right direction in a number of different policy fields simultaneously, including those affecting education, basic science, technological development and its corollary of mainstreaming sustainable ('green') technologies, business R&D and economic framework conditions.

Many dilemmas appear increasingly common to a wide range of countries, such as that of trying to find a balance between local and international engagement in research, or between basic and applied science, the generation of new knowledge and marketable knowledge, or public good science versus science to drive commerce.

The current trend towards a greater orientation of STI policy towards industrial and commercial development is also having international ramifications. The *UNESCO Science Report 2010* anticipated that international diplomacy would increasingly take the form of science diplomacy. This prophecy has come true, as illustrated by the case studies from New Zealand (Box 27.1) and Switzerland (Box 11.3). However, in some cases, things have taken an unexpected turn. Some governments are showing a tendency to tie research partnerships and science diplomacy to trade and commercial opportunities. It is revealing that Canada's innovation network is now managed by the Trade Commissioner Service at the Department of Foreign Affairs, Trade and Development, for instance, rather than being placed in the foreign service; this megadepartment was created in 2013 by amalgamating the Canadian International Development Agency and the Department of Foreign Affairs and International Trade. Australia has taken a similar step by subsuming AusAID into the Department of Foreign Affairs and Trade and giving foreign aid an increasingly commercial focus.

The global economic boom between 2002 and 2007 seemed to have 'lifted all boats' on the wave of prosperity and focused policy attention and resource allocation on innovation in many emerging and developing countries. This period witnessed a proliferation of STI policies, long-term planning ('vision') documents and ambitious targets around the world. Since the crisis of 2008–2009, slow economic growth and the tightening of public budgets appear to have made the art of crafting and implementing successful science and innovation policies much more difficult. The pressure being exerted on public interest science in Australia, Canada and the USA illustrates one of the consequences of the tightening of public R&D budgets. The challenge for low- and middle-income countries, on the other hand, will be to ensure that policies are well-funded, that their implementation is monitored and evaluated and that the bodies responsible for implementing the policy co-ordinate their efforts and are held accountable.

Some countries have either been historically equipped with relatively strong higher education systems and a wide pool of scientists and engineers or have been making important strides in these directions recently. Despite this, they are not yet seeing a strong focus on R&D and innovation in the business sector for reasons ranging from the sectorial specialization of their economies to a poor or deteriorating business environment. To varying degrees, a diverse range of countries are experiencing this phenomenon, including Canada, Brazil, India, Iran, the Russian Federation, South Africa and Ukraine.

Other countries have made great strides in economic reform, industrial modernization and international competitiveness but still need to complement their push for public-sector driven R&D with significant qualitative improvements in the spheres of higher education and basic research, in order to take their business R&D beyond experimental development towards more genuine innovation. Again, a wide range of countries find themselves confronted with this challenge, including China, Malaysia and Turkey. For some, the challenge will be to orient an FDI-driven industrial competitiveness more towards endogenous research, as in the case of Malaysia. For others, the challenge will be to foster healthy collaboration between the different components of the public research system. The current reform of academies of sciences in China, the Russian Federation and Turkey illustrates the tensions that can arise when the autonomy of these institutions is called into question.

Open science and open education within 'closed' borders?

Another trend worth noting is the steep rise in the number of researchers, who now number 7.8 million worldwide. This represents an increase of 21% since 2007 (Table 1.3). This growth is also reflected in the explosion of scientific publications. The competition to publish in a limited number of high-impact journals has increased dramatically, as has the competition among scientists to secure jobs in the most reputed research institutions and universities. Moreover, these institutions are themselves increasingly competing with one another to attract the world's best talent.

The Internet has brought with it 'open science', paving the way to online international research collaboration, as well as open access to publications and underlying data. At the same time, there has been a global move in the direction of 'open education' with the widespread development and availability of online university courses (MOOCS) provided by new global university consortia (see p. 4). In short, the academic research and higher education system is internationalizing rapidly, with major implications for its traditional national organization and funding. The same is happening in the private sector, which 'potentially has a much bigger role to play than universities in spreading the "resource balance" in science and technology around the world' (Chapter 2). Increasingly, it is considered a must to have an international composition of research staff in both research and innovation. As the saying goes, Silicon Valley was built on IC, a reference not to integrated circuits but to the contribution of Indians and Chinese to this innovation hub's success.

The fly in the ointment is that cross-border flows of knowledge in the form of researchers, scientific co-authorship, invention co-ownership and research funding are also strongly dependent on factors that have little to do with science. These days, mercantilism characterizes much of national STI policy-making. All governments are keen to increase high-tech exports but few are prepared to discuss removing non-tariff barriers (such as government procurement) that may be constraining their imports. Everyone wishes to attract foreign R&D centres and skilled professionals (scientists, engineers, doctors, etc.) but few are prepared to discuss frameworks for facilitating cross-border movement (in both directions). The EU's decision to adopt 'scientific visas' as of 2016 within its Innovation Union to facilitate the cross-border movement of specialists is one attempt to remove some of these barriers.

Import substitution has exerted a strong influence on development policy in recent decades. Today, there is a growing debate as to the merits of protectionist industrial policies. The authors of the chapter on Brazil (Chapter 8), for instance, argue that import substitution policies have removed the incentive for endogenous enterprises to innovate, since they do not have to compete internationally.

Good governance is good for science

Good governance accompanies progress at each stage of the innovation-driven development process. Absence of corruption in the university system is essential to ensure that institutions are producing qualified graduates. At the other end of the innovation cycle, a highly corrupt business environment is a strong disincentive for the emergence of innovation-driven competition. For instance, companies will have little incentive to invest in R&D, if they cannot rely on the justice system to defend their intellectual property. Scientific fraud is also more likely to occur in environments characterized by poor governance standards.

The *UNESCO Science Report* highlights numerous examples where countries have recognized the need for better governance to foster endogenous science and innovation. With exemplary frankness, Uzbekistan's Committee for Coordination of Science and Technology Development has identified 'strengthening the rule of law' as one of the country's eight priorities for boosting R&D to 2020 (Chapter 14). Southeast Europe's own *2020 Strategy* identifies 'effective public services, anti-corruption and justice' as being one of the five pillars of the region's new growth strategy. In neighbouring Moldova, 13% of the 2012 state programme for R&D has been allocated to the 'consolidation of the rule of law and utilization of cultural heritage in the perspective of European integration.' The chapter on the Arab States places considerable emphasis on the need to improve governance, transparency, the rule of law and the fight against corruption to reap greater benefits from investment in science and technology, together with 'enhancing reward for initiative and drive' and developing 'a healthy climate for business.' Last but not least, the chapters on Latin America and Southern Africa highlight the strong link between government effectiveness and scientific productivity.

The consequences for science of the 'resource curse'

Resource extraction can allow a country to accumulate significant wealth but long-term, sustained economic growth is seldom driven by reliance on natural resources. A number of countries appear to be failing to seize the opportunity offered by resource-driven growth to strengthen the foundations of their economies. It is tempting to infer from this that, in countries awash with natural resources, high-growth from resource extraction provides a disincentive for the business sector to focus on innovation and sustainable development.

The end of the latest commodities boom, coupled with the collapse in global oil prices since 2014, has underscored the vulnerability of national innovation systems in a wide range of resource-rich countries that are currently struggling to remain competitive: Canada (Chapter 4), Australia (Chapter 27), Brazil (Chapter 8), the oil-exporting Arab States (Chapter 17), Azerbaijan (Chapter 12), Central Asia (Chapter 14) and the Russian Federation (Chapter 13). Other countries with a traditionally heavy reliance on commodity exports for their economic expansion have been making more decisive efforts to prioritize knowledge-driven development, as illustrated by the chapters on Iran (Chapter 15) and Malaysia (Chapter 26).

Under normal circumstances, resource-rich countries can afford the luxury of importing the technologies they need for as long as the bonanza lasts (Gulf States, Brazil, etc.). In exceptional cases where resource-rich countries are faced with an embargo on technology, they tend to opt for import substitution strategies. For instance, since mid-2014, the Russian Federation (Chapter 13) has broadened its import substitution programmes in response to trade sanctions that are affecting imports of key technologies. The case of Iran (Chapter 15) illustrates how a long-running trade embargo can incite a country to invest in endogenous technological development.

It is worth noting that several oil-rent economies expressed interest in developing renewable energy *before* global oil prices began falling in mid-2014, including Algeria, Gabon, the United Arab Emirates and Saudi Arabia. The *UNESCO Science Report 2010* had observed a paradigm shift towards green growth. It is evident from the current report that this trend has since accelerated and is seducing an ever-greater number of countries, even if levels of public investment may not always be commensurate with ambitions.

The emphasis is often on developing coping strategies to protect agriculture, reduce disaster risk and/or diversify the national energy mix, in order to ensure long-term food, water and energy security. Countries are also becoming increasingly aware of the value of their natural capital, as illustrated by the recommendation in the *Gaborone Declaration on Sustainability* (2012) for African countries to integrate the value of natural capital into national accounting and corporate planning. Among high-income economies (EU, Republic of Korea, Japan, etc), a firm commitment to sustainable development is often coupled with the desire to maintain competitiveness in global markets that are increasingly leaning towards green technologies; global investment in renewable energy technologies increased by 16% in 2014, triggered by an 80% decrease in the manufacturing costs of solar energy systems. It is to be expected that the trend towards green growth will accentuate, as countries strive to implement the new Sustainable Development Goals.

Looking ahead: *Agenda 2030*

On 25 September 2015, the United Nations adopted the *2030 Agenda for Sustainable Development.* This ambitious new phase transitions from the Millennium Development Goals (2000–2015) to a new set of integrated Sustainable Development Goals (2015–2030). The new agenda is universal and, thus, applies to developing and developed countries alike. It comprises no fewer than 17 goals and 169 targets. Progress towards these goals over the next 15 years will need to be informed by evidence, which is why a series of indicators will be identified by March 2016 to help countries monitor their progress towards each target. The goals balance the three economic, environmental and social pillars of sustainable development, while embracing other pillars of the United Nations' mission related to human rights, peace and security. STI is woven into the fabric of *Agenda 2030*, since it will be essential for achieving many of these goals.

Although the Sustainable Development Goals have been adopted by governments, it is evident that they will only be reached if all stakeholder groups take ownership of them. The scientific community is already on board. As we have seen from the *UNESCO Science Report: towards 2030*, the focus of scientific discovery has shifted towards problem-solving, in order to tackle pressing developmental challenges.

This shift in research priorities is evident in the amount of research funds currently being allocated to applied science (see p. 6). In parallel, both governments and businesses are increasingly investing in the development of 'green technologies' and 'green cities'. At the same time, we should not forget that 'basic science and applied science are two sides of the same coin,' as recalled by the Scientific Advisory Board to the Secretary General of the United Nations (see p. 9). They are 'interconnected and interdependent [and], thus, complement each in providing innovative solutions to the challenges humanity faces on the pathway to sustainable development.' An adequate investment in both basic sciences and applied research and development will be critical to reaching the goals of *Agenda 2030.*

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Policy-makers should ... focus not just on designing incentives for firms to engage in R&D [but also] facilitate non-research-related innovation, particularly in relation to technology transfer.

Elvis Korku Avenyo, Chiao-Ling Chien, Hugo Hollanders, Luciana Marins, Martin Schaaper and **Bart Verspagen**

Car assembly plant in Lovech, Bulgaria in 2012.
Photo: © Ju1978 / Shutterstock.com

2 · Tracking trends in innovation and mobility

Elvis Korku Avenyo, Chiao-Ling Chien, Hugo Hollanders, Luciana Marins, Martin Schaaper and Bart Verspagen

INTRODUCTION

Innovation is spreading its reach across the globe

With the rise of the so-called 'emerging' economies, research and development (R&D) are spreading their reach across the globe. Multinational firms are playing an important role in this process. By establishing research facilities (R&D units) in foreign countries, they are fostering knowledge transfer and the accrued mobility of research personnel. Importantly, this phenomenon is a two-way street. Multinational firms from Brazil, the Russian Federation, India, China and South Africa (the BRICS countries) are not only a magnet for foreign multinationals; these firms 'born in the BRICS' are also purchasing high-tech companies in North America and Europe and thereby acquiring skilled personnel and a portfolio of patents overnight. Nowhere is this more visible than in China and India, which together now contribute more to global expenditure on business R&D than Western Europe (Figure 2.1). In 2014, for instance, the Indian firm Motherson Sumi Systems Ltd purchased Ohio-based Stoneridge Harness Inc.'s wiring harness for US$ 65.7 million (see Chapter 22).

Different work cultures

Both private and (semi-) public agents innovate but their different work cultures affect the way in which the knowledge generated is diffused. Traditionally, scientists working in public institutions like universities have been motivated by the desire to establish a reputation that is dependent on openness. Their success depends on being first to report a discovery by publishing it in widely accessible journals, on other scientists acknowledging this discovery and building upon it in their own work. This implies that making knowledge available to colleagues and the wider public is a key element of the work of academic scientists.

Scientists working in private firms, on the other hand, have a different motivation. Respecting their employer's interests calls for secrecy and the appropriation of knowledge rather than allowing it to circulate freely. The marketplace being characterized by competition, a firm is obliged to appropriate the knowledge that it develops – in the form of goods, services and processes – to prevent competitors from imitating the discovery at a lesser cost.

Firms use a whole range of strategies to protect their knowledge, from patents and other intellectual property rights to secrecy. Although they will eventually make this knowledge available to the general public through the market, this protection of their knowledge limits its diffusion. This trade-off between the right of firms to protect their knowledge and the public good is the basis of every system of intellectual property rights employed in the global economy.

Public knowledge is not affected by this trade-off but much of the knowledge generated today involves contributions from both public and private actors. This can affect the rate at which knowledge is diffused. One obvious example is the influence of new knowledge on agricultural productivity. The so-called Green Revolution in the mid-20th century depended almost exclusively on research done by public laboratories and universities. This made the knowledge generated by the Green Revolution readily available for farmers worldwide and provided a great boost to agricultural productivity in many developing countries. However, when the advent of genetic science and modern biotechnology in the late 20th century gave agricultural productivity another boost, the situation was very different because, by this time, private firms had come to play a leading role. They protected their knowledge, leading to a much stronger dependence of farmers and others on a handful of multinational firms that could act as monopolies. This has given rise to heated debates about the economic and ethical sides of private firms developing 'breakthrough' technologies but limiting the diffusion of these.

Private science is increasingly mobile

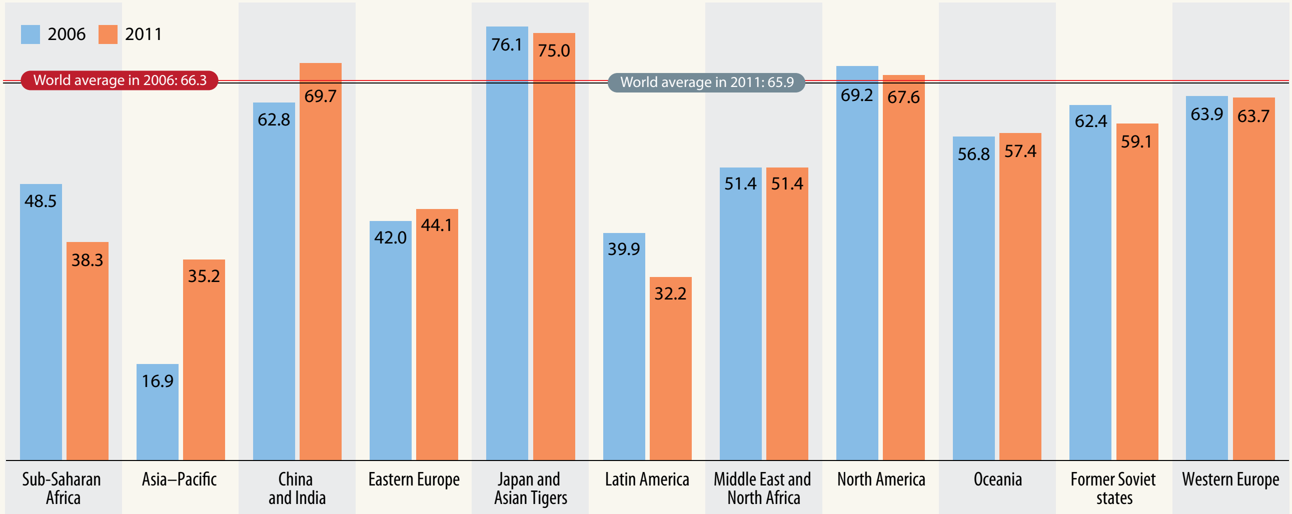
Another difference between the 'culture' of public and private science and technology concerns the degree of mobility. Private science is increasingly mobile, public science is not. Here, we are not referring to individual researchers working in the public and private sectors, who tend to see mobility as a way of furthering their careers. Rather, we are referring to differences at institutional level. Increasingly, firms are relocating their research laboratories abroad. Universities, by and large, remain much more immobile, with only a small minority setting up campuses abroad. Thus, the private sector potentially has a much bigger role to play than universities in spreading the 'resource balance' in science and technology around the world.

In 2013, the UNESCO Institute for Statistics launched its first international survey of innovation by manufacturing firms. For the first time, a database containing innovation-related indicators for 65 countries at different stages of development was made available to the public. In the following pages, we shall be exploring the types of innovation being implemented by private firms and the linkages they need with other socio-economic actors in order to innovate.

Figure 2.1: **Trends in business R&D, 2001–2011**

The contribution of business R&D to GERD has dropped since 2006 in sub-Saharan Africa, the Americas and the former Soviet states

Share of business R&D in GERD at national level, 2006 and 2011 (%)



1.08%

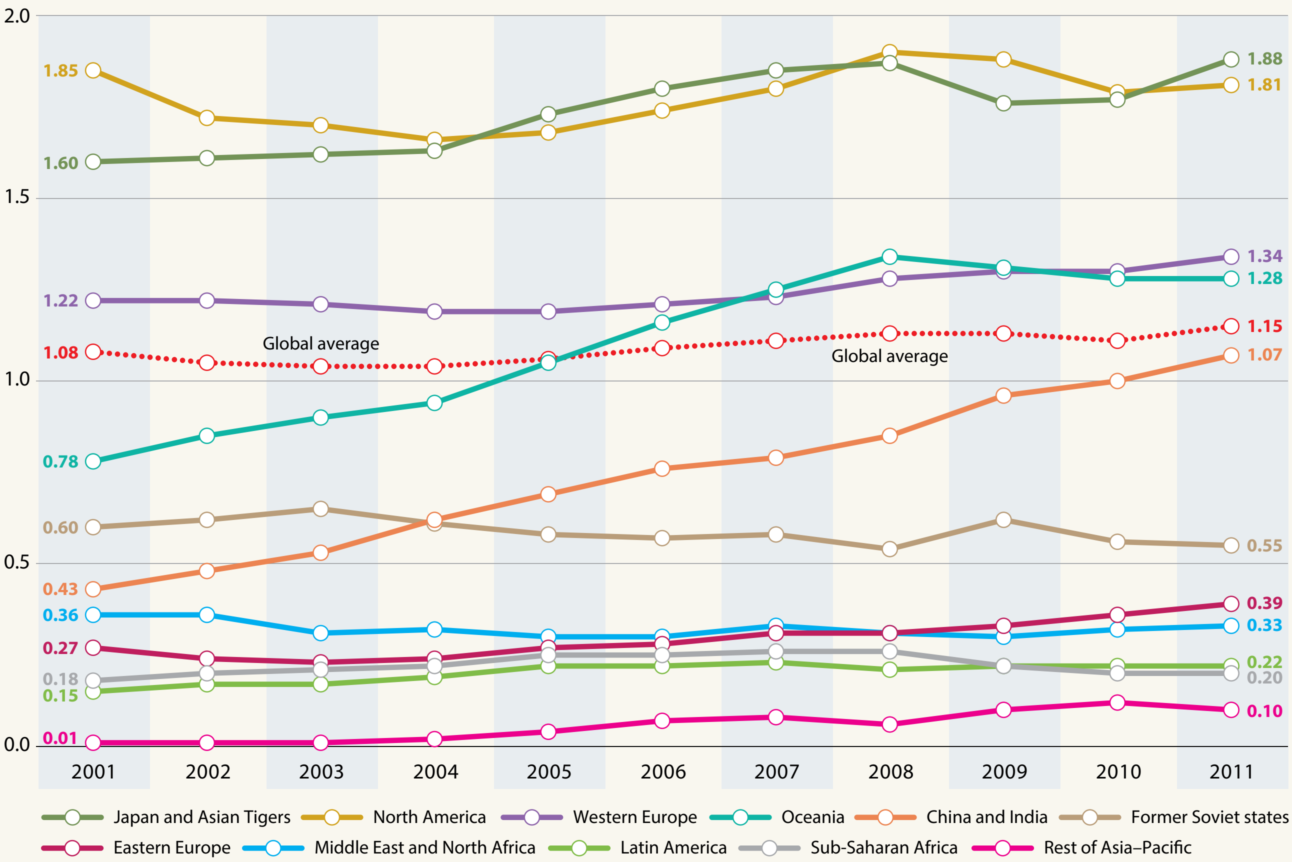
Global average for business R&D as a share of GDP in 2001

1.15%

Global average for business R&D as a share of GDP in 2011

Business R&D only contributes 0.2% of GDP in Latin America and sub-Saharan Africa

Business R&D as a share of national GDP, 2001–2011 (%)



5.1%

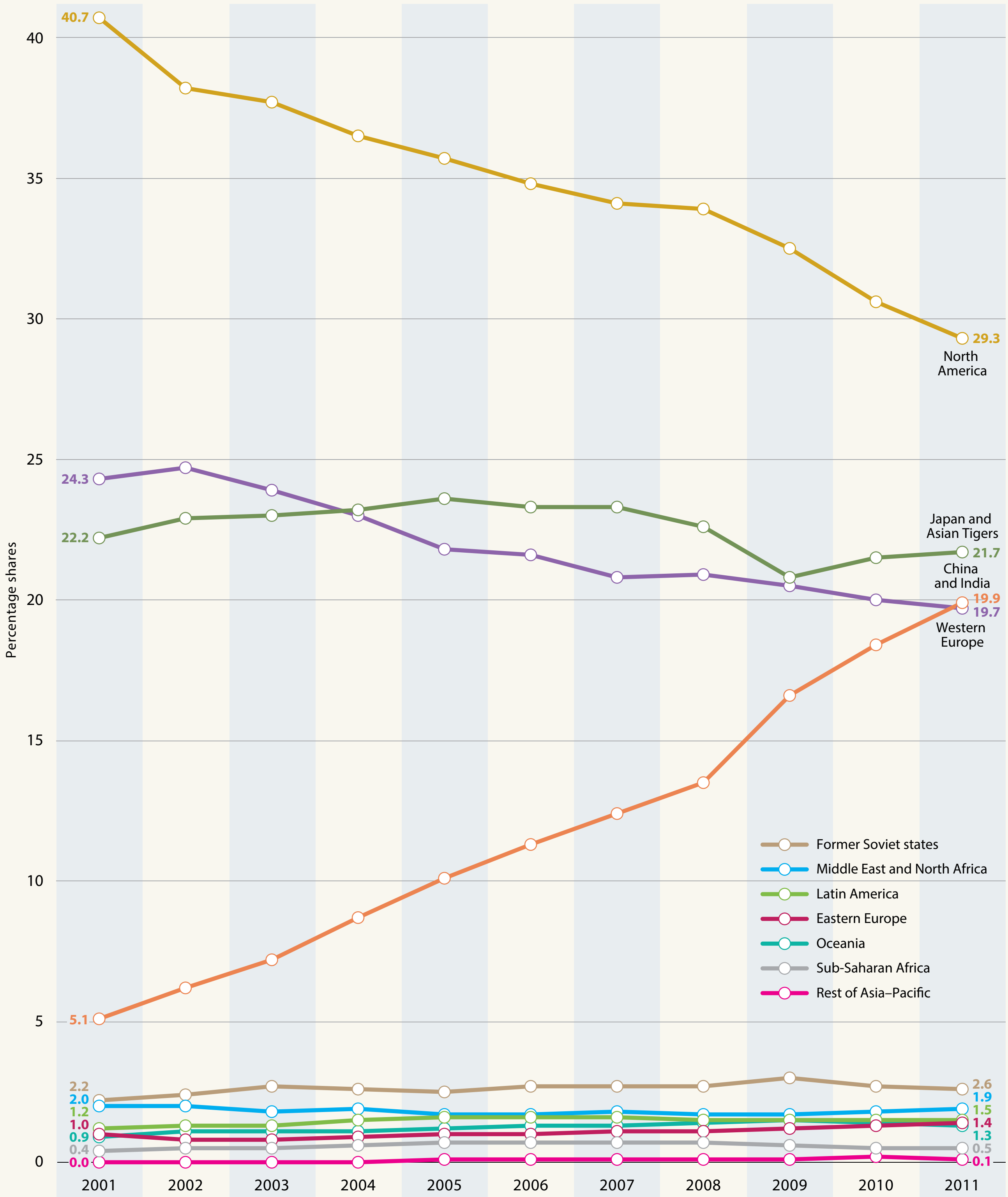
China and India's share of global business R&D in 2001

19.9%

China and India's share of global business R&D in 2011

China and India are capturing a greater share of business R&D, to the detriment of Western Europe and North America

World shares of business R&D, 2001–2011 (%), calculated in PPP$



Note: In the present chapter, the Middle East and North Africa encompasses Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Tunisia, Yemen and United Arab Emirates. See Annex 1 for the composition of the the Asian Tigers.

Source: Estimations by UNU-MERIT based on data from the UNESCO Institute for Statistics

We shall also be establishing a profile of where foreign direct investment (FDI) is going around the world. Instead of ranking countries from 'most to least or best to worst,' we shall be identifying common features, as well as dissimilarities, presented by firms in countries of different income levels which are engaging in innovation. The second part of our essay will be devoted to analysing current trends in scientific mobility and the implications of these trends for a country's capacity to innovate.

TRENDS IN INNOVATION

Innovative behaviour varies according to income level

The role played by innovation in the process of economic development has long been acknowledged. Some would even argue that this relationship was first evoked more than 200 years ago in the works of English economist Adam Smith (1776) or in those of German essayist Karl Marx (1867), long before the term was formally coined by the Austrian economist Joseph Schumpeter (1942).

In the second half of the 20th century, countries began gradually including innovation in their political agenda, which raised the need to provide policy-makers with empirical evidence. Over the past two decades, a lot of work has been done to standardize the international definition of innovation and design indicators. This work culminated in the first version of the *Oslo Manual* in 1992, subsequently updated by the Organisation for Economic Co-operation and Development (OECD) and Eurostat, the European statistics office, in 1997 and 2005. Despite these efforts, measuring innovation[1] remains a challenge and the variations in the methodological procedures adopted by countries – even when the guidelines of the *Oslo Manual* are followed – hinders the production of fully harmonized indicators.

According to the 2013 survey of firms, product innovation is the most common form of innovation in 11 high-income countries and process innovation in 12 high-income countries (Figure 2.2). In Germany, around half of firms are product innovators and almost as many are marketing innovators (48%) and organizational (46%) innovators, a profile similar to that found in Canada.

Among the low- and middle-income countries that responded to the questionnaire, the profile of innovation varies considerably from one country to another; in Costa Rica, for instance, 68% of manufacturing firms are product innovators; Cuba, on the other hand, has a high share of organizational innovators (65%), whereas marketing innovators prevail in Indonesia (55%) and Malaysia (50%). In the group of low- and middle-income countries surveyed, process innovation is the least implemented type. This is somewhat preoccupying, given the supportive role that process innovation plays in the implementation of other types of innovation.

Overall, marketing innovation is the least implemented type of innovation among the 65 countries surveyed. In addition, the share of innovators among manufacturing firms varies from 10% to 50%, regardless of the type of innovation being implemented, and only a few high-income countries present even shares for all four types of innovation.

Germany has the highest innovation rate among high-income countries

From this point on, the discussion will focus only on product and process innovation. Overall, the innovation rate found in high-income countries – in other words, the share of firms engaging actively in innovation – matches the share of innovative firms. This means that the innovation rate is chiefly composed of firms that have implemented at least one product or process innovation over the reference period covered by the national innovation survey, which is usually three years.

Germany presents the highest innovation rate among high-income countries. The fact that many firms have abandoned innovation altogether or are living off ongoing activities does not hamper Germany's innovative performance as, when these firms are set aside, Germany still has one of the highest shares of innovators: 59%.

A similar trend can be observed in the group of low- and middle-income countries surveyed, with some exceptions. In Panama, for instance, around 26% of the firms surveyed declared they had only abandoned or ongoing innovation activities. This means that, despite having an innovation rate of 73%, the share of firms actually implementing innovation in Panama only amounts to 47%.

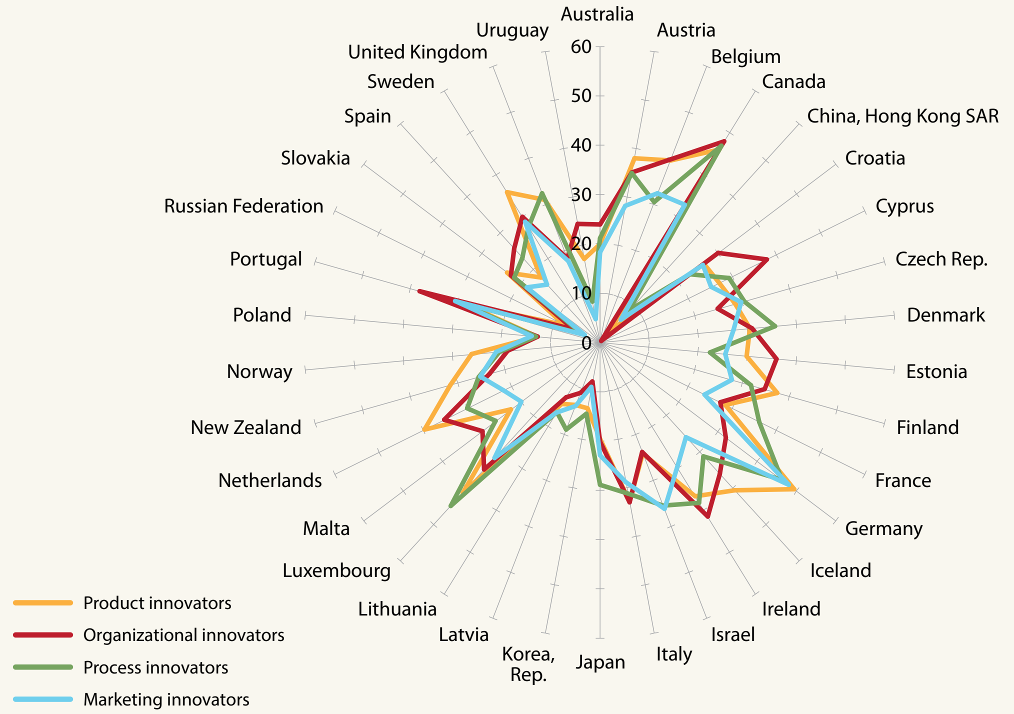
In the BRICS countries, product innovators prevail in South Africa and the Russian Federation, whereas China and India present similar shares of both types of innovators (Figure 2.3). In Brazil, the share of firms implementing process innovation is remarkably higher than the share implementing product innovation. In India, almost half of the innovation rate is composed of firms with abandoned or ongoing innovation activities.

1. See the glossary on p. 738 for the definition of terms related to innovation in the present chapter. For more information about the timeframe and methodology adopted by the countries surveyed, see UIS (2015).

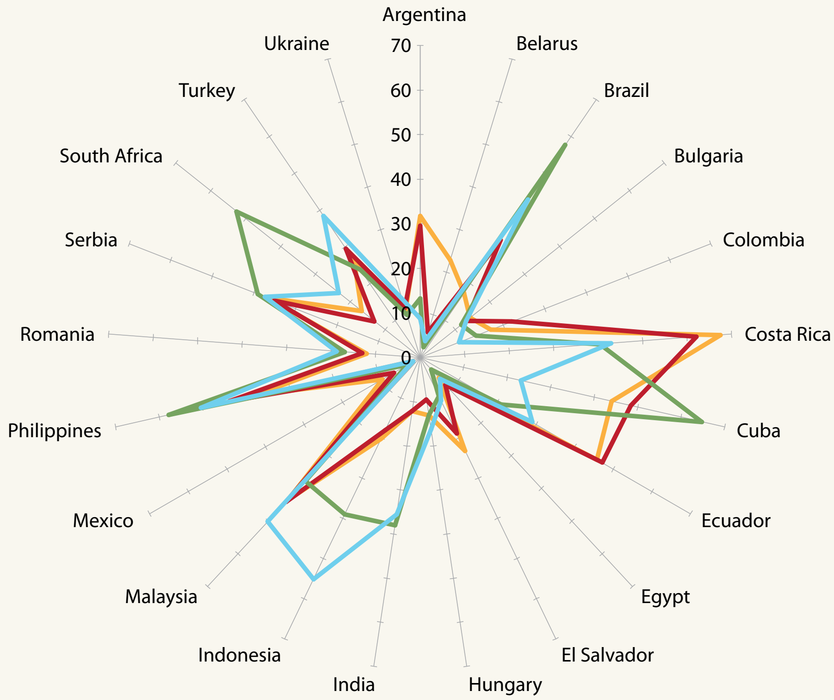
Figure 2.2: **Types of innovator around the world**

Share of manufacturing firms (%)

Types of innovator in high-income countries



Types of innovator in low- and middle-income countries



Source: UNESCO Institute for Statistics, September 2014

Figure 2.3: **Innovation rate of firms in the BRICS**
Share of manufacturing firms (%)

Source: UNESCO Institute for Statistics, September 2014

Firms still prefer to keep investment in knowledge at home

How do firms move their resources devoted to science, technology and innovation (STI) across national borders? Although it is hard to track this phenomenon, some trends can be deduced from a database on FDI related to knowledge, the fDi Markets[2] database. We shall be examining four project categories from this database: R&D projects, the hard core of private-sector investment in knowledge; design, development and testing, the largest category, which comprises less original research than the first category; education and training; and ICTs and internet infrastructure. A basic finding of the literature on firms' investment trends is that R&D and other forms of knowledge-related investment are traditionally less globalized than other forms of investment; although multinational firms often locate their production or services-related activities such as sales and customer support abroad, they are more reluctant to do the same for investment in knowledge. This is changing but there is still a tendency to keep investment in knowledge 'at home'. For instance, a survey of the largest spenders on R&D in the European Union (EU) in 2014 found that two out of three companies considered their home country to be the most attractive location for R&D (Box 2.1).

Two broad motives for the international re-location of R&D have been identified. The first is called home-base exploiting; in other words, the adaptation of existing knowledge for new markets in the targeted markets themselves, in order to benefit from local information and the skills of local workers. This leads to a re-location of R&D in those countries where the multinational firm is also manufacturing and selling its products.

A second motive is called home-base augmenting; this targets specific knowledge found at foreign locations. This approach stems from the idea that knowledge is specific to a given location and cannot easily be transferred over long geographical distances. A reason for this may be the existence of a university or public research laboratory with very specific expertise, or a common labour market offering the skills needed to implement the R&D project that the firm has in mind.

2. The fDi Markets database contains information about individual investment projects, the firm making the investment, its country of origin and destination, as well as the date and amount of the investment (US$ 1 000).

Box 2.1: **European companies rate countries' attractiveness for relocating their R&D**

A survey commissioned by the European Commission in 2014 of the biggest spenders on R&D in the EU has revealed that two out of three companies consider their home country to be the most attractive location for R&D.

Beyond the home country, the USA, Germany, China and India are considered the most attractive locations in terms of human resources, knowledge-sharing and proximity to other company sites, technology poles, incubators and suppliers.

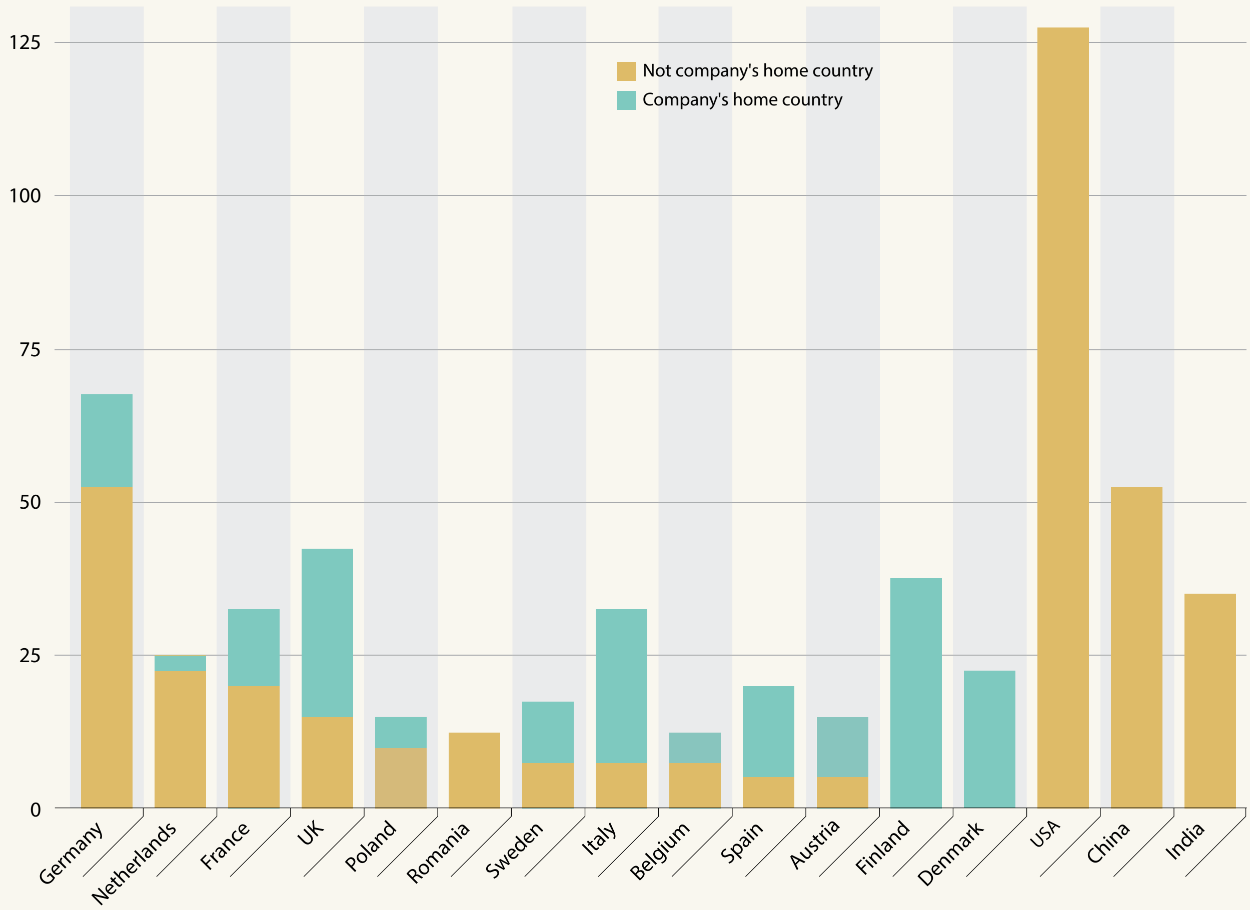
Within the EU, the quality of R&D personnel and knowledge-sharing opportunities with universities and public organizations are considered the most important criteria. Other important factors are proximity to other company sites (for Belgium, Denmark, Germany, France, Italy, Finland and Sweden) and the quantity of R&D personnel (for Italy, Austria, Poland and the UK).

Companies consider the USA as being more attractive for R&D in terms of market size and growth rate, whereas EU countries stand out for the quality of their R&D personnel in the labour market and the level of public support for R&D via grants, direct funding and fiscal incentives.

When contemplating the idea of setting up R&D units in China and India, EU companies tend to look first at market size and economic growth rate, as well as the quantity and labour cost of R&D personnel. China and India are not considered attractive in terms of intellectual property rights – especially as concerns enforcement – or public support for R&D via grants and direct funding, public–private partnerships and financing of non-R&D types of investment.

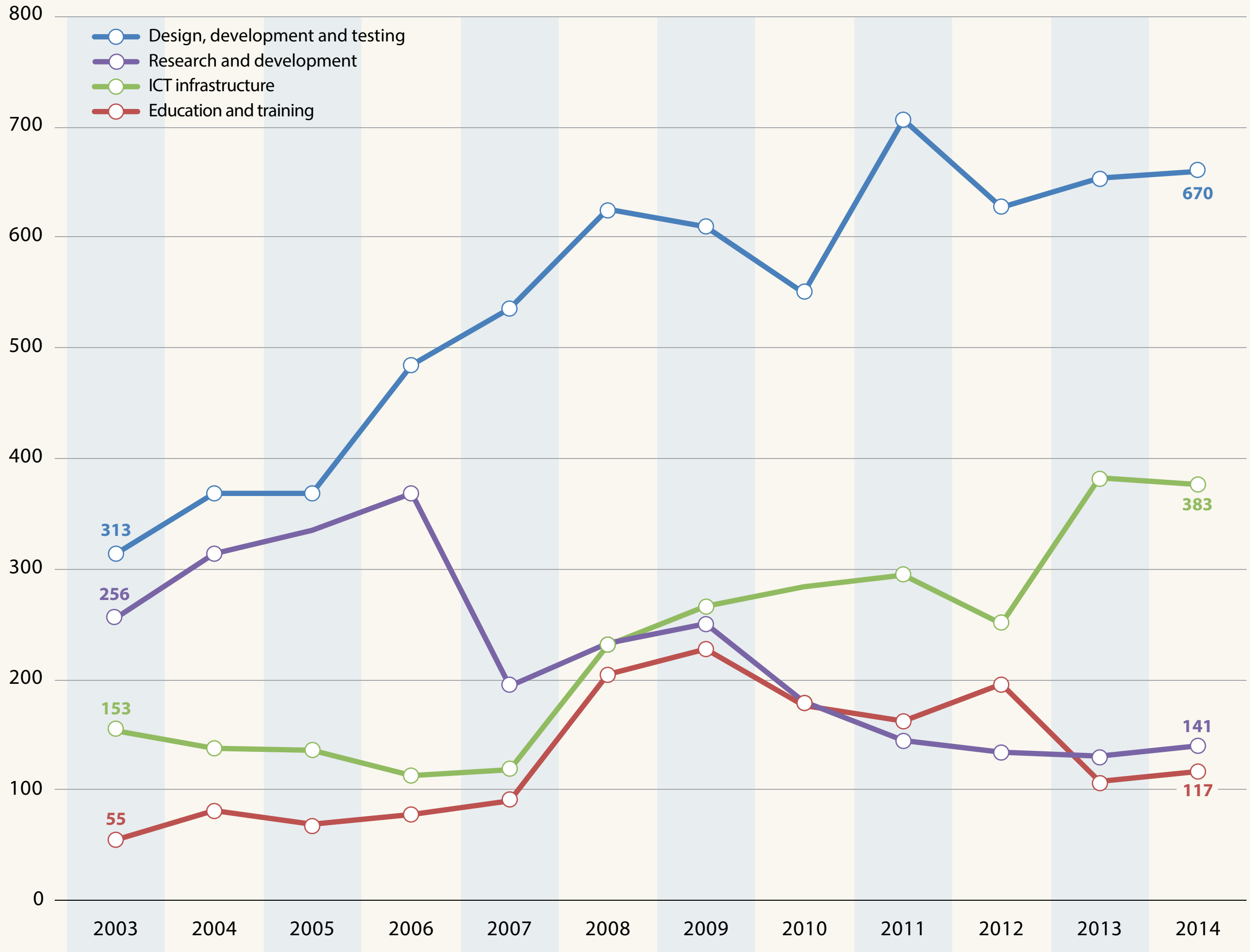
Source: (text and Figure 2.4): Executive Summary from: Joint Research Centre Institute for Prospective Technological Studies (2014) *The 2014 EU Survey on Industrial R&D Investment Trends.* See: http://iri.jrc.ec.europa.eu/survey14.html

Figure 2.4: **Most attractive countries for business R&D according to EU firms, 2014**



Note: Survey based on an attractiveness index compiled for 161 responses from 186 companies.

Figure 2.5: **Trend in number of projects in the FDI Markets database, 2003–2014**



Source: fDi Markets database, May 2015

Home-base augmenting R&D is generally seen as more 'radical', in the sense that it has greater implications for the technological capabilities of both the destination and the region in which the investment project originates. We have no way of distinguishing between these two motives directly but it would seem reasonable to expect that the 'design, development and testing' category will generally be aimed more at home-base exploiting projects than the R&D category.

A drop in the number of R&D-related FDI projects

Figure 2.5 presents an overview of the trends in the number of projects in each category. Note that the data for 2014 are incomplete. We prefer this simple count to studying the trends in invested dollars because the average investment amount per project stays roughly constant over time but varies greatly between the ICT infrastructure category and the other three. There are clear differences between the four categories, with the number of R&D projects clearly falling over time, the design category and the ICT infrastructure category rising over time and education fluctuating slightly.

The financial crisis is visible in aggregate economic indicators from 2008 onwards. The crisis does not seem to have had a marked influence on the investment projects recorded in the fDi Markets database. The top five sectors (out of 39) for FDI-related projects are software and IT services; communications; business services; pharmaceuticals; and semiconductors (Table 2.1). These five sectors cover 65% of all knowledge-related FDI projects. The R&D category is dominated by the three related sectors of pharmaceuticals, biotechnology and chemicals (57% of projects). As for the design, development and testing category, here, the trio of sectors in the top five concerns semiconductors, industrial machinery and chemicals. In the education category, the top ranking goes to business services, industrial machinery and original equipment manufacturers (OEM) in the automotive industry.

A growing tendency to converge

There is a strong concentration of private R&D in the developed parts of the globe, where about 90% of all R&D-related FDI projects originate, even if China's growing private

Table 2.1: **Sectorial distribution of knowledge-related FDI projects, 2003–2014**

Sector	Overall rank	Share of total projects (%)	Rank for R&D	Share of total projects (%)	Rank for design, development and testing	Share of total projects (%)	Rank for education	Share of total projects (%)	Rank for ICT infrastructure	Share of total projects (%)
Software & IT services	1	26	2	15	1	37	2	11	2	21
Communications	2	23	4	8	2	10	4	6	1	76
Business services	3	7	33		7	–	1	37	3	1
Pharmaceuticals	4	5	1	19	11	–	24	–	10	–
Semiconductors	5	4	6		3	7	14	–	10	–
Chemicals	–	–	3	8	5	5	–	–	–	–
Biotechnology	–	–	5	8	–	–	–	–	–	–
Industrial machinery	–	–	–	–	4	5	3	7	–	–
Automotive	–	–	–	–	–	–	5	6	–	–
Financial services	–	–	–	–	–	–	–	–	3	1
Transportation	–	–	–	–	–	–	–	–	5	0
Top 5 (%)	–	65	–	57	–	65	–	67	–	99

Source: fDi Markets database, May 2015

sector makes it a rising power (Figure 2.6). When Western Europe, North America, Japan and the Asian Tigers are on the receiving end of FDI, however, they only account for about 55% of all projects. This implies that FDI streams are tending to create a more even distribution of R&D around the world. Those parts of the world with a small share of global business R&D are attracting a relatively large share of R&D-related FDI projects from regions that are home to the great majority of private R&D (Figure 2.6).

Much of this tendency to 'converge' comes from China and India. Taken together, they attract almost 29% of all R&D-related FDI projects. China attracts the most but the number of projects is only about one-third larger than for India. By contrast, just 4.4% of these projects originate in these two countries. Africa stands out for the very low number of projects it attracts, less than 1% of the global total. As the first map[3] shows in Figure 2.6, both the destination and origin of projects are very concentrated, even within countries. China, India and, to a lesser extent, Brazil, attract numerous R&D projects but, within these large countries, only a small number of cities attract the majority of projects. In China, these locations are mostly located in coastal regions, including Hong Kong and Beijing. In India, it is Bangalore, Mumbai and Hyderabad in the south which attract the majority of projects. In Brazil, the two top cities are São Paulo and Rio de Janeiro. Africa is almost virgin territory, with the Johannesburg–Pretoria region being the only hotspot.

3. In order to keep the maps in Figure 2.6 readable, projects are documented only when at least one of the sides is not a high-income region, namely North America, Western Europe, Japan, the Asian Tigers and Oceania. Some projects do not have information on the cities.

Projects in design, development and testing paint a similar picture to that for R&D-related projects. China and India attract a slightly larger share of total FDI projects in this category, as do the other regions. Africa has crossed the 1% threshold for this category. It would seem that this type of project is more prone to globalization than those in the pure R&D category, perhaps because the knowledge embedded in design, development and testing is slightly easier to transfer – as evidenced by the larger number of FDI projects in this category – as the knowledge in this category is more akin to home-base exploiting than home-base augmenting. The map here shows the same hotspots in China, India, Brazil and South Africa as in the first map for R&D-related projects but also some additional ones, notably in Mexico (Guadalajara and Mexico City), Argentina (Buenos Aires) and South Africa (Cape Town).

In the learning and education category, the Middle East and Africa attract relatively large shares of projects. When it comes to ICT infrastructure, though, Latin America, Eastern Europe and Africa all stand out on the receiving end. The maps for these two categories tend to reproduce the same hotspots as the map of R&D-related FDI projects.

As an intermediate conclusion, we could say that the distribution of knowledge-related FDI projects is tending to become more evenly spread across the world. This is a slow trend clearly visible. However, even in terms of the very broad global regions that we used, there are large differences between different parts of the globe. Some parts of the world, such as China and India, are able to attract foreign R&D; others, such as Africa, are much less able to do so. Thus, even if convergence is taking place, it is not complete convergence in a geographical sense.

Figure 2.6: **Trends in knowledge-related FDI projects, 2003–2014**

Hardly any R&D-related projects are destined for Africa; most go to China and India

Share of total projects (%)

Source of R&D-related FDI projects	Destination of R&D-related FDI projects: Western Europe	China and India	Japan and Asian Tigers	North America	Latin America	Eastern Europe	Middle East and North Africa	Former Soviet states	Africa	Oceania	Total
Western Europe	10.6	8.3	4.3	6.0	1.8	2.4	1.1	0.8	0.5	0.5	36.2
China and India	1.7	0.3	0.7	0.9	0.1	0.1	0.4		0.1	0.1	4.4
Japan and Asian Tigers	2.0	4.6	2.5	2.0	0.1	0.2	0.1	0.3	0.0	0.2	12.1
North America	13.1	14.8	6.5	1.9	2.2	1.6	1.9	0.9	0.3	0.8	44.1
Latin America	0.1		0.0	–	0.0	–	–	–	–	0.0	0.2
Eastern Europe	0.2	0.0	0.0			0.0		0.1			0.4
Middle East and North Africa	0.3	0.3	0.0	0.3	–	0.1	–	0.0	–	–	1.1
Former Soviet states	0.2	0.0	–	0.1	–	–	–	0.0	–	–	0.3
Africa	0.0	–	–	–	–	–	–	–	–	–	0.0
Oceania	0.2	0.2	0.2	0.1	–	–	–	–	–	–	0.7
Total	28.4	28.7	14.3	11.3	4.3	4.5	3.5	2.2	0.8	1.6	

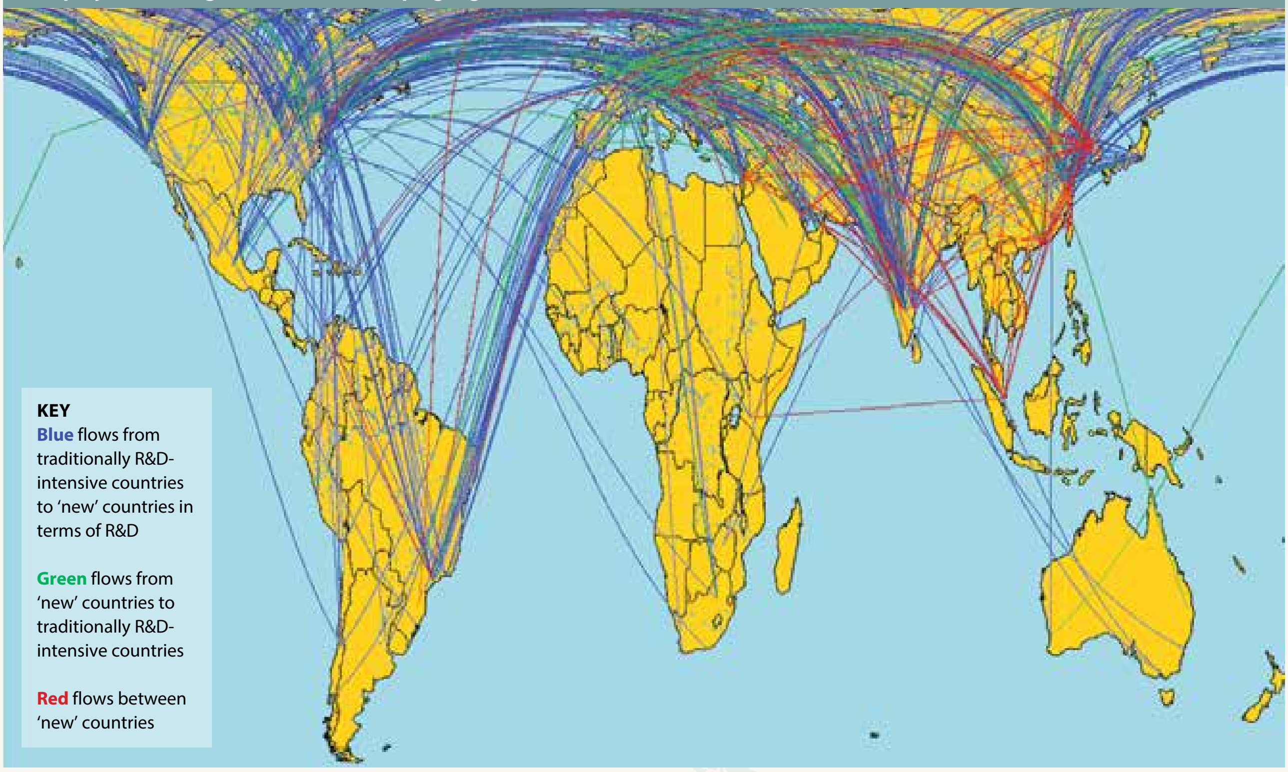
4.3%

Share of R&D-related projects destined for Latin America

28.7%

Share of R&D-related projects destined for China and India

R&D projects flowing to and from developing regions



Source: UNU-Merit

China and India are the greatest beneficiaries of projects in design, development and testing

Share of total projects (%)

Source of projects in design, development and testing	Destination: Western Europe	China and India	Japan and Asian Tigers	North America	Latin America	Eastern Europe	Middle East and North Africa	Former Soviet states	Africa	Oceania	Total
Western Europe	8.4	8.6	3.6	5.8	2.1	3.9	1.3	0.7	0.6	0.5	35.5
China and India	1.6	0.5	0.8	1.2	0.6	0.2	0.2	0.0	0.1	0.2	5.4
Japan and Asian Tigers	2.2	3.4	2.0	1.9	0.2	0.2	0.1	0.1	0.0	0.1	10.3
North America	11.0	17.4	5.4	2.0	2.8	2.5	1.5	1.0	0.3	0.9	44.9
Latin America	0.1	0.0	0.0	0.1	0.4	0.0	0.0		0.0	–	0.6
Eastern Europe	0.1	0.0	–	0.0	0.0	0.2	0.0	0.1		–	0.5
Middle East and North Africa	0.2	0.5	0.1	0.1	0.0	0.1	0.2	0.0	–	–	1.2
Former Soviet states	0.1	0.0	0.0	0.0	0.0	0.1	–	0.1	–	–	0.4
Africa	0.1	0.1	0.0	–	0.0	0.0	–	–	–	–	0.2
Oceania	0.1	0.1	0.1	0.1	–	–	0.0	0.0	0.0	0.1	0.6
Total	23.8	30.6	12.1	11.3	6.1	7.2	3.4	2.1	1.1	1.8	

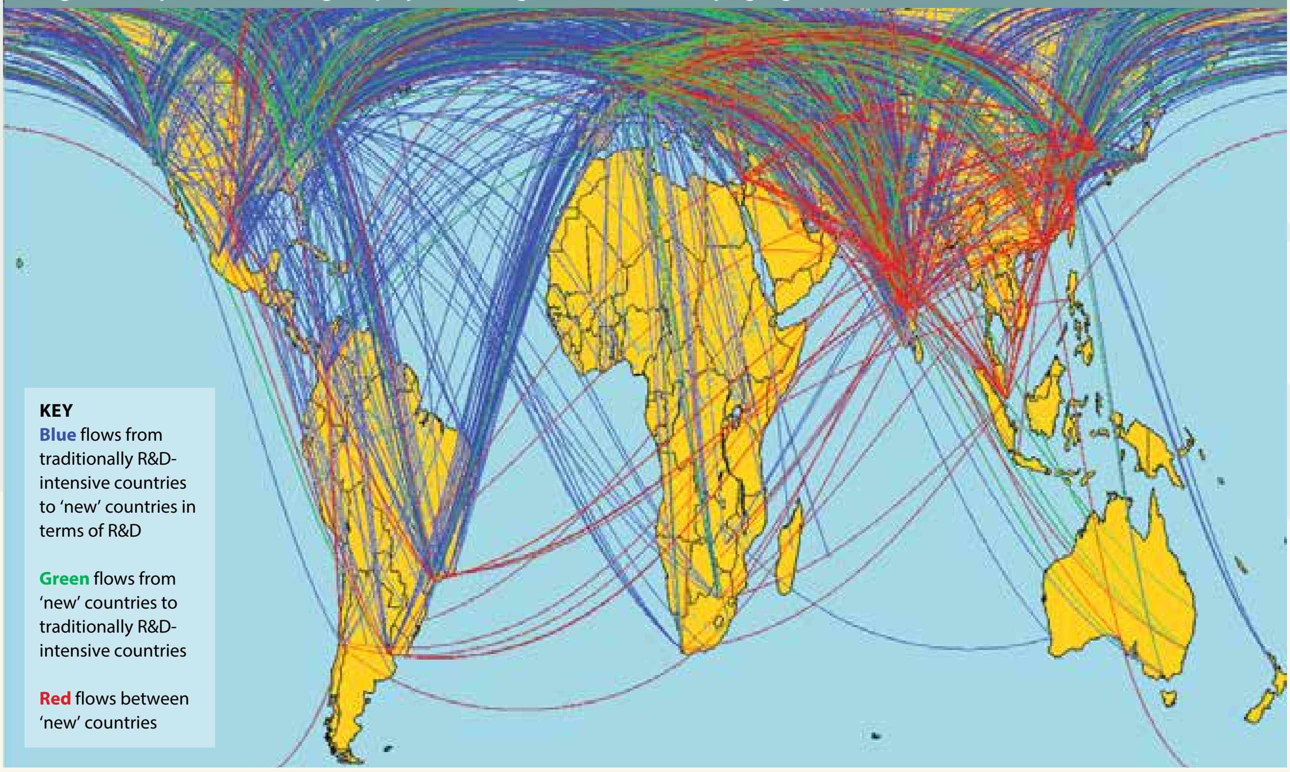
1.1%

Share of projects in design, development and testing destined for Africa

30.6%

Share of projects in design, development and testing destined for China and India

Design, development and testing FDI projects flowing to and from developing regions



Source: UNU-Merit

Figure 2.6 *(continued)*

Western Europe, China and India attract four out of ten projects in education

Share of total projects (%)

Source of FDI projets in education	Western Europe	China and India	Japan and Asian Tigers	North America	Latin America	Eastern Europe	Middle East and North Africa	Former Soviet states	Africa	Oceania	Total
	Destination of FDI projects in education										
Western Europe	8.6	7.6	5.2	4.3	2.2	2.4	4.0	1.8	2.2	0.9	39.2
China and India	0.7	0.9	0.8	0.5	0.9	0.2	2.0	0.1	1.1	0.1	7.1
Japan and Asian Tigers	2.3	3.0	2.0	1.5	0.6	0.7	0.7	0.2	0.5	0.3	11.8
North America	7.8	9.0	4.7	0.9	2.2	1.7	4.7	1.1	1.4	0.9	34.3
Latin America	0.1	0.7	0.1	–	0.1	–	–	–	0.1	–	1.1
Eastern Europe	0.2	–	–	0.1	–	–	–	0.1	–	–	0.3
Middle East and North Africa	0.5	0.5	0.2	0.1	0.1	–	1.2	–	0.1	–	2.7
Former Soviet states	–	0.1	0.1	–	–	–	0.1	0.1	–	–	0.3
Africa	–	–	–	–	–	–	0.1	–	0.5	–	0.5
Oceania	0.1	0.4	0.3	0.1	–	–	0.1	–	–	0.1	1.1
Total	20.4	22.1	13.3	7.5	5.9	4.9	12.8	3.4	5.9	2.2	

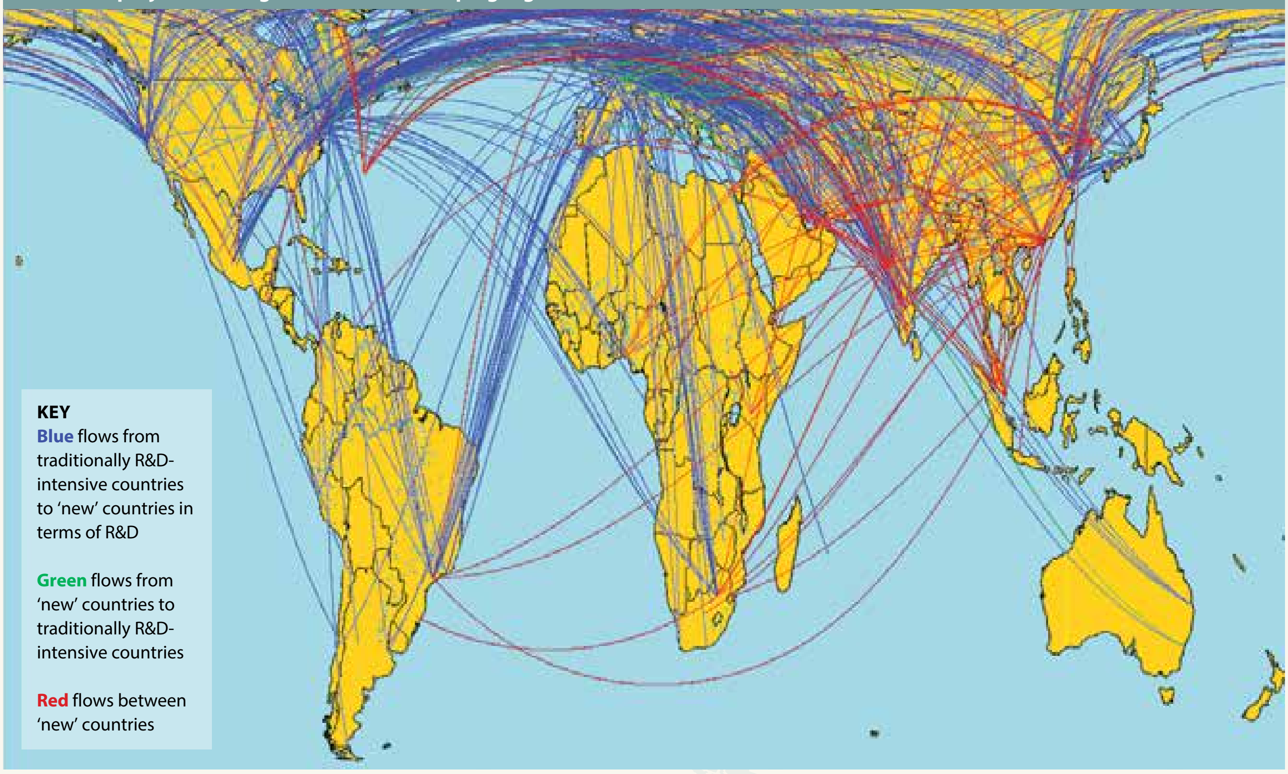
5.9%

Africa and Latin America attract the same share of projects in education

22.1%

Share of projects in education destined for China and India

Education projects flowing to and from developing regions



Source: UNU-Merit

Africa attracts more FDI projects in ICT infrastructure than in other categories

Share of total projects (%)

Source of projects in design, development and testing	Destination of FDI projects in ICT infrastructure										
	Western Europe	China and India	Japan and Asian Tigers	North America	Latin America	Eastern Europe	Middle East and North Africa	Former Soviet states	Africa	Oceania	Total
Western Europe	11.2	1.3	2.7	3.2	5.8	5.5	0.9	3.0	2.0	1.1	36.6
China and India	0.4	0.0	0.6	0.5	0.2	–	0.1	0.2	1.1	0.1	3.3
Japan and Asian Tigers	1.3	1.7	2.0	1.0	0.3	0.2	0.3	0.1	0.4	0.8	8.1
North America	13.0	3.5	7.0	2.4	4.4	1.4	0.6	0.5	0.7	2.4	35.8
Latin America	0.6	–	–	0.1	3.4	0.2	–	–	–	–	4.2
Eastern Europe	0.4	0.0	0.2	0.0	–	0.6	0.0	0.3	–	–	1.5
Middle East and North Africa	0.4	0.1	0.1	0.1	0.1	0.0	1.1	0.0	0.7	–	2.7
Former Soviet states	0.1	–	0.2	–	0.0	0.0	–	1.2	–	–	1.6
Africa	0.3	–	–		0.0	0.0	0.1		2.4		2.8
Oceania	0.2	0.1	0.2	0.1	0.0	–	–	–	–	0.1	0.8
Total	**27.8**	**6.7**	**13.0**	**7.5**	**14.3**	**7.9**	**3.2**	**5.3**	**7.2**	**4.5**	

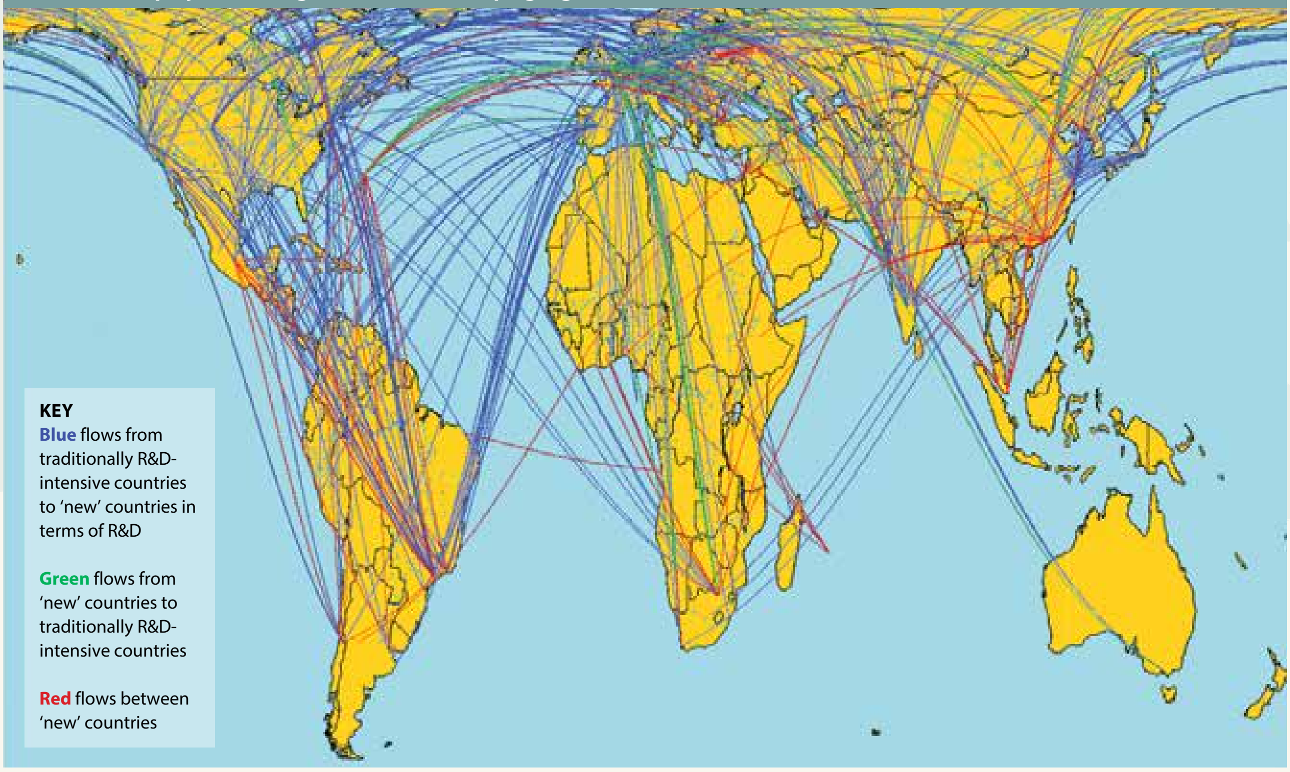
7.2%

Share of FDI projects in ICT infrastructure destined for Africa

14.3%

Share of FDI projects in ICT infrastructure destined for Latin America

Infrastructure projects flowing to and from developing regions



Source: UNU-Merit

Firms prefer in-house R&D to outsourcing

For years, R&D measures were used as a proxy for innovation on the assumption that engagement in R&D would automatically lead to the marketing of innovative products and processes. Nowadays, it has been recognized that the innovation process encompasses activities other than R&D. The relationship between these two phenomena is nevertheless still of great interest.

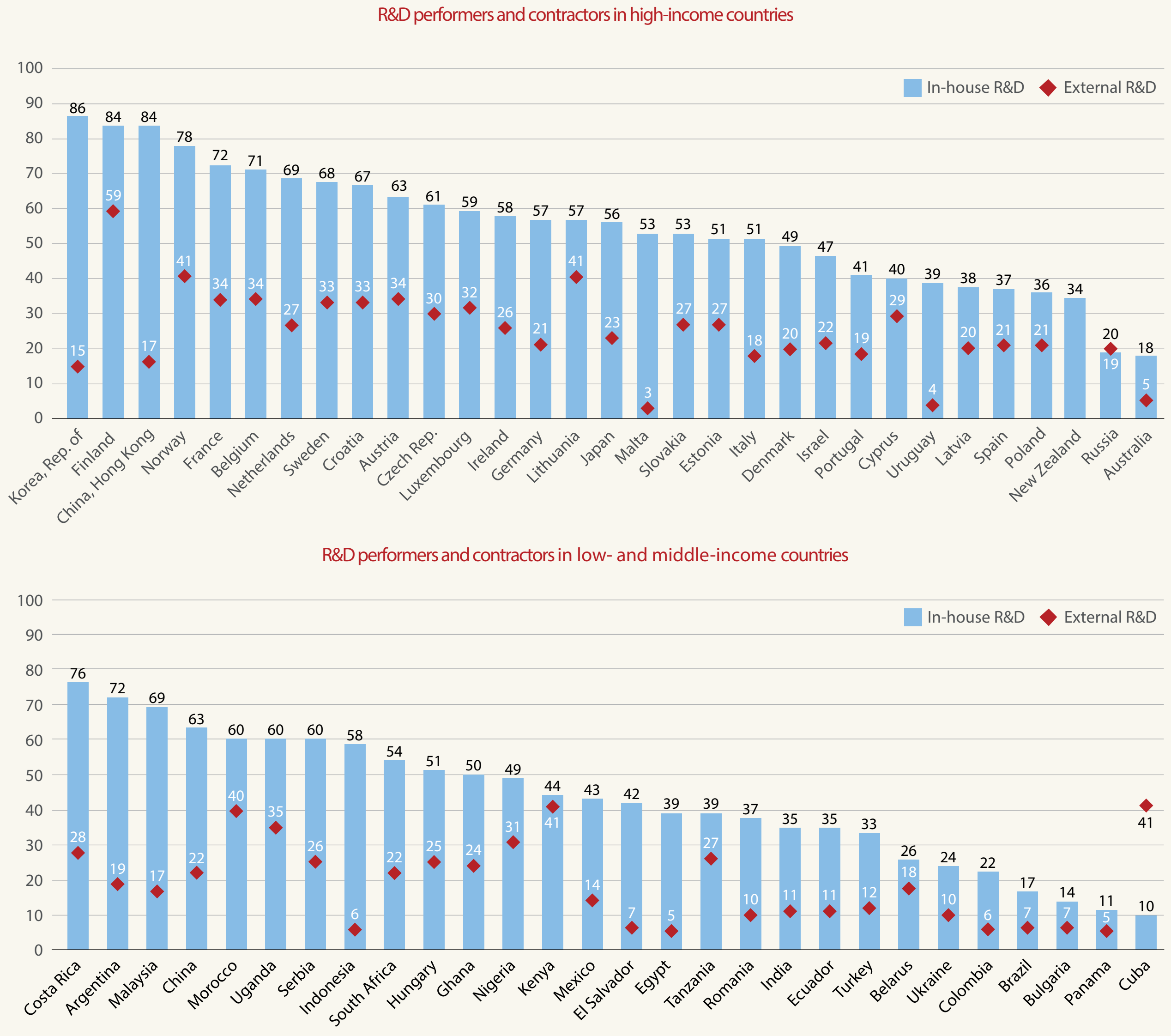
In the EU's Community Innovation Survey, which is followed by many countries worldwide, the harmonized questionnaire asks about engagement in in-house and outsourced (or external) R&D but also other activities related to innovation, such as the acquisition of machinery, equipment and software and the acquisition of other external knowledge.

Generally speaking, firms prefer in-house R&D to outsourcing, the most notable exception being Cuba (Figure 2.7). In the Republic of Korea, there is even a large gap between the share of firms performing R&D internally (86%) and externally (15%). This same phenomenon is to be found in Hong Kong (China): 84% and 17% respectively. On mainland China, almost two-thirds of firms perform in-house R&D (Box 2.2).

Overall, whereas, in 65% of high-income countries, more than half of firms perform in-house R&D, this is observed in only 40% of low- and middle-income countries. It is interesting to observe that not all firms active in innovation engage in R&D, whatever the income status of the country. This supports the argument that innovation is broader than R&D and that firms may be innovators without actually being R&D performers.

Figure 2.7: **Firms with in-house or external R&D among surveyed countries**

Share of innovation-active firms (%)



Source: UNESCO Institute for Statistics, September 2014

Box 2.2: **Innovation in the BRICS**

The great majority of firms in low- and middle-income economies acquire machinery, equipment and software to give themselves the technological edge that will enable them to innovate. The BRICS countries are no exception to the rule.

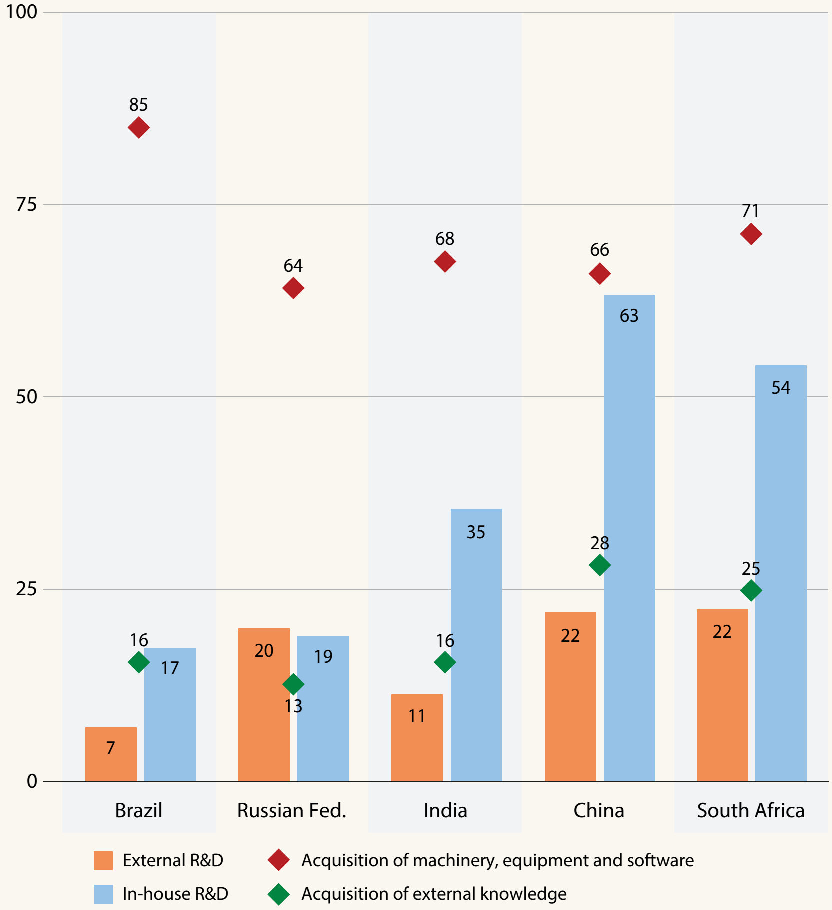
Among BRICS countries, China is the country with the highest share of firms engaging in the acquisition of external knowledge. In China, about 30% of firms engaged in innovation purchase existing know-how and licence patented and non-patented inventions or other types of external knowledge.

China also has the greatest proportion of firms performing in-house R&D (63%). This is slightly lower than the proportion of firms acquiring machinery, equipment and software. The gap between these two activities is much higher in India, the Russian Federation and, above all, Brazil.

The Russian Federation has a slightly higher share of firms outsourcing R&D than performing it in-house. Brazil has the lowest rate of outsourcing of the five countries, just 7% of firms.

Figure 2.8: **Profile of the type of innovation done by firms in BRICS countries**

Share of innovation-active manufacturing firms (%)



Source: UNESCO Institute for Statistics, September 2014

Little interaction with universities

As the innovation process is interactive, firms tend to rely on their ties to other sources of knowledge for information and co-operation. Internal sources of information are most frequently rated as highly important by firms in countries of all income levels. This is even the predominant source of information in all but one high-income country (Table 2.2). Only in the Russian Federation is another source of information highly important, that supplied by clients or customers.

In the other BRICS countries, both customers and internal sources predominate as highly important sources of information: in China and India, 60% and 59% of firms respectively rate their customers as such. Also of note is that firms in Brazil and India rate their suppliers equally highly.

Although the majority of firms in low- and middle-income countries also rate internal sources of information as being highly important, there are more countries in this category where clients or customers prevail. Moreover, suppliers are rated as highly important by 53% of the firms active in innovation in Argentina, making them most important source of information in this country.

Cuba is the only country where as many as 25% of firms consider the government or public research institutes as being highly important sources of information. Overall, most firms do not consider government sources – including institutions of higher education – as highly important sources of information.

A similar situation prevails in terms of partnerships. Very few firms interact with government institutions such as universities and public research institutes (Table 2.3). The low proportion of firms co-operating with universities is of concern, given the contribution that the latter make to the generation and dissemination of knowledge and technology and their role as suppliers of graduates to firms (Figure 2.9).

Table 2.2: **Highly important sources of information for firms**
Share of innovation-active manufacturing firms (%)

	SOURCES OF INFORMATION									
	Internal	Market				Institutional		Other		
	Within your enterprise or enterprise group	Suppliers of equipment, materials, components or software	Clients or customers	Competitors or other enterprises in your sector	Consultants, commercial labs or private R&D institutes	Universities or other higher education institutions	Government or public research institutes	Conferences, trade fairs, exhibitions	Scientific journals and trade/ technical publications	Professional and industry associations
High-income countries										
Australia	72.9	28.6	42.1	21.0	13.7	1.2	2.9	10.0	23.0	16.3
Belgium	55.1	26.7	28.7	8.4	4.7	5.2	1.6	11.7	6.7	3.1
Croatia	44.0	27.7	33.2	14.5	5.3	2.7	0.5	14.1	8.2	2.4
Cyprus	92.8	71.9	63.4	48.1	41.3	6.0	5.5	63.0	31.5	20.4
Czech Rep.	42.7	21.8	36.8	18.5	3.9	4.3	2.3	13.3	3.8	1.9
Estonia	30.1	29.4	18.8	9.3	5.8	4.2	1.1	12.7	2.0	1.3
Finland	63.4	17.3	41.1	11.7	3.6	4.5	2.8	8.8	3.4	2.5
France	51.2	19.9	27.8	9.4	6.2	3.4	3.1	10.8	7.9	5.5
Israel	79.3	17.6	19.1	7.9	7.5	3.7	2.2	13.7	6.7	2.1
Italy	35.5	18.8	17.6	4.5	15.1	3.7	1.0	9.7	3.7	4.4
Japan	33.7	20.7	30.5	7.5	6.2	5.1	4.8	4.6	2.0	2.9
Latvia	44.4	23.3	23.9	16.5	7.8	3.4	1.6	20.2	7.1	3.4
Lithuania	37.5	15.6	18.9	12.2	4.1	2.9	3.8	13.1	2.2	0.5
Luxembourg	68.3	36.5	46.1	24.6	12.6	7.8	3.6	38.3	24.0	18.6
Malta	46.0	39.0	38.0	21.0	10.0	4.0	2.0	13.0	2.0	3.0
New Zealand	86.4	51.0	76.3	43.1	43.4	10.2	16.0	45.9	48.3	21.4
Norway	79.1	50.4	78.3	30.0	9.4	7.2	10.5	10.5	16.0	30.4
Poland	48.2	20.2	19.2	10.1	5.2	5.8	7.3	14.8	10.3	4.8
Portugal	33.9	18.5	30.3	10.2	5.9	3.2	2.2	13.9	6.0	4.3
Korea, Rep.	47.4	16.1	27.7	11.3	3.4	3.9	6.1	6.7	5.2	4.9
Russian Fed.	32.9	14.1	34.9	11.3	1.7	1.9	–	7.4	12.0	4.1
Slovakia	50.5	27.2	41.6	18.1	2.8	2.5	0.6	12.4	13.6	1.4
Spain	45.5	24.2	20.9	10.4	8.7	5.0	7.7	8.7	4.7	3.9
Uruguay	52.9	24.2	40.3	21.2	13.6	5.8	–	27.1	18.0	–
Low- and middle-income countries										
Argentina	26.4	52.7	36.3	16.4	28.5	40.0	42.4	–	–	–
Brazil	41.3	41.9	43.1	23.8	10.2	7.0	–	–	–	–
Bulgaria	28.6	22.4	26.1	13.6	5.5	–	–	13.6	9.4	5.1
China	49.5	21.6	59.7	29.6	17.1	8.9	24.7	26.7	12.0	14.8
Colombia	97.6	42.5	52.6	32.1	28.4	16.2	8.0	43.7	47.3	24.5
Cuba	13.6	–	11.5	5.1	–	19.6	24.7	–	–	–
Ecuador	67.0	34.9	59.0	27.1	10.7	2.0	2.2	22.2	42.5	6.3
Egypt	75.9	32.1	16. 1	17.0	2.7	1.8	0.9	22.3	13.4	4.5
El Salvador	–	26.4	40.3	5.4	15.2	3.8	1.8	13.9	10.3	–
Hungary	50.5	26.4	37.4	21.3	13.0	9.9	3.3	16.6	9.6	7.7
India	58.5	43.3	59.0	32.6	16.8	7.9	11.0	29.7	15.1	24.5
Indonesia	0.4	1.3	1.8	1.3	0.9	0.4	0.4	0.9	0.9	0.9
Kenya	95.7	88.2	90.3	80.6	52.7	37.6	39.8	71.0	64.5	72.0
Malaysia	42.4	34.5	39.0	27.9	15.0	9.5	16.7	28.1	21.7	23.6
Mexico	92.2	43.6	71.9	44.0	19.0	26.4	23.6	36.9	24.5	–
Morocco	–	51.3	56.4	15.4	17.9	6.4	12.8	43.6	34.6	25.6
Nigeria	51.7	39.3	51.7	30.0	14.6	6.8	4.1	11.5	7.1	20.2
Panama	43.6	10.9	15.2	6.6	5.2	2.4	2.4	5.2	0.5	1.9
Philippines	70.7	49.5	66.2	37.9	21.2	10.1	7.1	21.7	16.7	15.7
Romania	42.1	31.8	33.5	20.5	5.2	3.3	2.0	14.3	10.2	3.5
Serbia	36.2	18.3	27.3	10.5	7.8	5.3	2.6	14.8	10.3	5.7
South Africa	44.0	17.9	41.8	11.6	6.9	3.1	2.3	12.9	16.7	8.4
Tanzania	61.9	32.1	66.7	27.4	16.7	7.1	11.9	16.7	9.5	20.2
Turkey	32.6	29.1	33.9	18.0	5.2	3.7	2.8	19.7	9.4	6.9
Uganda	60.9	24.8	49.0	23.0	12.2	3.2	5.0	16.4	8.3	11.3
Ukraine	28.6	22.4	21.9	11.0	4.7	1.9	4.6	14.7	9.1	4.0

Source: UNESCO Institute for Statistics, September 2014

Table 2.3: **Partners with which firms co-operate in innovation**

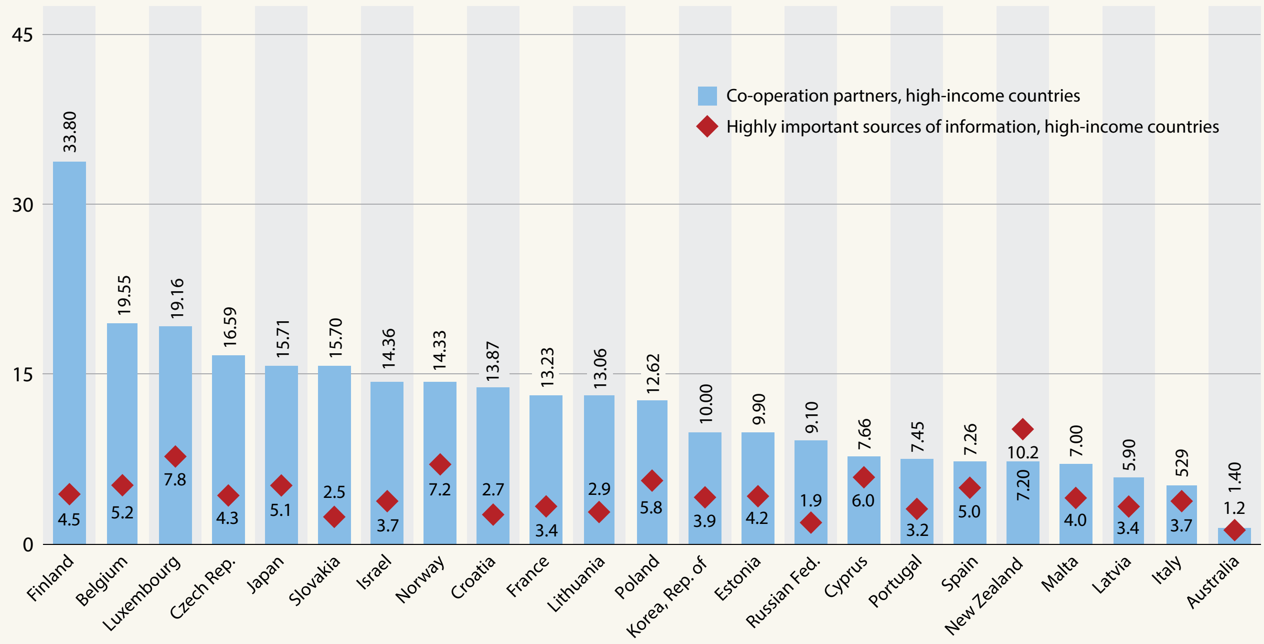
Share of innovation-active manufacturing firms (%)

	CO-OPERATION						
	Other enterprises within your enterprise group	Suppliers of equipment, materials, components or software	Clients or customers	Competitors or other enterprises in your sector	Consultants, commercial labs or private R&D institutes	Universities or other higher education institutions	Government or public research institutes
High-income countries							
Australia	21.4	49.4	41.6	21.4	36.2	1.4	5.6
Austria	21.2	30.2	22.8	8.0	20.2	24.7	11.6
Belgium	17.7	32.4	19.2	9.3	16.5	19.6	10.8
Croatia	8.6	26.1	21.6	13.9	12.3	13.9	9.1
Cyprus	8.1	51.9	45.5	37.0	34.0	7.7	9.4
Czech Rep.	14.5	25.6	21.1	10.0	14.0	16.6	6.6
Denmark	16.8	28.9	25.1	9.1	17.2	14.5	10.5
Estonia	20.3	23.6	23.1	10.5	11.3	9.9	2.5
Finland	23.6	38.1	41.6	33.2	34.2	33.8	24.8
France	16.1	23.6	20.2	9.8	14.3	13.2	10.8
Germany	8.6	14.2	13.5	3.0	8.7	17.1	8.1
Iceland	6.2	9.5	23.7	3.8	1.9	10.4	15.6
Ireland	15.4	19.6	17.0	4.1	15.1	13.0	10.0
Israel	–	28.8	40.1	15.4	20.3	14.4	10.1
Italy	2.2	6.7	5.1	2.7	6.6	5.3	2.2
Japan	–	31.7	31.5	19.9	16.9	15.7	14.4
Korea, Rep.	–	11.5	12.8	8.1	6.3	10.0	12.8
Latvia	14.0	20.8	19.6	14.0	10.6	5.9	1.9
Lithuania	17.7	31.3	24.2	11.3	14.8	13.1	8.6
Luxembourg	22.8	31.7	29.9	19.2	22.8	19.2	22.8
Malta	13.0	12.0	8.0	4.0	7.0	7.0	3.0
Netherlands	14.5	26.3	14.7	7.7	13.7	11.0	7.8
New Zealand	–	18.2	18.7	16.6	–	7.2	5.9
Norway	16.8	22.1	22.0	7.6	19.4	14.3	18.1
Poland	11.2	22.7	15.2	7.7	10.1	12.6	9.0
Portugal	5.1	13.0	12.2	4.7	8.3	7.5	4.8
Russian Fed.	12.6	16.7	10.9	3.9	5.1	9.1	15.6
Slovakia	18.6	31.5	27.8	20.8	16.1	15.7	10.8
Spain	5.5	10.4	6.7	3.5	6.3	7.3	9.7
Sweden	33.3	35.9	30.7	14.2	29.7	18.3	8.8
UK	6.2	9.4	11.0	3.8	4.5	4.7	2.5
Low- and middle-income countries							
Argentina	–	12.9	7.6	3.5	9.3	14.5	16.1
Brazil	–	10.0	12.8	5.2	6.2	6.3	–
Bulgaria	3.9	13.6	11.2	6.4	5.8	5.7	3.0
Colombia	–	29.4	21.0	4.1	15.5	11.2	5.3
Costa Rica	–	63.9	61.1	16.5	49.6	35.3	8.1
Cuba	–	15.3	28.5	22.1	–	14.9	26.4
Ecuador	–	62.4	70.2	24.1	22.1	5.7	3.0
Egypt	–	3.6	7.1	0.9	7.1	1.8	0.9
El Salvador	–	36.9	42.1	1.3	15.3	5.5	3.4
Hungary	15.5	26.9	21.1	16.4	20.1	23.1	9.9
Indonesia	–	25.7	15.9	8.0	10.2	8.4	4.9
Kenya	–	53.8	68.8	54.8	51.6	46.2	40.9
Malaysia	–	32.9	28.8	21.2	25.5	20.7	17.4
Mexico	–	–	–	9.7	–	7.0	6.1
Morocco	–	25.6	–	–	19.2	3.8	–
Panama	–	64.5	0.5	18.5	3.8	1.4	7.6
Philippines	91.2	92.6	94.1	67.6	64.7	47.1	50.0
Romania	2.8	11.7	10.6	6.2	5.9	7.2	3.1
Serbia	16.6	19.4	18.3	13.0	12.4	12.5	9.8
South Africa	14.2	30.3	31.8	18.6	21.1	16.2	16.2
Turkey	10.4	11.6	10.7	7.4	7.9	6.4	6.6
Ukraine	–	16.5	11.5	5.3	5.7	4.2	6.6

Source: UNESCO Institute for Statistics, September 2014

Figure 2.9: **Firms' linkages with universities and related institutions**

Share of innovation-active manufacturing firms (%)



TRENDS IN SCIENTIFIC MOBILITY

The diaspora can boost innovation at home and abroad

Although new technologies like the internet have opened up possibilities for virtual mobility, physical movement remains crucial to cross-fertilize ideas and spread scientific discoveries across time and space. The following discussion will be examining recent trends in international scientific mobility, defined as the cross-border physical movement of people who participate in research training or research work. For the purpose of this analysis, we shall draw on the international learning mobility and career of doctorate-holders studies undertaken jointly by the UNESCO Institute for Statistics, OECD and Eurostat.

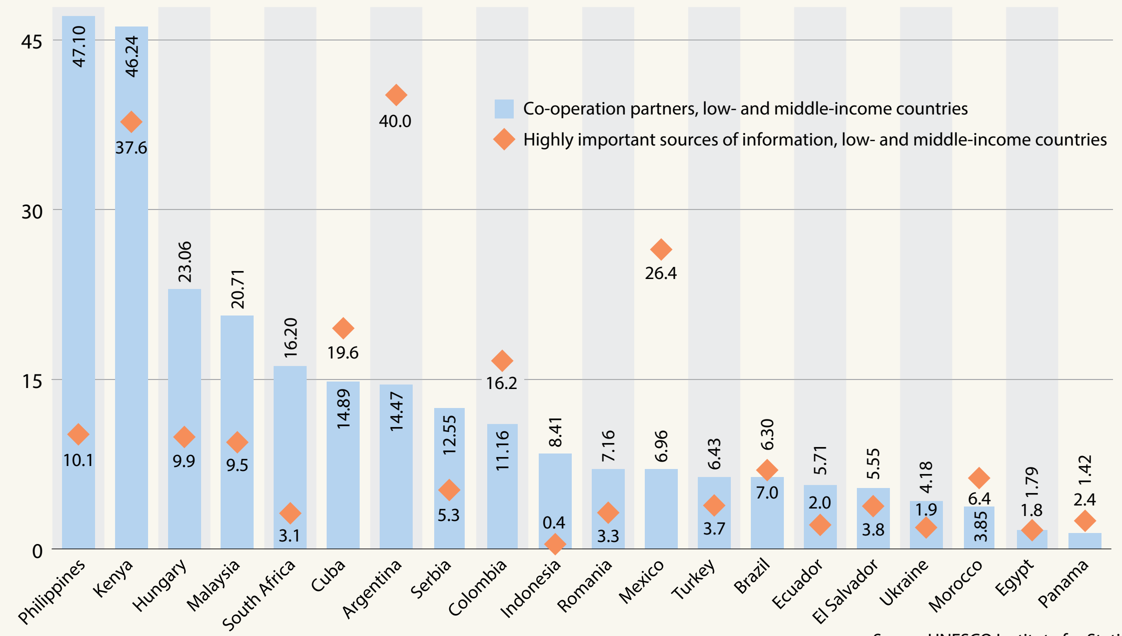
There is a wealth of evidence to support the claim that diaspora knowledge networks can transform the local and international environment for innovation. As far back as the 1960s and 1970s, the Korean and Taiwanese diaspora were persuaded to leave California's Silicon Valley to establish science parks in their homeland (Agunias and Newland, 2012). Another example is the Colombian network of scientists and engineers abroad, which was set up in 1991 to reconnect expatriates with their home country (Meyer and Wattiaux, 2006).

A more recent case study concerns the Indian diaspora's role in India's information technology (IT) industry, which contributed as much as 7.5% to India's GDP in 2012. Perhaps the most famous Indian expatriate in the IT industry is Satya Nadella, an engineer who was appointed chief executive officer of Microsoft in 2014 after joining the multinational in 1992. In the 1990s, many Indians working in the USA's IT industry began collaborating with their counterparts in India and outsourcing their work. A 2012 survey shows that 12 of the top 20 IT firms in India have expatriate Indians as founders, co-founders, chief executive officers or managing directors (Pande, 2014). In 2009, the Indian government launched the Global Indian Network of Knowledge to facilitate knowledge exchange between the diaspora and India in business, IT and education (Pande, 2014).

Between 2006 and 2015, the Dutch government implemented the Temporary Return of Qualified Nationals projects to help a number of post-conflict countries build their technological capacity and transfer knowledge. The voluntary return of highly qualified overseas nationals to Afghanistan for a maximum of six months to help rebuild their country has already brought about technological change and innovation in education, engineering and health (Siegel and Kuschminder, 2012). Elsewhere, temporary returnees have introduced new technology, revised university curricula and trained local instructors, among other things. One factor contributing to the project's success is the participants' substantial knowledge of the local language and culture.

Scientific mobility nurtures international research collaboration

When Woolley *et al.* (2008) surveyed scientists in six Asia–Pacific countries, they found that those who had obtained research degrees and trained overseas were also active participants in international research collaboration. Jöns (2009) discovered



Source: UNESCO Institute for Statistics, September 2014

that research collaboration between visiting academics and their German colleagues survived beyond the end of the academic's stay. Meanwhile, Jonkers and Tijssen (2008) found that the growth in China's internationally co-authored publications could be explained by the high population of the Chinese scientific diaspora established in various host countries; they also found that Chinese returnees had an impressive record of international copublications.

International scientific collaboration is obviously invaluable for tackling global scientific issues such as climate change and water, food or energy security and for integrating local and regional actors into the global scientific community. It has also been widely used as a strategy for helping universities improve the quality and quantity of their research output. Halevi and Moed (2014) argue that countries in a phase of *building up* their capacity begin establishing projects with foreign research teams in scientifically advanced countries, in particular; these projects are often funded by foreign or international agencies with a focus on specific topics. This trend is evident in countries such as Pakistan and Cambodia where the great majority of scientific articles have international co-authors (see Figures 21.8 and 27.8). Later, when countries' research capacity increases, they move on to the phase of *consolidation and expansion.* Ultimately, countries enter the phase of *internationalization:* their research institutions start functioning as fully fledged partners and increasingly take the lead in international scientific co-operation, as has happened in Japan and Singapore (see Chapters 24 and 27).

Competition for skilled workers likely to intensify

A number of governments are keen to promote scientific mobility as a route to building research capacity or maintaining an innovative environment. In the coming years, the competition for skilled workers from the global pool will most likely intensify. This trend will depend in part on factors such as levels of investment in science and technology around the world and demographic trends, such as low birth rates and ageing populations in some countries (de Wit, 2008). Countries are already formulating broader policies to attract and retain highly skilled migrants and international students, in order to establish an innovative environment or maintain it (Cornell University *et al.*, 2014).

Brazil and China are among countries showing a renewed policy interest in promoting mobility. In 2011, the Brazilian government launched the Science without Borders programme to consolidate and expand the national innovation system through international exchanges. In the three years to 2014, the government awarded 100 000 scholarships to talented Brazilian students and researchers to study fields of science, technology, engineering and mathematics at the world's top universities. In addition to promoting outbound mobility, the Science without Borders programme provides highly qualified researchers from overseas with grants to work with local researchers on joint projects (See box 8.3).

China, the country with the largest number of students living abroad, has seen a shift in its own policy on scientific mobility. For many years, the Chinese government fretted about brain drain. In 1992, the government began encouraging students who had settled abroad to return home for short visits to mainland China (see Box 23.2). In 2001, the government adopted a liberalized policy inviting the diaspora to contribute to modernizing the country without any obligation to move back to China (Zweig *et al.*, 2008). In the past decade, the government's ambition of increasing the number of world-class universities has spawned a rash of government scholarships for study abroad: from fewer than 3 000 in 2003 to over 13 000 in 2010 (British Council and DAAD, 2014).

Regional schemes in Europe and Asia promoting mobility

There are also regional policies promoting scientific mobility. Launched in 2000, the EU's European Research Area exemplifies this trend. To enhance the competitiveness of European research institutions, the European Commission has launched a range of programmes to facilitate researchers' international mobility and strengthen multilateral research co-operation within the EU. For instance, the EU's Marie Skłodowska-Curie actions programme provides researchers with grants to promote transnational, intersectorial and interdisciplinary mobility.

Another initiative that is influencing cross-border mobility is EU's requirement for publicly funded institutions to announce their vacancies internationally to provide an open labour market for researchers. Moreover, the 'scientific visa' package expedites administrative procedures for researchers applying from non-EU countries. Around 31% of post-doctoral researchers in the EU have worked abroad for over three months at least once in the past ten years (EU, 2014).

A similar initiative that is still in the early stages is the *Plan of Action on Science, Technology and Innovation, 2016–2020* (APASTI) adopted by the Association of Southeast Asian Nations. APASTI aims to strengthen scientific capacity in member states by fostering exchanges among researchers both within the region and beyond (see Chapter 27).

More international PhD students are studying science and engineering

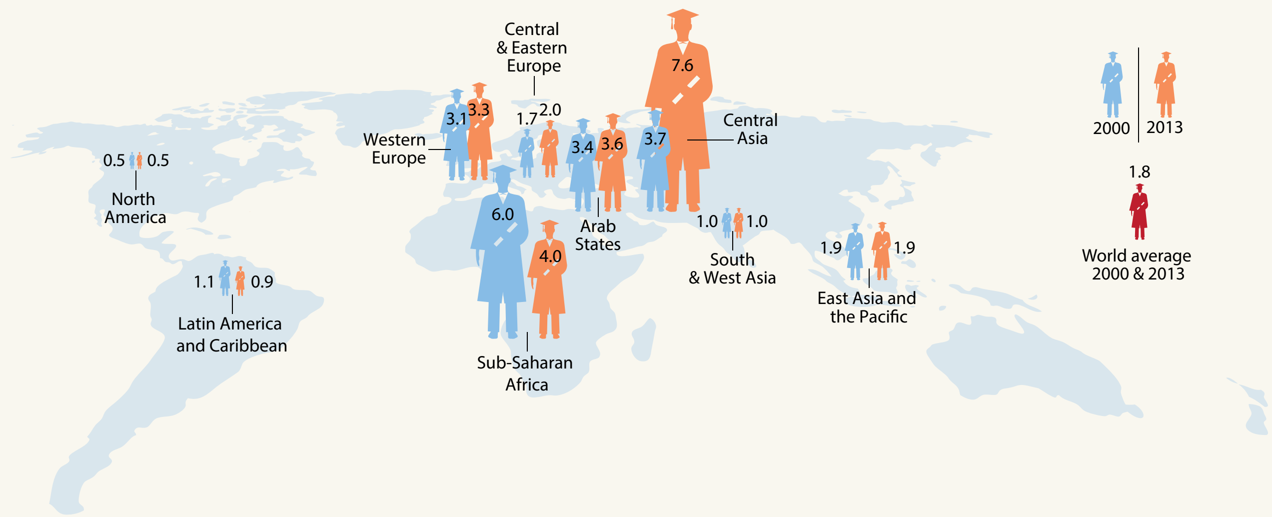
Here, we shall be analysing trends in the cross-border migration of university students and doctorate-holders. Over the past two decades, the number of students pursuing higher education abroad has more than doubled from 1.7 million (1995) to 4.1 million (2013). Students from the Arab States, Central Asia, sub-Saharan African and Western Europe are more likely to study abroad than their peers from other regions (Figure 2.10).

The data used in the analysis on the following pages are drawn from the UNESCO Institute for Statistics' database; they are the fruit of joint data collections undertaken with the OECD and Eurostat annually for mobile students and every three years for PhD-holders. The survey excludes students on short-term exchange programmes. In 2014, more than 150 countries representing 96% of the world's tertiary student population reported data on international students. In addition, 25 mainly OECD countries have reported data on doctorate-holders for the years 2008 or 2009.

We can observe four distinct trends in the mobility of international students at doctoral level and among students enrolled in science and engineering programmes. Firstly, the latter two broad fields are the most popular educational programmes for international

Figure 2.10: **Outbound mobility ratio among doctoral students, 2000 and 2013**

By region of origin (%)

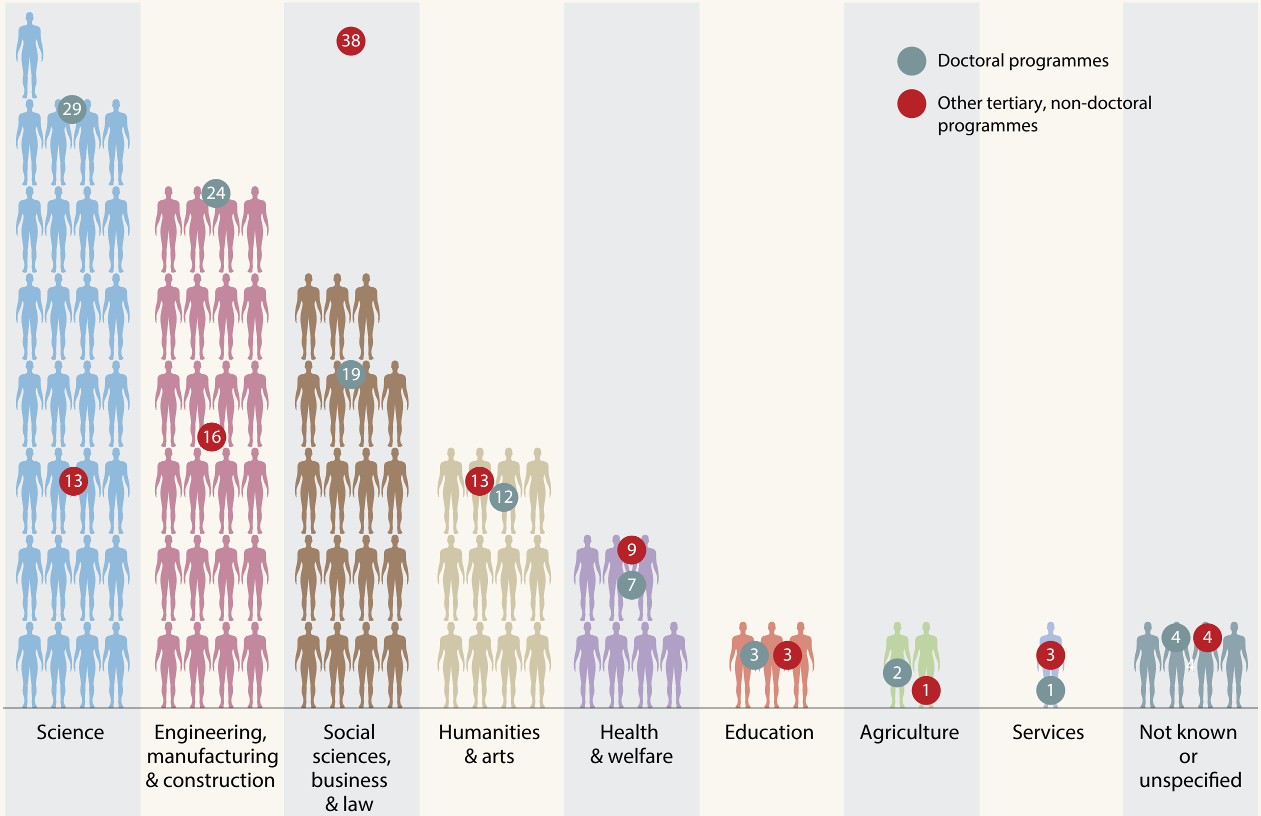


Note: The outbound mobility ratio is the number of students from a given country (or region) enrolled in tertiary programmes abroad, expressed as a percentage of total tertiary enrolment in that country (or region).

Source: UNESCO Institute for Statistics, June 2015

Figure 2.11: **Distribution of international students, 2012**

By type of programme and field of education (%)



Note: Data concern 3.1 million international students enrolled in 44 mainly OECD and/or EU countries.

Source: UNESCO Institute for Statistics, October 2014

doctoral students: out of a total of 359 000 international doctoral students in 2012, 29% were enrolled in science programmes and 24% in engineering, manufacturing and construction programmes (Figure 2.11). By comparison, in non-doctoral programmes, international students studying science and engineering constitute the second- and third-largest groups after social sciences, business and law. Among these students, a relatively large proportion comes from countries with a medium-level of technological capability, such as Brazil, Malaysia, Saudi Arabia, Thailand and Turkey (Chien, 2013).

There has been a notable shift in the profile of international doctoral students away from social sciences and business towards science and engineering programmes. Between 2005 and 2012, the number of international doctoral enrolments in science and engineering grew by 130%, compared to a rise of 120% reported in other fields.

The second distinctive trend is the concentration of international doctoral students in a smaller number of host countries than non-doctoral students. The USA (40.1%), UK (10.8%) and France (8.3%) host the bulk of international doctoral students. The USA hosts nearly half of doctoral students enrolled in S&T fields (Figure 2.12).

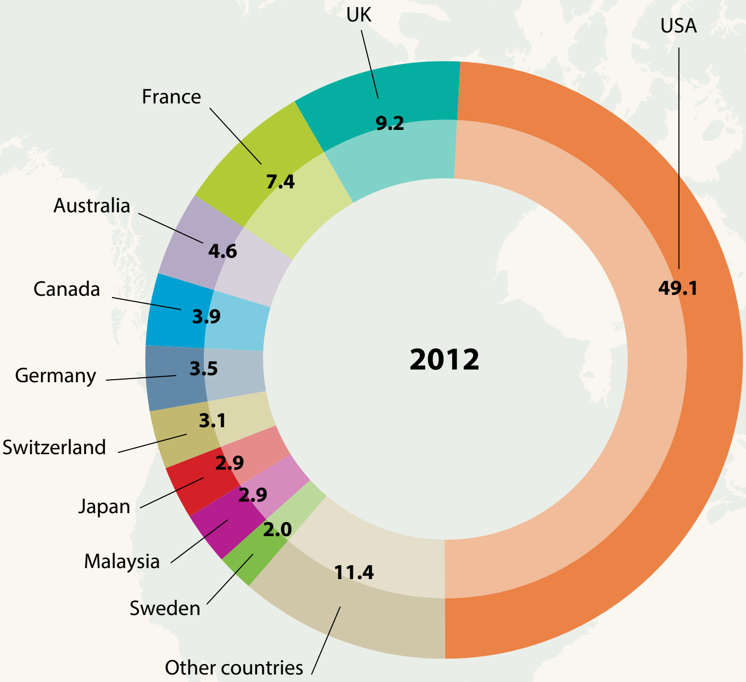
There is a marked variation in the inbound mobility rate of doctoral students: three in ten students in the USA are from overseas, compared to more than four in ten in the UK and France (Figure 2.12). The rate is even higher in Luxembourg, Liechtenstein and Switzerland, where more than half of doctoral students come from abroad.

Thirdly, the proportion of doctoral students pursuing a degree abroad varies greatly from one country to the next. The ratio of students from a given country enrolled in doctoral programmes abroad (or outbound mobility ratio) ranges from a low of 1.7% in the USA to a high of 109.3% in Saudi Arabia (Figure 2.12). Saudi Arabia thus has more doctoral students enrolled in programmes abroad than at home. This relatively high outbound mobility ratio is consistent with Saudi Arabia's long tradition of government sponsorship of its citizens' academic study abroad. Viet Nam had the next highest ratio of 78.1% in 2012, with approximately 4 900 enrolled abroad and 6 200 domestically. This high ratio is the result of the Vietnamese government's policy of sponsoring the doctoral training of its citizens overseas, in order to add 20 000 doctorate-holders to the faculty of Vietnamese universities by 2020 to improve its higher education system (British Council and DAAD, 2014).

Figure 2.12: **Preferred destinations of international doctoral students, 2012**

The USA alone hosts nearly half of international doctoral students enrolled in science and engineering fields

Distribution of international doctoral students in science and engineering programmes by host country, 2012 (%)



49.1%

Share of international doctoral students enrolled in science and engineering programmes in the USA

9.2%

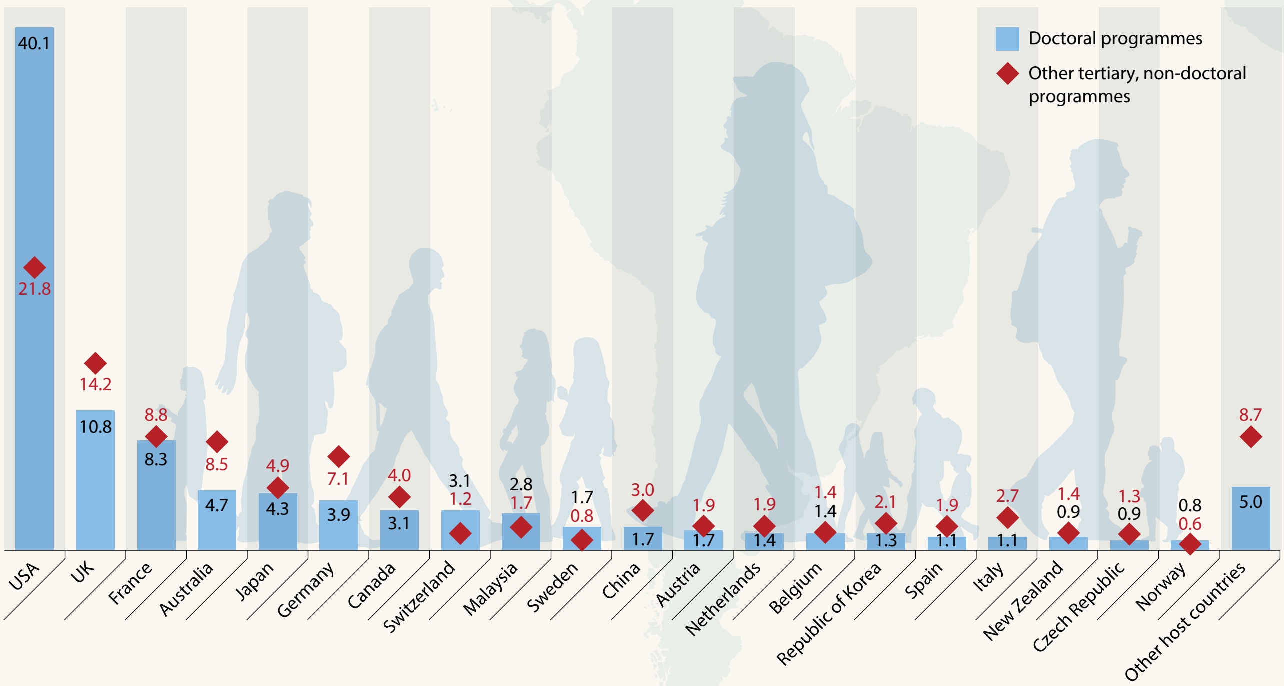
Share of international doctoral students enrolled in science and engineering programmes in the UK

7.4%

Share of international doctoral students enrolled in science and engineering programmes in France

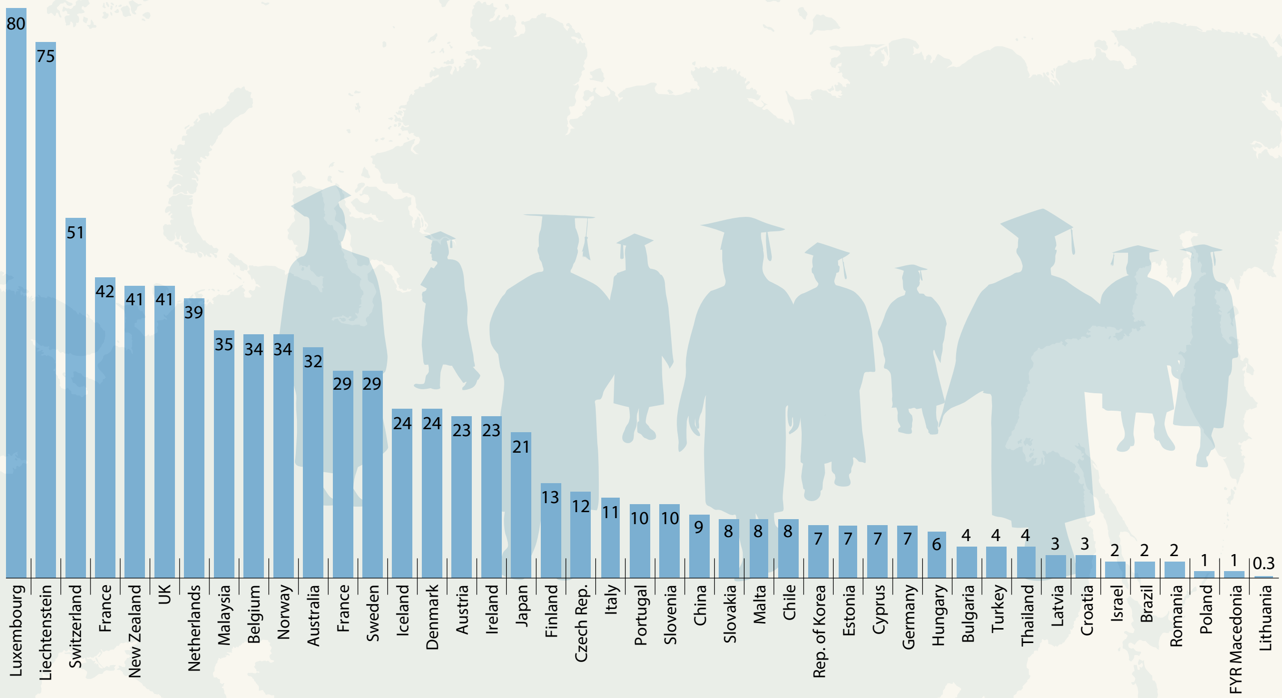
The USA hosts four out of ten international doctoral students

Share of international students by type of programme and host country, 2012 (%)



Most doctoral students in Luxembourg, Liechtenstein and Switzerland are international students

Share of international doctoral students in individual host countries, or inbound mobility rate, 2012 (%)



5 600 Number of Saudi doctoral students being trained overseas in 2012

5 200 Number of Saudi doctoral students being trained in Saudi Arabia in 2012

Saudi Arabia has more doctoral students enrolled in programmes abroad than at home

Countries with more than 4 000 doctoral students enrolled abroad in 2012

Country of origin	Number of outbound	Outbound mobility ratio*	Top destinations
China	58 492	22.1	USA, Japan, UK, Australia, France, Rep. of Korea, Canada, Sweden
India	30 291	35.0	USA, UK, Australia, Canada, France, Rep. of Korea, Switzerland, Sweden
Germany	13 606	7.0	Switzerland, Austria, UK, USA, Netherlands, France, Sweden, Australia
Iran	12 180	25.7	Malaysia, USA, Canada, Australia, UK, France, Sweden, Italy
Korea, Rep.	11 925	20.7	USA, Japan, UK, France, Canada, Australia, Switzerland, Austria
Italy	7 451	24.3	UK, France, Switzerland, USA, Austria, Netherlands, Spain, Sweden
Canada	6 542	18.0	USA, UK, Australia, France, Switzerland, New Zealand, Ireland, Japan
USA	5 929	1.7	UK, Canada, Australia, Switzerland, New Zealand, France, Rep. of Korea, Ireland
Saudi Arabia	5 668	109.3	USA, UK, Australia, Malaysia, Canada, France, Japan, New Zealand
Indonesia	5 109	13.7	Malaysia, Australia, Japan, USA, UK, Rep. of Korea, Netherlands, France
France	4 997	12.3	USA,UK, Malaysia, Switzerland, France, Japan, Germany, China
Viet Nam	4 867	78.1	France, U.S., Australia, Japan, Rep. of Korea, UK, New Zealand, Belgium
Turkey	4 579	9.2	USA, UK, France, Netherlands, Switzerland, Austria, Canada, Italy
Pakistan	4 145	18.0	UK, USA, Malaysia, France, Sweden, Australia, Rep. of Korea, New Zealand
Brazil	4 121	5.2	USA, Portugal, France, Spain, UK, Australia, Italy, Switzerland

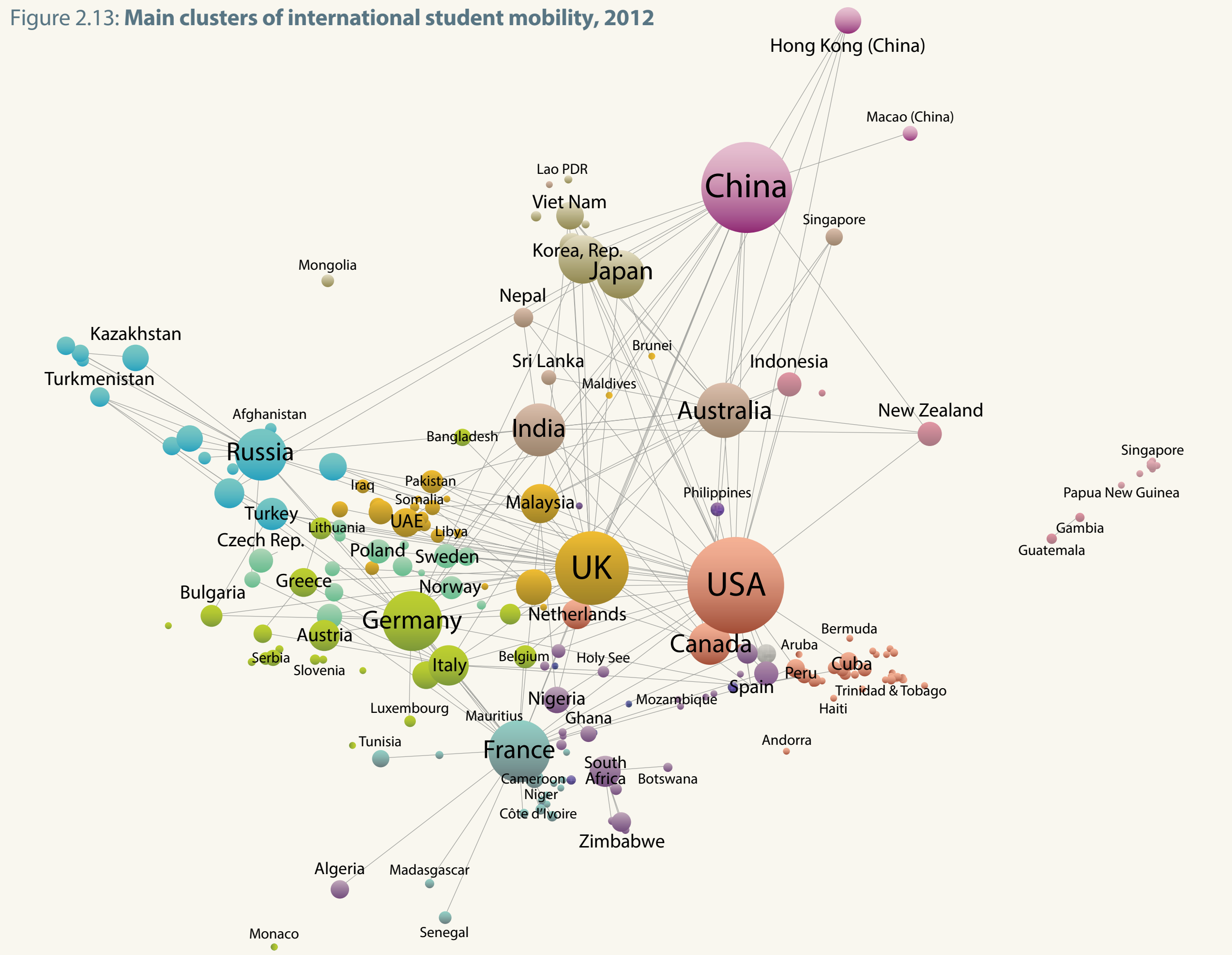
* The number of students from a given country enrolled in doctoral programmes abroad, expressed as a percentage of total doctoral enrolment in that country

Note: The UNESCO Institute for Statistics recognizes that Germany is a top destination for international doctoral students. However, due to data unavailability, Germany is absent from the top destinations listed here.

Note: Data for the tables and graphics in Figure 2.12 concern 3.1 million international students enrolled in 44 mainly OECD and/or EU countries.

Source: UNESCO Institute for Statistics, October 2014; Institute of International Education (2013) *Open Doors Report on International Educational Exchange*

Figure 2.13: **Main clusters of international student mobility, 2012**



Source: Data from UNESCO Institute for Statistics, October 2014; map created using VOSviewer

Fourthly, at least six noticeable networks (or clusters) of international student mobility can be identified (Figure 2.13). It should be noted that, although the flows of students are directional, the network shown in the map is undirected. Moreover, the distance between two countries approximately reflects the number of tertiary-level students migrating between the countries. A smaller distance indicates a stronger relation. The colours reflect the different clusters of the student mobility network. The size of the bubbles (countries) reflects the sum of student numbers from a given country who study abroad and the number of international students studying in that country. For instance, in 2012, approximately 694 400 Chinese students studied abroad and, the same year, China hosted 89 000 international students. The total number of international students originating from and flowing into China amounts to 783 400. By comparison, approximately 58 100 US students studied abroad in 2012 and, the same year, the USA hosted 740 500 international students. In total, there are 798 600 international students originating from and flowing into the USA. As a result, the sizes of the bubbles for China and the USA are comparable, even though the trends are reversed.

Bilateral ties between host and home countries in terms of geography, language and history shape these clusters to a certain extent. The USA cluster embraces Canada, several Latin American and Caribbean countries, the Netherlands and Spain. The UK cluster encompasses other European countries and its former colonies, such as Malaysia, Pakistan and the United Arab Emirates. India, a former colony of the UK, has maintained ties to the UK but is now also part of the cluster constituted by Australia, Japan and countries located in East Asia and the Pacific. Similarly, France leads its cluster, which consists of its former colonies in Africa. Another cluster groups mainly Western European countries. Additionally, the historical link between the Russian Federation and former Soviet states shapes a distinct cluster. Lastly, it is worth noting that South Africa plays an important role in the student mobility network in the southern part of Africa (see Chapter 20).

International mobility of doctorate-holders

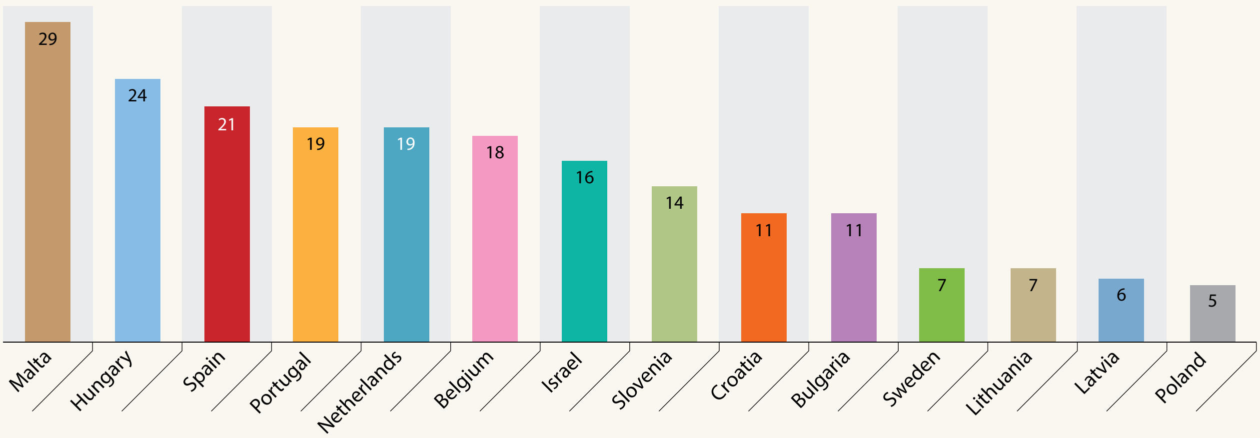
The careers of doctorate-holders survey reveals that, on average, between 5% and 29% of citizens with a doctorate have gained research experience abroad for three months or longer in the past 10 years (Figure 2.14). In Hungary, Malta and Spain, the proportion is over 20%, whereas in Latvia, Lithuania, Poland and Sweden, it is under 10%.

The main destinations for these mobile researchers' previous sojourn abroad were the USA, UK, France and Germany (Auriol *et al*., 2013). Studies conducted across Europe have shown that a high level of mobility by qualified personnel between sectors (such as universities and industries) and across countries contributes to the overall professionalism of the labour force, as well as to the innovative performance of the economy (EU, 2014).

Academic factors often lie behind the researcher's decision to uproot him- or herself. The move may offer better access to publishing opportunities, for instance, or enable the scientist to pursue a research direction that may not be possible at home. Other motivations include other job-related or economic factors and family or personal reasons (Auriol *et al*., 2013).

The presence of foreign doctorate-holders and researchers has long been acknowledged as adding cultural capital to the local community and expanding the talent pool of an economy (Iversen *et al.,* 2014). The careers of doctorate-holders survey reveals that Switzerland hosts the highest percentage (33.9%) of foreign doctorate-holders, followed by Norway (15.2%) and Sweden (15.1%) [Figure 2.15].

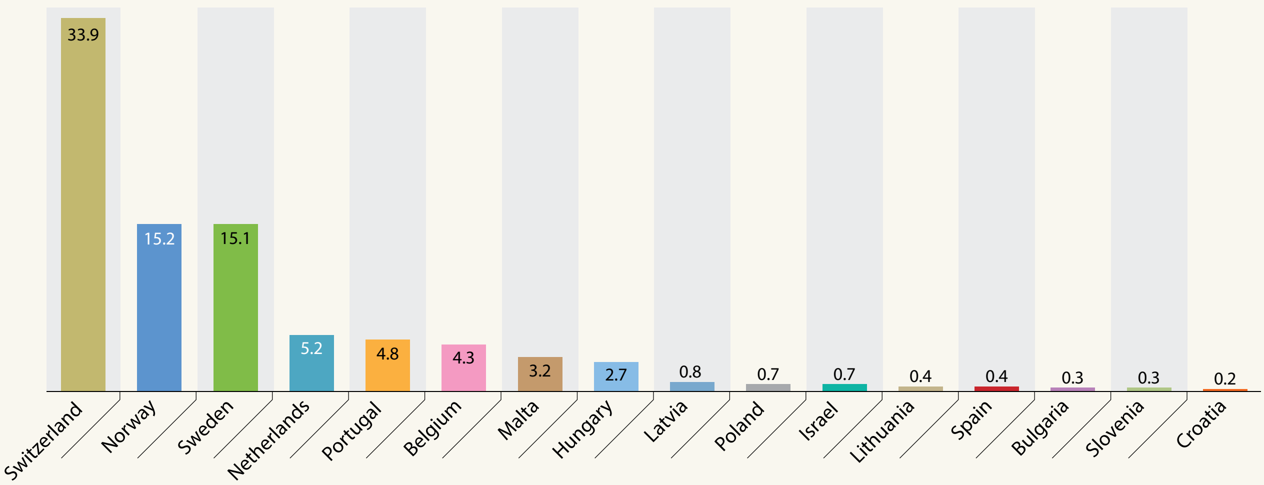
Figure 2.14: **Percentage of national citizens with a doctorate who lived abroad in the past ten years, 2009**



Note: The data cover sojourns of three months or more abroad. Data for Belgium, Hungary, the Netherlands and Spain refer to graduation years from 1990 onwards. For Spain, there is limited coverage of doctorate-holders for 2007–2009.

Source: UNESCO Institute for Statistics/OECD/Eurostat data collection on careers of doctorate-holders, 2010

Figure 2.15: **Percentage of foreign doctorate-holders in selected countries, 2009**



Source: UNESCO Institute for Statistics/OECD/ /Eurostat data collection on careers of doctorate-holders, 2010

CONCLUSION

Innovation is occurring in countries of all income levels

Although most R&D is taking place in high-income countries, innovation is pervasive and is occurring in countries across the full spectrum of income levels. Indeed, much innovation is occurring without any R&D activity at all; in the majority of countries surveyed in 2013, innovation unrelated to R&D implicated more than 50% of firms. R&D is a crucial component of the innovation process but innovation is a broader concept that goes beyond R&D alone.

Policy-makers should take note of this phenomenon and, accordingly, focus not just on designing incentives for firms to engage in R&D. They also need to facilitate non-research-related innovation, particularly in relation to technology transfer, since the acquisition of machinery, equipment and software is generally the most important activity tied to innovation.

In addition, the reliance of firms on market sources such as suppliers and clients to develop innovation highlights the important role played by external agents in the innovation process. One concern for policy-makers should be the low importance attached by most firms to maintaining linkages with universities and government research institutions, even though strengthening university–industry ties is often an important target of policy instruments.

International scientific mobility can nurture an innovative environment by enhancing skills, knowledge networks and scientific collaboration. International knowledge networks do not form naturally, however, and the potential benefits stemming from such networks are not automatic. Lessons learned from past and current success stories show that four main ingredients are required to sustain these international knowledge networks: firstly, a demand-driven approach; secondly, the presence of a local scientific community; thirdly, infrastructural support and committed leadership; and, lastly, quality higher education to upgrade the skills of the general population.

Over the past decade, there has been significant growth in cross-border scientific mobility, a trend that is showing no sign of letting up. Creating an enabling environment to facilitate cross-border mobility and collaboration is becoming a priority for national governments. To accompany this trend, governments need to introduce programmes which teach scientists and engineers to be sensitive to cultural differences in research, research management and leadership and to ensure research integrity across borders.

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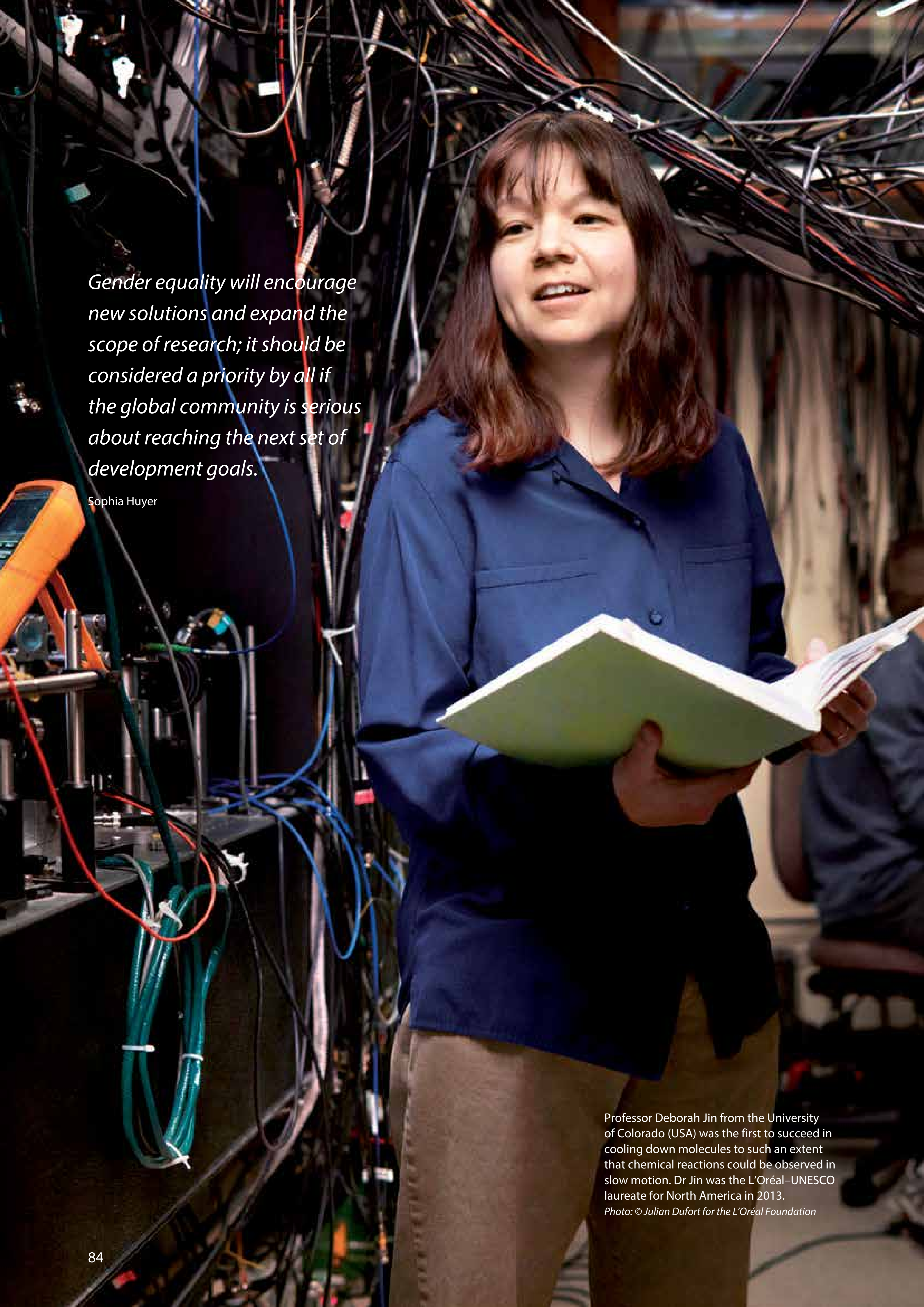


Gender equality will encourage new solutions and expand the scope of research; it should be considered a priority by all if the global community is serious about reaching the next set of development goals.

Sophia Huyer

Professor Deborah Jin from the University of Colorado (USA) was the first to succeed in cooling down molecules to such an extent that chemical reactions could be observed in slow motion. Dr Jin was the L'Oréal–UNESCO laureate for North America in 2013.
Photo: © Julian Dufort for the L'Oréal Foundation

3 · Is the gender gap narrowing in science and engineering?

Sophia Huyer

INTRODUCTION

Women underrepresented in decision-making on climate change

As the global community prepares to make the transition from the Millennium Development Goals to the Sustainable Development Goals in 2015, it is turning its attention from a focus on poverty reduction to a broader perspective combining socio-economic and environmental priorities. Over the next 15 years, scientific research will play a key role in monitoring relevant trends in such areas as food security, health, water and sanitation, energy, the management of ocean and terrestrial ecosystems and climate change. Women will play an essential role in implementing the Sustainable Development Goals, by helping to identify global problems and find solutions.

Since men tend to enjoy a higher socio-economic status, women are disproportionately affected by droughts, floods and other extreme weather events and marginalized when it comes to making decisions on recovery and adaptation (EIGE, 2012). Some economic sectors will be strongly affected by climate change but women and men will not necessarily be affected in the same way. In the tourism sector, for instance, women in developing countries tend to earn less than their male counterparts and occupy fewer managerial positions. They are also overrepresented in the non-agricultural informal sector: 84% in sub-Saharan Africa, 86% in Asia and 58% in Latin America (WTO and UN Women, 2011). There are, thus, clear gender differences in the ability to cope with climate-change-induced shocks.

Despite these gender differences, women are not represented equally in the key climate-change related sectors of science as skilled workers, professionals or decision-makers. Although they are fairly well represented in some related science disciplines – including health, agriculture and environmental management – they are very much a minority in other fields that will be vital for the transition to sustainable development, such as energy, engineering, transportation, information technology (IT) and computing – the latter being important for warning systems, information-sharing and environmental monitoring.

Even in those scientific fields where women are present, they are underrepresented in policy-making and programming. The Former Yugoslav Republic of Macedonia is a case in point. In this country, women are well-represented in governmental decision-making structures related to climate change, such as energy and transportation, environment and health services. They are also comparatively well-represented in related scientific disciplines. Many of them serve on the National Climate Change Committee. However, when it comes to designing and implementing plans, interpreting decisions and monitoring results, women are a rare commodity (Huyer, 2014).

TRENDS IN RESEARCH

Gender parity remains elusive among researchers

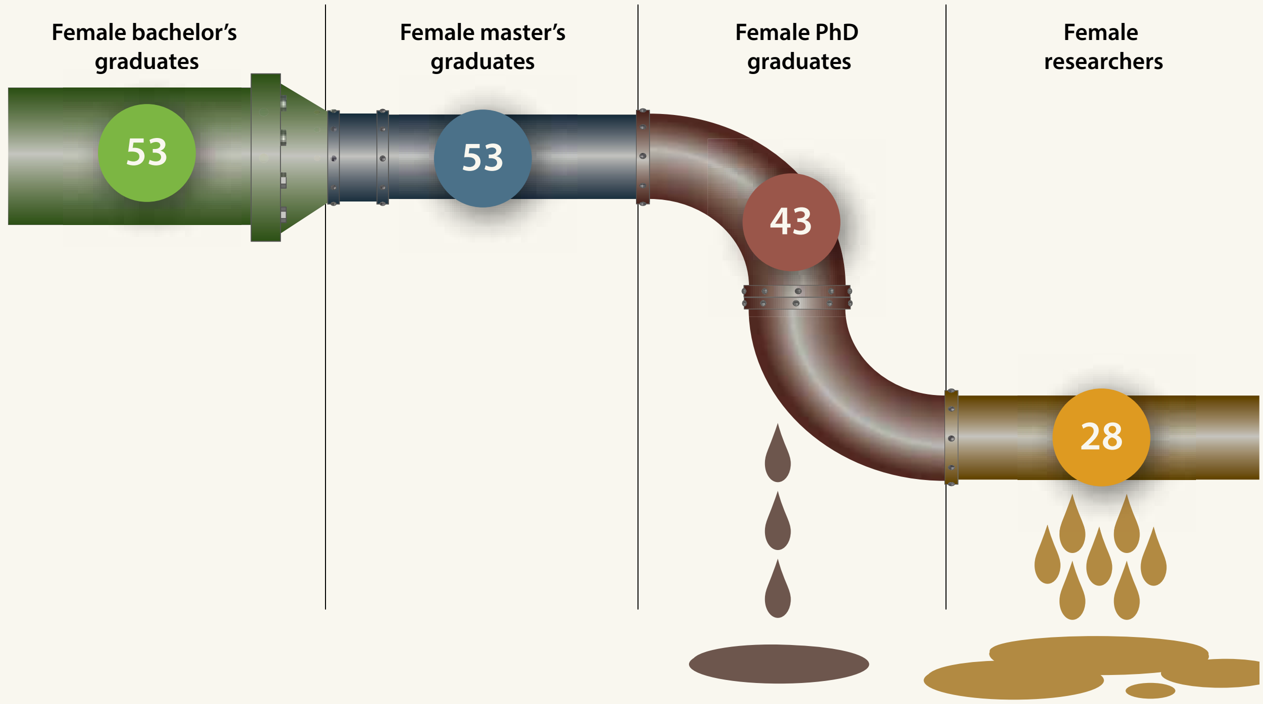
When it comes to women's participation in research overall, globally, we are seeing a leaky pipeline. Women are actively pursuing bachelor's and master's degrees and even outnumber men at these levels, since they represent 53% of graduates, but their numbers drop off abruptly at PhD level. Suddenly, male graduates (57%) overtake women (Figure 3.1). The discrepancy widens at the researcher level, with men now representing 72% of the global pool. The high proportion of women in tertiary education is, thus, not necessarily translating into a greater presence in research.

Although women account for just 28%[1] of global researchers, according to available data, this figure masks wide variations at both the national and regional levels (Figure 3.2). Women are highly represented in Southeast Europe (49%), for instance, and in the Caribbean, Central Asia and Latin America (44%). One in three researchers is a woman in the Arab States (37%), the European Union (33%) and the European Free Trade Association (34%), which are closely followed by sub-Saharan Africa (30%).

For many regions, gender parity (45–55% of researchers) is a legacy of the former Soviet bloc, which stretched across Central Asia, the Baltic States and Eastern Europe to Southeast Europe. One-third of the member states of the European Union (EU) today were once part of the Soviet bloc. Over the past decade, several Southeast European countries have managed to recover the gender parity in research that they had lost in the 1990s following the break-up of the former Yugoslavia: Croatia, FYR Macedonia, Montenegro and Serbia (see Table 10.4).

1. This estimate by the UNESCO Institute for Statistics for 137 countries excludes North America, owing to the international incomparability of these data. The global share of female researchers would not rise more than a few percentage points, however, even if the share of female researchers in the USA could be included in the calculation. Hypothetically, a 40% share of female researchers in the USA would push the global share up from 28.4% to 30.7%.

Figure 3.1: **The leaky pipeline: share of women in higher education and research, 2013 (%)**



Source: UNESCO Institute for Statistics estimates based on data from its database, July 2015

Countries in other regions have made great strides. In Asia, Malaysia, the Philippines and Thailand have all achieved gender parity (see Figure 27.6) and, in Africa, Namibia and South Africa are on the verge of joining this select club (see Figure 19.3). The countries with the highest proportion of female researchers are Bolivia (63%) and Venezuela (56%). Lesotho has slipped out of this category after experiencing a precipitous drop from 76% to 31% between 2002 and 2011.

Some high-income countries have a surprisingly low proportion of female researchers. Just one in four researchers is a woman in France, Germany and the Netherlands, for instance. Even lower proportions are to be found in the Republic of Korea (18%) and Japan (15%). Despite the government's efforts to improve this ratio (see Chapter 24), Japan still has the lowest proportion of female researchers of any member of the Organisation for Economic Co-operation and Development (OECD).

The lowest participation rate of all comes from Saudi Arabia: 1.4% (see Figure 17.7), down from 18.1% in 2000. However, this figure only covers the King Abdulaziz City for Science and Technology. Participation is also very low in Togo (10%) and Ethiopia (13%) and has almost halved in Nepal since 2002 from 15% to 8% (see Figure 21.7).

The glass ceiling still intact

Each step up the ladder of the scientific research system sees a drop in female participation until, at the highest echelons of scientific research and decision-making, there are very few women left. In 2015, the EU Commissioner for Research, Science and Innovation Carlos Moedas called attention to this phenomenon, adding that the majority of entrepreneurs in science and engineering tended to be men. In Germany, the coalition agreement signed in 2013 introduces a 30% quota for women on company boards of directors (see Chapter 9).

Although data for most countries are limited, we know that women made up 14% of university chancellors and vice-chancellors at Brazilian public universities in 2010 (Abreu, 2011) and 17% of those in South Africa in 2011 (Figure 3.3). In Argentina, women make up 16% of directors and vice-directors of national research centres (Bonder, 2015) and, in Mexico, 10% of directors of scientific research institutes at the National Autonomous University of Mexico. In the USA, numbers are slightly higher at 23% (Huyer and Hafkin, 2012). In the EU, less than 16% of tertiary institutions were headed by a woman in 2010 and just 10% of universities (EU, 2013). At the main tertiary institution for the English-speaking Caribbean, the University of the West Indies, women represented 51% of lecturers but only 32% of senior lecturers and 26% of full professors in 2011 (Figure 6.7). Two reviews of national academies of science produce similarly low numbers, with women accounting for more than 25% of members in only a handful of countries, including Cuba, Panama and South Africa. Indonesia deserves an honorary mention at 17% (Henry, 2015; Zubieta, 2015; Huyer and Hafkin, 2012).

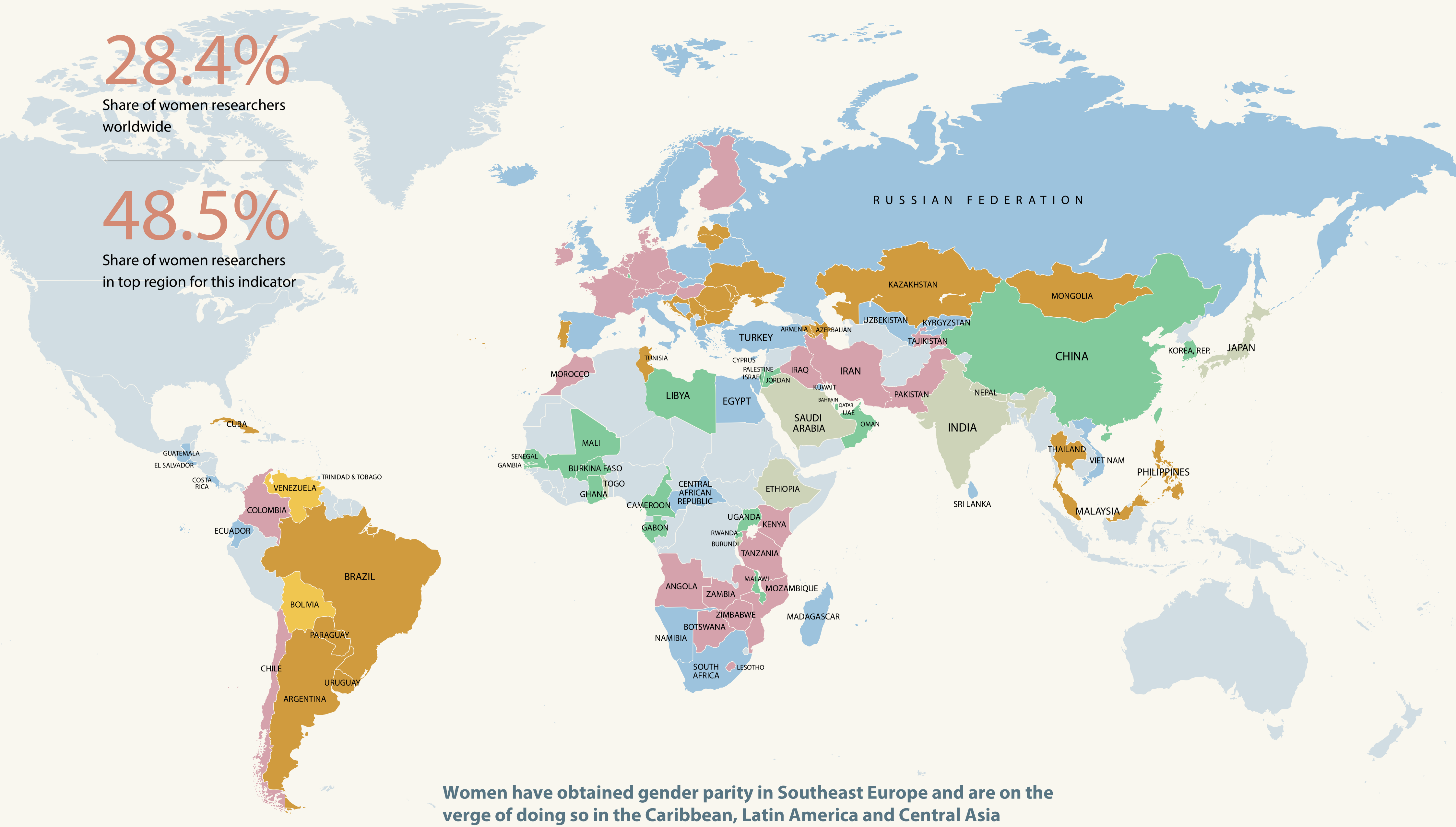
Table 3.1: **Female researchers by field of science, 2013 or closest year (%)**

	Year	Natural sciences	Engineering and technology	Medical sciences	Agricultural sciences	Social sciences and humanities
Albania	2008	43.0	30.3	60.3	37.9	48.1
Angola	2011	35.0	9.1	51.1	22.4	26.8
Armenia	2013	46.4	33.5	61.7	66.7	56.3
Azerbaijan	2013	53.9	46.5	58.3	38.5	57.4
Bahrain	2013	40.5	32.1	45.9	–	43.0
Belarus	2013	50.6	31.5	64.6	60.1	59.5
Bosnia & Herzegovina	2013	43.7	29.6	58.1	42.7	47.0
Botswana	2012	27.8	7.9	43.6	18.1	37.5
Bulgaria	2012	51.0	32.4	58.8	55.6	55.8
Burkina Faso	2010	10.1	11.6	27.7	17.4	35.9
Cabo Verde	2011	35.0	19.6	60.0	100.0	54.5
Chile	2008	26.5	19.0	34.4	27.8	32.7
Colombia	2012	31.8	21.6	52.5	33.6	39.9
Costa Rica	2011	36.7	30.9	60.8	31.5	53.6
Croatia	2012	49.7	34.9	56.1	45.8	55.5
Cyprus	2012	38.7	25.4	46.3	22.8	43.6
Czech Rep.	2012	28.2	12.8	50.6	36.1	42.2
Egypt	2013	40.7	17.7	45.9	27.9	49.7
El Salvador	2013	35.4	17.7	65.0	35.5	46.4
Estonia	2012	38.2	32.0	65.0	49.7	61.8
Ethiopia	2013	12.2	7.1	26.1	7.6	13.3
Gabon	2009	31.4	20.0	58.3	30.2	17.0
Ghana	2010	16.9	6.6	20.8	15.5	22.3
Greece	2011	30.7	29.5	43.0	33.1	46.0
Guatemala	2012	44.1	43.5	60.6	17.2	53.6
Hungary	2012	24.0	20.0	48.1	37.8	44.8
Iran	2010	34.3	19.6	29.5	24.5	25.5
Iraq	2011	43.6	25.7	41.4	26.1	33.7
Japan	2013	12.6	5.3	30.8	21.5	31.9
Jordan	2008	25.7	18.4	44.1	18.7	31.7
Kazakhstan	2013	51.9	44.7	69.5	43.4	59.1
Kenya	2010	14.4	11.2	20.0	30.4	37.1
Korea, Rep.	2013	27.4	10.3	45.6	25.6	40.4
Kuwait	2013	41.8	29.9	44.9	43.8	34.7
Kyrgyzstan	2011	46.5	30.0	44.0	50.0	48.7
Latvia	2012	47.6	34.7	63.7	59.5	65.9
Lesotho	2009	42.0	16.7	–	40.0	75.0
Lithuania	2012	43.9	34.1	61.5	56.5	65.4
FYR Macedonia	2012	40.4	40.1	64.2	45.5	52.0
Madagascar	2011	34.6	18.7	33.8	24.9	44.8
Malawi	2010	22.2	6.5	17.5	12.5	32.8
Malaysia	2012	49.0	49.8	50.8	48.9	51.6
Mali	2006	7.2	15.1	14.9	25.9	12.2
Malta	2012	27.2	17.2	49.3	26.2	34.8
Mauritius	2012	36.4	19.4	41.7	45.4	51.9
Moldova	2013	45.7	29.0	52.5	45.4	61.0
Mongolia	2013	48.7	45.9	64.2	54.6	40.6
Montenegro	2011	56.7	37.0	58.5	54.5	49.0
Morocco	2011	31.5	26.3	44.1	20.5	27.1
Mozambique	2010	27.8	28.9	53.1	20.4	32.0
Netherlands	2012	23.3	14.9	42.8	31.9	40.8
Oman	2013	13.0	6.2	30.0	27.6	23.1
Pakistan	2013	33.8	15.4	37.0	11.0	39.9
Palestine	2007	21.2	9.6	25.5	11.8	27.9
Philippines	2007	59.5	39.9	70.2	51.3	63.2
Poland	2012	37.0	20.6	56.3	49.7	47.3
Portugal	2012	44.5	28.5	60.8	53.2	52.5
Qatar	2012	21.7	12.5	27.8	17.9	34.3
Romania	2012	46.8	39.0	59.1	51.0	49.8
Russian Fed.	2013	41.5	35.9	59.5	56.4	60.3
Saudi Arabia	2009	2.3	2.0	22.2	–	–
Senegal	2010	16.7	13.0	31.7	24.4	26.1
Serbia	2012	55.2	35.9	50.4	60.0	51.8
Slovakia	2013	44.3	25.8	58.5	45.5	52.1
Slovenia	2012	37.5	19.5	54.2	52.8	51.0
Sri Lanka	2010	40.0	27.0	46.4	38.2	29.8
Tajikistan	2013	30.3	18.0	67.6	23.5	29.3
Togo	2012	9.0	7.7	8.3	3.2	14.1
Trinidad & Tobago	2012	44.2	32.6	52.3	39.6	55.3
Turkey	2013	36.0	25.6	47.3	32.9	41.8
Uganda	2010	17.1	23.3	30.6	19.7	27.0
Ukraine	2013	44.5	37.2	65.0	55.0	63.4
Uzbekistan	2011	35.4	30.1	53.6	24.9	46.5
Venezuela	2009	35.1	40.4	64.9	47.6	62.8
Zimbabwe	2012	25.3	23.3	40.0	25.5	25.6

Source: UNESCO Institute for Statistics, August 2015

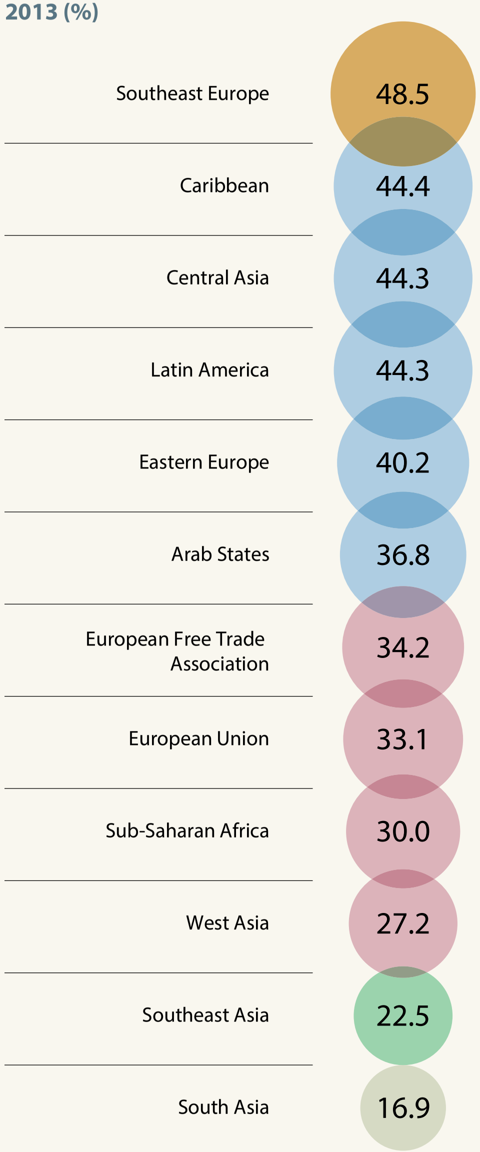
Chapter 3

Figure 3.2: **Share of female researchers by country, 2013 or closest year (%)**



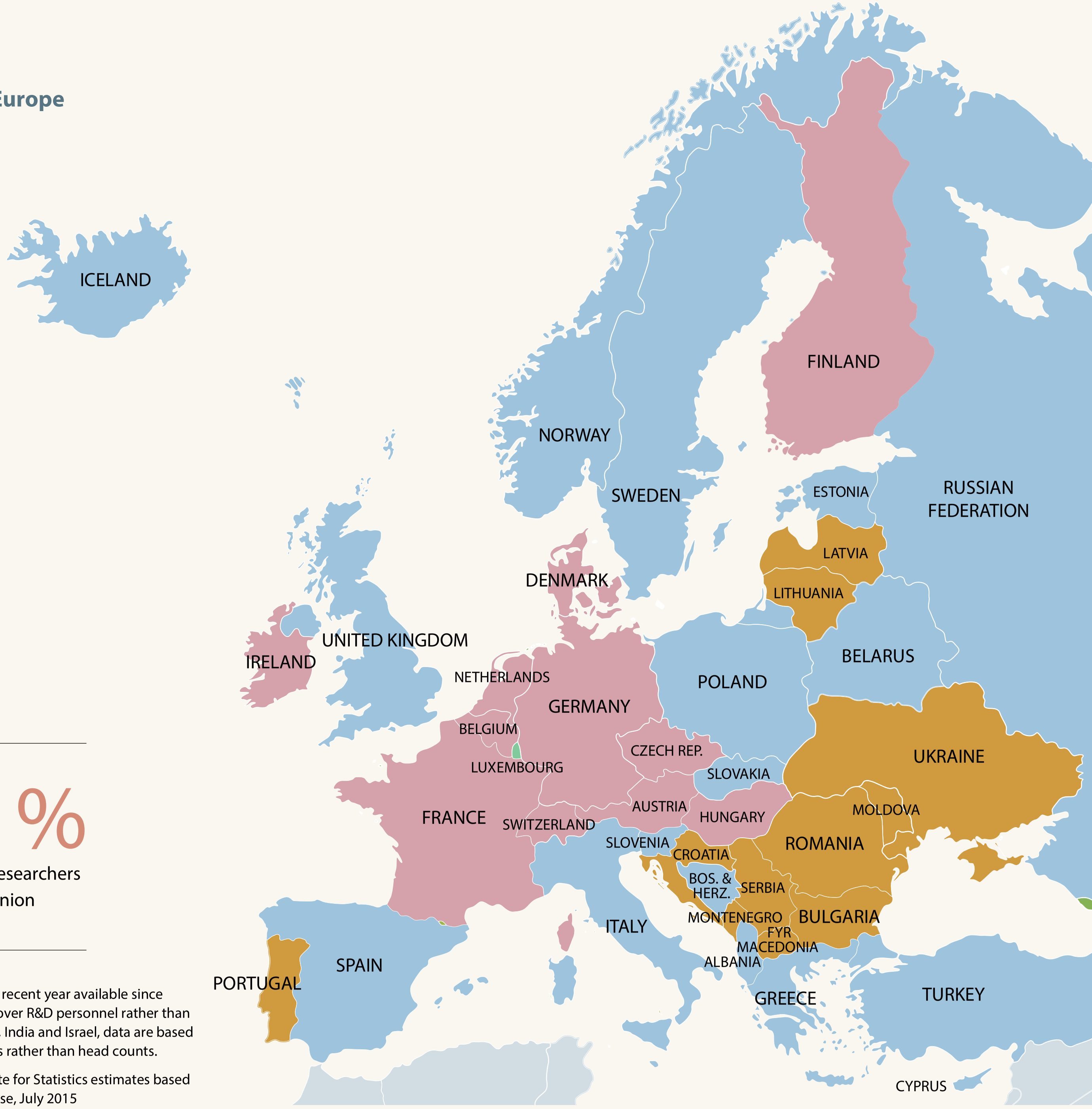
Women have obtained gender parity in Southeast Europe and are on the verge of doing so in the Caribbean, Latin America and Central Asia

Regional shares of female researchers, 2013 (%)



Note: Data are unavailable for North America. The regional averages are based on available data and are derived by using the nearest year's data, whenever data are missing for 2013.

Spotlight on Europe



- 0–14.9%
- 15–24.9%
- 25–34.9%
- 35–44.9%
- 45–54.9%
- 55% or more
- Data unavailable

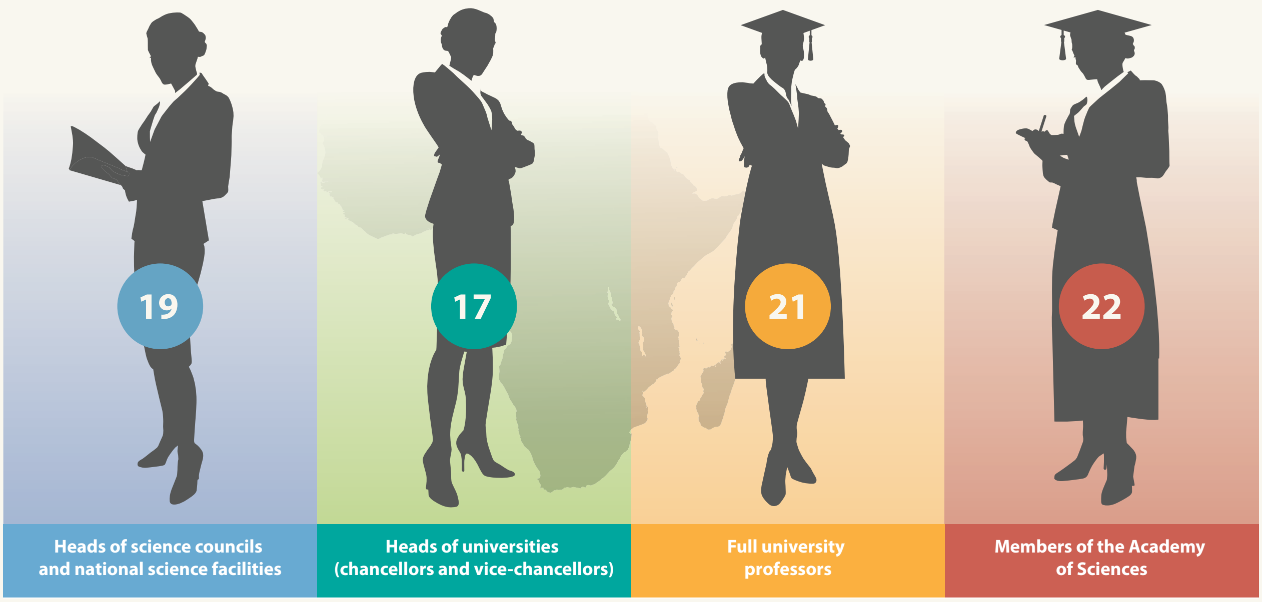
33.1%

Share of women researchers in the European Union

Note: Data for the most recent year available since 2007. For China, data cover R&D personnel rather than researchers. For Congo, India and Israel, data are based on full-time equivalents rather than head counts.

Source: UNESCO Institute for Statistics estimates based on data from its database, July 2015

Figure 3.3: **Share of women in selected South African institutions, 2011(%)**



Note: The data for the share of women among full university professors are for 2009.

Source: ASSAf (2011)

These trends are evident in other spheres of scientific decision-making, with women being underrepresented as peer reviewers, on editorial boards and research councils. A survey of 10 highly regarded journals in environmental biology, natural resource management and plant sciences reviewed the number of women on editorial boards and among editors from 1985 to 2013. The study found that women made up 16% of subject editors, 14% of associate editors and 12% of editors-in-chief (Cho *et al*., 2014).

TRENDS IN TERTIARY EDUCATION

The scales have tipped in favour of female students

The absence of women from the highest echelons of science and related decision-making is surprising, given the progress towards gender parity observed at all levels of education in recent decades. The pendulum has even swung the other way, with there now being a global gender imbalance in favour of female students, albeit not in all regions. Female university students dominate in North America (57%), Central and South America (49–67%) and even more so across the Caribbean[2] (57–85%). Europe and West Asia show a similar trend, with the notable exception of Turkey and Switzerland, where females make up around 40% of tertiary enrolment, and Liechtenstein (about 21%). In most Arab states, the same trend towards gender parity can be observed, the exceptions here being Iraq, Mauritania and Yemen, where figures for women drop to 20–30%. Data from Morocco show a cyclical pattern from 2000 but a general rise to 47% in 2010.

In sub-Saharan Africa, numbers are substantially lower, reflecting a gender imbalance in education at all levels (see Chapters 18–20). Shares of women graduates at the tertiary level range from the low teens to more than half, as in Namibia (58%) and South Africa (60%). Female representation has dropped substantially in Swaziland, from a high of 55% in 2005 to 39% in 2013. In South Asia, the participation of women in tertiary education remains low, with the notable exception of Sri Lanka at 61%.

Overall, women are more likely to pursue tertiary education in countries with relatively higher levels of national income. The lowest ratios of women to men tend to be found in low-income countries, most of which are situated in sub-Saharan Africa. Examples are Ethiopia (31%), Eritrea (33%), Guinea (30%) and Niger (28%). In Central African Republic and Chad, male tertiary students are 2.5 times more common than female ones (Table 19.4). Notable exceptions among the 31 low-income countries are Comoros (46%), Madagascar (49%) and Nepal (48%).

The same pattern can be found in countries with relatively low GDP per capita in other regions but there are signs that the trend is waning. In Asia, female students face considerable disparities in Afghanistan (share of women tertiary students: 24%), Tajikistan (38%), and Turkmenistan (39%) but the share has become much more favourable to women in recent years

2. Antigua and Barbuda, Barbados, Cuba, Dominican Republic and Jamaica in Cambodia (38% in 2011) and Bangladesh (41% in 2012). In the Arab States, the lowest participation rate concerns Yemeni women (30%). Djibouti and Morocco have each increased the share of female students to more than 40%.

A slight rise in national wealth may correlate to a drop in gender disparities. Sub-Saharan African countries with higher levels of wealth also report higher participation rates for women than men in tertiary education. For example, 59% of tertiary students are women in Cabo Verde and 54% in Namibia. However, there are notable exceptions among high-income[3] countries. Men continue to outnumber women in tertiary education in Liechtenstein, Japan and Turkey.

Empirical research and anecdotal observations highlight several reasons for the growing participation of women in higher education. Education is perceived as a means of moving up the social ladder (Mellström, 2009). Having a tertiary education brings individual returns in the form of higher income levels, even though women are obliged to have more years of education under their belt than men to secure jobs of comparable pay – a pattern found in countries of all income levels. Many countries are also anxious to expand their skilled labour force, in order to develop a knowledge economy and increase their global competitiveness, examples being Iran (see Chapter 15) and Malaysia (see Chapter 26). Another explanation lies in the active campaign for gender equality undertaken by numerous organizations in recent decades.

TRENDS IN TERTIARY SCIENCE EDUCATION

Women now dominate graduates in health

Although women tertiary graduates generally outnumber their male counterparts – with national and regional variations –, this is not necessarily the case when the data are broken down by field into science, engineering, agriculture and health.[4] The good news is that the share of female graduates in scientific fields is on the rise. This trend has been most marked since 2001 in all developing regions except Latin America and the Caribbean, where women's participation was already high.

The presence of women varies according to the field of study. Women now dominate the broad fields of health and welfare in most countries and regions but not the rest of the sciences; they are least likely to figure among engineering graduates, for instance. There are also exceptions to the rule. In Oman, for instance, women make up 53% of engineering graduates (Table 3.2). Women are a minority among health and welfare graduates in four sub-Saharan countries[5] and two Asian ones: Bangladesh (33%) and Viet Nam (42%).

The second-most popular field of science for women is science. While numbers are not as high as for health and welfare, the share of women studying science is on a par with that of men or slightly higher in many mainly Latin American and Arab countries. In the 10 countries reporting data from Latin America and the Caribbean, females make up 45% or more of tertiary graduates in science. They make up over half of graduates in Panama and Venezuela, the Dominican Republic and in Trinidad and Tobago (the latter having a very small graduate population). In Guatemala, as much as 75% of science graduates are female. Eleven out of 18 Arab States also have a majority of female science graduates.[6] The countries in South Asia reporting data – Bangladesh and Sri Lanka – reveal averages of 40–50%, whereas some east and southeast Asian countries show percentages of 52% or more: Brunei Darussalam (66%), Philippines (52%), Malaysia (62%) and Myanmar (65%). Japan and Cambodia have low shares of 26% and 11% respectively and the Republic of Korea a share of 39%.

Graduation rates for women in Europe and North America range from a high of 55% in Italy, Portugal and Romania to a low of 26% in the Netherlands. Next come Malta and Switzerland with 29% and 30% respectively. The majority of countries fall in the 30–46% range.

Within the broad field of science, some interesting trends can be observed. Women graduates are consistently highly represented in the life sciences, often at over 50%. However, their representation in the other fields is inconsistent. In North America and much of Europe, few women graduate in physics, mathematics and computer science but, in other regions, the proportion of women may be close to parity in physics or mathematics. This may explain the decrease in science students in some countries; often, an increase in agriculture or engineering occurs at the expense of science, suggesting a redistribution of female participation rather than an overall increase.

More women are graduating in agriculture

Trends in agricultural science tell an interesting story. Around the world, there has been a steady increase in female graduates since 2000. The reasons for this surge are unclear, although anecdotal evidence suggests that one explanation may lie in the growing emphasis on national food security and the food industry.

3. defined as countries with per capita GDP above PPP$ 10 000

4. 'Science' here is defined as encompassing life sciences, physical sciences, mathematics, statistics and computer sciences; 'engineering' includes manufacturing and processing, construction and architecture; 'agriculture' includes forestry, fisheries and veterinary science; 'health and welfare' includes medicine, nursing, dental studies, medical technology, therapy, pharmacy and social services.

5. Benin, Burundi, Eritrea and Ethiopia

6. Algeria, Bahrain, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Tunisia and United Arab Emirates

Table 3.2: **Share of female tertiary graduates in four selected fields, 2013 or closest year (%)**

	Year	Science	Engineering	Agriculture	Health & welfare
Albania	2013	66.1	38.8	41.5	72.7
Algeria	2013	65.4	32.4	56.5	64.6
Angola	2013	36.2	19.3	21.7	63.3
Argentina	2012	45.1	31.0	43.9	73.8
Austria	2013	33.3	21.2	55.9	70.8
Bahrain	2014	66.3	27.6	a	76.8
Bangladesh	2012	44.4	16.6	31.1	33.3
Belarus	2013	54.4	30.0	29.2	83.8
Bhutan	2013	25.0	24.9	15.5	52.6
Bosnia & Herzegovina	2013	46.8	37.5	46.9	74.2
Brazil	2012	33.1	29.5	42.3	77.1
Brunei Darussalam	2013	65.8	41.8	a	85.7
Burkina Faso	2013	18.8	20.6	16.8	45.9
Colombia	2013	41.8	32.1	40.9	72.0
Costa Rica	2013	30.5	33.7	37.4	76.9
Cuba	2013	44.9	28.3	30.0	68.2
Denmark	2013	35.4	35.3	67.4	80.0
Egypt	2013	49.6	25.3	46.6	54.4
El Salvador	2013	59.0	26.6	24.6	78.0
Eritrea	2014	35.0	15.8	29.8	26.3
Finland	2013	42.5	21.7	57.6	85.1
France	2013	37.8	25.6	50.1	74.4
Georgia	2013	47.7	23.1	27.5	74.4
Ghana	2013	27.1	18.4	17.2	57.6
Honduras	2013	35.9	37.4	28.3	74.7
Iran	2013	66.2	24.7	41.1	65.1
Kazakhstan	2013	61.5	31.0	43.0	79.8
Kuwait	2013	72.2	25.0	a	44.5
Kyrgyzstan	2013	61.3	25.8	27.9	77.1
Lao PDR	2013	39.1	10.6	30.7	59.8
Latvia	2013	38.7	26.8	48.7	92.3
Lesotho	2013	54.5	27.5	45.7	78.8
Lithuania	2013	41.8	21.8	50.9	84.3
FYR Macedonia	2013	37.6	39.1	48.5	75.3
Madagascar	2013	32.1	24.2	51.9	74.1
Malaysia	2012	62.0	38.7	54.4	62.9
Mongolia	2013	46.6	37.9	63.0	83.9
Mozambique	2013	35.6	34.4	40.6	47.4
Myanmar	2012	64.9	64.6	51.5	80.7
Nepal	2013	28.4	14.0	33.3	57.0
Netherlands	2012	25.8	20.9	54.5	75.1
New Zealand	2012	39.1	27.4	69.3	78.1
Norway	2013	35.9	19.6	58.9	83.6
Oman	2013	75.1	52.7	6.0	37.8
Palestine	2013	58.5	31.3	37.1	56.7
Panama	2012	50.5	35.9	54.0	75.6
Philippines	2013	52.1	29.5	50.7	72.1
Poland	2012	46.1	36.1	56.4	71.5
Portugal	2013	55.7	32.5	59.9	78.9
Qatar	2013	64.7	27.4	a	72.9
Korea, Rep.	2013	39.0	24.0	41.1	71.4
Moldova	2013	48.9	30.5	28.3	77.6
Rwanda	2012	40.3	19.6	27.3	61.9
Saudi Arabia	2013	57.2	3.4	29.6	52.0
Serbia	2013	46.2	35.0	46.5	73.3
Slovakia	2013	45.6	30.9	50.9	81.9
Slovenia	2012	39.9	24.4	59.1	81.8
South Africa	2012	49.1	28.5	48.6	73.7
Spain	2012	38.4	26.8	45.4	75.0
Sri Lanka	2013	47.4	22.4	57.4	58.1
Sudan	2013	41.8	31.8	64.3	66.4
Swaziland	2013	31.6	15.2	42.8	60.4
Sweden	2012	40.6	28.9	63.1	82.0
Switzerland	2013	31.8	14.0	30.1	74.4
Syria	2013	50.9	36.0	45.0	49.5
Tunisia	2013	63.8	41.1	69.9	77.5
Turkey	2012	48.2	24.8	45.0	63.4
Ukraine	2013	49.6	26.2	34.1	80.6
United Arab Emirates	2013	60.2	31.1	54.1	84.6
UK	2013	45.7	22.2	64.1	77.3
USA	2012	40.1	18.5	48.3	81.5
Viet Nam	2013	a	31.0	36.7	42.3
Zimbabwe	2013	47.7	21.4	40.3	50.0

a = not applicable *Note:* Engineering includes manufacturing and construction. The oldest data are for 2012.

Source: UNESCO Institute for Statistics, August 2015

Another possible explanation is that women are highly represented in biotechnology. For example, in South Africa, women were underrepresented in engineering (16%) in 2004 and in 'natural scientific professions' (16%) in 2006 but made up 52% of employees working in biotechnology-related companies.

At the same time, women are poorly represented in agricultural extension services in the developing world. Better understanding of women's incursion into this sector, as well as their career paths, may shed some light on the barriers and opportunities for women in the other sciences.

Women least present in engineering

Women are consistently least represented in engineering, manufacturing and construction. In many cases, engineering has lost ground to other sciences, including agriculture. However, there are regional exceptions: the share of women graduating as engineers has risen in sub-Saharan Africa, the Arab States and parts of Asia. Of the 13 sub-Saharan countries reporting data, seven observe substantial increases (more than 5%) in women engineers since 2000.[7] However, less than 20% of women still graduate in engineering, with the notable exceptions of Liberia and Mozambique. Of the seven Arab countries reporting data, four observe a steady percentage or an increase;[8] the highest scores come from the United Arab Emirates and Palestine (31%), Algeria (31%) and Oman, with an astonishing 53%. Some Asian countries show similar rates: 31% in Viet Nam, 39% in Malaysia and 42% in Brunei Darussalam.

The numbers in Europe and North America are generally low: 19% in Canada, Germany and the USA and 22% in Finland, for example, but there are some bright spots: 50% of engineering graduates are women in Cyprus and 38% in Denmark.

Fewer female graduates in computer science

An analysis of computer science shows a steady decrease in female graduates since 2000 that is particularly marked in high-income countries. Exceptions in Europe include Denmark, where female graduates increased from 15% to 24% between 2000 and 2012, and Germany, which saw an increase from 10% to 17%. These are still very low levels. In Turkey, the proportion of women graduating in computer science rose from a relatively high 29% to 33%. Over the same period, the share of women graduates slipped in Australia, New Zealand, the Republic of Korea and USA. The situation in Latin America and the Caribbean is worrying: in all countries reporting data, the share of women graduates in computer science has dropped by between 2 and 13 percentage points.

This should be a wake-up call. Female participation is falling in a field that is expanding globally as its importance for national economies grows, penetrating every aspect of daily life. Could this be a symptom of the phenomenon by which 'women are the first hired and the first fired?' In other words, are they being pushed out once a company gains prestige and raises the remuneration of staff, or when companies run into financial difficulties?

Women engineers well-regarded in Malaysia and India

There are exceptions. The Malaysian information technology (IT) sector is made up equally of women and men, with large numbers of women employed as university professors and in the private sector. This is a product of two historical trends: the predominance of women in the Malay electronics industry, the precursor to the IT industry, and the national push to achieve a 'pan-Malayan' culture beyond the three ethnic groups of Indian, Chinese and Malay. Government support for the education of all three groups is available on a quota basis and, since few Malay men are interested in IT, this leaves more room for women. Additionally, families tend to be supportive of their daughters' entry into this prestigious and highly remunerated industry, in the interests of upward mobility (Mellström, 2009).

In India, the substantial increase in women undergraduates in engineering may be indicative of a change in the 'masculine' perception of engineering in the country. It is also a product of interest on the part of parents, since their daughters will be assured of employment as the field expands, as well as an advantageous marriage. Other factors include the 'friendly' image of engineering in India, compared to computer sciences, and the easy access to engineering education resulting from the increase in the number of women's engineering colleges[9] over the last two decades (Gupta, 2012).

TRENDS FROM A REGIONAL PERSPECTIVE

Latin America tops world for female participation

Latin America has some of the world's highest rates of women studying scientific fields; it also shares with the Caribbean one of the highest proportions of female researchers: 44%. Of the 12 countries reporting data for the years 2010–2013, seven have achieved gender parity, or even dominate research: Bolivia (63%), Venezuela (56%), Argentina (53%), Paraguay (52%), Uruguay (49%), Brazil (48%) and Guatemala (45%). Costa Rica is just a whisker behind, with 43%. Chile has the lowest score among countries for which there are recent data (31%). The Caribbean paints a similar picture, with Cuba having achieved gender parity (47%) and Trinidad and Tobago being on the cusp (44%).

7. Benin, Burundi, Eritrea, Ethiopia, Madagascar, Mozambique and Namibia

8. Morocco, Oman, Palestine and Saudi Arabia

9. Fifteen women's engineering colleges have been established in the country since 1991.

Factoring in specific scientific fields changes some of these dynamics. As in most other regions, the great majority of health graduates are women (60–85%). Women are also strongly represented in science. More than 40% of science graduates are women in each of Argentina, Colombia, Ecuador, El Salvador, Mexico, Panama and Uruguay. The Caribbean paints a similar picture, with women graduates in science being on a par with men or dominating this field in Barbados, Cuba, Dominican Republic and Trinidad and Tobago. In engineering, women make up over 30% of the graduate population in seven Latin American countries[10] and one Caribbean country – the Dominican Republic. Of note is the decrease in women engineering graduates in Argentina, Chile and Honduras.

The discouraging news is that the participation of women in science has consistently dropped over the past decade. This trend has been observed in all sectors of the larger economies: Argentina, Brazil, Chile and Colombia. Mexico is a notable exception, having recorded a slight increase. Some of the decrease may be attributed to women transferring to agricultural sciences in these countries.

Another negative trend is the drop in female doctoral students and in the labour force. Of those countries reporting data, the majority signal a significant drop of 10–20 percentage points in the transition from master's to doctoral graduates, a trend which augurs ill for employers.

Despite the substantial participation by women in the science and technology sector, attitudes and institutional practices persist in Latin America that devalue a women's ability. For example, a review of the software and information services industry in Latin America found that a glass ceiling persists, with substantial gender disparities in management positions and on boards of directors. National reviews of women's representation in science in the region refer to obstacles relating to the work–life balance and disadvantages to women in science and research who are expected to both manage the household and put in full-time and even overtime at the same rates as men (ECLAC, 2014; Bonder, 2015).

Gender parity in Eastern Europe and Central Asia

Most countries in Eastern Europe, West and Central Asia have attained gender parity in research (Armenia, Azerbaijan, Georgia, Kazakhstan, Mongolia and Ukraine) or are on the brink of doing so (Kyrgyzstan and Uzbekistan). This trend is reflected in tertiary education, with some exceptions in engineering and computer science. Although Belarus and the Russian Federation have seen a drop over the past decade, women still represented 41% of researchers in 2013.

One in three researchers is a woman in Turkey (36%) and Tajikistan (34%). Participation rates are lower in Iran (26%) and Israel (21%), although Israeli women represent 28% of senior academic staff. At university, Israeli women dominate medical sciences (63%) but only a minority study engineering (14%), physical sciences (11%), mathematics and computer science (10%) [see Chapter 16].

There has been an interesting evolution in Iran. Whereas the share of female PhD graduates in health remained stable at 38–39% between 2007 and 2012, it rose in all three other broad fields. Most spectacular was the leap in female PhD graduates in agricultural sciences from 4% to 33% but there was also a marked progression in science (from 28% to 39%) and engineering (from 8% to 16%) [see Figure 12.3].

Southeast Europe: a legacy of gender parity

With the exception of Greece, all the countries of Southeast Europe were once part of the Soviet bloc. Some 49% of researchers in these countries are women (compared to 37% in Greece in 2011). This high proportion is considered a legacy of the consistent investment in education by the Socialist governments in place until the early 1990s, including that of the former Yugoslavia. Moreover, the participation of female researchers is holding steady or increasing in much of the region, with representation broadly even across the four sectors of government, business, higher education and non-profit.

In most countries, women tend to be on a par with men among tertiary graduates in science. Between 70% and 85% of graduates are women in health, less than 40% in agriculture and between 20% and 30% in engineering. Albania has seen a considerable increase in the share of its women graduates in engineering and agriculture.

EU: female researcher pool growing fastest

Women make up 33% of researchers overall in the EU, slightly more than their representation in science (32%). Women constitute 40% of researchers in higher education, 40% in government and 19% in the private sector, with the number of female researchers increasing faster than that of male researchers. The proportion of female researchers has been increasing over the last decade, at a faster rate than men (5.1% annually over 2002–2009 compared with 3.3% for men), which is also true for their participation among scientists and engineers (up 5.4% annually between 2002 and 2010, compared with 3.1 % for men).

Despite these gains, women's academic careers in Europe remain characterized by strong vertical and horizontal segregation. In 2010, although female students (55%) and graduates (59%) outnumbered male students, men outnumbered women at the PhD and graduate levels (albeit by a small margin). Further along in the research career, women

10. Argentina, Colombia, Costa Rica, Honduras, Panama, Uruguay represented 44% of grade C academic staff, 37% of grade B academic staff and 20% of grade A academic staff.[11] These trends are intensified in science, with women making up 31% of the student population at the tertiary level to 38% of PhD students and 35% of PhD graduates. At the faculty level, they make up 32% of academic grade C personnel, 23 % of grade B and 11 % of grade A. The proportion of women among full professors is lowest in engineering and technology, at 7.9 %. With respect to representation in science decision-making, in 2010 15.5% of higher education institutions were headed by women and 10% of universities had a female rector. Membership on science boards remained predominantly male as well, with women making up 36% of board members.

The EU has engaged in a major effort to integrate female researchers and gender research into its research and innovation strategy since the mid-2000s. Increases in women's representation in all of the scientific fields overall indicates that this effort has met with some success; however, the continued lack of representation of women at the top level of faculties, management and science decision making indicate that more work needs to be done. The EU is addressing this through a gender equality strategy and cross-cutting mandate in Horizon 2020, its research and innovation funding programme for 2014–2020.

A lack of data for other high-income countries

In Australia, New Zealand and the USA, women make up the great majority of graduates in fields related to health. The same can be said of agriculture, in New Zealand's case. Both Australia and the USA have seen a modest progression in the share of female graduates in these two broad fields: 43–46% in agriculture and 76–77% in health for Australia and 47.5–48% in agriculture and 79–81% in health for the USA. Just one in five women graduate in engineering in these two countries, a situation that has not changed over the past decade. In New Zealand, women jumped from representing 39% to 70% of agricultural graduates between 2000 and 2012 but ceded ground in science (43–39%), engineering (33–27%) and health (80–78%). As for Canada, it has not reported sex-disaggregated data for women graduates in science and engineering. Moreover, none of the four countries listed here has reported recent data on the share of female researchers.

South Asia: the lowest shares of women

South Asia is the region where women make up the smallest proportion of researchers: 17%. This is 13 percentage points below sub-Saharan Africa. Of those countries in South Asia reporting data, Nepal has the lowest representation of all at 8% (2010), a substantial drop from 15% in 2002. Only 14% of researchers are women in the region's most populous country, India. The percentage of female researchers is highest in Sri Lanka but has receded somewhat to 37% (2010) from the 42% reported in 2006. Pakistan is gradually catching up (20% in 2013) [see Figure 21.7].

A breakdown of the research labour force reveals that South Asian women are most present in the private non-profit sector – they make up 60% of employees in Sri Lanka – followed by the academic sector: 30% of Pakistani and 42% of Sri Lankan female researchers. Women tend to be less present in the government sector and least likely to be employed in the business sector, accounting for 23% of employees in Sri Lanka and just 5% in Nepal (Figure 3.4).

Women have achieved parity in science in both Sri Lanka and Bangladesh but are less likely to undertake research in engineering. They represent 17% of the research pool in Bangladesh and 29% in Sri Lanka. Many Sri Lankan women have followed the global trend of opting for a career in agricultural sciences (54%) and they have also achieved parity in health and welfare. In Bangladesh, just over 30% choose agricultural sciences and health, which goes against the global trend. Although Bangladesh still has progress to make, the share of women in each scientific field has increased steadily over the past decade.

Southeast Asia: women often on a par with men

Southeast Asia presents a different picture entirely, with women basically on a par with men in some countries: they make up 52% of researchers in the Philippines and Thailand, for example. Other countries are close to parity, such as Malaysia and Viet Nam, whereas Indonesia and Singapore are still around the 30% mark. Cambodia trails its neighbours at 20%. Female researchers in the region are spread fairly equally across the sectors of participation, with the exception of the private sector, where they make up 30% or less of researchers in most countries.

The proportion of women tertiary graduates reflects these trends, with high percentages of women in science in Brunei Darussalam, Malaysia, Myanmar and the Philippines (around 60%) and a low of 10% in Cambodia. Women make up the majority of graduates in health sciences, from 60% in Laos to 81% in Myanmar – Viet Nam being an exception at 42%. Women graduates are on a par with men in agriculture but less present in engineering: Viet Nam (31%), the Philippines (30%) and Malaysia (39%); here, the exception is Myanmar, at 65%.

In the Republic of Korea, women make up about 40% of graduates in science and agriculture and 71% of graduates in health sciences but only 18% of female researchers overall. This represents a loss in the investment made in educating girls and women up through tertiary education, a result of traditional

11. Grade A is the highest grade/post at which research is normally conducted; grade B researchers occupy mid-level positions; grade C is the first grade/post to which a newly qualified PhD-holder would normally be recruited (European Commission, 2013).

views of women's role in society and in the home. Kim and Moon (2011) remark on the tendency of Korean women to withdraw from the labour force to take care of children and assume family responsibilities, calling it a 'domestic brain drain'.

Women remain very much a minority in Japanese science (15% in 2013), although the situation has improved slightly (13% in 2008) since the government fixed a target in 2006 of raising the ratio of female researchers to 25% (see Chapter 24). Calculated on the basis of the current number of doctoral students, the government hopes to obtain a 20% share of women in science, 15% in engineering and 30% in agriculture and health by the time the current *Basic Plan for Science and Technology* ends in 2016. Today, Japanese female researchers are most common in the public sector in health and agriculture, where they represent 29% of academics and 20% of government researchers (see Figure 24.5). One of the main thrusts of Abenomics, Japan's current growth strategy, is to enhance the socio-economic role of women. Consequently, the selection criteria for most large university grants now take into account the proportion of women among teaching staff and researchers (Chapter 24).

Arab States: a high share of female students

At 37%, the share of female researchers in the Arab States compares well with other regions. The countries with the highest proportion of female researchers are Bahrain and Sudan, at around 40%. Jordan, Libya, Oman, Palestine and Qatar have percentage shares in the low twenties. The country with the lowest participation of female researchers is Saudi Arabia, even though they make up the majority of tertiary graduates, but the figure of 1.4% covers only the King Abdulaziz City for Science and Technology.

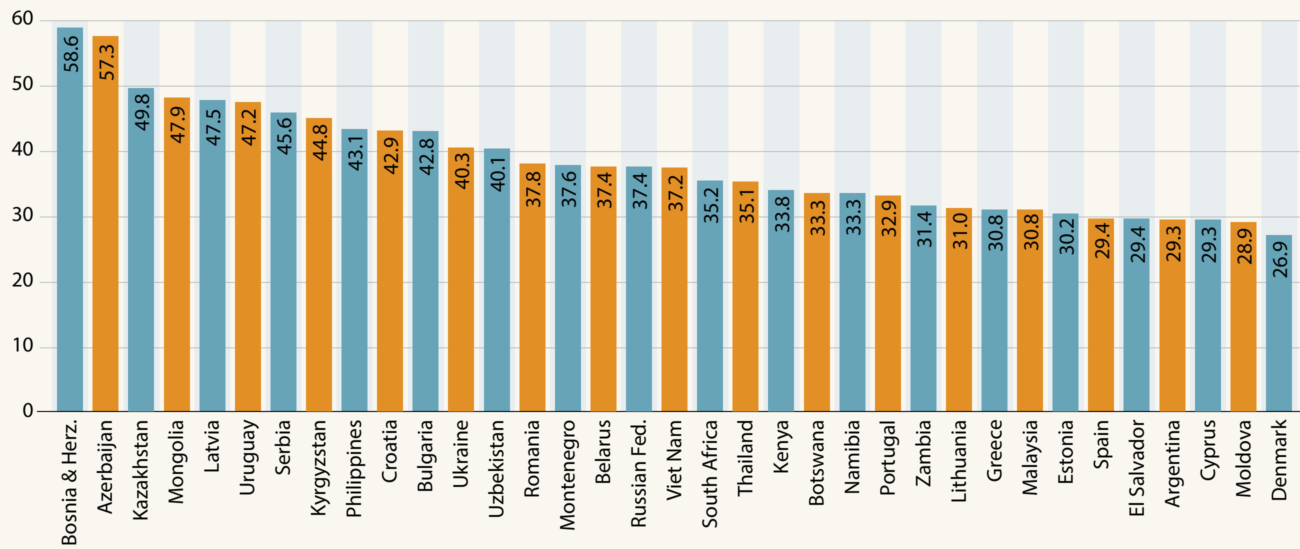
Female researchers in the region are primarily employed in government research institutes, with some countries also seeing a high participation of women in private non-profit organizations and universities. With the exception of Sudan (40%) and Palestine (35%), fewer than one in four researchers in the business enterprise sector is a woman; for half of the countries reporting data, there are barely any women at all employed in this sector.

Despite these variable numbers, the percentage of female tertiary-level graduates in science and engineering is very high across the region, which indicates that there is a substantial drop between graduation and employment and research. Women make up half or more than half of science graduates in all but Sudan and over 45% in agriculture in eight out of the 15 countries reporting data.[12] In engineering, women make up 53% of graduates in Oman, with rates of 25–38% in the majority of the other countries – which is high in comparison to other regions. Interestingly, the participation of women is somewhat lower in health than in other regions, possibly on account of cultural norms restricting interactions between males and females. Iraq and Oman have the lowest percentages (mid-30s), whereas Iran, Jordan, Kuwait, Palestine and Saudi Arabia are at gender parity in this field. The United Arab Emirates and Bahrain have the highest rates of all: 83% and 84%.

Why such a high proportion of female engineering students in the region? The case of the United Arab Emirates offers

12. Algeria, Egypt, Jordan, Lebanon, Sudan, Syria, Tunisia and UAE

Figure 3.4: **Share of women among researchers employed in the business enterprise sector, 2013 or closest year (%)**



Note: Data are in head counts. The oldest data are for the Philippines and Israel (2007), Iran, Lesotho and Zambia (2008) and Thailand (2009).

Source: UNESCO Institute for Statistics, August 2015 some insights. The government has made it a priority to develop a knowledge economy, having recognized the need for a strong human resource base in science, technology and engineering. With just 1% of the labour force being Emirati, it is also concerned about the low percentage of Emirati citizens employed in key industries (see Chapter 17). As a result, it has introduced policies promoting the training and employment of Emirati citizens, as well as a greater participation of Emirati women in the labour force. Emirati female engineering students have said that they are attracted to a career in engineering for reasons of financial independence, the high social status associated with this field, the opportunity to engage in creative and challenging projects and the wide range of career opportunities.

Once Arab women scientists and engineers graduate, they may come up against barriers to finding gainful employment. These include a misalignment between university programmes and labour market demand – a phenomenon which also affects men –, a lack of awareness about what a career in their chosen field entails, family bias against working in mixed-gender environments and a lack of female role models (Samulewicz *et al*, 2012; see also Chapter 17).

One of the countries with the smallest female labour force is developing technical and vocational education for girls as part of a wider scheme to reduce dependence on foreign labour. By 2017, the Technical and Vocational Training Corporation of Saudi Arabia is to have constructed 50 technical colleges, 50 girls' higher technical institutes and 180 industrial secondary institutes. The plan is to create training placements for about 500 000 students, half of them girls. Boys and girls will be trained in vocational professions that include information technology, medical equipment handling, plumbing, electricity and mechanics (see Chapter 17).

Sub-Saharan Africa: solid gains

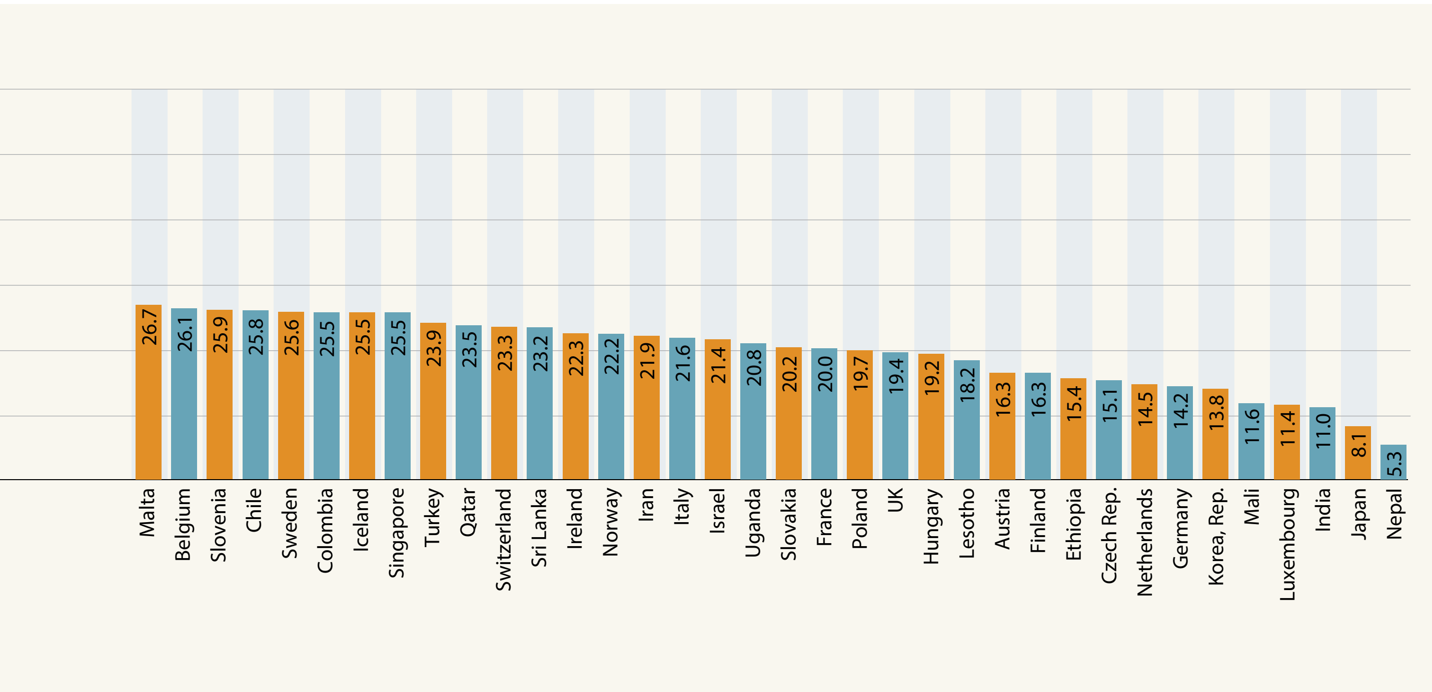
Just under one in three (30%) researchers in sub-Saharan Africa is a woman. Much of sub-Saharan Africa is seeing solid gains in the share of women among tertiary graduates in scientific fields. In two of the top four countries for women's representation in science, women graduates are part of very small cohorts: they make up 54% of Lesotho's 47 tertiary graduates in science and 60% of those in Namibia's graduating class of 149. South Africa and Zimbabwe, which have larger graduate populations in science, have achieved parity, with 49% and 47% respectively. The next grouping clusters seven countries poised at around 35–40%,[13] whereas the rest are grouped around 30% or below.[14] Burkina Faso ranks lowest, with women making up 18% of its science graduates.

Female representation in engineering is fairly high in sub-Saharan Africa in comparison with other regions. In Mozambique, Lesotho, Angola and South Africa, women make up between 28% (South Africa) and 34% (Mozambique) of science graduates. Numbers of female graduates in agricultural science have been increasing steadily across the continent, with eight countries reporting the share of women graduates of 40% or more.[15] In health, this rate ranges from 26% and 27% in Benin and Eritrea to 94% in Namibia.

13. Angola, Burundi, Eritrea, Liberia, Madagascar, Mozambique and Rwanda

14. Benin, Ethiopia, Ghana, Swaziland and Uganda

15. Lesotho, Madagascar, Mozambique, Namibia, Sierra Leone, South Africa, Swaziland and Zimbabwe



POLICY ISSUES

Progress but a persistent 'generation effect'

Concrete progress is being made in much of the world in increasing the share of women studying scientific disciplines. Moreover, female participation at tertiary level is expanding beyond life and health sciences. We are also seeing progress in the recognition of female scientists at national, regional and global levels. The African Union has instigated awards for women scientists, for instance (see Chapter 18). In the past five years, five Nobel prizes have been awarded to women for work in medicine, physiology and chemistry.[16] In 2014, the Iranian Maryam Mirzakhani became the first woman to receive the prestigious Fields Medal awarded by the International Mathematical Union.

However, the data also show that gender equality in science is not a natural result of these trends – it is not simply a matter of waiting for female tertiary graduates to make their way through the system. Gaps and barriers persist throughout the scientific research system. This has been systematically documented in Europe and the USA, where a decade or so of injecting policy, programming and funding into the system to promote gender equality in research have not produced as much progress as expected. Indeed, in the USA, numbers have remained stagnant and even decreased in some fields over the past decade, whereas there has been little change in the gender balance in the EU for positions of leadership and prestige (EU, 2013). Eurostat uses the term 'generation effect' to refer to a gender imbalance in the research population which increases with age rather than evening out. Despite increases in numbers of female students, the gender gap in scientific research in Europe is still disproportionately high, making it less likely women will automatically 'catch up' to men (EU, 2013).

Getting more women into science isn't working

A combination of factors reduces the proportion of women at each stage of a scientific career: the graduate-level environment; the maternal wall/glass ceiling; performance evaluation criteria; the lack of recognition; lack of support for leadership bids; and unconscious gender bias.

With regard to the graduate-level environment, a 2008 study of the career intentions of graduate students in chemistry in the UK found that 72% of women had planned to become a researcher at the start of their studies but, by the time they completed their PhD, only 37% still harboured this career goal. This was the result of a number of factors which 'discourage women more than men from planning a career in research, especially in academia'. Female students were more likely to encounter problems with their supervisor such as favouritism or victimization, or to feel that their supervisor was oblivious to their personal life, or to feel isolated from their research group. They were also more likely to be uncomfortable with the research culture of their group in terms of working patterns, work hours and competition among peers. As a result, female students viewed an academic career as offering a solitary existence; they felt intimidated by the competitive atmosphere and that an academic career demanded too much of a sacrifice from them concerning other aspects of their life. Many female students also spoke of having been advised against pursuing a scientific career, owing to the challenges they would face as a woman (Royal Society of Chemistry, 2008). In Japan, female engineering undergraduates complained of experiencing difficulties in approaching instructors with questions and had trouble engaging with learning both in and outside the classroom (Hosaka, 2013).

The 'maternal wall' results from expectations that a woman's job performance will be affected by her taking a leave of absence to have children, or by absences from work to take care of the family (Williams, 2004). In some countries, once women have embarked on a scientific career, their trajectories tend to be less stable than those of men and characterized by shorter term and temporary work, rather than full-time positions (Kim and Moon, 2011). Some of these challenges stem from a working and research environment where women are expected to fit in and 'become one of the boys' rather than one which encourages flexible working arrangements to accommodate the life situations of both women and men. In East Africa, barriers facing female researchers include difficulty in travelling to conferences or in participating in field work, on the assumption that they are the primary domestic caregiver at home (Campion and Shrum, 2004). The maternal wall is supplemented by the 'glass ceiling,' whereby a woman's performance tends to be more closely scrutinized than that of men, obliging women to work harder to prove themselves (Williams, 2004).

Women should not have to choose between two sacrifices

Women who do take leave for family reasons sacrifice progress in their careers, particularly in the research environment. When they return, they are either considered as having fallen behind in their career, compared to their peers, or in need of retraining in their field. Changing the current system of performance appraisal and reward to accommodate women's child-bearing years without obliging them to sacrifice their careers is the single most important step towards rectifying this imbalance.

In many countries, the work–life balance and family responsibilities are also emerging concerns for men (CMPWASE, 2007).

16. See: www.nobelprize.org/nobel_prizes/lists/women.html

Women have less access to research funding

Performance evaluation includes productivity measurements, such as the number of authored publications and patents, the citation rate of these papers and the amount of research funding obtained. In science, productivity is measured in terms of research, teaching and service (such as committee membership), with research tending to carry the most weight. Publication in high-prestige journals or conference proceedings ranks highest and teaching lowest. Studies in the USA indicate that female faculty tend to focus on teaching and service more than research, particularly in terms of the number of authored publications. At the same time, young researchers are expected to spend 80–120 hours per week in the laboratory, putting women with children at an immediate disadvantage (CMPWASE, 2007).

Universally, the publication rate of female researchers is lower than that for men, although there are data gaps. South African women authored 25% of published articles in 2005, Korean women 15% in 2009 (Kim and Moon, 2011) and Iranian women about 13%, with a focus on chemistry, medical and social sciences (see Chapter 15). Recent research suggests that the main explanation for this trend lies in women's limited access to funding and generally lower status: women are less represented than men at prestigious universities and among senior faculty, the very positions where researchers publish the most (Ceci and Williams, 2011). For example, in East Africa in 2004, the lack of equal access to funding and interaction with regional and international collaborators decreased the likelihood of female researchers being published in prestigious international journals (Campion and Shrum, 2004).

If women in all countries are penalized when it comes to research funding, the same goes for patents. 'In all countries, across all sectors and in all fields, the percentage of women obtaining patents is … less than their male counterparts' (Rosser, 2009). Globally, patenting rates by women are highest in pharmaceutical fields (24.1%), followed by basic chemicals (12.5%), machine tools (2.3%) and energy machinery (1.9 %). In Europe, the share of patent applications made by women was around 8% in 2008. About 94% of US patents are owned by men (Frietsch *et al.,* 2008; Rosser, 2009). Research on this topic suggests that ability is not an issue. Rather, women scientists tend not to understand or show interest in the patenting process, or to focus on research with a social impact rather than on technical processes that can be patented (Rosser, 2009).

A persistent bias that women cannot do as well as men

The number of women who have been recognized as leaders by high-prestige societies or through awards remains low, despite some high-profile exceptions. Lack of recognition of women's achievements contributes to the misconception that women cannot do science or, at least, not as well as men. This gender bias can be conscious or unconscious. In one study, all faculty, both male and female, rated a male applicant for a laboratory position significantly higher than a female applicant. The participants in the study also selected a higher starting salary and offered more career mentoring to the male (Moss-Racusina *et al.,* 2012).

Science remains one of the few sectors where gender bias is common and considered acceptable by some. In June 2015, 72 year-old Nobel laureate Sir Tim Hunt criticized the presence of women in his laboratories, explaining that he considered them a distraction and overly emotional. Weeks later, Matt Taylor from the European Space Agency wore a shirt with a garish pin-up girl pattern when making a major announcement about the Rosetta Project space probe. After people expressed indignation via social media, both men made public apologies.

Pragmatic reasons to hire a woman

Companies and institutions are increasingly aware that a diverse labour force will improve their performance and enable them to reach more segments of their target customer or client base or relevant stakeholders. Diversity in research also expands the pool of talented researchers, bringing in fresh perspectives, talent and creativity. Google recently recognized its own need for a more diverse labour force for the very reasons cited above. '[Google] is not where we want to be when it comes to diversity', according to Laszlo Bock, Google's senior vice president for people operations (Miller, 2014). Women make up just 17% of Google's technicians and one in four of its top executives. Ethnic diversity is also low, with 1% Afro-American, 2% Hispanic and 34% Asian employees in the USA.

Conversely, the attrition of talented women from the science system represents a serious loss in investment. Many governments are setting targets for raising the share of GDP spent on research and development (R&D), 60% of which goes on human resources. If governments are serious about reaching their targets, many more researchers will need to be hired. Widening the pool of talented researchers will increase the rate of progress towards reaching government targets and ensure that the money spent on educating half of these potential researchers does not go down the drain (Sheehan and Wyckoff, 2003). Many countries recognize that a greater gender balance and diversity in science and research would increase their competitiveness in a globalized economy. Malaysia and the United Arab Emirates have both instituted policies fostering greater diversity in the labour force, including women, and are seeing positive results. Science in both the public and private sectors in the Republic of Korea, on the other hand, is characterized by a strong, persistent gender imbalance in scientific research and industry.

The scientific endeavour itself suffers when women do not participate equally in research and industry (Figure 3.4). Feminist critiques of science have shown that the way in which experiments are set up, the way research questions are defined and the type of conclusions drawn from research findings are all influenced by gender (Rosser, 2009). How many inventions have never seen the light of day as a result of women's absence from research? What important considerations from a gender perspective are being overlooked? It was not until 1993 that aspirin was found to have a totally different effect on heart disease in men and women, reducing the chances of a heart attack in men but not of a stroke, while reducing the risk of a stroke in women but not of a heart attack (Kaiser, 2005).

Simply and perhaps most importantly, women should have the same opportunities as men to understand and benefit from the fruits of research, contribute to society, earn a living and choose a fulfilling profession. The United Nations has made a strong commitment to gender mainstreaming – be it in research, legislation, policy development or in activities on the ground – as part of its mandate to ensure that both women and men are in a position to influence, participate in and benefit from development efforts.[17] UNESCO has embraced this commitment by establishing gender equality as one of its two global priorities, along with Africa. UNESCO considers gender equality not only to be a fundamental human right but also a building block of sustainable, peaceful societies. This commitment includes promoting a greater participation by women in science, technology, innovation and research. This is why the UNESCO Institute of Statistics systematically collects gender-disaggregated data, which it then makes freely available to the public through interactive websites (Box 3.1).

Moving forward: policies for gender equality

Among industrialized countries, the EU and the USA have both adopted strong policies and funding incentives to foster the participation of women in science. Horizon 2020, the EU programme funding research and innovation from 2014 to 2020, treats gender as a cross-cutting issue; it implements a strategy to promote gender equality in research and innovation, including gender balance in research teams, gender balance on expert panels and advisory groups and the integration of gender aspects in the content of research and innovation projects to improve scientific quality and societal relevance.

In the USA, the Science and Engineering Equal Opportunity Act of 1980 mandates equal opportunities for men and women in education, training and employment in scientific and technical fields. As a result, the National Science Foundation supports and undertakes research, data collection and other activities to assess, measure and increase the participation of women in science, technology, engineering and mathematics. One of its programmes, ADVANCE, offers fellowships and awards for institutional transformation and leadership to increase the participation of women in research and reward excellence.[18]

A number of low- and middle-income countries have also developed policies in one or more areas to integrate women and gender issues more effectively into science. In 2003, the Department of Science and Technology of South Africa convened an advisory body to advise it on priorities, key directions and successful strategies for increasing the participation of women in science. This agenda is set in a national context of gender equality and driven by a national 'gender machinery' consisting of a group of co-ordinated structures within and beyond government: SET4W is part of the National Advisory Council on Innovation, a national body appointed by the Minister of Science and Technology to advise him or her, as well as the Department of Science and Technology and the National Research Foundation. Set4W provides advice on policy issues at the nexus of science, technology, innovation and gender (ASSAf, 2011).

The Brazilian approach combines policy with robust mechanisms for implementation. The high level of female representation in various sectors is a result of strong support for gender equality. Women's rights both inside and outside the home have been strengthened and the participation of women and girls in education and employment has been encouraged. This strategy has proven highly successful,

17. See: ww.un.org/womenwatch/osagi/gendermainstreaming.htm

18. www.nsf.gov/crssprgm/advance/

Box 3.1: Explore the data

Women in Science is an interactive data tool developed by the UNESCO Institute for Statistics. It lets you explore and visualize gender gaps in the pipeline leading to a research career: from the decision to enrol in a doctorate degree course to the scientific fields that women pursue and the sectors in which they work. By presenting both regional and country-level data, this product provides a global perspective on the gender gap in research, with an emphasis on science, technology, engineering and mathematics. Available in English, French and Spanish, it may be accessed at http://on.unesco.org/1n3pTcO.

In addition, the eAtlas of Research and Experimental Development lets you explore and export interactive maps, charts and ranking tables for more than 75 indicators on the human and financial resources devoted to R&D. Go to: http://on.unesco.org/RD-map.

Both products are automatically updated with the latest data. They can be easily embedded on websites, blogs and social media sites.

Source: UNESCO Institute for Statistics

gender parity having been attained in the national labour force. The government has also increased investment in R&D and programmes fostering science and engineering education for all (see Chapter 7). The availability of scholarships, coupled with transparency in competitions at graduate levels, has encouraged many women to enter science (Abreu, 2011).

Systematic collection of gender-disaggregated data

To support policy implementation and research, both the EU and USA systematically collect gender-disaggregated data. In the USA, the National Science Foundation is also required to prepare and submit reports to the US Congress (parliament) on policy and programming to promote minority participation in these fields and to eliminate discrimination in science and engineering by sex, race, ethnic group or discipline. Since 2005, Eurostat has been given a mandate to collect gender-disaggregated data by qualification, sector, field of science, age, citizenship, economic activity and employment in the business enterprise sector. South Africa and Brazil also collect comprehensive gender-disaggregated data.

Creating a level playing field in the workplace

Extensive research has been undertaken in Europe and the USA to identify models which ensure that countries can benefit from the talent, creativity and accomplishments of both sexes when it comes to science and engineering. A number of approaches can be taken to promote an equitable and diverse workplace (CMPWASE, 2007; EU, 2013):

- Address unconscious bias in hiring and performance assessment;
- Implement sexual harassment training and policies and ensure redress for victims of harassment;
- Address the institutional culture and processes that penalize a woman's family life: performance evaluation in relation to hiring, tenure and promotion needs to accept flexible publication and research schedules to ensure that women (and men) who interrupt their career during their child-bearing years will not jeopardize their future career;
- Institutional gender policies need to be supported at the highest levels of governance;
- Decision-making and selection processes should be open, transparent and accountable. All professional, grant, selection and hiring committees should reflect a balance between male and female members;
- Modernize human resources management and the work environment;
- Eliminate the gender pay gap, including the gender research funding gap;
- Make resources available to parents for retraining or re-entering the labour force; and
- Ensure that women and men can take advantage of travel, conference and funding opportunities equally.

UN Women and the UN Global Compact have joined forces to produce the Women's Empowerment Principles, a set of guidelines for business on how to empower women in the workplace, marketplace and community. These guidelines are intended to promote best practice by outlining the gender dimensions of corporate responsibility and the role of business in sustainable development; the guidelines thus apply both to businesses and to governments in their interactions with the business world. Companies are asked to use a set of seven principles to assess company policies and programmes; develop an action plan for integrating gender considerations; communicate progress to stakeholders; use the Women's Empowerment Principles for guidance in reporting; raise awareness about the Women's Empowerment Principles and promote their implementation; and share good practices and lessons learned with others.

Box 3.2: **The CGIAR: advancing the careers of women in global research**

The Consultative Group on International Agricultural Research (CGIAR) established its Gender and Diversity programme in 1999 with a mandate to promote the recruitment, advancement and retention of women scientists and other professionals. A Gender Monitoring Framework was designed for the CGIAR in 2013 to monitor progress in addressing:

- what CGIAR has done in its own work place(s) to raise the share of women in senior positions and those seeking out CGIAR as an employer of choice; and
- progress in gender mainstreaming achieved throughout the CGIAR system, using such indicators as the number of male and female staff in key leadership positions, the integration of gender considerations into research priority-setting, implementation and evaluation and, lastly, the extent to which research budgets and expenditure are allocated with respect to gender.

In 2014, women made up 31% of the CGIAR leadership. The CGIAR Consortium has since hired a Senior Advisor on Gender and Research to advise centres on related issues in the workplace. Reports are also submitted to the CGIAR Fund Council every six months to monitor the performance of the Gender and Diversity programme.

Source: CGIAR (2015)

CONCLUSION

A need to 'fix the system'

Although more women are studying for degrees related to health, science and agriculture than before and there is even a gender imbalance in favour of women at the tertiary level overall, the sheer drop in female researchers to less than 30% globally indicates that serious barriers remain to the full participation of women in science and engineering. At the transition from master's to PhD level then, as they climb the rungs of the career ladder, a number of women are 'lost' to science.

Even women who embark on a career in science or engineering often leave their jobs for family reasons or change career paths more often than men. Recent research indicates that approaches to this problem need to change, an affirmation supported by the data. The approach of getting more women to study science and choose a scientific career needs replacing with an approach oriented towards 'fixing the system,' that is, addressing the points of attrition, barriers and culture that are causing women to abandon science.

The following steps, among others, can foster greater diversity in the scientific labour force:

Governments are encouraged to:

- collect data disaggregated by gender consistently in key sectors;
- implement policies that promote the participation of women in society and the labour force, as well as in science and innovation; and
- take steps to ensure that science and education systems are accessible, of a high quality and affordable.

Research, science and government institutions are encouraged to:

- commit to the equal representation of women in science, research and innovation management and decision-making;
- support a commitment to gender equality and diversity through funding, programming and the monitoring of progress; and
- introduce fellowships and grants to increase the representation of underrepresented groups.

Employers and governments are encouraged to:

- adopt open, transparent and competitive recruitment and advancement policies;
- adopt strategies to promote diversity in education and the workplace, including targets for the participation of different groups, financial support and access to employment opportunities; and
- ensure supplementary support for women in the form of training, access to finance and backing for entrepreneurship.

Gender equality is more than a question of justice or equity. Countries, businesses and institutions which create an enabling environment for women increase their innovative capacity and competitiveness. The scientific endeavour benefits from the creativity and vibrancy of the interaction of different perspectives and expertise. Gender equality will encourage new solutions and expand the scope of research. This should be considered a priority by all if the global community is serious about reaching the next set of development goals.

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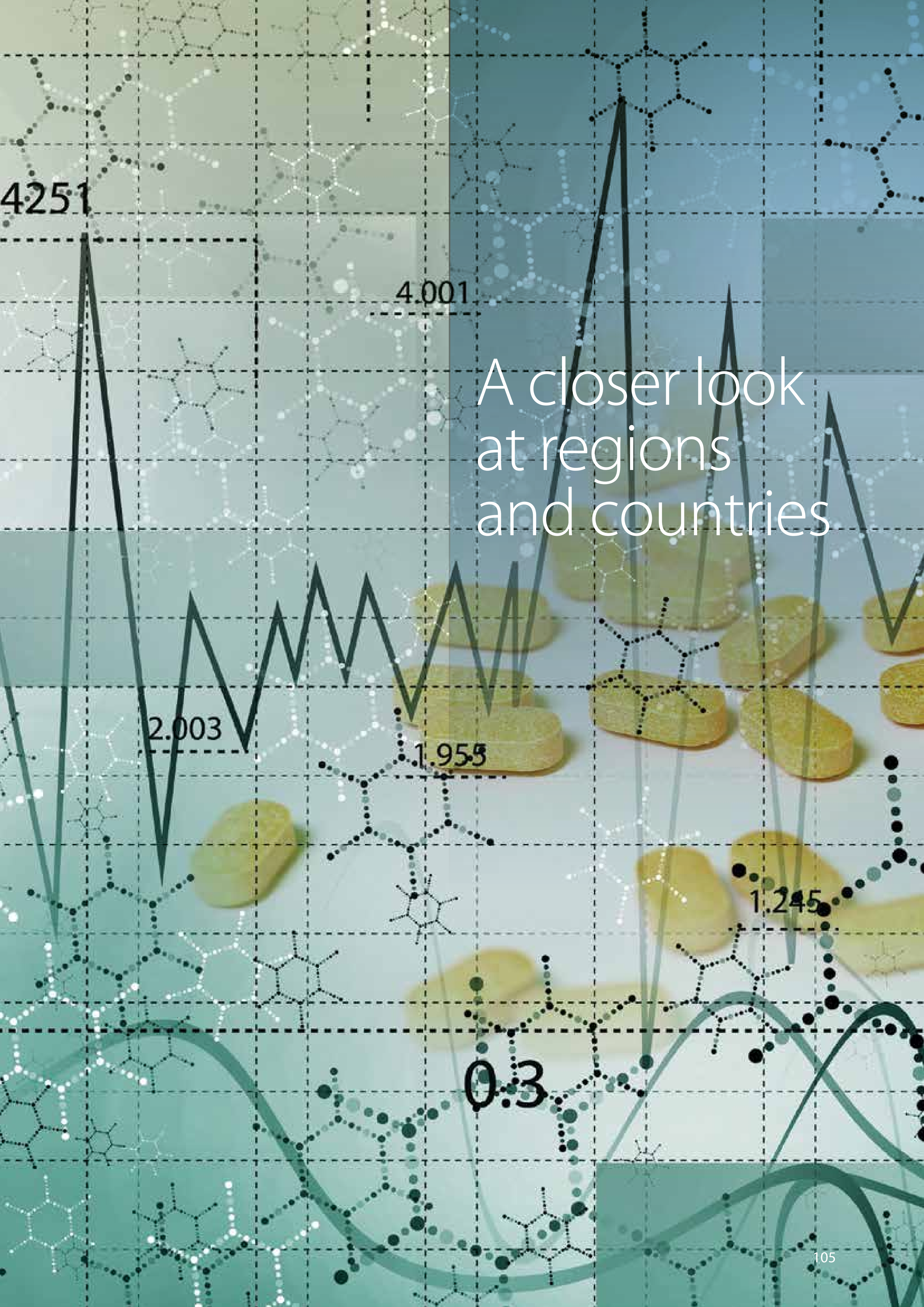


A closer look at regions and countries

Science powers commerce – but not only.

Paul Dufour

A truck driver gives *Hitchbot*, the talking, hitchhiking robot, a ride part of the way to its destination, during a Canadian experiment to test public attitudes towards robots.
Photo: © Norbert Guthier: www.guthier com

4 · Canada

Paul Dufour

INTRODUCTION

Priorities: job creation and balancing the books

When last we reviewed the Canadian science, technology and innovation (STI) scene in the *UNESCO Science Report 2010*, a federal Conservative government had been in power since 2006[1]. Since then, Canada has weathered the fiscal downturn fairly well, in part because of its sound financial banking services industry but also because the Canadian economy relied heavily on its endowment of energy sources and other natural resources, assets that are always in demand in the fast-paced emerging global environment.

When the shockwaves from the US financial crisis turned a healthy budget surplus of CAN$ 13.8 billion in 2006 into a budget deficit of CAN$ 5.8 billion two years later, the government reacted by adopting a stimulus package in January 2009. This package encouraged consumer spending and investment through tax breaks and other measures, in an attempt to reverse the downturn.

The package was costly (CAN$ 35 billion) and left the government deeper in debt: the deficit peaked at CAN$ 55.6 billion in 2009–2010. Balancing the budget by 2015 became the cornerstone of the government's multi-year *Economic Action Plan* (2010), which promised 'responsible fiscal management' to ensure 'ongoing economic growth and job creation over the longer term'. In 2014, the government projected that the deficit would fall to CAN$ 2.9 billion by 2014–2015, with a return to a budget surplus the following year. In 2015, the latter is very much in doubt. In order to meet its deficit target, the government sold its remaining shares in the General Motors bailout of 2009. However, as oil prices have plummeted since mid-2014, it is not clear what impact this will have on the overall fiscal health of the Canadian economy.

One of the government's key strategies has been to create jobs[2] by expanding trade. In his introduction to the *Global Markets Plan* adopted in 2013, the Minister of International Trade Ed Fast recalled that 'today, trade is equivalent to more than 60% of our annual GDP and one in five Canadian jobs is directly linked to exports'. The main goal of *Canada's Global Commerce Strategy* (2007) was to 'extend our reach to new emerging markets'; by 2014, Canada had concluded free trade agreements with no fewer than 37 countries, including a major deal with the European Union (EU). Its successor, the *Global Markets Action Plan* (2013), fine-tuned this strategy by eliminating trade barriers and cutting red tape to boost trade with established and emerging markets[3] considered to hold the greatest promise for Canadian business.

Concerns about public interest science, business R&D and education

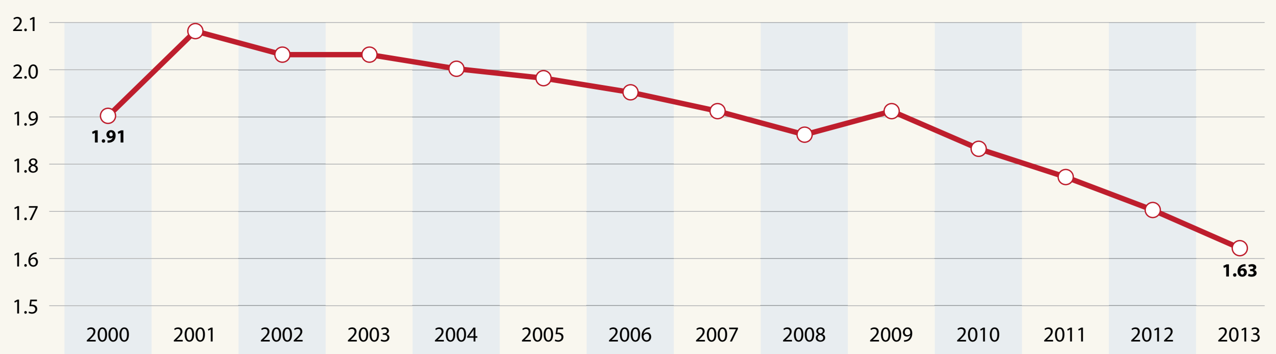
The government's incremental approach to policy-making over the past decade has translated into a lack of bold moves to stimulate funding for science and innovation. The organizational ecology of science and technology (S&T) has undergone some change, with a growing focus on economic returns from investment in knowledge. In parallel, gross domestic expenditure on research and development (GERD) as a percentage of GDP has been dropping (Figure 4.1).

1. The Conservative Party came to power in the 2006 federal election. Initially, a minority government, it won its first majority government in the 2011 elections. Stephen Harper has been prime minister since 2006.

2. The unemployment rate has remained steady since 2000, at between 6% and 8% of the active population. In April 2015, for instance, 6.8% of Canadians were unemployed (Statistics Canada).

3. The following emerging markets are considered as being priorities for foreign direct investment, technology and talent and/or part of regional trading platforms: Brazil, China (including Hong Kong), Chile, Colombia, Indonesia, India, Israel, Malaysia, Mexico, Peru, the Philippines, Republic of Korea, Saudi Arabia, Singapore, South Africa, Thailand, Turkey, United Arab Emirates and Viet Nam

Figure 4.1: **GERD/GDP ratio in Canada, 2000–2013 (%)**



Source: Statistics Canada

Some challenges addressed in the *UNESCO Science Report 2010* have not been tackled and others are emerging. Two important weaknesses persist. The first is the lacunae of aggressive private-sector commitment to innovation. Canada continues to slide in overall global competitiveness rankings, in large part because of its underinvestment in innovation. According to the latest *World Competitiveness Report* (WEF, 2014), Canada's private-sector spending on R&D ranks just 27th in the world, compared to 19th for university–industry collaboration on R&D. For government procurement of advanced technology – a key driver of technological innovation in the world's most competitive economies –, Canada ranks 48th.

The second weakness concerns the lack of a strong national agenda for talent and science education when it comes to orchestrating effective skills, education and training for the 21st century. With a number of indicators suggesting a decline in the prestige of higher education in Canada, this is becoming an urgent issue.

A third vulnerability has emerged since the release of the *UNESCO Science Report 2010*. Since the adoption of the multi-year austerity budget in 2010, the government has been downsizing science agencies and departments. Recent surveys of Canada's scientific community reveal acute concerns at the impact of cuts on public interest science and basic science, as well as on Canada's international standing.

The present chapter will focus largely on analysing these three challenges. To set the scene, we shall begin by examining what the data tell us.

TRENDS IN R&D

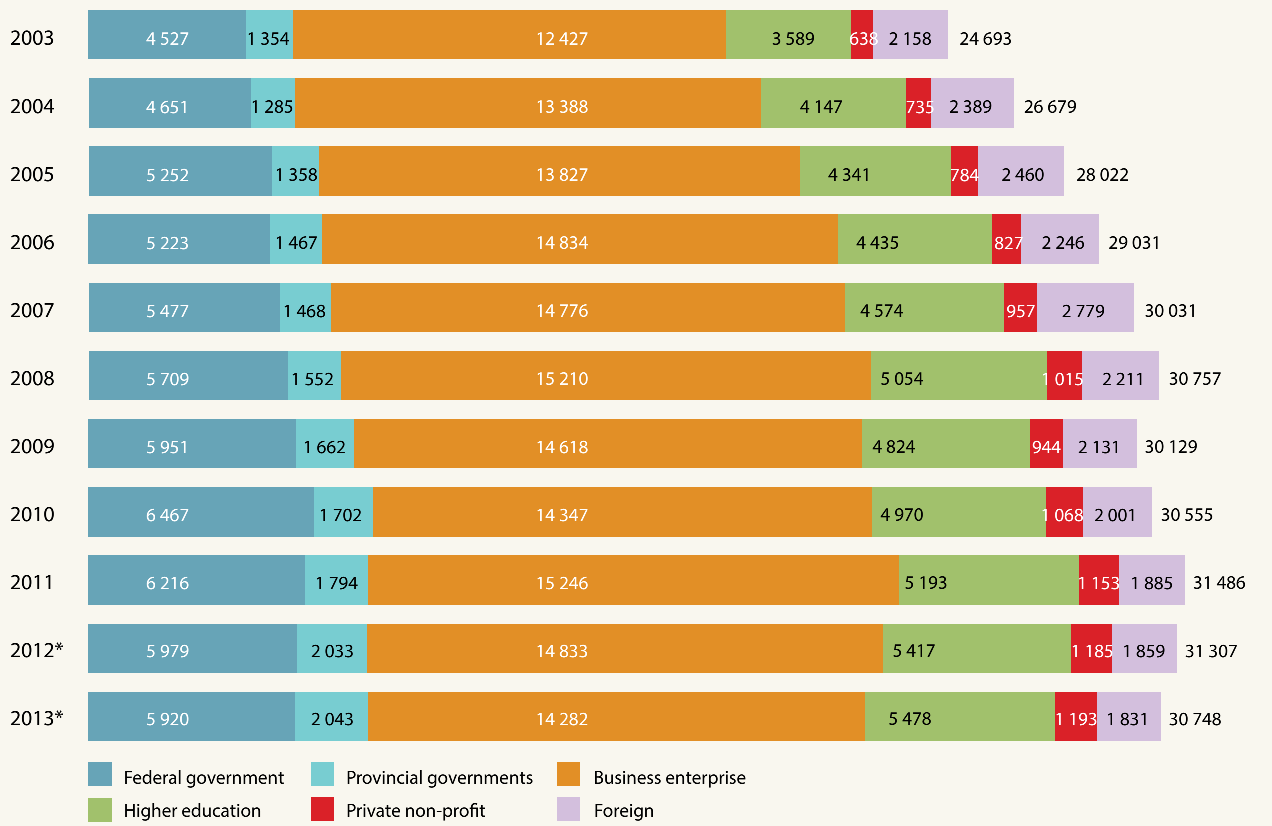
Canada's R&D effort at its lowest level for a decade

At 1.63%, Canada's GERD/GDP ratio sank to its lowest ebb in a decade in 2013. This is because the rise in GERD since 2004 (15.2%) had failed to keep pace with GDP (+42.9%). Between 1997 and 2009, R&D had been buoyed by continuous budget surpluses then by the federal stimulus package in 2009. GERD had even peaked in 2001 at 2.09% of GDP (Figure 4.1).

Between 2010 and 2013, the trend went into reverse. Federal in-house R&D became a casualty of the government's determination to balance the budget through its *Economic Action Plan* (2010). Government funding of R&D sagged by

Figure 4.2: **GERD in Canada by funding sector, 2003–2013**

In CAN$ millions



Source: Statistics Canada

* preliminary data

just over CAN$ 600 million, or over 10%, and continues to decline, with projected spending in 2013 of CAN$ 5.8 billion (Figure 4.2). Some infrastructure projects are nevertheless being pursued for specialized facilities. For instance, a global High Arctic Research Station is being established in Canada's high north, the participation of Canada in the Thirty Metre Telescope has received a boost of CAN$ 243.5 million over ten years and Canada's National Science and Technology Museum will be closed until 2017 for refurbishment.

The end to stimulus spending coincided with a 10.6% increase in GDP between 2008 and 2012; it is the combination of these two factors which drove the GERD/GDP ratio down to 1.63% in 2013.

A worrying slump in industrial R&D

It is a characteristic of Canadian science that the federal government agencies fund about one-tenth and universities four-tenths of all R&D. Much of the country's R&D effort relies on the dynamism of the business enterprise sector, which funds and performs the other half. The slump in industrial R&D in recent years is thus a worrying trend: in 2013, business-financed R&D accounted for 46.4% of overall spending, compared to 51.2% in 2006. Over the same period, foreign funding sources also shrank from 7.7% to 6.0% of the total, according to the UNESCO Institute for Statistics.

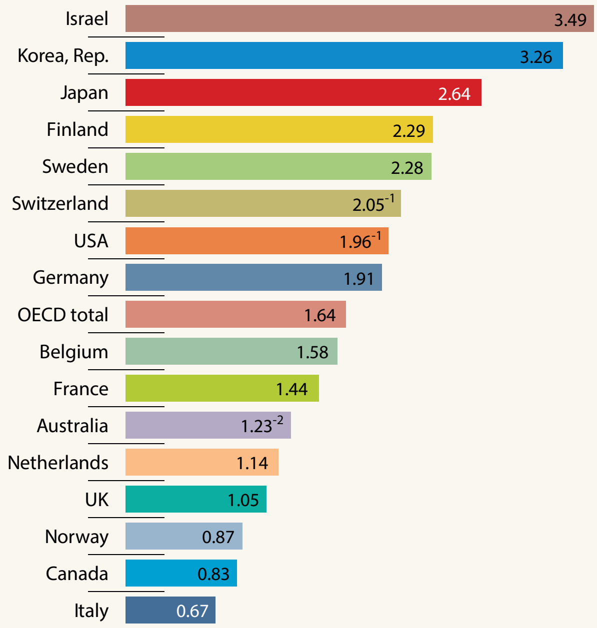
A 6.9% decline in federal funding of R&D is the main contributor to a stagnant year for Canadian R&D in 2014, according to the latest data from Statistics Canada. The agency released a brief report in January 2015 which projected

Table 4.1: **GERD intentions in Canada by performing sector and source of funds, 2013 and 2014 (%)**

	2013	2014	
Research and development spending intentions	CAN$ millions		% change
Total, performing sector	**30 748**	**30 572**	**-0.6**
Business enterprises	15 535	15 401	-0.9
Higher education	12 237	12 360	1.0
Federal government	2 475	2 305	-6.9
Provincial government and provincial research organizations	339	338	-0.3
Private non-profit	161	169	5.0
Total, funding sector	**30 748**	**30 572**	**-0.6**
Business enterprises	14 282	14 119	-1.1
Federal government	5 920	5 806	-1.9
Higher education	5 478	5 533	1.0
Provincial government and provincial research organizations	2 043	2 066	1.1
Foreign	1 831	1 842	0.6
Private non-profit	1 193	1 207	1.2

Note: Components may not add up to totals because of rounding.
Source: Statistics Canada, January 2015

Figure 4.3: **Business expenditure on R&D in Canada and other OECD countries as a share of GDP, 2013 or closest year (%)**



-n = data are for *n* years before reference year

Source: UNESCO Institute for Statistics, August 2015

CAN$ 30.6 billion in R&D spending in 2014, down marginally from CAN$ 30.7 billion the previous year (Table 4.1).

This situation contrasts with that of other members of the Organisation for Economic Co-operation and Development (OECD), where the GERD/GDP ratio has recovered to pre-2008 levels. Among the G7 countries, only Canada registered declines between 2008 and 2012. Business expenditure on R&D (BERD) tells a similar story (Figure 4.3). Canada's BERD/GDP ratio peaked at 1.3% in 2001 before falling to 0.8% by 2013. In the OECD, BERD has increased from 1.4% on average in 2004 to 1.6% in 2013. Sectors that have experienced an erosion in R&D spending in Canada include pharmaceuticals, chemicals, primary metals and fabricated metals.

The cutback in industrial R&D spending has also taken its toll on the number of personnel engaged in R&D. Between 2008 and 2012, their number dropped from 172 744 to 132 156, representing a 23.5% decline in industrial R&D jobs. According to the most recent analysis by Statistics Canada, the number of R&D personnel in industry declined by 13 440 (9.2%) between 2011 and 2012, the second largest drop since 2008–2009 when 17 560 jobs were shed (Table 4.2).

Industry has not been the only sector to experience job losses, according to the latest data from Statistics Canada. There were fewer R&D personnel of all types in the federal and provincial governments in 2012 (Table 4.2).

Table 4.2: **R&D personnel in Canada by sector, 2008–2012**

Sector	2008	2009	2010	2011	2012
Federal government	16 270	17 280	17 080	16 960	16 290
researchers	7 320	7 670	8 010	7 850	7 870
technicians	4 700	5 170	4 900	4 760	4 490
support staff	4 250	4 440	4 170	4 350	3 930
Provincial governments	2 970	2 880	2 800	2 780	2 780
researchers	1 550	1 500	1 600	1 600	1 620
technicians	890	880	770	750	750
support staff	530	500	430	420	420
Business	172 740	155 180	144 270	145 600	132 160
researchers	98 390	93 360	94 530	97 030	88 960
technicians	52 080	47 190	38 570	39 290	32 950
support staff	22 280	14 630	11 180	9 280	10 240
Higher education	62 480	60 180	67 590	70 010	71 320
researchers	49 450	47 350	53 970	56 090	57 510
technicians	6 790	6 680	7 150	7 310	7 250
support staff	6 240	6 150	6 470	6 610	6 550
Private non-profit	2 190	1 240	1 300	1 240	1 390
researchers	500	340	530	520	590
technicians	900	470	540	500	510
support staff	790	430	230	220	290
Total	**256 650**	**236 760**	**233 060**	**236 590**	**223 930**
researchers	157 200	150 220	158 660	163 090	156 550
technicians	65 350	63 380	51 930	52 620	45 950
support staff	34 090	26 150	22 470	20 880	21 430

Source: Statistics Canada, CANSIM table 358-0159; *Research Money*, 22 December 2014

POLICY ISSUES IN INDUSTRIAL R&D

Weak business innovation translates into poor productivity growth

The perennial weakness of Canada's innovation performance by the private sector remains a major challenge. A synthesis report from the Council of Canadian Academies makes for depressing reading (CCA, 2013a). This document summarizes the main findings of seven different reports, from which two main conclusions emerge: Canadian academic research, overall, is relatively strong and well-regarded internationally. Canadian business innovation, by contrast, is weak by international standards; this is the primary cause of Canada's poor productivity growth.

The report asks (CCA, 2013a):

> *How has Canada's economy sustained relative prosperity, despite weak innovation and correspondingly feeble productivity growth? The answer is that Canadian firms have been as innovative as they have needed to be. Until the early 2000s, their competitiveness was supported by an ample labour supply and a favourable exchange rate, which made productivity growth less urgent. Since then, the boom in commodity prices has supported Canadian incomes in the aggregate.*

The report notes that Canada's fundamental challenge will be to transform its commodity-based economy into an economy capable of providing a larger number of markets with a greater variety of goods and services, where firms must compete primarily through product and marketing innovation. As more Canadian firms develop strategies that focus on innovation out of sheer necessity, they will create a much more powerful 'business pull' on Canada's strong S&T capacity.

Indeed, a second report by the Council of Canadian Academies on *The State of Industrial R&D in Canada* has concluded that Canadian industrial R&D remains weak for a host of complex, often poorly understood reasons, although four key industries display considerable strength (CCA, 2013b):

- aerospace products and parts manufacturing;
- information and communication technologies (ICTs);
- oil and gas extraction; and
- pharmaceutical drug manufacturing.

The panel's report found that, whereas R&D activity is extensive and spread across a wide range of industries, the relationship between R&D and S&T is asymmetrical. When examined by geographical location, the panel found that Canada's strengths in industrial R&D were clustered in certain parts of the country. Ontario and Quebec are dominant in aerospace; the majority of the ICT industry is found in Ontario, Quebec and British Columbia; oil and gas are most prevalent in British Columbia and Alberta; and pharmaceuticals are most often located in Ontario, Quebec and British Columbia.

The report goes a step further and examines the alignment of strengths in industrial R&D with strengths in S&T and economics (Figure 4.4). It points out that, whereas there is some congruence between these areas, there is a significant lack of alignment that is not fully understood (CCA, 2013b):

> *With Canada's strong post-secondary education system and a foundation of world-class university research, the underpinnings for robust investment in industrial R&D exist. But attempting to connect such scientific strength and industrial R&D in a direct, linear relationship is overly simplistic, particularly as the R&D-intensive industries [count] for a smaller part of the Canadian economy than of other advanced economies.*

Figure 4.4: **Canada's strengths in S&T, industrial R&D and economics**

SCIENCE & TECHNOLOGY STRENGTHS

- Clinical medicine
- Historical studies
- Information & communication technologies
- Physics & astronomy
- Psychology & cognitive science
- Visual & performing arts

STRENGTHS IN INDUSTRIAL R&D

- Aerospace products & parts manufacturing
- ICTs
- Oil & gas extraction
- Pharmaceutical & drug manufacturing

ECONOMIC STRENGTHS

- Aerospace
- Oil & gas extraction
- Construction
- Forestry
- Financial, insurance & real estate
- Retail & wholesale trade

Source: adapted from CCA (2013b)

How best to incite private investment in high-potential companies?

Along with some of the provinces, the federal government has been experimenting with different mechanisms to help reshape the business culture in this area. These have had limited success. For example, in January 2013, the government announced its *Venture Capital Action Plan*, a strategy for deploying CAN$ 400 million in new capital over the next 7–10 years to leverage private sector-led investment in the form of venture capital funds.

Within this *Action Plan*, the government allocated CAN$ 60 million in 2013 over five years, with an additional CAN$ 40 million in 2014, to help outstanding incubator and accelerator organizations expand their services to worthy entrepreneurs. The Canada Accelerator and Incubator Program (CAIP[4]) subsequently made a call for research proposals on 23 September 2013 which attracted close to 100 applicants. CAIP is delivered by the National Research Council's Industrial Research Assistance Program, which evaluated these proposals on the basis of strict eligibility and selection criteria, including:

- the extent to which the project would encourage the growth of early-stage firms that represent superior investment opportunities;
- the potential of the project to develop entrepreneurial networks with other important firms and organizations, in order to provide entrepreneurs with a broader range of specialized services;
- the ability of the organization to demonstrate matching resources, either financial or in-kind (i.e. mentoring resources, administrative support) for the proposed activities; and
- a credible demonstration that the proposed activities would be incremental to existing operations.

An 'unnecessarily complicated' funding system

The private sector's reluctance to invest in high-potential companies has been a subject for debate in recent years. When Tom Jenkins submitted his panel's review of federal support for R&D to the Minister of State for Science and Technology in October 2011, he observed that, 'relative to the size of the Canadian economy, government support for business R&D in Canada is among the most generous in the world, yet we're near the bottom of the pack when it comes to seeing business R&D investment…What we found was a funding system that is unnecessarily complicated and confusing to navigate' (Jenkins *et al*., 2011). One of the panel's key recommendations was to create an Industrial Research and Innovation Council to deliver the federal government's 60 business innovation programmes – spread over 17 departments at the time. The government has not heeded this advice.

The *Venture Capital Action Plan* received mixed reviews, with some questioning the wisdom of using taxpayer money to nurture venture capital funds when this role fell naturally to the private sector.

In the longer-term, any attempt to develop more evidence on what works for Canada's unique knowledge economy will require a more thoughtful and co-ordinated approach than the *Venture Capital Action Plan*. Indeed, a report exploring ten policy criteria that could provide a more robust framework for innovation policy in Canada has been developed recently by scholars (University of Ottawa, 2013). Their report draws on evidence spanning 60 years to establish these ten criteria, which include:

- the policy should not prejudge the practical value of any category of knowledge;
- the policy should enable measurements that encompass the process of innovation (and not just the input and output); and
- the policy should favour 'open' knowledge regimes over 'proprietary' ones.

Science diplomacy to commercial ends

By 2014, half of Canada's scientific papers were co-authored by foreign partners, compared to an OECD average of 29.4% (Figure 4.5). Canada's collaboration rate with its closest partner, the USA, has been in decline: 38% of international papers were co-authored with US scientists in 2000 but only 25% in 2013, according to Science–Metrix.

In Canada, research partnerships and science diplomacy are increasingly being tied to trade and commercial opportunities. It is revealing that Canada's innovation network is managed by the Trade Commissioner Service at the Department of Foreign Affairs, Trade and Development, rather than being placed in the foreign service. This mega-department was created within Canada's *Economic Action Plan 2013* by amalgamating the Department of Foreign Affairs and International Trade and the Canadian International Development Agency, which had been in existence since 1968.

Two recent schemes illustrate the trend towards commercializing science diplomacy: the International Science and Technology Partnerships Canada (ISTPCanada) programme and the Canada–EUREKA partnership.

4. CAIP is providing support over a five-year period in the form of non-repayable contributions of up to CAN$ 5 million a year to a limited number of best-in-class accelerators and incubators.

Box 4.1: **Canada, China and Israel to share agro-incubator**

In September 2013, Canada, Israel and China agreed to establish a joint incubator for the development and commercialization of agricultural technologies derived from collaborative research.

The incubator has since been established in the Yangling Agricultural Hi-tech Industries Demonstration Zone, known as the 'agricultural epicentre of China'. The incubator will enable commercial firms from all three countries to engage in collaborative R&D while connecting them to market opportunities and accelerating the commercialization of emerging agro-technologies. In 2012, Canadian agricultural exports to China exceeded CAN$ 5 billion.

At the signing of the agreement, Dr Henri Rothschild, President and CEO of International Science and Technology Partnerships Canada and of the Canada–Israel Industrial R&D Foundation, observed that 'the resulting innovations will open up new Asian markets for collaborators, while enabling the development of the sustainable use of marginal lands, improved food quality and safety'.

Mr Michael Khoury, Consul for Economic Affairs at the Consulate General of Israel, welcomed the incubator as an opportunity for Israel 'to build on our collaboration with Canada and China to date and bring our multidisciplinary strengths to bear on this critical sector'.

Mr Wang Jun Quan, Deputy Director-General of the Administrative Committee of the Yangling Agricultural High-tech Industries Demonstration Zone, expressed pride at hosting the incubator and at facilitating collaboration with innovators from Canada and Israel. 'This centre will address the agricultural needs of Yangling and further establish this region as a global hub for agro-innovation', he said.

Source: ISTP Canada press release, 3 October 2013

ISTPCanada was launched in 2007 to 'connect Canadian innovators to global R&D partners, funding and markets' The programme was mandated by the Department of Foreign Affairs, Trade and Development to facilitate new R&D partnerships between Canadian companies or research institutions (including universities) and their counterparts from four key trading partners: Brazil, China, India and Israel. Three of Canada's ten provinces participated in the programme: Alberta, British Columbia and Ontario. Between 2007 and March 2012, ISTPCanada developed 24 early-stage partnerships with China, 16 with India, 5 with Brazil and a further 5 multilateral activities with all three countries. See Box 4.1 for an example. It also funded 29 bilateral R&D[5] projects: 17 with China, 8 with India and 4 with Brazil. ISTP covered up to 50% of the Canadian costs of approved joint research projects proposed by companies, universities/colleges and private research institutes. It claimed an almost four-fold leverage on every dollar invested in R&D projects; thus, it estimates that the CAN$ 10.9 million it invested in R&D projects between 2007 and 2012 generated CAN$ 37.9 million. ISTPCanada shut down in 2015, owing to lack of support from the responsible government department.[6]

The Canada–Eureka partnership gives Canadian companies greater access to European markets. Eureka is a pan-European intergovernmental initiative designed to support the competitiveness of European companies by fostering market-oriented R&D via international collaboration. The partnership agreement was signed on 22 June 2012 in Budapest (Hungary), the National Research Council having been designated Canada's National Project Coordinator Office for Eureka. At the signing, Gary Goodyear, then Minister of State for Science and Technology, said that 'our government's top priority is the economy – creating jobs, growth and long-term prosperity for Canadian workers, businesses and families. Through our participation in the Eureka Initiative, Canadian companies will be better positioned to access international markets and accelerate technology development leading to commercialization.'

Small innovative Canadian companies have rapidly taken advantage of Canada's status as an associate member of the Eureka network. By September 2014, 15 projects had been launched for the development of technologies ranging from virtual machining to water desalination. Valued at more than CAN$ 20 million, these market-driven industrial R&D projects have helped Canadian firms partner one-on-one, and in clusters, with companies from Europe but also from Israel and the Republic of Korea.

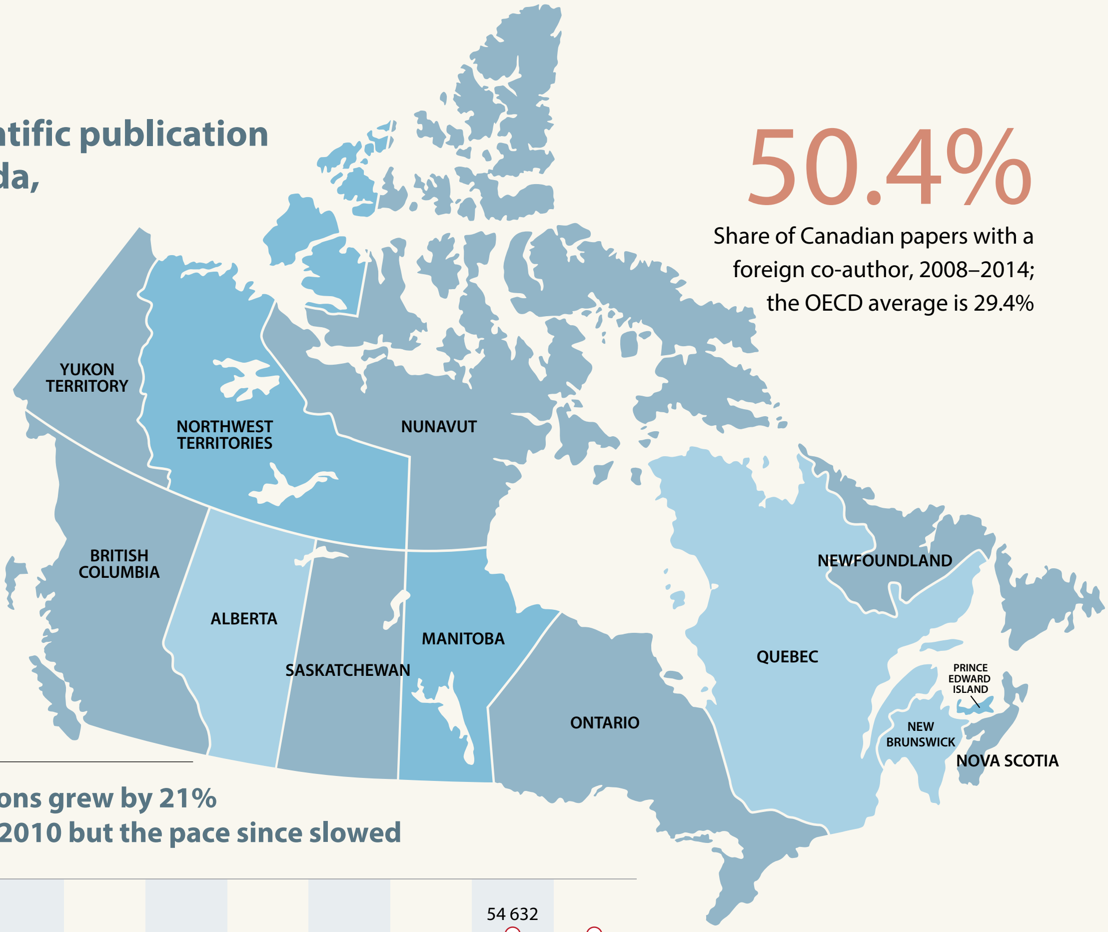
5. ISTPCanada's main partners are: in China, the Ministry of Science and Technology and China Association for International Exchange of Personnel; in India, the Global Innovation and Technology Alliance, Department of Science and Technology and Department of Biotechnology; and in Brazil: the São Paulo Research Foundation (FAPESP) and Minas Gerais Research Foundation (FAPEMIG).

6. In a premonitory interview published in the 10 February 2015 issue of *Research Money*, CEO Pierre Bilodeau commented that ISTPCanada's future looked uncertain, as money and time were running out to renew its mandate. After no further funding was forthcoming, ISTPCanada closed its office in April 2015.

Figure 4.5: **Scientific publication trends in Canada, 2005–2014**

1.25

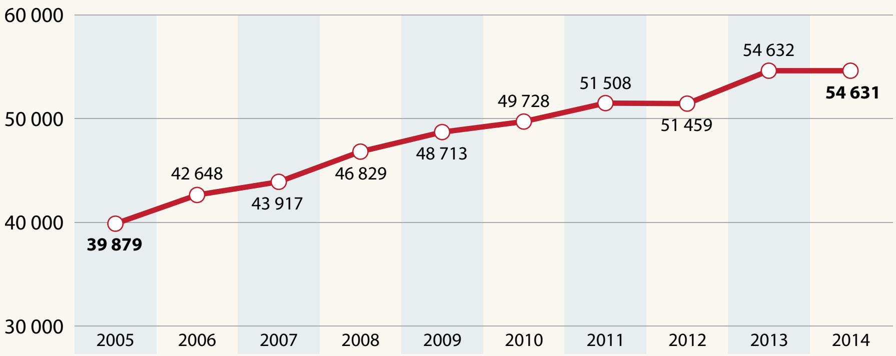
Average citation rate for Canadian publications, 2008–2012; the OECD average is 1.08



50.4%

Share of Canadian papers with a foreign co-author, 2008–2014; the OECD average is 29.4%

Canadian publications grew by 21% between 2005 and 2010 but the pace since slowed

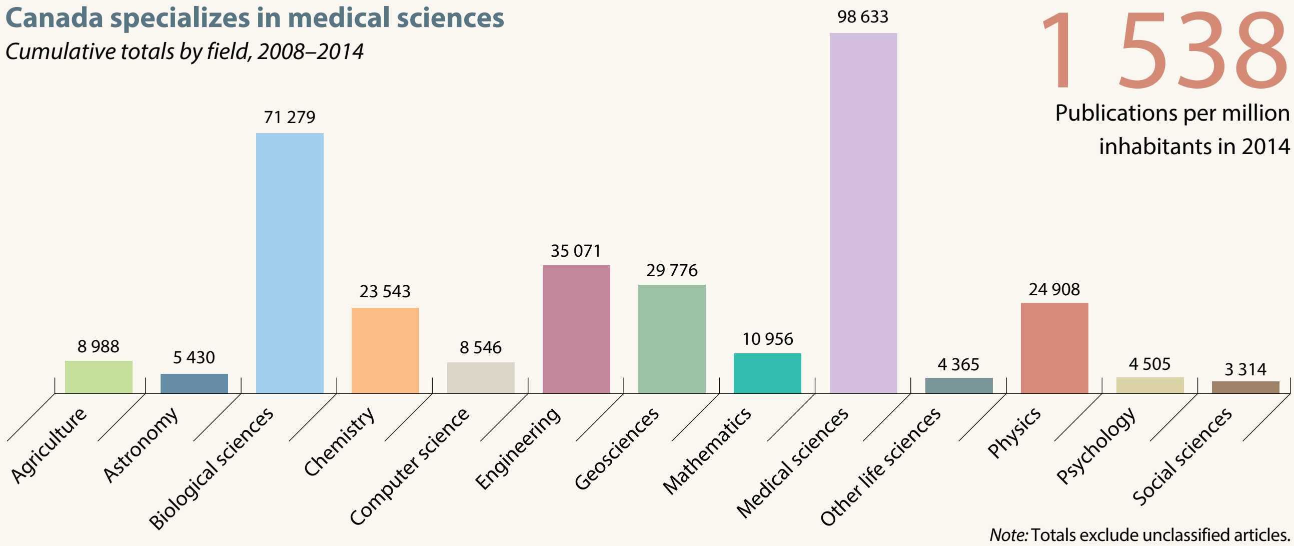


13.1%

Share of Canadian papers among 10% most-cited, 2008–2012; the OECD average is 11.2%;

Canada specializes in medical sciences

Cumulative totals by field, 2008–2014



1 538

Publications per million inhabitants in 2014

Note: Totals exclude unclassified articles.

Canada publishes most with US partners

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Canada	USA (85 069)	UK (25 879)	China (19 522)	Germany (19 244)	France (18 956)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

POLICY ISSUES IN PUBLIC INTEREST SCIENCE

Budget cuts: a threat to Canada's global knowledge brand?

Canada's global knowledge brand is at risk. Government science and federal scientists have become a target for cuts. This has led to a first-ever mobilization of different interests to parry this troubling trend. The budget cuts are partly a consequence of the government's austerity budget but they also reflect an ideological bent that is predisposed to downsizing the public service. In an unprecedented series of documented public cases, the Canadian government has been accused of eroding support for public good science and even of muzzling its own scientists (Turner, 2013).

The Professional Institute of the Public Service of Canada (PIPSC) has catalogued the concerns of government scientists through two surveys. The first of these drew over 4 000 responses (PIPSC, 2013). It found that that nearly three out of every four federal scientists (74%) surveyed believed the sharing of scientific findings had become too restricted in the past five years; nearly the same number (71%) believed political interference had compromised Canada's ability to develop policy, law and programmes based on scientific evidence. According to the survey, nearly half (48%) were aware of actual cases in which their department or agency had suppressed information, leading to incomplete, inaccurate or misleading impressions by the public, industry and/or other government officials.

The second survey[7] (PIPSC, 2014) argued that continued cuts within government science would further affect the government's ability to develop and implement evidence-based policies. *Vanishing Science: the Disappearance of Canadian Public Interest Science* observed that, 'between 2008 and 2013, a total of CAN$ 596 million (in constant 2007 dollars) has been cut from science and technology budgets at federal science-based departments and agencies and 2 141 full-time equivalent (FTE) positions have been eliminated' (PIPSC, 2014).

The report stated that these cuts 'have resulted in the loss of whole programmes, including the Environment Canada-funded National Roundtable on the Environment and the Economy – for 25 years the leading federal advisory panel on sustainable development –, the Hazardous Materials Information Review Commission and the Canadian Foundation for Climate and Atmospheric Sciences, as well as the Ocean Contaminants and Marine Toxicology Program' funded by the Department of Fisheries and Oceans (PIPSC, 2014). See Figure 4.6 and Table 4.3.

The report opined that 'the worst is yet to come. Between 2013 and 2016, a combined CAN$ 2.6 billion will be cut from 10 federal science-based departments and agencies[8] alone, including a projected 5 064 FTE positions' (PIPSC, 2014). According to the UNESCO Institute for Statistics, 9 490 FTE researchers were employed in the government sector in 2010 and a further 57 510 in the university sector.

The report expressed concern that a recent shift in budget priorities towards greater support for commercial ventures would be detrimental to basic science and public interest science. It cited a slated 'decrease in internal S&T funding[9] of CAN$ 162 million in 2013–2014, much of which is devoted to public health, public safety and the environment, compared to a CAN$ 68 million increase in support for commercial ventures' (PIPSC, 2014). The authors cited a public opinion poll by Environics in November 2013, in which 73% of respondents felt that the top priority for government scientific activity should be the protection of public health, safety and the environment (PIPSC, 2014).

The survey also reflected federal scientists' concerns that new departmental policies on intellectual property and obtaining permission to publish, as well as restrictive policies on travel to international conferences, were compromising Canada's international scientific collaboration (PIPSC, 2014). Indeed, a recent report assessing the media policies of federal science departments had this to say (Magnuson-Ford and Gibbs, 2014):

- Media policies in Canadian federal science departments were graded for openness of communication, protection against political interference, rights to free speech and protection for whistleblowers. Overwhelmingly, current policies do not support open communication between federal scientists and the media.
- Government media policies do not support open and timely communication between scientists and journalists, nor do they protect scientists' right to free speech.
- Government media policies do not protect against political interference in science communication.
- Over 85% of departments assessed (12 out of 14) received a grade of C or lower.

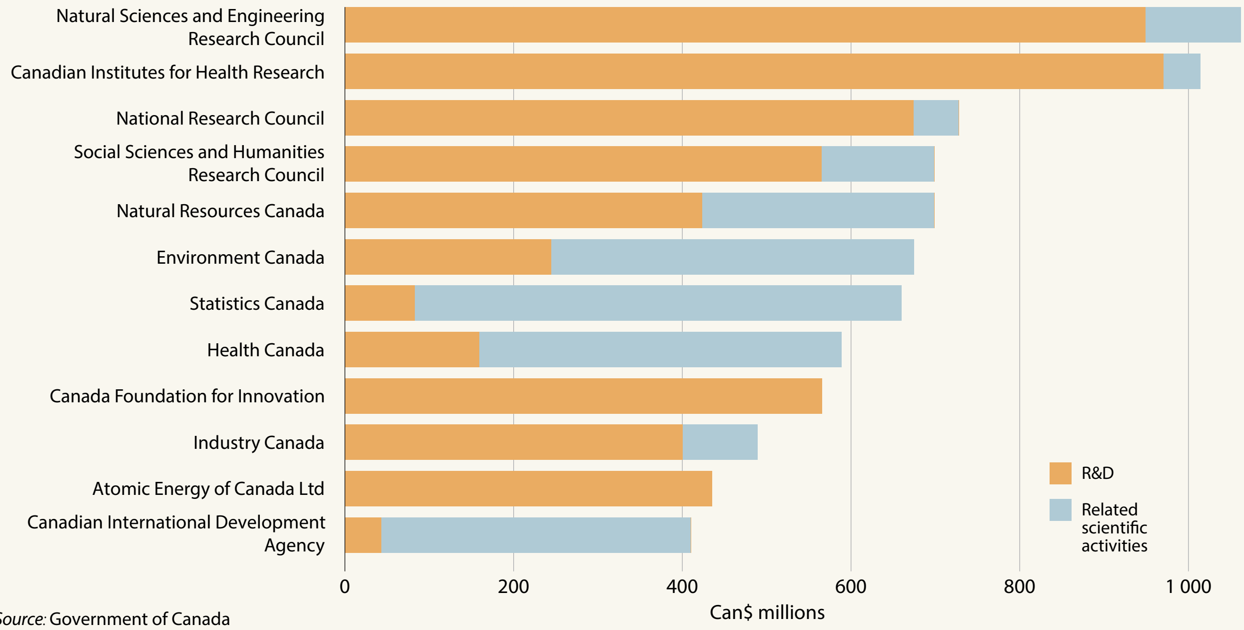
7. Invitations to participate in the online survey of federal scientists were sent to 15 398 PIPSC members – scientists, researchers and engineers – engaged in scientific work in over 40 federal departments and agencies. Of these, 4 069 (26%) responded (PIPSC, 2014).

8. Agriculture Canada, Canadian Food Inspection Agency, Canadian Space Agency, Environment Canada, Fisheries and Oceans Canada, Health Canada, Industry Canada, National Research Council, Natural Resources Canada , Public Health Agency of Canada

9. Internal science refers in the present chapter to R&D conducted within science-based departments and agencies.

Figure 4.6: **Major Canadian federal science departments and agencies**

by spending intentions for 2012



Source: Government of Canada

Table 4.3: **Canadian federal S&T spending by socio-economic objective, 2011–2013**

	2010/2011		2011/2012		2012/2013	
	Intramural	Extramural	Intramural	Extramural	Intramural	Extramural
	CAN$ millions					
Total	2 863	4 738	2 520	4 381	2 428	4 483
Exploration and exploitation of the Earth	90	77	86	92	59	93
Transport	64	56	60	58	51	49
Telecommunications	46	52	41	35	34	35
Other infrastructure and general planning of land use	44	76	42	37	35	43
Control and care of the environment	200	227	208	225	121	251
Protection and improvement of human health	280	1 432	264	1 415	240	1 512
Production, distribution and rational utilization of energy	717	269	545	257	561	161
Agriculture	360	179	354	154	409	1603
Fisheries	7	29	7	21	6	17
Forestry	70	90	69	58	70	54
Industrial production and technology	206	801	182	799	153	937
Social structures and relationships	156	222	125	243	141	264
Space exploration and exploitation	78	228	74	268	61	195
Non-oriented research	247	938	240	641	211	636
Other civil research	21	4	14	2	16	1
Defence	276	57	211	76	258	71

Note: Federal S&T spending is the sum of spending on R&D and related scientific activities. Non-programme (indirect) costs are excluded from intramural expenditure.

Source: Statistics Canada, August 2014

The federal government's response to the survey

As a partial response to these critiques, the federal government instituted a confidential examination of government science in mid-2014, led by an expert panel reporting to a group of deputy ministers responsible for science and research. The review was designed to provide an informed external perspective of government science and to come up with ideas and approaches for performing science differently in science-based departments and agencies to meet current and future challenges, while recognizing the nature and value of internal science. The expert panel offered its confidential advice in late 2014. It is unclear whether any action has been taken since on the basis of this report.

In October 2013, the federal government announced its intention to launch a revised federal STI strategy to refresh its seven-year old predecessor outlined by the prime minister in May 2007. A short discussion paper accompanied consultations in January 2014 which took place under the aegis of the former Minister of State for Science and Technology, Greg Rickford[10]. He was replaced in March 2014 by another junior science minister, Ed Holder, who has inherited the file.

In December 2014, Prime Minister Harper launched the revised strategy, entitled *Seizing Canada's Moment: Moving Forward in Science, Technology and Innovation*. This is essentially a progress report on what the government has undertaken since 2007. There is no earmarked funding for any of the fresh commitments.

The new strategy differs from its predecessor announced in 2007, in that innovation has been added as its central pillar (Table 4.4). *Seizing Canada's Moment* states that 'the 2014 *Strategy* puts innovation front and centre – in fostering business innovation, in building synergies with Canada's research capacities and in using its skilled and innovative workforce. It emphasizes the need for

10. In May 2014, Greg Rickford took over the joint portfolio of Minister of Natural Resources and Minister for the Federal Economic Development Initiative for Northern Ontario; the latter initiative had been entrusted to him in 2011.

Table 4.4: **Canada's federal priorities for 2007 and 2014**

Federal S&T strategy of 2007		**Federal S&T strategy of 2014**	
Priority area	*Subpriorities*	***Priority area***	*Subpriorities*
Environmental science and technologies	Water: health, energy, security Cleaner methods of extracting, processing and using hydrocarbon fuels, including reduced consumption of these fuels	**Environment and agriculture**	Water: health, energy, security Biotechnology Aquaculture Sustainable methods of accessing energy and mineral resources from unconventional sources Food and food systems Climate change research and technology Disaster mitigation
Natural resources and energy	Energy production in the oil sands Arctic: resource production, climate change adaptation, monitoring; Biofuels, fuel cells and nuclear energy	**Natural resources and energy**	Arctic: responsible development and monitoring Bio-energy, fuel cells and nuclear energy Bio-products Pipeline safety
Health and related life sciences and technologies	Regenerative medicine Neuroscience Health in an ageing population Biomedical engineering and medical technologies	**Health and life sciences**	Neuroscience and mental health Regenerative medicine Health in an ageing population Biomedical engineering and medical technologies
Information and communication technologies	New media, animation and games Wireless networks and services Broadband networks Telecom equipment	**Information and communication technologies**	New media, animation and games Communications networks and services Cybersecurity Advanced data management and analysis Machine-to-machine systems Quantum computing
		Advanced manufacturing	Automation (including robotics) Lightweight materials and technologies Additive manufacturing Quantum materials Nanotechnology Aerospace Automotive

Source: compiled by author

Chapter 4

businesses of all sizes to define and implement for themselves the science, technology and innovation they require to compete nationally and internationally.' Importantly, the strategy exhorts a sort of volunteerism by the business sector in reshaping its approach to investing in innovation. As such, it leaves the market to develop its own model.

In the meantime, public policy initiatives targeting STI are being put forward on several fronts, in the hope of effecting change by moral suasion. We shall briefly discuss some key topics currently under debate.

A desire to become a 'global energy superpower'

Early on in his mandate, Canada's current prime minister argued that Canada was aiming to become a global energy superpower.[11] Indeed, the government's preoccupation with finding new energy markets for oil and gas – especially the Alberta oil (tar) sands – has been remarkable but not without controversy both in Canada and abroad, as illustrated by Canada being named Fossil of the Year by environmentalists at several international meetings on climate change[12].

Not all sectors of the Canadian economy have fared as well as oil sands. Since 2002, there has been a remarkable increase in the real value of Canada's exports from the energy, metals and minerals, industrial and agricultural sectors, and a considerable drop in exports from the electronics, transportation, consumer goods and forestry sectors. In 2002, just under 13% of Canadian exports were energy-related products; by 2012, that proportion had grown to over 25%. From 1997 to 2012, oil's national share of commodity production value rose from 18% to 46%, nearly as much as the economic value generated from natural gas, forestry, metals and mining, agriculture and fishing combined. Many manufacturing companies, especially in the hard-hit automobile and consumer goods sectors, have retooled, in order to serve the resource sector, further contributing to an economy that is increasingly unbalanced and reliant on commodities; for over a decade now, R&D conducted by the private sector in the energy sector has been heavily concentrated in oil and gas.

Some attention has been paid to clean energy…

Leaving aside the use of conventional energy, some attention has also been paid to clean or renewable energy (Figure 4.7). In 2008, the federal government announced a green energy target: by 2020, 90% of all electricity generated in Canada was to come from non-greenhouse gas emitting sources. These sources include nuclear energy, clean coal, wind and hydroelectricity. By 2010, 75% of electricity was generated from these sources.

In the 2009 budget, the federal government created a Clean Energy Fund of more than CAN$ 600 million to fund various projects, with the majority of the money (CAN$ 466 million) going to carbon capture and storage projects. Canada also has programmes designed to support various forms of renewable energy, including wind energy, small hydropower, solar thermal, solar photovoltaic, marine energy, bio-energy and nuclear.

The Program of Energy Research and Development (PERD) is operated by Natural Resources Canada to advance key clean energy technologies that will contribute to a reduction of greenhouse gas emissions. PERD funds R&D performed by 13 federal departments and agencies, which are at liberty to collaborate with partners from industry, funding agencies, the university sector and associations.

Provincial governments have also played a strong role in energy production. Some have also invested in schemes to stimulate energy research. Quebec, for example, has a well-developed clean-tech cluster that is supported through various programmes and instruments. British Columbia has developed a bio-energy strategy designed to ensure that biofuel production meets 50% or more of the province's renewable fuel requirements by 2020; develop at least 10 community energy projects that convert local biomass into energy by 2020; and establish one of Canada's most comprehensive provincial biomass inventories of waste to energy opportunities. In the absence of federal leadership on climate change and energy, several provinces have also developed their own carbon pricing schemes.

In June 2014, Canada's Minister of Natural Resources co-chaired a national roundtable discussion on energy innovation in Canada, along with the Chair of Sustainable Development Technology Canada. The national roundtable was the sixth and final roundtable in a series of thematic roundtables held across the country since November 2013. Each event focused on a specific area of energy technology: distributed power generation; next-generation transportation; energy efficiency; long-term R&D opportunities and; unconventional oil and gas, including carbon capture and storage.

The roundtables focused largely on identifying barriers to accelerating energy innovation in Canada and how best to align efforts and enhance collaboration, in order to make Canada more competitive both domestically and abroad. A number of prevailing themes emerged from these discussions, including:

- building national leadership to promote innovation by engaging key players within governments, utilities, industry and academia;

11. Remarks by the Prime Minister of Canada, St Petersburg G8 Summit, 2006

12. In 2011, Canada became the first signatory to withdraw from the Kyoto Protocol to the United Nations Framework Convention on Climate Change, an agreement with binding targets adopted in 1997. The Kyoto Protocol expired in 2012.

- enhancing alignment, co-ordination and collaboration to maximize the impact of investment in innovation;
- providing certainty through policy measures;
- enhancing market access opportunities to foster a domestic market and support companies in demonstrating their technologies at home;
- greater information-sharing to break down barriers; and
- addressing energy literacy and consumer awareness through education.

The Government of Canada plans to use the discussions from these roundtables as a guide to identifying the best means of collaborating with private and public sector groups interested in promoting energy innovation in Canada.

Sustainable Development Technology Canada has been a key player in the energy debate. Created in 2001, this non-profit foundation finances and supports the development and demonstration of clean technologies. As of December 2013, 57 of Sustainable Development Technology Canada's more mature companies had received CAN$ 2.5 billion in follow-on financing. The foundation operates three funds:

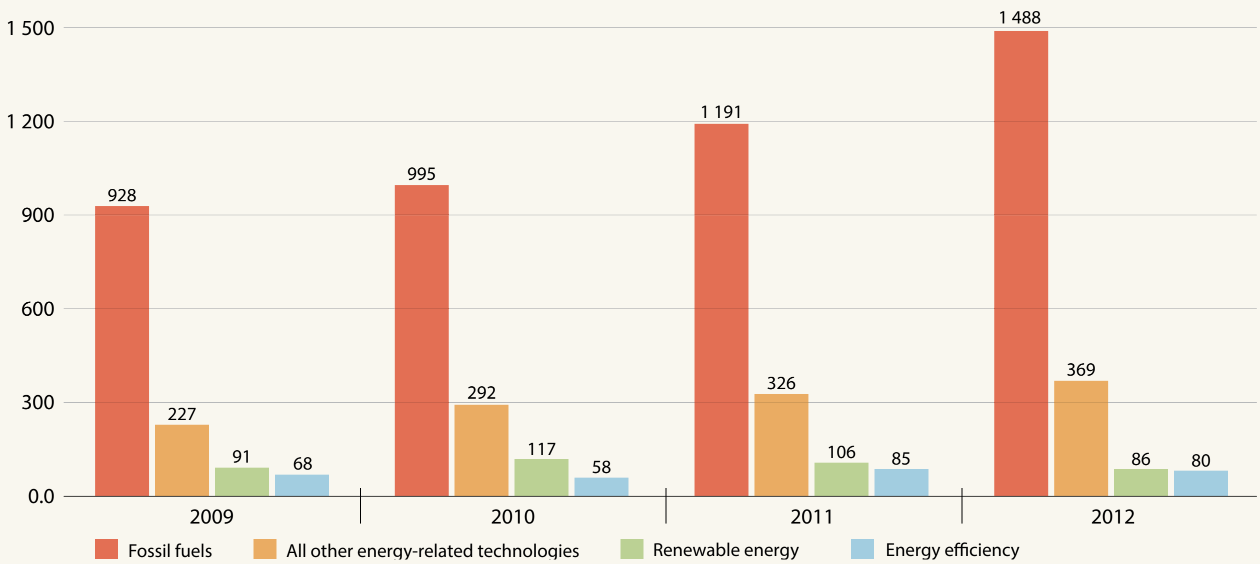
- the Sustainable Development Tech Fund has used CAN$ 684 million allocated by the federal government to support 269 projects that address climate change, air quality, clean water and clean soil;
- the NextGen Biofuels Fund supports the establishment of first-of-a-kind large demonstration-scale facilities for the production of next-generation renewable fuels.
- the Sustainable Development Natural Gas Fund seeks to support technologies in the residential sector: small-scale affordable combined heat and power units, ultra-efficient water heaters, technologies that improve the efficiency of residential heating and/or cooling.

Another group dabbling in renewable energy is the National Research Council (NRC), Canada's largest public research organization. In retooling its mandate into that of a research and technology organization over the past year, it has launched a series of so-called flagship programmes which focus on research for industrial markets. The NRC's Algal Carbon Conversion Flagship aims to provide Canadian industry with solutions to divert CO_2 emissions into algal biomass, which could then be processed into biofuels and other marketable products.

In 2013, the Harper government abolished its sole source of independent, external advice on sustainable development issues (including energy), the National Roundtable on the Environment and the Economy. This agency had a mandate to raise awareness among Canadians and their government of the challenges of sustainable development. In over 25 years, it had released dozens of reports on priority issues.

Other groups have produced numerous reports on clean energy. Among these is the Council of Canadian Academies, which responds to federal requests for scientific assessments required for public policy input (among other clients). A 2013 report addresses how new and existing technologies can be used to reduce the environmental footprint of oil (tar) sands development on air, water and land. In 2014, the Council of

Figure 4.7: **Canadian expenditure on energy-related industrial R&D, 2009–2012**
By area of technology, in millions of current CAN$



Source: Statistics Canada, August 2014

Canadian Academies also published a report written by an expert panel on the state of knowledge concerning the potential environmental impact from the exploration, extraction and development of Canada's shale gas resources (CCA, 2014a).[13]

Lastly, the Canadian Academy of Engineering has produced an analytical report of note on progress regarding various renewable energy options for Canada. Bowman and Albion (2010) concluded that a Canadian network had been established in bio-energy but could find no evidence of a plan to organize, fund and undertake demonstration projects for the most promising bioenergy applications. In respect of other Canadian energy opportunities, the academy noted that:

- advances in solar heating and power were now ready for wider application and that this could provide the basis for a rejuvenated Canadian manufacturing sector;
- wind power in Canada had expanded to close to 4 000 MW but progress towards grid integration, load forecasting, cost-effective electrical energy storage and the development of a Canadian design and fabrication capability remained limited;
- projects were in place to upgrade tar sands bitumen to higher value products but this would require major funding to move from the pilot stage to the field demonstration stage; and that
- hydrogen was an active research area that counted several demonstration projects related to British Columbia's Hydrogen Highway and an inter-university programme on the production of hydrogen through the thermo-chemical splitting of water.

13. In 2006, the CCA had been asked to address the challenge of safely extracting gas from gas hydrates. Its report cited estimates suggesting that the total amount of natural gas bound in hydrate form may exceed all conventional gas resources – coal, oil and natural gas combined. It also identified challenges linked to extracting gas from the hydrates, including the potential impact on environmental policy and unknown effects on communities (CCA, 2006).

Box 4.2: **Genomics is a growing priority for Canada**

Genome Canada is Canada's principal player in genomics research. Constituted as a non-profit corporation in 2000, it works as a co-operative and collaborative network, with six* regional genome centres, combining national leadership with the ability to respond to regional and local needs and priorities. This has allowed regional expertise to be translated into applications for those who can use them most effectively.

For instance, livestock, energy and crop improvement projects are located in Alberta, Saskatchewan and Manitoba, aquaculture and wild fisheries in the coastal regions, forestry in western Canada and Quebec and human health research predominantly in Atlantic Canada, Ontario, Quebec, and British Columbia. With the financial support of the Canadian government for over almost 15 years (totalling CAN$ 1.2 billion) and co-funding from provinces, industry, national and international funding organizations, philanthropists, Canadian institutions and others, Genome Canada and the regional Genome Centres have together invested over CAN$ 2 billion in genomics research, across all provinces in all life science sectors.

Genome Canada has also invested CAN$ 15.5 million in a new Genomics Innovation Network. The network is comprised of ten 'nodes,' each of which receives core operational funding from Genome Canada, with matching funds from various public and private sector partners. The Genomics Innovation Network allows innovation centres across Canada to collaborate and harness their collective strength to advancing genomics research. Each node provides Canadian and international researchers with access to the leading-edge technologies required to conduct research in genomics, metabolomics, proteomics and related areas.

Within the federal government, there is also a capacity for genomics research. The ongoing value of government-performed genomics research received an endorsement in 2014 with the renewal of the Genomics Research and Development Initiative (GRDI) and funding of CAN$ 100 million over five years.

With this latest slice of funding, GRDI has brought in the Canadian Food Inspection Agency as a full member and is allocating greater resources to interdepartmental projects. Discussions were initiated with Genome Canada in 2011 to find a mechanism for formal collaboration.

Participating departments and agencies are also finding that GRDI funding is attracting resources from other sources. In its annual report for financial year 2012–2013, the initiative reported that its investment that year of CAN$ 19.9 million had leveraged a further CAN$ 31.9 million for an annual total of CAN$ 51.8 million. The National Research Council had achieved the highest leverage, using its initial endowment of CAN$ 4.8 million to attract an additional CAN$ 10.1 million.

* Genome British Columbia, Genome Alberta, Genome Prairie, Ontario Genomics Institute, Genome Quebec and Genome Atlantic

Source: compiled by author

...but clean energy remains the poor relation
According to Statistics Canada, energy-related R&D rose by 18.4% from 2011 to CAN$ 2.0 billion in 2012, mostly as a result of increases in R&D expenditure on fossil-fuel technologies. R&D spending on the latter was concentrated in oil (tar) sands and heavy crude oil technologies, up 53.6% to CAN$ 886 million, and in crude oil and natural gas technologies, almost unchanged at CAN$ 554 million.

By contrast, R&D spending on energy-efficient technologies fell by 5.9% to CAN$ 80 million and spending on renewable energy technologies fell by 18.9% to CAN$ 86 million between 2011 and 2012 (Figure 4.7).

In short, whereas green energy and clean-tech are receiving some attention from the private sector and policy circles, they are no match for the scale of support and advocacy behind conventional sources, including tar sands. Moreover, with the global decline in oil prices since mid-2014, the overall strategy of investing capital (political and otherwise) in this one sector has now put Canada's economic health in jeopardy.

Although energy questions currently consume much of the policy and incentive focus for R&D support, other areas have also received some attention in recent years. Genomics, for instance, has risen to the top of the priority list for support (Box 4.2). This is hardly surprising, since Canada is particularly prolific in clinical medicine and biomedical research (Figure 4.5).

POLICY ISSUES IN HIGHER EDUCATION

The talent and skills conundrum
A national debate is under way as to what kinds of skills, training and talent Canada needs for the 21st century. This is not a new debate but it has taken on a fresh urgency with the accumulation of warning signs, particularly as regards higher education. For one thing, Canada is slipping in higher education rankings. According to the *World Competitiveness Report* published by the World Economic Forum in 2014, Canada ranks second in the world for primary school enrolment, yet only 23rd for secondary enrolment and 45th for post-secondary enrolment.

A report from the government's own Science, Technology and Innovation Council has commented on the need to address the talent base. Canada's share of human resources in S&T in the manufacturing labour force amounts to only 11.5% – among the lowest in OECD countries. Canada's higher education investment in R&D (HERD) as a proportion of GDP has fluctuated, declining to 0.65% in 2013. With this decline, Canada's rank among 41 economies has dropped from fourth in 2008 and third in 2006 to ninth.

Meanwhile, reports from both the Council of Canadian Academies and the Science, Technology and Innovation Council (STIC) have pointed to shifts in Canada's position with respect to research excellence (STIC, 2012; CCA, 2013a). They have noted a need for improvement in two strategic areas: the production of doctoral graduates per 100 000 population and higher education expenditure on R&D as a share of GDP (Figures 4.8 and 4.9).

This public policy challenge stems largely from the fact that Canada has no central authority responsible for education, no ministry of education. Rather, the responsibility for training and education tends to fall to provincial governments, with the exception of periodic attempts by the central government to weigh in and provide incentives and other forms of moral suasion.

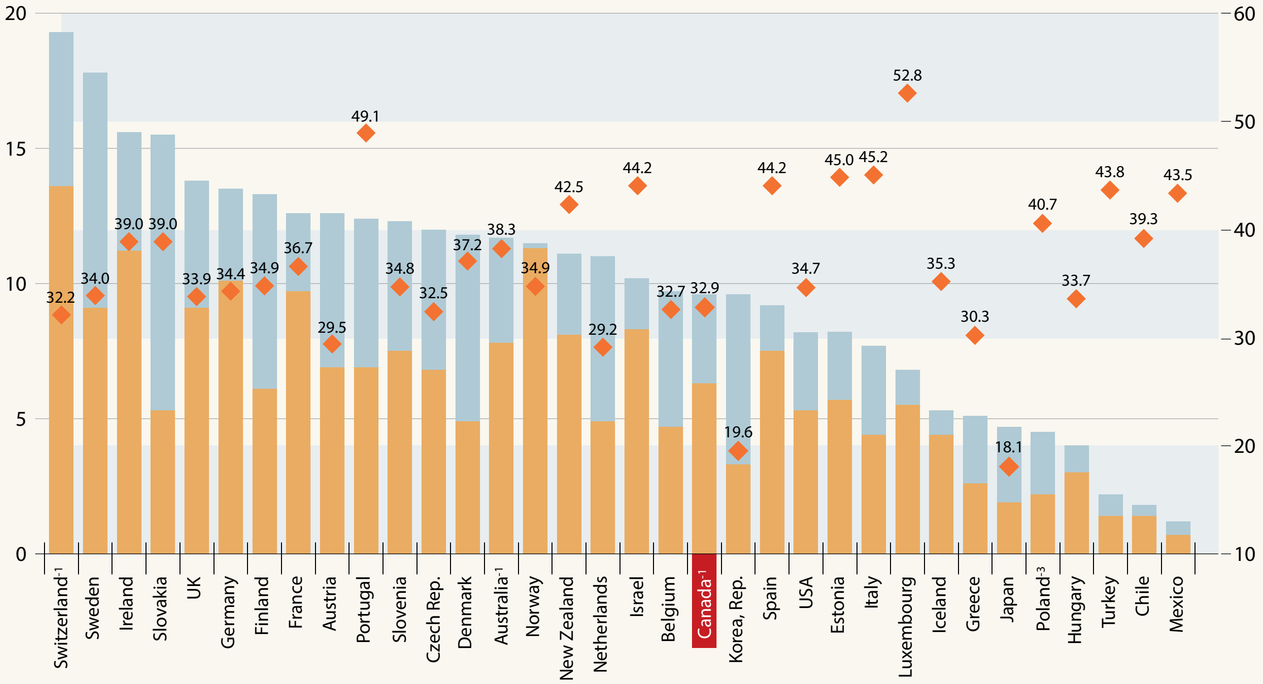
While education remains almost exclusively a provincial matter, responsibility for R&D is undefined constitutionally. As a result, different levels of government intervene with various policy instruments, leading to varying outcomes.

This makes for a complex web of actors and recipients, often with unco-ordinated leadership, not to mention a certain confusion.

To be sure, the focus on job creation has increased somewhat, with assessments currently under way to examine the country's educational assets. For instance, the Council of Canadian Academies has been called in to assess how well-prepared Canada is to meet future requirements for skills in science, technology, engineering and mathematics (STEM). The council's assessment examined the role of STEM skills in fostering productivity, innovation and growth in a rapidly changing demographic, economic, and technological environment, as well as the extent and nature of the global market for STEM skills. It also assessed how STEM skills were likely to evolve, which skills were likely to be most important for Canada and how well Canada was positioned to meet future needs in terms of STEM skills through education and international migration.

There are also some new incentives to encourage foreign scholars to come to Canada and, reciprocally, to increase the engagement of Canadian students internationally, but this tends to be piecemeal in approach. In addition, some adjustments have been made to Canada's immigration policy, in part to attract new talent and skills.

Figure 4.8: **Doctoral graduates in Canada and other OECD countries, 2012**

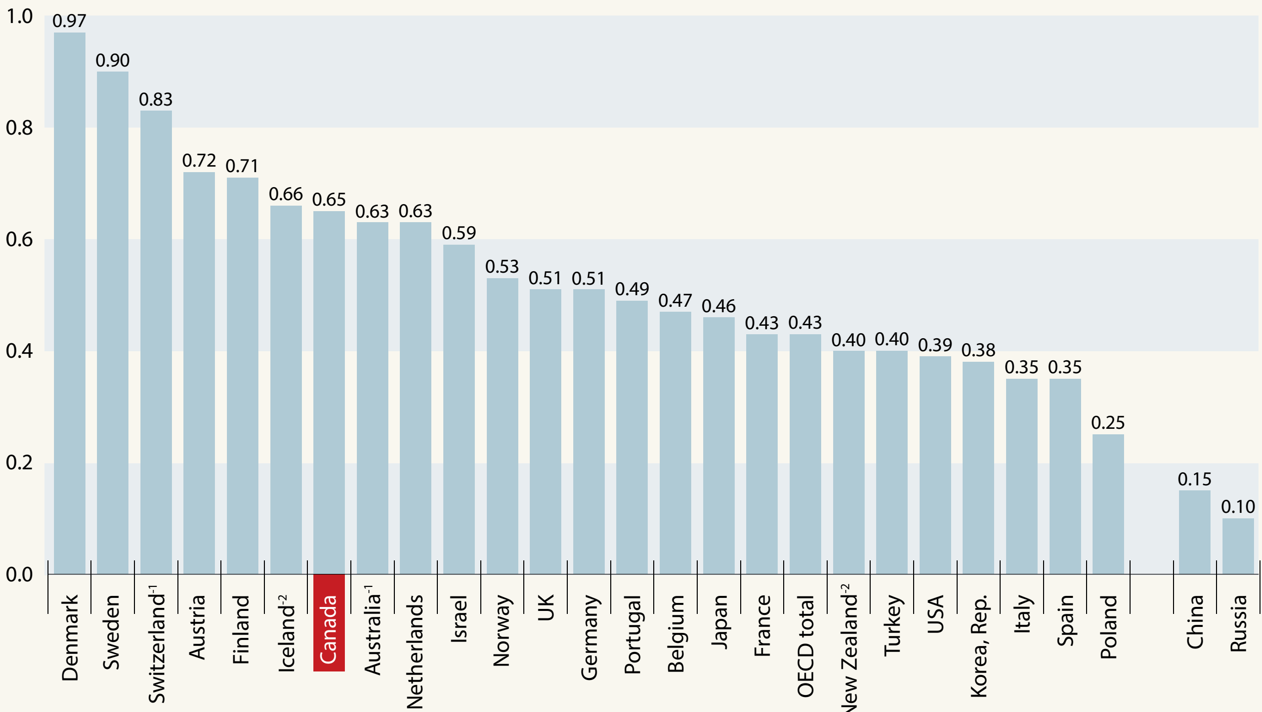


-*n* = data are for *n* years before reference year

Source: UNESCO Institute for Statistics, April 2015

Figure 4.9: **Spending on R&D in higher education in Canada and other OECD countries as a share of GDP, 2013 (%)**

Non-OECD countries are given for comparison



-*n* = data are for *n* years before reference year

Source: OECD (2015) Main Science and Technology Indicators

The future of education will be international

In 2011, the federal government commissioned an expert panel to examine the question of international education. The Advisory Panel on Canada's International Education Strategy was led by Amit Chakma, President and Vice-Chancellor of the University of Western Ontario. The panel was asked to make recommendations regarding how to maximize economic opportunities for Canada in the field of international education, including greater engagement with emerging key markets, a focus on attracting the brightest international students, encouraging Canadians to study abroad, expanding the delivery of Canadian education services abroad and building bigger partnerships between Canadian and foreign institutions.

The report was commissioned in the context of the federal government's *Global Commerce Strategy* (2007–2013), the precursor to its *Global Markets Action Plan*. Among the expert panel's final recommendations in August 2012 were to:

- double the number of international students choosing Canada from 239 131 to 450 000 by 2022 without displacing any domestic students;
- create 50 000 opportunities per year for Canadian students to go abroad for study and cultural exchanges;
- introduce 8 000 new scholarships for international students, co-funded by the Canadian federal and provincial governments;
- improve education visa processing to provide consistent and timely processing for high-quality candidates;
- target promotional efforts towards priority markets, including China, India, Brazil, the Middle East and North Africa, while maintaining traditional markets like the USA, France and UK, and develop Canada's education 'brand,' to be used by all partners in priority markets;
- improve linkages and collaboration between Canadian and international educational institutions and research institutes and;
- entrench a pan-Canadian approach in the international education sector with all key stakeholders and align activities to advance shared objectives better.

Box 4.3: The Canadian public has a positive attitude towards science

A survey of Canada's science culture

In August 2014, the Council of Canadian Academies released an assessment of Canada's science culture, based on a survey of 2 004 Canadians.

The expert panel assessed gender imbalances in science, the participation of aboriginal communities and the influence of a bilingual culture on popular science, among other issues.

The survey revealed that Canadians had positive attitudes towards science and technology and few reservations about science, compared to citizens of other countries. Canadians also showed above-average levels of support for public funding of research, compared to other countries.

The report also revealed an extensive popular science culture in Canada, with over 700 programmes or organizations: museums, science weeks and festivals, science fairs, etc.

Here are the study's main findings:

- 93% of Canadians surveyed were moderately or very interested in scientific discoveries and technological developments; for this measure, Canada ranks 1st out of 33 countries for which data are available.
- Respondents who were younger, male, highly educated and/or had high incomes showed a greater interest in science; this is consistent with findings from other countries.
- About 42% of respondents exhibited sufficient knowledge to grasp basic concepts and understand general media coverage of scientific issues but less than half had sufficient knowledge to understand current public debates about issues involving science and technology.
- Canada ranks first among OECD countries for overall post-secondary educational attainment (diplomas and degrees) but only 20% of first university degrees are in the sciences and engineering.
- More than half (51%) of those who hold degrees in science, technology, engineering or mathematics are immigrants.

Testing public attitudes towards robots

In 2014, a team of academics in communication, multimedia and mechatronics decided to test whether robots could trust humans. Scientists from the Universities of Ryerson, McMaster and Toronto built a 'friendly' robot using artificial intelligence and technologies for speech recognition and processing. They then equipped Hitchbot (the hitchhiking robot) with a GPS and left it by the roadside on a summer's day, after publicizing the experiment. Would Canadian motorists pick Hitchbot up and carry the robot towards its ultimate destination 6 000 km distant? The experiment was a success, with motorists posting photos of themselves with Hitchbot on Facebook and other social media (see photo, p.106).

Source: CCA (2014b); for Hitchbot: press release

In 2014, the government responded to several of the report's recommendations through the release of its *Comprehensive International Education Strategy*. For instance, the government assigned CAN$ 5 million per year to addressing the first objective of doubling the number of students; it also highlighted the need to focus resources and efforts on priority markets aligned with Canada's *Global Markets Action Plan,* namely Brazil, China, India, Mexico, North Africa and the Middle East and Viet Nam.

In June 2014, two advocacy groups, the Council of Chief Executives and the Canadian International Council, argued in their joint report that one of the reasons why Canada – with 120 000 international students – trailed countries such as the UK (427 000) and Australia (almost 250 000) was the lack of a unified brand to promote itself (Simon, 2014).

Their report noted that Canada was the only developed country without a national ministry of education. Using 2011 UNESCO rankings of international students per country, the report underscored Canada's eighth place ranking. Its ability to attract students from China, the biggest source of foreign students, was dismal, it noted, at only 3.8%. The report proposed that Canada create a new organization to brand international education as being central to both domestic and foreign policy, which would be known as Education Canada.

Eight out of ten universities seek high-quality partnerships

Universities across Canada are taking a more strategic approach to internationalization. According to a recent survey, Canadian universities are deeply committed to internationalization. Fully 95% identify it as part of their strategic planning and 82% view it as one of their top five priorities; 89% of respondents say that the pace of internationalization on their campuses has accelerated (either greatly or somewhat) during the past three years (AUCC, 2014).

The commitment of universities to internationalization is also becoming more sophisticated. For example, the pursuit of high-quality partnerships is now a priority for 79% of institutions. Evaluation is also growing: today, 59% of Canadian universities track the implementation of their internationalization strategies within their quality assessment and assurance procedures and just over three-fifths assess their success in supporting international students.

The most common top priority for internationalization is undergraduate student recruitment, identified by 45% universities as being their highest priority and by 70% as figuring among their top five priorities. The next top-rated priorities are to pursue strategic partnerships with universities overseas and to expand international academic research collaboration.

With regard to Canadian education abroad, more than 80% of universities which responded to the survey offer a degree or certificate programme abroad with international partners and 97% offer opportunities for Canadian students to do academic coursework abroad. However, outbound student mobility remains low: just 3.1% of full-time undergraduates (about 25 000) had an international experience in 2012–2013 and only 2.6% had chalked up a for-credit experience abroad (up slightly from 2.2% in 2006). Cost and inflexible curricular or credit transfer policies are perceived as being major barriers to greater student participation.

Not surprisingly, China is overwhelmingly the top focus for almost all the efforts by Canadian universities to internationalize their institutions. China has become Canada's third-biggest partner in terms of joint scientific authorship (Figure 4.5).

As for Canadian students themselves, their preferred destinations for an overseas experience remain the traditional English-speaking and major Western European nations, despite their universities' geographical focus on developing powers.

FOSTERING AN INNOVATION CULTURE

New programmes and a facelift for others

The federal budget of 2014 contains a major new funding programme called the Canada First Research Excellence Fund (CFREF). In announcing the federal strategy for STI in 2014, the prime minister also launched the competition for this new programme.

Pegged at CAN$ 50 million for the first year (2015–2016), CFREF is designed to drive Canadian post-secondary institutions to excel globally in research areas that create long-term economic advantages for Canada. The fund joins programmes such as the Canada Excellence Research Chairs and the Canada Research Chairs. Once implemented, it will presumably contribute significantly to research across all disciplines. CFREF will be available to all post-secondary institutions on a competitive, peer-reviewed basis.

The fund will be administered by the Social Sciences and Humanities Research Council of Canada, in collaboration with the Natural Sciences and Engineering Research Council of Canada and the Canadian Institutes of Health Research. These three funding councils collaborate trilaterally on issues such as open access. Each is currently undergoing a transformation to centre it more on its core mission.

The Canadian Institutes for Health Research have undergone a retooling of their own business model. Meanwhile, the Natural Sciences and Engineering Research Council has launched a consultation on its strategic plan to 2020, which will lay greater emphasis on developing a science culture, global outreach and discovery (basic) research.

For its part, the Social Sciences and Humanities Research Council is examining the vital role of social sciences and humanities in knowledge production and their contribution to future social issues, including challenges such as:

- What new ways of learning will Canadians need to adopt at university, in particular, to thrive in an evolving society and labour market?
- What effects will the quest for energy and natural resources have on our society and our position on the world stage?
- How are the experiences and aspirations of Aboriginal Peoples in Canada essential to building a successful shared future?
- What might the implications be for Canada of a global peak population?
- How can emerging technologies be leveraged to benefit Canadians?
- What knowledge will Canada need to thrive in an interconnected, evolving global landscape?

Last but not least, it is worth noting that another unique education cum training programe continues to receive federal support. The federal government announced in its 2013 and 2014 budgets a combined CAN$ 21 million investment in industrial research and training for postdoctoral fellows through a former programme of the Networks of Centres of Excellence[14] known as Mitacs. Mitacs co-ordinates collaborative industry–university research projects with human capital development. Since 1999, Mitacs has been promoting academic–industrial R&D while supporting the development of future innovation leaders. In particular, Mitacs:

- helps companies identify their innovation needs and matches them with academic expertise;
- fosters cutting edge research tied to commercial outcomes;
- builds international research networks, creating innovation leaders in Canada and abroad; and
- provides professional and entrepreneurship skills training for graduate students, so that they have the tools to meet emerging innovation needs.

Business-led Networks of Centres of Excellence

The Business-led Networks of Centres of Excellence (NCE) programme also fosters an innovation culture. Led by a non-profit consortium of industrial partners, each of these large-scale collaborative research networks focuses on specific challenges identified by a given industrial sector. The programme's partnership model places academic and private-sector partners on an equal footing; it allows networks to fund private sector partners directly so they can conduct research at their own facilities.

The programme was created in 2007 and made permanent in the 2012 federal budget, with annual funding of CAN$ 12 million. It proposes funding on a competitive basis. Matching requirements mean that at least half of each network's research costs are paid by the partners. In 2014, the newly formed Refined Manufacturing Acceleration Process (ReMAP) network was awarded CAN$ 7.7 million over five years through this programme, for instance, to develop technologies of benefit to the electronics sector. The research partnership involves academics, research organizations and a wide range of companies.

There is some debate as to whether the current mix of NCEs should not be more closely aligned with the federal government's most recent STI priorities, as outlined in its 2014 strategy. As Table 4.5 illustrates, the match is not evenly distributed across the five redefined priority areas (Watters, 2014).

Table 4.5: **Networks of centres of excellence in Canada by sector, 2014**

	Number	Share of total (%)	Share of total funding (%)	Total (CAN$ millions)
ICTs	6	14	8	81.7
Natural resources	6	14	8	83.3
Manufacturing/Engineering	2	5	9	88.9
Cross-sectorial	4	9	8	76.9
Environment	5	11	24	235.1
Health and life sciences	25	48	42	420.8
Total	**44**	**100**	**100**	**986.6**

Source: Watters (2014)

14. Since their inception in 1989, the Networks of Centres of Excellence have administered national funding programmes on behalf of the Natural Sciences and Engineering Research Council, Canadian Institutes of Health Research and Social Sciences and Humanities Research Council of Canada, in partnership with Industry Canada and Health Canada. These programmes support large-scale, multidisciplinary collaboration between universities, industry, government and non-profit organizations. The programme has expanded over the years to comprise: 16 NCEs; 23 Centres of Excellence for the Commercialization of Research and 5 Business-led Networks of Centres of Excellence.

Chapter 4

CONCLUSION

Science powers commerce (but not only)

The Canadian research landscape continues to evolve across the country along with a somewhat muted global reach. Research partnerships and science diplomacy are increasingly tied to trade and commercial opportunities. The international development envelope is now embedded in one large department, since the elimination of the Canadian International Development Agency.

The research system has become more complex, with a diversity of programmes that have often been established unilaterally at the federal level, prompting corresponding responses at provincial levels. There has been a marked increase in policy guidance, with a view to setting research priorities to suit the political agenda of the incumbent government. Several areas continue to attract high-level policy attention, including northern education and research infrastructure, along with global health – especially maternal and newborn child health –through a multi-million dollar Grand Challenges Canada programme that catalyses partnerships and support using an integrated approach to innovation.

A key consideration has been the impact of austerity budgets in Canada, which limit the ability of public policy to make up for shortfalls in research funding overall, in a context of rising enrolments and diminishing success rates for research grants. This trend is particularly visible in basic research – also known as discovery research – where the returns are often seen to be long-term and thus stretching well beyond the term of individual government mandates. As a result, there has been a tendency to focus support on more applied research, or that which can be shown to have a commercial outcome. Perhaps the best expression of this is Prime Minister Harper's mantra that 'science powers commerce.' That is true. Science does power commerce – but not only. The current drive to steer so-called public good science (e.g. regulatory, environmental) towards business and commercial outcomes reflects a focus on short term goals and a rapid return on investment in research that is short-sighted. This trend suggests that federal funding for basic research and public good science may continue to decline in Canada, even though the business world itself relies on the generation of new knowledge to nurture the commercial ideas of tomorrow.

With the federal election looming in late 2015, political parties have been jockeying for attention on issues that matter to the Canadian public. STI will receive some attention from all political parties in the run-up to the election. The official opposition New Democratic Party, for example, has outlined plans to introduce a Parliamentary Science Officer with a mandate to provide policy-makers with sound information and expert advice on all scientific matters of relevance. The Liberal Party has introduced a draft bill to re-instate the long-form census at Statistics Canada, eliminated by the Conservative government. However, history has shown that such endeavours turn out to be marginal at best, since science and technology are rarely at the centre of decision-making and budgetary outlays. Rather, they essentially receive 'CPA' – continuous partial attention – from all governments.

Canada will be celebrating its 150th birthday in 2017. If the country is serious about reinvigorating its knowledge culture and positioning itself as a world leader via STI, a more concerted and co-ordinated national effort will be required with demonstrated leadership from all stakeholders. An opportunity exists to seize the day – but Canada must engage all stakeholders in an open and transparent fashion.

KEY TARGETS FOR CANADA

- Double the number of international students choosing Canada to 450 000 by 2022, without displacing any domestic students;
- Raise the share of electricity generated in Canada from non-greenhouse gas emitting sources to 90%, including nuclear energy, clean coal, wind and hydroelectricity;
- Cut CAN$ 2.6 billion from 10 federal science-based departments and agencies between 2013 and 2016.

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The future looks brighter for business than for basic research.

Shannon Stewart and Stacy Springs

A nurse uses a light therapy device to treat the side-effects of chemotherapy and radiotherapy in a cancer patient, during a trial at Birmingham Hospital in 2011 run by the University of Alabama. This High Emissivity Aluminiferous Luminescent Substrate (HEALS) technology uses 288 powerful light-emitting diodes (LEDs) to provide intense light. HEALS light therapy was developed from experiments carried out at the International Space Station.
Photo ©: Jim West/Science Photo Library

5 · United States of America

Shannon Stewart and Stacy Springs

INTRODUCTION

A fragile recovery

The US economy has recovered from the 2008–2009[1] recession. The stock market has hit new heights and GDP has been on the upswing since 2010, despite having stuttered in a few quarters. At 5.5%, the 2015 unemployment rate is well below its 2010 peak of 9.6%.

After a sharp deterioration in 2008, the USA's public finances are on the mend. The combined federal and state fiscal deficit should improve to 4.2% of GDP in 2015, thanks to increasingly robust economic growth, even though it will remain one of the highest among G7 countries (Figure 5.1). The federal budget deficit (2.7% of GDP) will make up just under two-thirds of the total deficit, according to projections[2] by the Congressional Budget Office. This is a big improvement on the situation in 2009, when the federal deficit peaked at 9.8% of GDP.

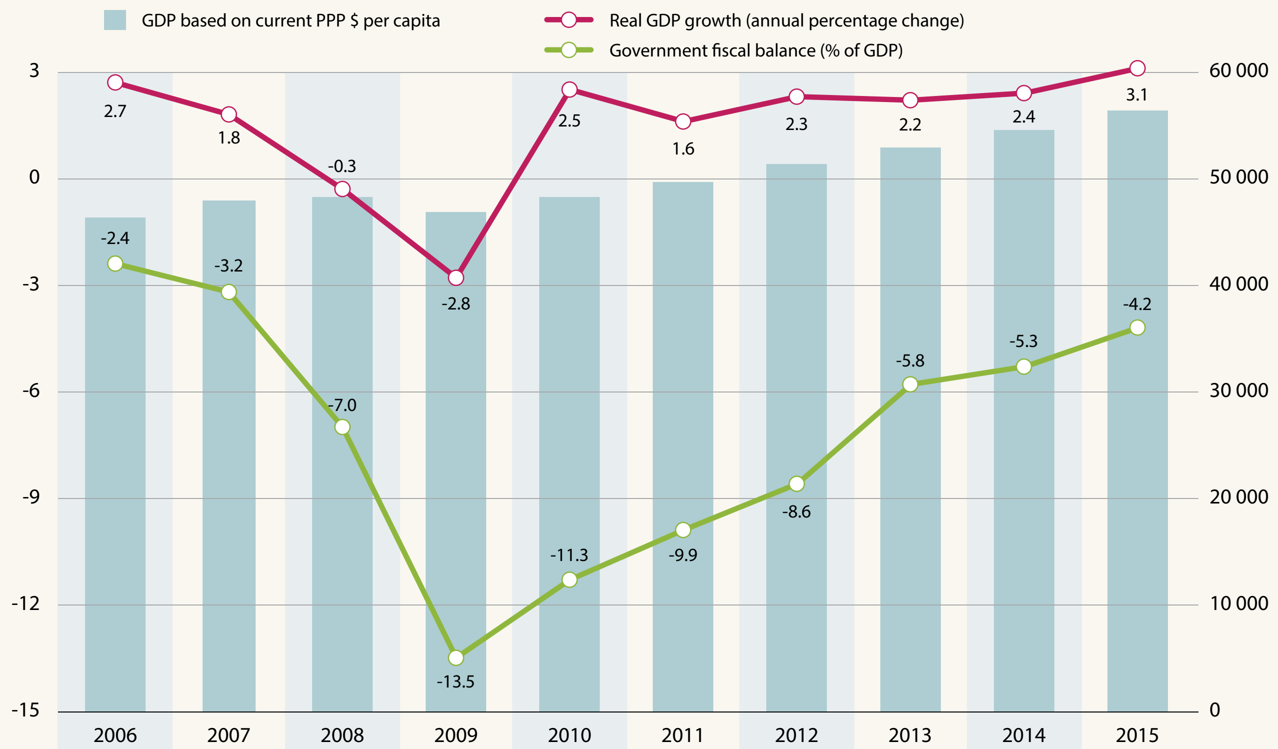
1. According to the US National Bureau of Economic Research, the USA was in recession from December 2007 to end June 2009.

2. See: https://www.cbo.gov/publication/49973

Since 2010, federal investment in research and development (R&D) has stagnated in the wake of the recession. Despite this, industry has largely maintained its commitment to R&D, particularly in growing, high-opportunity sectors. As a result, total R&D spending has dipped only slightly and the balance of spending has shifted further towards industrial sources since 2010, from 68.1% to 69.8% of the total. Gross domestic expenditure on research and development (GERD) is now rising, as is the share performed by the business enterprise sector (Figures 5.2 and 5.3).

The recovery remains fragile, however. Despite the decline in unemployment, there are still 8.5 million job-seekers. The long-term unemployed – those out of a job for 27 weeks or more – still number about 2.5 million. A further 6.6 million are employed part-time but would prefer full-time employment and 756 000 have given up looking for work. Wages remain stagnant and many of those who lost their jobs during the recession have since found positions in growth areas but with lower salaries. The average hourly wage rose by just 2.2% over the 12 months ending in April 2015.

Figure 5.1: **GDP per capita, GDP growth and public sector deficit in the USA, 2006–2015**

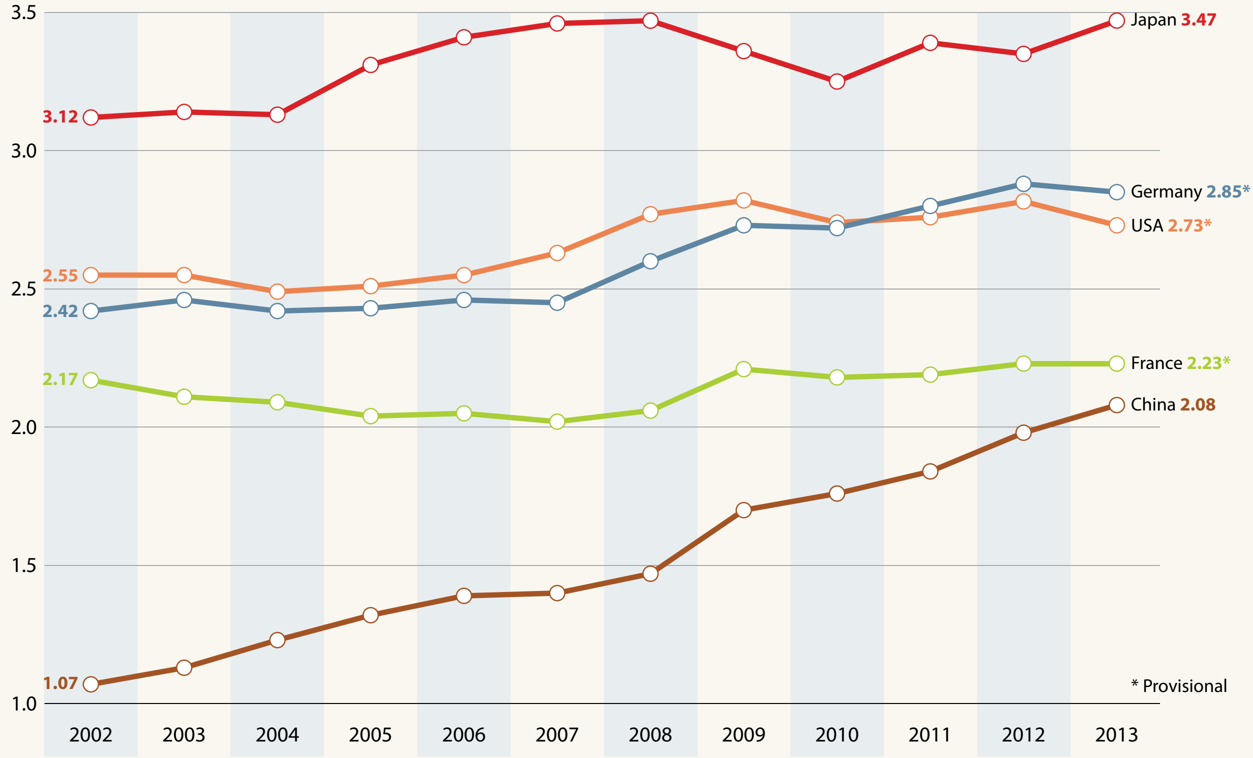


Note: Data for 2015 are estimates. General government fiscal balance is also known as net lending/borrowing. The fiscal balance covers both the federal and state governments.

Source: IMF Data Mapper online, August 2015

Figure 5.2: **GERD/GDP ratio in the USA, 2002–2013 (%)**

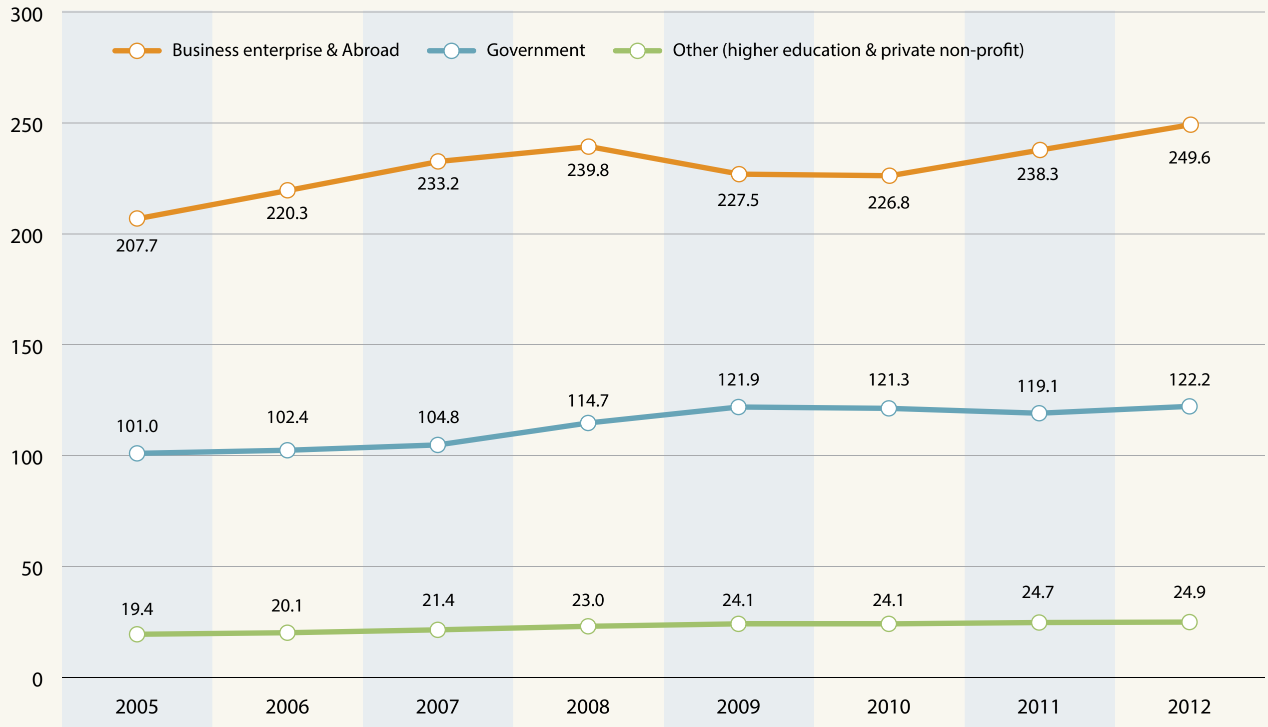
Other countries are given for comparison (%)



Source: UNESCO Institute for Statistics, August 2015. USA data for 2013 from OECD Main Science and Technology Indicators, August 2015

Figure 5.3: **Distribution of GERD in the USA by source of funds, 2005–2012**

In constant 2005 billion PPP$



Source: UNESCO Institute for Statistics, August 2015

Funding from the economic stimulus package of 2009, formally known as the American Recovery and Reinvestment Act, may have buffered immediate job losses for those working in science and technology, since a significant portion of this stimulus package went to R&D. A study by Carnivale and Cheah (2015) showed that students who had majored in science, technology, engineering and mathematics were less affected by unemployment than the average American: only 5% were unemployed in 2011–2012. Those graduates having studied physical sciences were the least affected of all. However, average salaries for recent graduates have declined across all disciplines. Moreover, although the Industrial Research Institute indicates that businesses plan to hire people with experience and new graduates – albeit fewer than last year – cutbacks looming in the federal budget for R&D in 2015 and 2016 throw a pall over the economic future of publicly funded R&D funding.

Flat federal research budgets

Although the president makes an annual budget request, the ultimate authority on federal funding of science in the USA is Congress (bicameral parliament). Control of Congress was divided between the two main political parties from 2011 onwards, with Republicans controlling the House of Representatives and Democrats the Senate, until the Republicans gained control over the latter in January 2015. In spite of the efforts made by the government to increase allocations to research, congressional priorities have largely prevailed (Tollefson, 2012). Most federal research budgets have remained flat or declined in inflation-adjusted dollars over the past five years, as part of the congressional austerity drive to trim US$ 4 trillion from the federal budget to reduce the deficit. Since 2013, Congress has withheld approval of the federal budget presented by the government several times. This bargaining chip has been possible since 2011, when Congress passed a law stipulating that about US$ 1 trillion in automatic budget cuts across the board would start to take effect in 2013 if Congress and the White House could not agree on a plan to reduce the deficit. The deadlock over the budget in 2013 led to an administrative shutdown for several weeks, effectively putting federal employees on leave without pay. The effects of budgetary austerity and sequestration linger in federal investment, making it difficult for young scientists to establish a career, as we shall see later.

This austerity drive may be explained, at least in part, by the perception of there being a lesser need for R&D than before. With two lengthy interventions in Afghanistan and Iraq winding down, the focus of research has shifted away from military technologies, causing defence-related R&D to decline accordingly. On the other hand, federal research investment in the life sciences has failed to keep pace with inflation, in spite of the emerging needs of an ageing population; in parallel, federal investment in energy and climate research has been modest.

In his 2015 State of the Union address, President Obama set forth his policy priorities for the future as being the pursuit of the fight against climate change and a new Precision Medicine Initiative. The executive's priorities are being taken forward largely thanks to collaboration between the government, industry and non-profit sectors. Some milestones built on this collaborative model are the BRAIN Initiative, the Advanced Manufacturing Partnership and the American Business Act on Climate Pledge that recently received a US$ 140 billion commitment from its partners in industry. These three initiatives are discussed in the next section.

On the international scene, the USA is having to contend with the gradual, inexorable shift from a monopolar structure to a more pluralistic and globalized playing field for science. This shift is mirrored at many levels of US science, ranging from education to patent activity. For instance, the Organisation for Economic Co-operation and Development (OECD) projects that China will exceed the USA in R&D spending by about 2019 (see also Chapter 23). Although the USA is the current world leader in R&D, its lead is narrowing and is projected to narrow further or even disappear in the near future.

GOVERNMENT PRIORITIES

Climate change: the science policy priority

Climate change has been the Obama administration's top priority for science policy. One key strategy has been to invest in alternative energy technologies as a way of reducing the carbon emissions that lead to climate change. This includes increasing the availability of funding for basic research in the field of energy at universities, loans for businesses and other incentives for R&D. In the aftermath of the financial crisis, the White House effectively leveraged the ensuing economic crisis as an opportunity to invest in science, research and development. Since then, however, political difficulties have forced the president to scale down his ambitions.

In the face of Congressional opposition, the president has taken steps to address climate change to the extent that his executive powers allow. For instance, he vetoed a congressional bill in March 2015 that would have authorized construction of the Keystone XL pipeline to carry oil from tar sands in Canada across the USA to the Gulf of Mexico. He has also overseen the creation of ambitious new fuel standards for cars and trucks, for instance. In 2014, his top scientist, John Holdren, Director of the Office of Science and Technology

Policy and Co-Chair of the President's Council of Advisors on Science and Technology,[3] organized and issued the *National Climate Assessment*, a thorough, peer-reviewed examination of the effects of climate change on the USA. On the grounds that the USA needs to maintain its energy independence, the president has nevertheless authorized fracking and, in 2015, approved oil drilling in the Arctic Ocean.

The government has elected to use the power of the Environmental Protection Agency to regulate greenhouse gas emissions. The Environmental Protection Agency wishes to reduce power plants' carbon emissions by 30% across the USA. Some states are also supporting this policy, since each state is free to fix its own emission targets. California is one of the most rigorous, in this regard. In April 2015, the state governor imposed a 40% carbon emissions reduction target by 2030 over 1990 levels. California has been experiencing severe drought for several years.

The USA will only be able to reach its emissions reduction targets with the involvement of industrial stakeholders. On 27 July 2015, 13 large US companies committed to investing US$ 140 billion in low carbon emission projects, as part of the American Business Act on Climate Pledge announced by the White House. Six of the signatories have made the following pledges:

- Bank of America undertakes to increase its investment in favouring the environment from US$ 50 billion at present to US$ 125 billion by 2025;
- Coca-cola undertakes to reduce its carbon footprint by one-quarter by 2020;
- Google, the world leader for the purchase of renewable energy to run its data centres, pledges to triple its purchases over the next decade;
- Walmart, the world leader in distribution (supermarket chains) pledges to increase its production of renewable energy by 600% and double the number of its supermarkets running on renewable energy by 2020;
- Berkshire Hathaway Energy (Warren Buffett group) will double its investment in renewable energy, currently US$ 15 billion; and
- Alcoa, the aluminium manufacturer, undertakes to halve its carbon emissions by 2025.

3. This group of distinguished scientists advises the president through written reports. Recent topics include individual privacy in big data contexts, education and work training and health care delivery issues. The council's reports tend to focus more closely on the president's policy agenda than those of the national academies of science.

Better health care: the Patients' Bill of Rights

Better health care has been a priority of the Obama administration. The Patient Protection and Affordable Care Act was signed into law by the president in March 2010 and upheld by the Supreme Court in a decision rendered in June 2012. Touted as the 'Patients' Bill of Rights,' it sets out to give a maximum of citizens health care coverage.

The Biologics Price Competition and Innovation Act is part of this law. It creates a pathway for abbreviated licensure for biological products that are shown to be 'biosimilar' to, or 'interchangeable' with, an approved biological product. The act was inspired by the Drug Price Competition and Patent Restoration Act (1984), more commonly known as the Hatch-Waxman Act, which encouraged development of generic drug competition as a cost containment measure for high-priced pharmaceuticals. Another inspiration for the act was the fact that the patents for many biologic drugs will expire in the next decade.

Although the Biologics Price Competition and Innovation Act was passed in 2010, the first biosimilar was only approved in the USA by the Food and Drug Administration (FDA) in 2015: Zarxio, made by Sandoz. Zarxio is a biosimilar of the cancer drug Neupogen, which boosts the patient's white blood cells to ward off infection. In September 2015, a US court ruled that the Neupogen brand manufacturer Amgen could not block Zarxio from being sold in the USA. Neupogen costs about US$ 3 000 per chemotherapy cycle; Zarxio hit the US market on 3 September at a 15% discount. In Europe, the same drug had been approved as early as 2008 and has been safely marketed there ever since. The lag in development of an approval pathway in the USA has been criticized for impeding access to biological therapies.

The true cost savings from the use of biosimilars is difficult to assess. A 2014 study by the Rand Institute estimates a range of US$ 13–66 billion in savings over 2014–2024, depending upon the level of competition and FDA regulatory approval patterns. Unlike generics, biosimilars cannot be approved on the basis of minimal and inexpensive tests to prove bioequivalence. Since biological drugs are complex, heterogeneous products derived from living cells, they can only be shown to be highly similar to the appropriate reference product and therefore require demonstration that there are no clinically meaningful differences in safety and efficacy. The extent to which clinical trials are required will largely determine the cost of development.

The Affordable Care Act included financial incentives for health care providers to adopt electronic health records: up to US$ 63 750 for a physician whose practice includes a minimum of 30% of patients covered by Medicaid, a federally funded, state-run programme for those with limited income. According to an annual report submitted to Congress in October 2014, more than six of ten hospitals electronically exchanged patient health information with providers outside their organization and seven out of ten health-care providers electronically prescribed new prescriptions. One of the benefits of electronic health records is that this system makes it easier to analyse swaths of patient health data to individualize and personalize care. It was President George W. Bush who, in 2004, initiated a plan for Americans to have electronic health records by 2014, in order to reduce medical errors, optimize treatment and consolidate medical records for better, more cost-efficient care.

Cures for the 21st century

The goal of the 21st Century Cures bill is to streamline drug discovery, development and approval by relaxing barriers to information-sharing, increasing regulatory transparency and modernizing standards for clinical trials. The bill includes an innovation fund of US$ 1.75 billion per year for five years for one of the USA's main science agencies, the National Institutes of Health (NIH), and US$ 110 million per year for five years for the FDA. Endorsed by a number of industry groups, it enjoys strong support. In a rare moment of bipartisanship, the bill passed the House on 10 July 2015. At the time of writing in August 2015, the bill has not yet been taken up by the Senate.

Were the bill to pass into law, it would alter the way in which clinical trials are conducted by allowing new and adaptive trial designs that factor in personalized parameters, such as biomarkers and genetics. This provision has proven controversial, with doctors cautioning that overreliance on biomarkers as a measure of efficacy can be misleading, as they may not always reflect improved patient outcomes. The bill also includes specific provisions to incentivize the development, and facilitate the approval, of drugs for rare diseases and new antibiotics, including the prospect of limited release to special populations – the first time that an identified subpopulation for a particular disease will be treated differently from a regulatory perspective. (For another approach to speeding up the process of drug approval through pre-competitive collaboration, see the Accelerating Medicines Partnership, Box 5.1.)

The BRAIN Initiative: a 'grand challenge'

In 2009, the Obama administration published its *Strategy for American Innovation*, which was updated two years later. This strategy emphasizes innovation-based economic growth as a way of raising income levels, creating better-quality jobs and improving quality of life. One element of this strategy are the 'grand challenges' introduced by the president in April 2013, three months into his second term of office, to help catalyse breakthroughs in priority areas, by combining the efforts of public, private and philanthropic partners.

The Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative is one of the 'grand challenges' announced by the president in April 2013. The goal of this project is to leverage genetic, optical and imaging technologies to map individual neurons and complex circuits in the brain, eventually leading to a more complete understanding of this organ's structure and function.

So far, the BRAIN Initiative has obtained commitments of over US$ 300 million in resources from federal agencies (NIH, FDA, National Science Foundation, etc.), industry (National Photonics Initiative, General Electric, Google, GlaxoSmithKline, etc.) and philanthropy (foundations and universities).

The first phase is focusing on the development of tools. The NIH has created 58 awards totalling US$ 46 million, guided by the scientific vision of the chairs Drs Cori Bargmann and William Newsome. For its part, the Defense Advanced Research Projects Agency has focused on tools to create electrical interfaces with the nervous system to treat motor damage. Industrial partners are developing improved solutions that the project will require in terms of imaging, storage and analysis. Universities across the country have committed to aligning their neuroscience centres and core equipment with the objectives of the BRAIN Initiative.

A Precision Medicine Initiative

Defined as delivering the right treatment to the right patient at the right time, precision medicine tailors treatments to patients based on their unique physiology, biochemistry and genetics. In his 2016 budget request, the president asked for US$ 215 million to be shared by the NIH, National Cancer Institute and FDA to fund a Precision Medicine Initiative. As of August 2015, the budget had not yet been voted upon. Between 2005 and 2010, pharmaceutical and biopharmaceutical companies increased their investment in precision medicine by roughly 75% and a further increase of 53% is projected by 2015. Between 12% and 50% of the products in their drug development pipelines are related to personalized medicine (See Box 5.2).

A focus on advanced manufacturing

One of the federal government's major priorities has been to steer advanced manufacturing towards enhancing US competitiveness and job creation. In 2013, the president launched the Advanced Manufacturing Partnership Steering Committee 2.0 (AMP 2.0). Based on recommendations of the co-chairs representing the industrial, labour and academic sectors, he also called for the creation of a Nationwide Network for Manufacturing Innovation, a series of connected institutes for manufacturing innovation to 'scale up advanced manufacturing technologies and processes.' Congress approved this request, enabling the president to sign the Revitalize American Manufacturing Act into law in September 2014 for an investment of US$ 2.9 billion. These funds, which are to be matched by private and non-federal partners, will be used to create an initial network of up to 15 institutes, nine of which have already been determined or established.

Box 5.1: **The Accelerating Medicines Partnership**

The Accelerating Medicines Partnership was launched by the National Institutes of Health (NIH) in Washington DC on 4 February 2014. This public–private partnership involves the NIH and the Food and Drug Administration on the government side, 10 major biopharmaceutical companies and several non-profit organizations. Government bodies and industry are sharing the US$ 230 million budget (see Table 5.1).

Over the next five years, the partnership will develop up to five pilot projects for three common but difficult-to-treat diseases: Alzheimer's disease, type 2 (adult onset) diabetes and the autoimmune disorders, rheumatoid arthritis and lupus. The ultimate goal is to increase the number of new diagnostics and therapies for patients and reduce the time and cost of developing them.

'Currently, we are investing too much money and time in avenues that don't pan out, while patients and their families wait,' said NIH director Francis S. Collins, at the launch. 'All sectors of the biomedical enterprise agree that this challenge is beyond the scope of any one sector and that it is time to work together in new ways to increase our collective odds of success.'

Developing a new drug takes well over a decade and has a failure rate of more than 95%. As a consequence, each success costs more than US$1 billion. The most expensive failures happen in late phase clinical trials. It is thus vital to pinpoint the right biological targets (genes, proteins and other molecules) early in the process, so as to design more rational drugs and better tailored therapies.

For each pilot project, scientists from NIH and industry have developed research plans aimed at characterizing effective molecular indicators of disease, called biomarkers, and distinguishing those biological targets most likely to respond to new therapies (known as targeted therapies). They will thus be able to focus on a small number of molecules. Laboratories will share samples, such as blood or brain tissue from deceased patients, to identify biomarkers. They will also participate in NIH clinical trials.

The partnership will be managed through the Foundation for the NIH. One critical component is that industry partners have agreed to make the data and analyses arising from the partnership accessible to the broad biomedical community. They will not use any discoveries to develop their own drug until these findings have been made public.

Source: www.nih.gov/science/amp/index.htm

Table 5.1: **Parameters of the Accelerating Medicines Partnership, 2014**

Government partners	Industrial partners	Partners among non-profit organizations
Food and Drug Administration	AbbVie (USA)	Alzheimer's Association
National Institutes of Health	Biogen (USA)	American Diabetes Association
	Bristol-Myers Squibb (USA)	Lupus Foundation of America
	GlaxoSmithKline (UK)	Foundation for the NIH
	Johnson & Johnson (USA)	Geoffrey Beene Foundation
	Lilly (USA)	PhRMA
	Merck (USA)	Rheumatology Research Foundation
	Pfizer (USA)	USAgainstAlzheimer's
	Sanofi (France)	
	Takeda (Japan)	

Research focus	Total project (US$ millions)	Total NIH (US$ millions)	Total industry (US$ millions)
Alzheimer's Disease	129.5	67.6	61.9
Type 2 Diabetes	58.4	30.4	28.0
Rheumatoid Arthritis and Lupus	41.6	20.9	20.7
Total	**229.5**	**118.9**	**110.6**

These include institutes focusing on additive manufacturing like three-dimensional (3D) printing, digital manufacturing and design, lightweight manufacturing, wide band semiconductors, flexible hybrid electronics, integrated photonics, clean energy and revolutionary fibres and textiles. The goal for these innovation hubs will be to ensure sustainable collaborative innovation among industry, academia and government stakeholders in order to develop and demonstrate advanced manufacturing technologies that increase commercial productivity, bring together the best talent from all sectors to demonstrate cutting-edge technology and create a talent pipeline for advanced manufacturing.

A shift away from human spaceflight

In recent years, the focus of the National Aeronautics and Space Administration (NASA) has shifted away from human spaceflight, as part of a cost-cutting drive. In a reflection of this trend, the showpiece space shuttle programme was retired in 2011 and its successor cancelled. US astronauts now rely on Russian-operated Soyouz rockets to transport them to and from the International Space Station. In parallel, a partnership between NASA and the privately owned US company SpaceX is gaining traction but SpaceX does not yet have human flight capabilities. In 2012, SpaceX's Dragon became the first commercial spacecraft to fly cargo to and from the International Space Station.

In 2015, the US spacecraft New Horizons achieved a flyby of the dwarf planet Pluto in the Kuiper belt, 4.8 billion km from Earth, which astrophysicist Neil deGrasse Tyson likened to 'a hole-in-one on a two-mile golf shot.' John Holdren, the president's top scientist, noted that the USA had become the first nation to explore our entire Solar System.

CONGRESSIONAL PRIORITIES

A drive to cut research funding

The Republican leadership of the House Committee on Science, Space and Technology has been vocally sceptical of the Obama administration's climate change agenda. It has also striven to reduce funding for geosciences and alternative energy research, while intensifying political oversight. Individual members of Congress have criticized specific grants for being wasteful and unscientific, a strategy that resonates with the public.

Congress is able to set science-related policy directly through the passage of legislation that affects both matters of funding and law. The topics can vary widely: Congress takes up bills ranging from flood preparedness to nanotechnology, from offshore drilling to treatments for addiction. Below are three examples of enacted legislation that is having a large impact on US science policy: the America COMPETES Act, budgetary sequestration and the Food Safety Modernization Act.

Greater congressional control over grant funding

The America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act (America COMPETES Act) was first passed in 2007 before being reauthorized and fully funded in 2010; it will be taken up again before the end of the current legislature in January 2017. The aim of this act is to bolster US research and innovation through investment in education, teacher training, loan guarantees for innovative manufacturing technologies and scientific infrastructure. It also requires periodic assessment of progress in these areas and the general competitiveness of US science and technology. Its primary focus is education and its effects on this sector are discussed in detail in the section on Trends in Education (see p. 148).

At the time of writing in August 2015, the America COMPETES Reauthorization Act of 2015 has been passed by the House but not by the Senate. If passed, the new act will create a level of congressional control over the grant schemes funded by the National Science Foundation. The law would require every grant funded by NSF to be 'in the national interest' and each grant announcement to be accompanied by a written justification from the agency indicating how the grant meets any of the seven subsets of 'national interest' outlined by the bill. These seven subsets are defined as having the potential to:

- increase economic competitiveness in the USA;
- advance the health and welfare of the American public;
- develop an American labour force trained in science, technology, engineering and mathematics that is globally competitive;
- increase public scientific literacy and public engagement with science and technology in the USA;
- increase partnerships between academia and industry in the USA;
- support the national defence of the USA; or
- promote the progress of science in the USA.

Sequestration has squeezed research budgets

As we saw in the introduction, sequestration is a set of automatic budget reductions aimed at reducing the federal deficit. Since 2013, the agencies that fund R&D have received blanket cuts ranging from 5.1% to 7.3% and can expect their budgets to remain flat through 2021. Made outside the normal budget appropriations schedule, these cuts caught many institutions by surprise, particularly the universities and government laboratories that depend on federal funding.

Since most research universities depend heavily on federal grants to fund their activities, sequestration forced an immediate and significant across-the-board cut to their

Box 5.2: Industrial trends in the USA in life sciences

Industrial investment on the rise
The USA carries out 46% of global R&D in life sciences, making it the world leader. In 2013, US pharmaceutical companies spent US$ 40 billion on R&D inside the USA and nearly another US$ 11 billion on R&D abroad. Some 7% of the companies on Thomson Reuters' Top 100 Global Innovators list for 2014 are active in life science industries, equal to the number of businesses in consumer products and telecommunications.

Pharmaceutical companies pursued mergers and acquisitions actively in 2014 and 2015. In the first half of 2014, the value of this type of activity totalled US$ 317.4 billion and, in the first quarter of 2015, the drug industry accounted for a little more than 45% of all US mergers and acquisitions.

In 2014, venture capital investment in the life sciences was at its highest level since 2008: in biotechnology, US $6.0 billion was invested in 470 deals and, in life sciences overall, US$ 8.6 billion in 789 deals. Two-thirds (68%) of the investment in biotechnology went to first-time/early-stage development deals and the remainder to the expansion stage of development (14%), seed-stage companies (11%) and late-stage companies (7%).

Astronomic rise in prescription drug prices
In 2014, spending on prescription drugs hit US $374 billion. Surprisingly, this hike in spending was fuelled by the costly new drugs on the market for treating hepatitis C (US$ 11 billion) rather than by the millions of newly insured Americans under the Patient Protection and Affordable Care Act of 2010 (US$ 1 billion). About 31% of this spending went on specialty drug therapies to treat inflammatory conditions, multiple sclerosis, oncology, hepatitis C and HIV, etc., and 6.4% on traditional therapies to treat diabetes, high cholesterol, pain, high blood pressure and heart disease, asthma, depression and so on.

From January 2008 to December 2014, the price of commonly prescribed generic drugs decreased by almost 63% and the price of commonly used branded drugs increased by a little more than 127%. However, a new trend in the USA, where drug consumer prices are largely unregulated, has been the acquisition of pharmaceuticals through licensing, purchase, a merger or acquisition, thus raising consumer prices astronomically. The *Wall Street Journal* has reported increases of as much as 600% for some branded drugs.

Costly orphan drugs
Orphan diseases affect fewer than 200 000 patients per year. Since 1983, over 400 drugs and biologic products for rare diseases have been designated by the FDA (2015), 260 alone in 2013. In 2014, sales of the top 10 orphan drugs in the USA amounted to US$ 18.32 billion; by 2020, orphan drugs sales worldwide are projected to account for 19% (US$ 28.16 billion) of the total US$ 176 billion in prescription drug spending.

However, orphan drugs cost about 19.1 times more than non-orphan drugs (on an annual basis) in 2014, at an average annual cost per patient of US$ 137 782. Some are concerned that the incentives given to pharmaceutical companies to develop orphan drugs by the FDA's orphan drug products programme is taking the companies' attention away from developing drugs that will benefit more of the population.

Medical devices: dominated by SMEs
According to the US Department of Commerce, the market size of the medical device industry in the USA is expected to reach US$ 133 billion by 2016. There are more than 6 500 medical device companies in the USA, more than 80% of which have fewer than 50 employees. Observers of the medical device field foresee the further development and emergence of wearable health monitoring devices, telediagnosis and telemonitoring, robotics, biosensors, 3-D printing, new in vitro diagnostic tests and mobile apps that enable users to monitor their health and related behaviour better.

Biotechnology clusters
Biotechnology clusters are characterized by talent from top-notch universities and university research centres; first-rate hospitals, teaching and medical research centres; (bio)pharmaceutical companies ranging from start-ups to large companies; patent activity; NIH research grant funding and state-level policies and initiatives. The latter focus on economic development but also on creating jobs within states, support for advanced manufacturing and public–private partnerships to meet demand for talent (education and training). State-level policies also invest public monies in R&D and the commercialization of the resulting product or process, in addition to boosting state-led exports.

One overview classifies the USA's biotechnology clusters by region: San Francisco Bay Area; Southern California; the mid-Atlantic region (Delaware, Maryland and Virginia and the capital, Washington, DC); the mid-West (Illinois, Iowa, Kansas, Michigan, Minnesota, Missouri, Ohio, Nebraska and Wisconsin); Research Triangle Park and the State of North Carolina; Idaho; Montana; Oregon and Washington State; Massachusetts; Connecticut, New York, New Jersey, Pennsylvania and Rhode Island; and Texas.

Another overview ranks clusters by city or metropolitan area: San Francisco Bay area, Boston/Cambridge, Massachusetts, San Diego, Maryland/suburban Washington, DC, New York, Seattle, Philadelphia, Los Angeles and Chicago.

Source: compiled by authors

research budgets. As a result, universities scrambled to reduce the budgets of projects already under way by reducing staff and student positions, delaying equipment purchases and cancelling fieldwork. Federal grants that were already funded – as well as those being solicited – all suffered from cuts to their budgets. In general, the crisis has reduced morale among young and even established scientists and encouraged many to switch career paths. Some are even moving overseas to places where there appears to be more research money available.

A major law to limit food contaminants

Since the *UNESCO Science Report 2010*, the largest single piece of legislation covering scientific issues to pass into law has been the Food Safety Modernization Act (2011). This law introduced a major overhaul of the food safety system and includes a new focus on imported foods, in particular. The overriding goal is to move from coping with contamination to preventing it.

The passage of the Food Safety Modernization Act coincided with growing consumer awareness of food safety and purity. Regulation and consumer demand are leading to some reforms within the food industry to limit the use of antibiotics, hormones and some pesticides.

TRENDS IN R&D INVESTMENT

R&D intensity has been sustained

Generally speaking, US investment in R&D rose with the economy in the first years of the century before receding slightly during the economic recession then rising again as growth resumed. GERD amounted to US$ 406 billion (2.82% of GDP) in 2009. After dipping briefly, R&D intensity recovered to 2009 levels in 2012, when GERD reached 2.81% of GDP, before dropping again in 2013 (Figure 5.2).

The federal government is the primary funder of basic research, at 52.6% in 2012; state governments, universities and other non-profits funded 26%. Technological development, on the other hand, is primarily funded by industry: 76.4% to the federal government's 22.1% in 2012.

Comparing them directly, the development phase is significantly more costly; therefore, private industry provides the largest input in absolute terms. Business enterprises contributed 59.1 % of US GERD in 2012, down from 69.0 % in 2000. Private non-profits and foreign entities each contribute a small fraction of total R&D, 3.3% and 3.8%, respectively. GERD figures are derived from the UNESCO Institute of Statistics R&D data, which were, themselves, derived from OECD statistics.

Figure 5.3 shows trends in GERD by funding source from 2005 to 2012 in current billions of dollars and constant 2005 dollars. Business sector funding of R&D (including R&D from abroad), which had contracted by 1.4% during 2008-2010, has since rebounded by 6% (between 2010 and 2012). In global terms, R&D funded by government has remained fairly stagnant since 2008, despite the Recovery Act funding of 2009 and some political talk on fostering innovation-led recovery (Figure 5.4). However, the global picture masks the sharp drop in defence R&D; that carried out by the Department of Defense contracted by 27% in real terms between 2010 and 2015 (budget request).

A steep decline in defence spending

Among the 11 agencies that conduct the majority of federally funded R&D, most have seen flat R&D budgets over the past five years, the Department of Defense even experiencing a steep decline. At its peak in 2010, the Department of Defense spent US$ 88.6 billion on R&D; in 2015, it is expected to spend only US $64.6 billion. This reflects the winding down of the interventions in Afghanistan and Iraq and the reduced need for military technologies.

According to testimony given in February 2015 by Andrew Hunter (2015) of the Center for Strategic and International Studies before the US House of Representatives Committee on Small Business, the Department of Defense contracted US$ 36 billion in R&D through industry in 2012 but only US$ 28 billion in 2013. Hunter noted that 2014 defence contract obligations appeared to show a 9% decrease over the previous year, consistent with the US army's gradual withdrawal of troops from Afghanistan by 2016.

Non-defence federal R&D contracts were slightly above US$ 10 billion in 2014, a drop of 6% over the previous year. Hunter suggested that this trend was due to a combination of decreasing federal budgets for specific research and the budget sequester instigated by Congress in 2013, which has enacted US $1 trillion in automatic cuts to the federal budget to reduce the budget deficit.

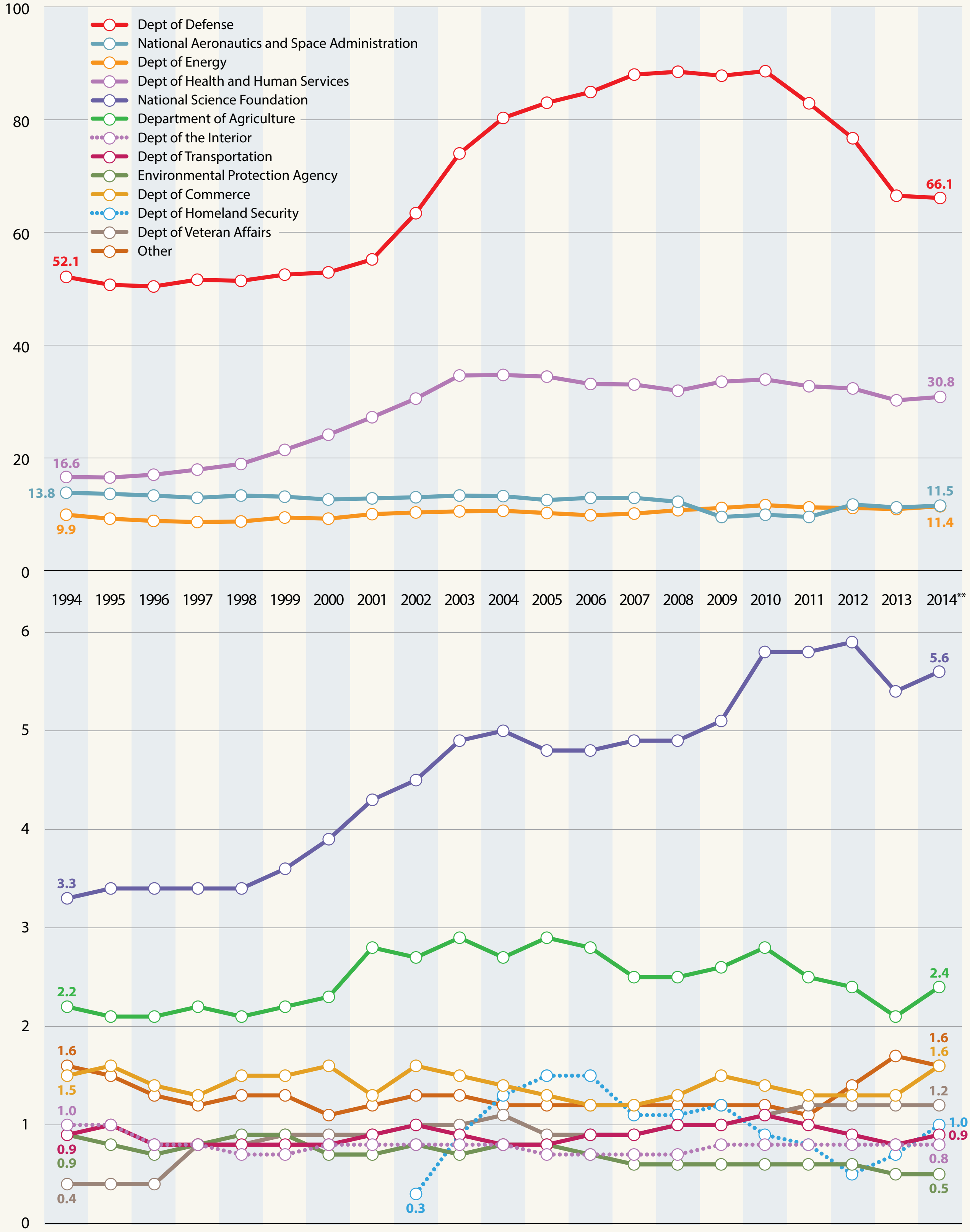
Alternative energy a priority

The main areas of non-defence R&D are public health and safety, energy, basic science and the environment. The Department of Health and Human Services saw a major increase in its budget as a result of a doubling of the NIH budget between 1998 and 2003. Since then, the department's budget has failed to keep pace with inflation, resulting in a gradual squeeze on the newly expanded pipeline of researchers and trainees.

Consistent with its focus on climate change, the government has energetically funded alternative energy initiatives. The new Advanced Research Projects Agency – Energy (ARPA-E) is modelled on the highly successful Defense Advanced Research Projects Agency programme. The latter was established in 2009 with US $ 400 million in funding from a federal stimulus package; its budget appropriations depend on the needs of the projects selected, ranging from

Figure 5.4: **R&D budget by US agency, 1994–2014**

*In billions of constant 2012 US$**



* excluding Recovery Act funding (20.5 billion US$ in 2009) ** 2014 data are provisional

Source: American Association for the Advancement of Science

US$ 180 million in 2011 to US$ 280 million in 2015. Projects are organized around seven themes, including efficiency, grid modernization and renewable energy.

The Department of Energy's budget has remained relatively stable over the past seven years. It rose fairly steeply between 2008 and 2010 from US$ 10.7 billion to US$ 11.6 billion but had fallen back to US$ 10.9 billion by 2013 (Figure 5.4).

Wrangling ahead over the 2016 research budget

The president's planned 2016 budget for science and technology comprises small cuts to defence but an increase for all other R&D under the Department of Defense. It also proposes a small increase for the NIH, cuts in defence-related nuclear energy R&D, a 37.1% cut in Homeland Security R&D, a 16.2% cut in R&D in the field of education and a few other small cuts. The National Science Foundation would receive a 5.2% increase. The Department of Energy's Office of Science would receive US$ 4.9 billion, an increase over the past two years, within the department's wider budget of US$ 12.5 billion. Overall, this budget would result in a 6.5% increase in total R&D: 8.1% for defence and 4.7% for non-defence (Sargent, 2015).

Congress has agreed to small increases for the National Science Foundation, National Institute of Standards and Technology and some Department of Energy programmes for 2016 but insists on flat funding in 2017 that would actually translate into a decrease when adjusted for inflation. Although this would only mean a slight decrease in funding for the National Science Foundation under the Congressional budget, Congress also plans to cut funding to the foundation's Social Science Directorate by 44.9%.

Congress also intends to cut funding for environmental and geoscience research, to curb the study of climate change. Congress plans to decrease R&D funds for renewable energy and advanced energy projects under the Department of Energy, while raising funds for fossil fuel energy research. Moreover, future R&D budgets will only be allowed to grow in concert with GDP. Political wrangling will determine the actual budget but, at this point, the chances of seeing significant increases in federal R&D budgets look slim, even if there is some agitation on the part of Republicans to increase NIH's budget. Figure 5.5 shows a breakdown of funding allocations by discipline.

Federal funding: a roller coaster ride

Research funding has grown at an unpredictable rate for many scientific disciplines, a trend which is ultimately disruptive to training and research. In boom times, the pipeline of trainees swells but, often, by the time they complete their training, they are facing a period of austerity and unprecedented competition for grants. Declining federal support for R&D has the greatest impact on public good science, where there is little incentive for industry to step in.

A 2015 paper published in *Science Translational Medicine* by deans of US medical schools noted that 'support for the research ecosystem must be predictable and sustainable both for institutions and individual investigators' (Levine, *et al*., 2015). They pointed out that, without greater spending, biomedical research would contract, the ability to address patient health would recede and the biomedical field would make a smaller contribution to the national economy.

An uncertain future for the NIH budget

The NIH is the government's flagship biomedical research funding organization. Since 2004, NIH funding has remained flat and is even decreasing when inflation is taken into consideration. The only brief respite came from the government's stimulus package in 2009 to reboot the economy after the subprime crisis, the American Recovery and Reinvestment Act. The NIH budget today is lower than in 2003–2005, when it peaked at *circa* $35 billion per year. Since 2006, the success rate for grant proposals has hovered around 20%.

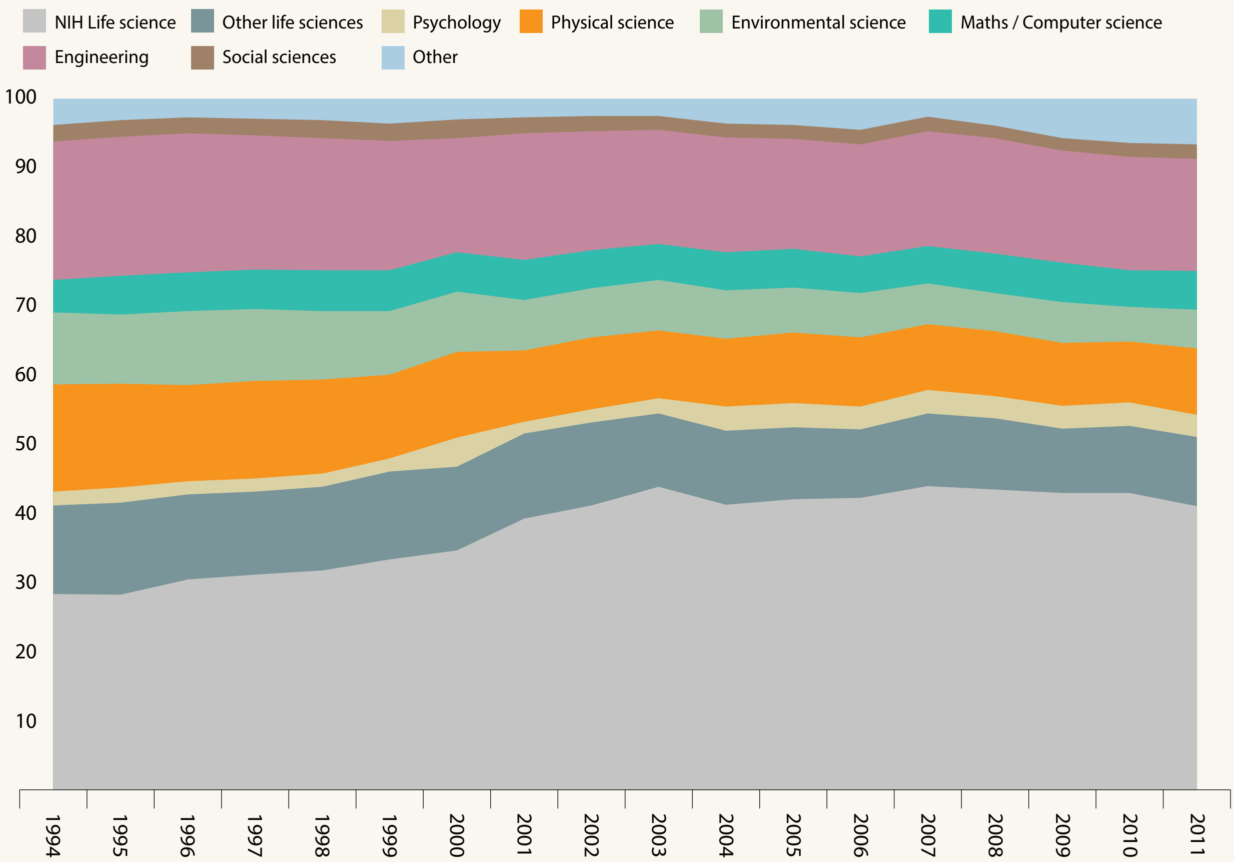
Furthermore, the average age of a researcher obtaining an NIH grant[4] for the first time is now 42 years. This raises the question of whether institutions are in a position to promote young faculty or give them tenure, as obtaining grants tends to be a pre-requisite for obtaining tenure. After reviewing the problems facing both the NIH and biomedical researchers, four top US scientists and administrators declared that the country was under the misconception 'that the research enterprise would expand forever' (Alberts *et al*., 2014). They noted that, after 2003, 'the demands for research dollars grew much faster than the supply' with the notable exception of the boost from the American Recovery and Reinvestment Act. The problem of dwindling funds has been exacerbated by the 2008 recession and the 2013 sequester of government funds. In 2014, NIH financial resources were 'at least 25% less in constant dollars than they were in 2003' (Alberts *et al*., 2014).

It is estimated that the NIH's 2016 budget will increase by 3.3% to US$ 31.3 billion, $1 billion more than in the FY2015 budget. Although this sounds promising, inflation of 1.6% and an increase in the Biomedical Research and Development Price Index[5] of 2.4% will eat into the budget increase. It will be worth watching to see whether there are moves in Congress to increase the NIH's budget. For now, the American Association for the Advancement of Science estimates that the FY2016 rate of grant funding will average 19.3%, a huge drop from the rate of 33.3% over the past decade but better than the FY2015 rate of 17.2%.

4. The majority of these grants correspond to what is known as the R01 mechanism, which limits the grant to US$ 250 million per year in direct costs for a circumscribed study of 1–5 years.

5. This index offers an estimate of inflation for goods and services purchased on the NIH's budget.

Figure 5.5: **Proportional allocation of federal R&D spending in the USA by discipline, 1994–2011 (%)**



Source: American Association for the Advancement of Science

NSF budget likely to remain flat

The National Science Foundation (NSF) is the USA's largest source of research grants for non-medical sciences. It funds most non-medical biological research and research in mathematics. At the time of writing in August 2015, the 2016 and 2017 NSF budgets have not yet been approved by Congress. Current estimates are that they will be flat for both years. The NSF has requested US$ 7.723 billion for 2015 in its submission to Congress, a 5% increase over the estimated budget. However, in the latest version of the America COMPETES Reauthorization Act of 2015, the House Committee on Science, Space and Technology has recommended an annual appropriation of US$ 7.597 billion for the 2016 and 2017 financial years, a mere 3.6% increase (US$ 263 million) over the current budget.

Although the NSF indicates an overall 23% success rate among grant applicants, some directorates have higher success rates than others. The average NSF grant runs to about US$ 172 200 per year for three years on average, which includes institutional overheads. A 23% success rate is considered fairly low, although success rates for some NSF programmes have been as low as 4–5% in some years.

Targeted cuts in 2016 to the Geosciences Directorate of 16.2% may have unintended consequences: in addition to climate change, the Geosciences Directorate also funds public interest research that is critical to tornado, earthquake and tsunami prediction and preparedness.

With the notable exception of the Departments of Defense and Energy, most government departments have much smaller research budgets than either the NIH or NSF (Figures 5.4 and 5.5). The Department of Agriculture requested a US $4 billion budget increase for 2016 but only a small portion of this department's US$ 25 billion in discretionary funds goes to research. Moreover, most of the research conducted by the Forest Service research is likely to be cut. As for the Environmental Protection Agency, it faces strong opposition from many Congressional Republicans who consider environmental regulations to be anti-business.

Six million work in science and engineering

The occupation of nearly six million US workers involved science or engineering in 2012. Over the period of 2005–2012, the USA had, on average, 3 979 full-time equivalent R&D researchers per million inhabitants. This is lower than some countries of the European Union (EU), Australia, Canada, Iceland, Israel, Japan, Singapore or the Republic of Korea but the USA also has a much larger population than any of these countries.

In 2011, GERD per researcher amounted to US$ 342 500 (in current dollars). In 2010, research and/or development was the primary or secondary activity of: 75.2 % of biological, agricultural and environmental life scientists; 70.3% of physical scientists, 66.5% of engineers, 49.4% of social scientists and 45.5% of computer and mathematical scientists.

The Bureau of Labor Statistics maps the distribution of jobs related to science and engineering across all 50 US states (Figure 5.6). Geographically speaking, there is a broad correlation between the proportion of inhabitants employed in these fields and the state's share of national GERD, although there are some stark differences. Depending on the location, these differences reflect the greater prevalence of academics in some states, or a heightened business focus on R&D. In some cases, the two are combined, since high-tech companies tend to gravitate towards those regions with the best universities. The State of California is home to the prestigious Stanford University and University of California, for instance, which rub shoulders with Silicon Valley, the name given to the area hosting the leading corporations (Microsoft, Intel, Google, etc.) and start-ups in information technology. The State of Massachusetts is known for its Route 128 around the city of Boston, which is home to numerous high-tech firms and corporations. Harvard University and the Massachusetts Institute of Technology are found within this state. Differences from one state to another may also reflect the budget available to each researcher, which varies according to sectorial specialization.

Only three states fall into the top category for both R&D spending as a share of GDP and the share of jobs in science and engineering: Maryland, Massachusetts and Washington. One can speculate that Maryland's position reflects the concentration of federally funded research institutions there. Washington State has a high concentration of high-tech firms like Microsoft, Amazon and Boeing. Taken together, the six states that are well above the mean in terms of GERD/GDP ratio account for 42% of all R&D in the USA: New Mexico, Maryland, Massachusetts, Washington, California and Michigan. The State of New Mexico is home to the Los Alamos National Laboratory but may otherwise have a relatively low GERD. As for Michigan, the engineering functions of most automobile manufacturers are located in this state. At the other end of the scale, Arkansas, Louisiana and Nevada are the only states that fall into the lowest category for both maps (Figure 5.6).

US supremacy in R&D gradually eroding

The USA invests more funds in R&D in absolute terms than the other G7 nations combined: 17.2% more in 2012. Since 2000, GERD in the USA has increased by 31.2%, enabling it to maintain its share of GERD among the G7 nations at 54.0% (54.2% in 2000).

As the home country of many of the world's leading high-tech multinationals, the US remains in the league of large economies with a relatively high GERD/GDP ratio. That ratio rose moderately since 2010 (which marked a moderate rebound from the 2008-9 contraction), albeit with a GDP growing slower than the average of last several decades.

China has overtaken the USA as the world's largest economy, or is about to do so, depending on the indicator.[6] China is also rapidly approaching the USA in terms of R&D intensity (Figure 5.5). In 2013, China's GERD/GPD ratio amounted to 2.08%, surpassing the EU average of 1.93%. Although it still trails the USA for this indicator (2.73% according to provisional data), China's R&D budget is growing fast and will 'surpass that of the USA by about 2022', according to a prediction by Battelle and *R&D Magazine* in December 2013. Several convergent factors cast doubt over the accuracy of Battelle's prediction: the deceleration in China's rate of economic growth to 7.4% in 2014 (see Chapter 23), the considerable drop in industrial production since 2012 and the major stock market slide in mid-2015.

The USA's R&D effort peaked in 2009 at 2.82% of GDP. Despite the recession, it was still 2.79% in 2012 and will slide only marginally to 2.73% in 2013, according to provisional data, and should remain at a similar level in 2014.

While investment in R&D is high, it has so far failed to reach the president's target of 3% of GDP by the end of his presidency in 2016. American supremacy is eroding in this respect, even as other nations – China, in particular – are carrying their own investment in R&D to new heights (Chapter 23).

TRENDS IN BUSINESS R&D

A rebound by business

The USA has historically been a leader in business R&D and innovation. However, the economic recession of 2008–2009 has had a lasting impact. While the major performers of R&D largely maintained their commitments, the pain of the US recession was felt mainly by small businesses and start-ups. Statistics released by the US Census Bureau showed that, in 2008, the number of business 'deaths' began overtaking the number of business 'births' and that the trend continued at least through 2012, the last year for which data are available (Figure 5.7). However, more recent data collected by the Kauffman Foundation suggest that the trend reversed in 2015.

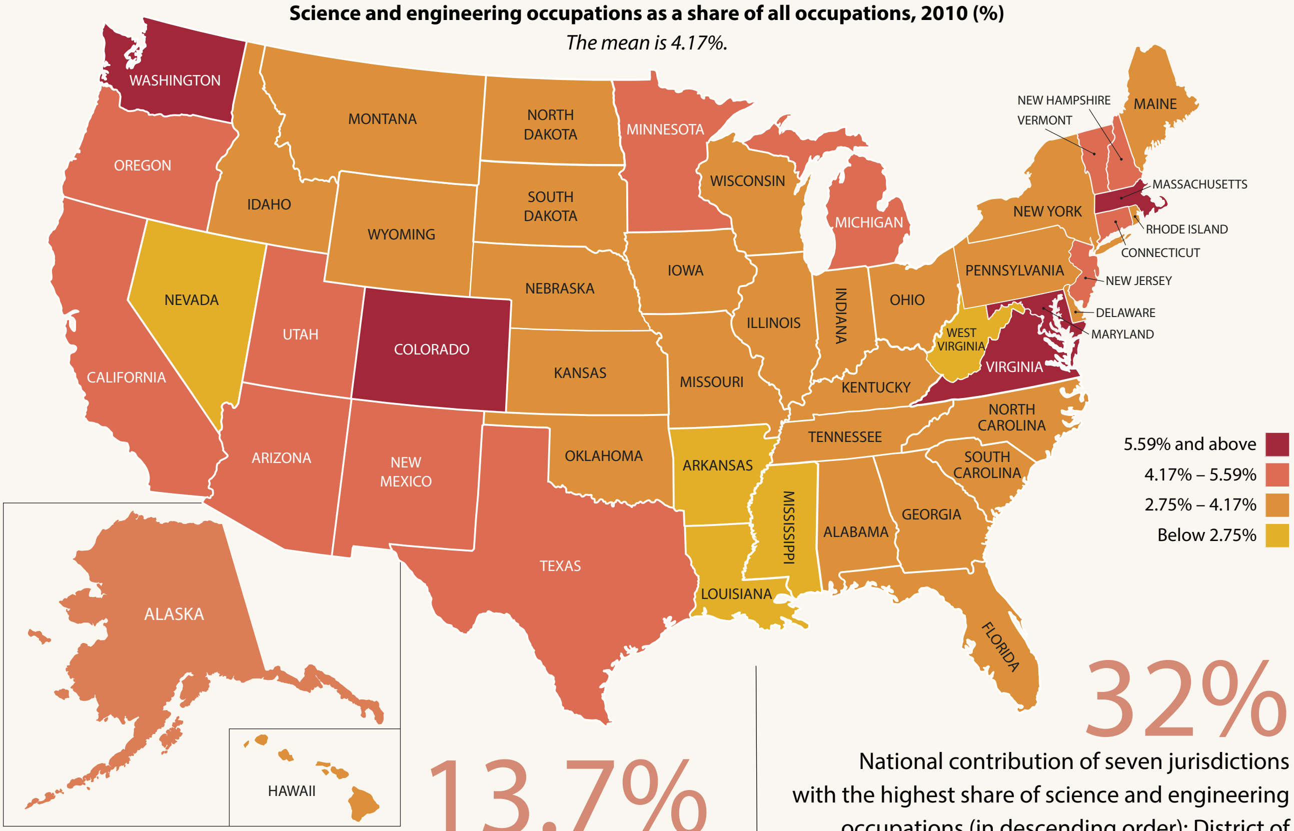
6. By 2015, the Chinese economy had overtaken the USA in terms of purchasing power parity (GDP in international dollars) but was still far from doing so in terms of GDP at market prices and exchange rates.

Figure 5.6: **Science and engineering in the USA by state, 2010**

Three states fall into the top category in both maps: Maryland, Massachusetts and Washington

Science and engineering occupations as a share of all occupations, 2010 (%)

The mean is 4.17%.



13.7%

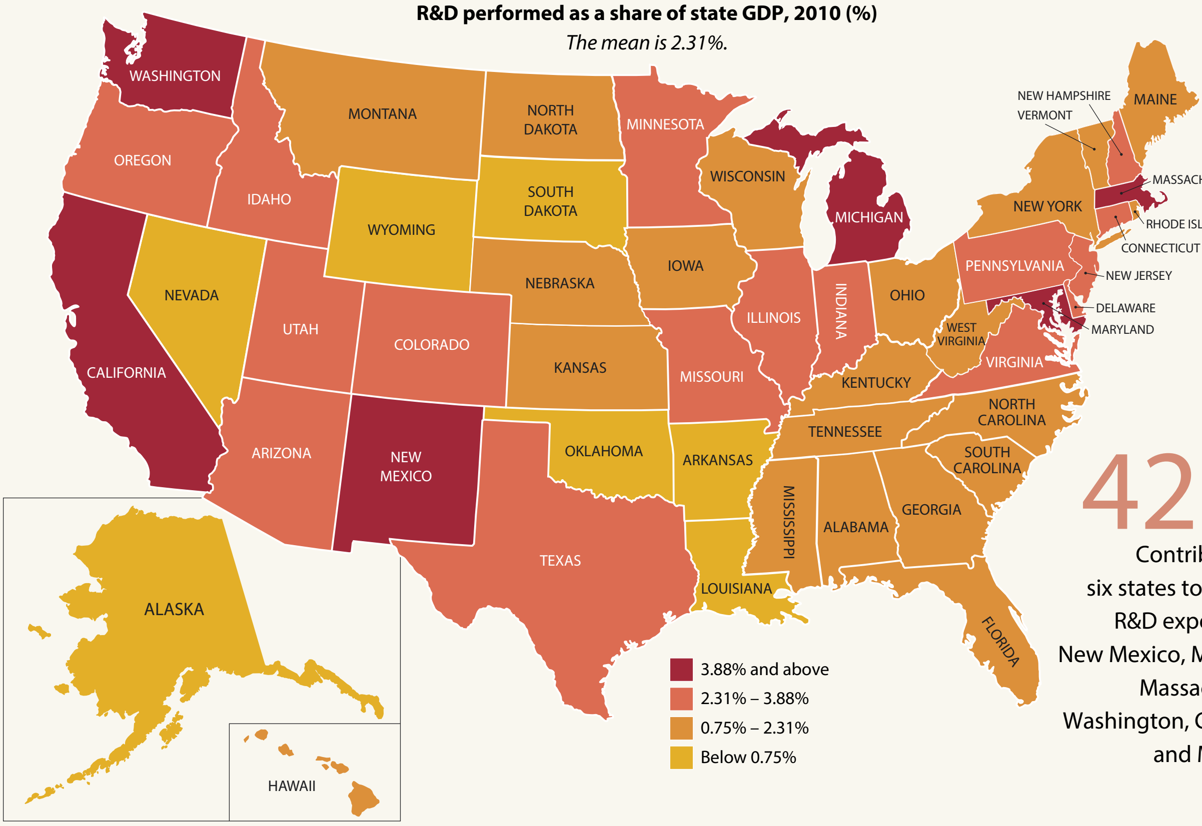
California's share of national science and engineering occupations, the top US state for this indicator

32%

National contribution of seven jurisdictions with the highest share of science and engineering occupations (in descending order): District of Columbia, Virginia, Washington, Maryland, Massachusetts, Colorado and California

R&D performed as a share of state GDP, 2010 (%)

The mean is 2.31%.



42%

Contribution of six states to national R&D expenditure: New Mexico, Maryland, Massachusetts, Washington, California and Michigan

Source: Bureau of Labor Statistics, Occupational Employment Statistics Survey (various years); National Science Foundation (2014) Science and Engineering Indicators

In 2012, business R&D activity was mainly concentrated in the States of California (28.1%), Illinois (4.8%), Massachusetts (5.7%), New Jersey (5.6%), Washington State (5.5%), Michigan (5.4%), Texas (5.2%), New York (3.6%) and Pennsylvania (3.5%). Science and engineering (S&E) employment is concentrated in 20 major metropolitan areas, comprising 18% of all S&E employment. The metropolitan areas with the greatest share of jobs in science and engineering in 2012 were all situated in the northeast, in Washington DC, Virginia, Maryland and West Virginia. Second was the Boston metropolitan area in the State of Massachusetts and third was the Seattle metropolitan area in Washington State.

Retiring baby boomers may leave jobs unfilled

Concern about the retirement of the 'baby boomers[7]' leaving R&D jobs unfilled is a major worry of company executives. The federal government will, thus, need to provide adequate funding to train the next generation of employees with skills in science, technology, engineering and mathematics.

Many of the initiatives announced by the president focus on public–private partnerships like the American Apprenticeship Grants competition. This scheme was announced in December 2014 and is being implemented by the Department of Labor with an investment of US$ 100 million. The competition encourages public–private partnerships between employers, business associations, labour organizations, community colleges, local and state governments and NGOs to develop high-quality apprenticeship programmes in strategic areas, such as advanced manufacturing, information technology, business services and health care.

Signs of inertia rather than a return to growth

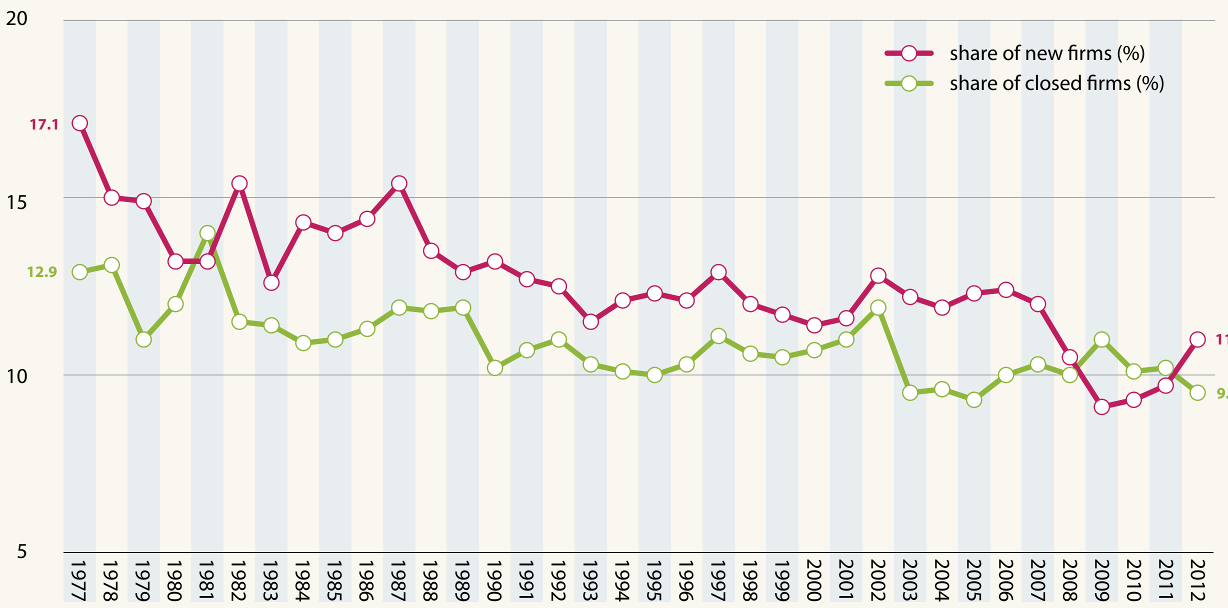
The recession has been bad for US business research spending. From 2003 to 2008, this type of expenditure had followed a generally upward trajectory. In 2009, the curve inverted, as expenditure fell by 4% over the previous year then again in 2010, albeit by 1–2% this time. Companies in high-opportunity industries like health care cut back less than those in more mature industries, such as fossil fuels. The largest cutbacks in R&D spending were in agriculture production: -3.5% compared to the average R&D to net sales ratio. The chemicals and allied products industry and electronic equipment industry, on the other hand, showed R&D to net sales ratios that were 3.8% and 4.8% higher than average. Although the amount of R&D spending increased in 2011, it was still below the level of 2008 expenditure.

By 2012, the growth rate of business-funded R&D had recovered. Whether this continues will be contingent on the pursuit of economic recovery and growth, levels of federal research funding and the general business climate. Battelle's 2014 *Global R&D Funding Forecast* (published in 2013) had predicted a 4.0% increase in R&D funded by business in the USA from 2013 to 2014 to US$ 307.5 billion – about one-fifth of global R&D.

The industry information provider, IBIS World, shows business R&D expenditure increasing in 2015, decreasing in 2017–2018 then rising again, but only slightly, in 2019 (Edwards, 2015). IBIS attributes this to the transition from dependence on

7. Those born between 1946 and 1964 in the aftermath of the Second World War, when there was a surge in the birth rate.

Figure 5.7: **Survival rate of US start-ups, 1992–2010**



Source: US Census Bureau, Business Dynamic Statistics, published by Gallup federal investment to a more self-sustained model. Although research expenditure will keep rising, the rate of increase is likely to be in the 2% per year range and, with decreases in some years, overall growth may be relatively flat. The Industrial Research Institute's forecast for 2015 is based on a survey of 96 research leaders: it forecasts that companies will maintain flat growth of R&D budgets over 2014 levels. The IRI report states that 'data on 2015 is indicative of inertia, not a return to growth' (IRI, 2015).

Venture capital has fully recovered

The one bright spot in the financial picture for technology-related companies is the burgeoning venture capital market. The National Venture Capital Association (NVCA) reported in 2014 that venture capital investment totaled US$ 48.3 billion for 4 356 deals. This, says NVCA, is 'an increase of 61% in dollars and a 4% increase in deals over the prior year….' The software industry dominated these deals, with US$ 19.8 billion having been invested in 1 799 deals. Second came internet-specific companies, which garnered US$ 11.9 billion in investment through 1 005 deals. The life sciences, including biotechnology and medical devices, received US$ $8.6 billion in 789 deals (Box 5.2). The *STI Outlook 2014* published by the Organisation for economic Co-operation and Development estimates that venture capital investment in the USA 'has fully recovered.'

Mergers, acquisitions and moves offshore

In the quest for talent, access to new markets and unique products, some traditional performers of R&D have been actively engaging in mergers and acquisitions. In the 12 months from 30 June 2014 to 30 June 2015, 12 249 deals were concluded in the USA, 315 of which represented more than US$ 1 billion. Notable among them was a flurry of acquisitions by technology giants Yahoo, Google and Facebook, each seeking to add new talent and products to its stable. On the other hand, several pharmaceutical companies have made strategic mergers in recent years to relocate their headquarters overseas to order to gain a tax advantage, including Medtronic and Endo International. Pfizer's own attempt to take over the British pharmaceutical company Astrazeneca aborted in 2014, after Pfizer admitted plans to cut research spending in the combined company (Chapter 9).

Some US companies are taking advantage of globalization to move their R&D activities overseas. Some multinational companies specializing in pharmaceuticals, in particular, may be moving at least some of their R&D to Asia on a large scale. The Industrial Research Institute actually notes in its report a decrease in the number of foreign-supported laboratories in China but this finding stems from a small sample of business executives (IRI, 2015).

Factors that can influence the decision to move R&D offshore include tax advantages but also the availability of local talent, streamlining the speed to market and the opportunity to adapt products to a local market. However, offshoring comes with a potential drawback: the added organizational complexity can make the company less adaptive and flexible. Experts from the *Harvard Business Review* have suggested on several occasions that there is an optimal point of offshoring for any given business that depends on the industry and market.

High R&D spending fosters greater sales

Does high corporate R&D spending result in greater net sales? The answer is yes. The financial benefits seem to be highly contextual and selective. Bloomberg estimated in March 2015 that US corporate R&D grew by 6.7% in 2014, the biggest growth since 1996. Bloomberg estimates that 18 big companies catalogued in Standard & Poor's 500 Index increased R&D by 25% or more from 2013 and that these straddle a range of sectors from pharmaceuticals to hospitality and information technology. Bloomberg also considers that the 190 companies in this index that declare R&D outperform the index.[8]

On the other hand, Hesseldahl (2014) discussed a report from Bernstein Research on technology companies that arrived at the opposite conclusion. It claimed that 'companies that spent the most on R&D tended to have shares that underperformed the markets over time and also relative to those companies that spent less.' In fact, companies spending the most on R&D relative to sales saw their average share price decline by 26% after five years, not precluding growth in the interim. Those technology companies that invested a middle amount of R&D also saw a decline (15%) after five years. Only some of the companies that invested the least in R&D saw their share price rise after five years, although many of those companies experienced share price losses. John Bussey (2012) of the *Wall Street Journal* has noted that those companies investing the most in R&D are not necessarily the best innovators with the best financial performance for each R&D dollar spent. From this, we can conclude that corporate investment in R&D should be primarily determined by a fundamental need for specific R&D.

Tax credits undermined by uncertainty

The federal government and most of the 50 states that make up the USA offer R&D tax credits for particular industries or companies in particular areas. Congress usually renews a federal R&D tax credit every few years. According to Emily Chasan (2012) from *The Wall Street Journal*, since companies cannot rely on these credits being renewed, they do not factor them in when making decisions about investing in R&D.

A report by Rubin and Boyd (2013) for the State of New York on its numerous business tax credits stated that 'there is no conclusive evidence from research studies conducted since the mid-1950s to

8. See: www.bloomberg.com/news/articles/2015-03-26/surge-in-r-d-spending-burnishes-u-s-image-as-innovation-nation show that business tax incentives create net economic gains to the states above and beyond what would have been attained in the absence of the incentives. Nor is there conclusive evidence from the research that state and local taxes, in general, have an impact on business location and expansion decisions.'

Indeed, companies decide to invest in R&D based on a single factor: the need for R&D. Tax incentives tend to reward these decisions after-the-fact. Furthermore, many small companies fail to recognize that they are eligible to claim the credit and, thus, fail to take advantage of it.

Transition to a 'first to file' model

In 2013, US residents filed 287 831 patents, almost the same number as non-residents (283 781). In China, on the other hand, just 17% of patents were filed by non-residents and there were as many as 704 836 resident applications to the State Intellectual Property Office (see Figure 23.5). Likewise, in Japan, non-residents accounted for just 21% of patent applications. The picture changes somewhat when one examines the number of patents in force. Although China is catching up fast, it still trails the USA, Japan and the EU for this indicator (Figures 5.8 and 5.9).

The America Invents Act of 2011 moved the USA from a 'first to invent' system to a 'first to file' model, the most significant patent reform since 1952. The act will limit or eliminate lengthy legal and bureaucratic challenges that used to accompany contested filings. However, the pressure to file early may limit the inventor's ability to exploit the period of exclusivity fully. It may also disadvantage very small entities, for which the legal costs of preparing an application are the main barrier to filing. This legislation has also fostered the rise of what are familiarly known as patent trolls (Box 5.3).

A post-industrial country

The USA has run a negative trade balance since at least 1992. The balance for trade in goods is consistently negative. The deficit reached a high of US$ 708.7 billion in 2008 before falling precipitously to US$ 383.8 billion the following year. In 2014, the balance stood at US$ 504.7 and will remain negative into 2015. High-tech imports have been lower in value than exports and led mostly (in terms of value) by computers and office machines, electronics and telecommunications (Figure 5.10).

The USA lost its world leadership for the volume of high-tech exports to China some time ago. However, up until 2008, it was still the largest exporter of high-tech goods excluding computing and communications equipment. Much of the latter has become commoditized and is now assembled in China and other emerging economies, with high-tech, value-added components being produced elsewhere. The USA imported US$ 105.8 billion worth of computers and office machines in 2013 but exported just US$ 17.1 billion worth of the same.

Since the crisis of 2008–2009, the USA has also fallen behind Germany for high-tech exports (Figure 5.10). The last year in which the USA showed a positive trade balance for aerospace technology was 2008, the year it exported nearly US$ 70 billion worth of aerospace products. In 2009, the value of aerospace imports overtook that of exports, a trend that lasted through 2013. The USA's trade in armaments managed to conserve a slight positive balance between 2008 and 2013. The USA's trade in chemistry products has been near-equal, with greater value in imports in 2008 and 2011–2013. Trade in electrical machinery has been fairly constant, with imports representing nearly double the value of exports. The USA also lags far behind its competitors in electronics and telecommunications, with imports worth US$ 161.8 billion in 2013 and exports worth just US$ 50.5 billion. Until 2010, the USA was a net exporter of pharmaceuticals but has become a net importer since 2011. The other area where the USA's exports are slightly higher in value than its imports is scientific instruments but here the difference is slight.

When it comes to trade in intellectual property, however, the USA remains unrivalled. Income from royalties and licensing amounted to US$ 129.2 billion in 2013, the highest in the world. Japan comes a distant second, with receipts of US$ 31.6 billion that year. The USA's payments for use of intellectual property amounted to US$ 39.0 billion in 2013, exceeded only by Ireland (US$ 46.4 billion).

The USA is a post-industrial country. Imports of high-tech products far exceed exports. New cellphones, tablets and smart watches are not manufactured in the USA. Scientific instruments that were once made in the USA are increasingly being made overseas. However, the USA profits from a technologically skilled workforce that, second to China in size, still produces a large volume of patents and can still profit from the license or sale of those patents. Within the USA's scientific R&D industries, 9.1% of products and services are concerned with the licensing of intellectual property rights.

Together with Japan, the USA remains the largest single source of triadic patents, which are a proxy for an economy's ambition and its effort to pursue technology-driven competitiveness in the principal advanced country markets. Since the mid-2000s, the USA has falling triadic patenting numbers, along with other large advanced economies, but triadic patenting resumed growth in the USA in 2010 (Figure 5.8).

Five corporations in top 20 for R&D spending

The top 11 USA-based multinational corporations for R&D funding in 2014 were responsible for a total of US$ 83.7 billion in R&D expenditure (see Table 9.3). The top five have figured among the world's top 20 for at least 10 years: Intel, Microsoft, Johnson & Johnson, Pfizer and IBM. The top international firm for R&D investment in 2014 was the German corporation Volkswagen, followed closely by the Korean Samsung (see Table 9.3).

Box 5.3: The rise (and fall?) of patent trolls

'Patent troll' is a term used widely to designate firms that are formally called patent assertion entities. These firms make no products but rather focus on buying dormant patents from other firms, often at a low price. Ideally, the patent they purchase is broad and vague. The troll then threatens high-tech firms with litigation for infringement of its patent, unless the firm agrees to pay a licensing fee that may run into the hundreds of thousands of dollars. Even if the firm is convinced that it has not infringed the patent, it will often prefer to pay the licensing fee rather than risk litigation, as cases can take years to settle in court and entail exorbitant legal costs.

Patent trolls have become a nightmare for companies in Silicon Valley, in particular, including giants Google and Apple. However, trolls also harass small start-up companies, some of which have been forced out of business.

The business is so lucrative that the number of patent trolls has grown exponentially in the USA: in 2012, 62% of patent litigation was brought by patent trolls.

The America Invents Act of 2011 set out to limit the power of patent trolls by preventing ligitators from attacking several companies at once in a single lawsuit. In reality, this has had the opposite effect by multiplying the number of lawsuits.

In December 2013, the House of Representatives passed a bill that would have required a judge to determine early on in the legal process whether a given patent was valid. However, the bill failed to pass into law after being shelved by the Senate Judiciary Committee in May 2014 following intense lobbying by pharmaceutical and biotech companies and universities, which feared the new law would make it hard for them to defend their own patents.

Ultimately, reform may come not from Congress but from the judiciary. A decision by the US Supreme Court on 29 April 2014 should make patent trolls think twice in future before bringing frivolous lawsuits. The decision departs from the so-called American Rule, which generally requires litigants to bear their own legal costs. It brings litigation closer to the English rule of 'loser pays,' whereby the unsuccessful litigant is forced to bear the legal costs of both parties – which may explain why patent trolls are much less common in the UK.

In August 2014, US judges cited the Supreme Court judgment in their decision on an appeal filed by Google against patent troll Vringo, which was claiming hundreds of millions of US dollars. The judges found against Vringo in the appeal on the grounds that neither of its two patents was valid.

Source: Fisher, D. (2014) Patent trolls face higher risks as Supreme Court loosens fee-shifting rule. *Forbes.com* 29 April; Wyatt, E. (2014) Legislation to protect against 'patent trolls' is shelved. NY Times Online, 21 May; Chien, C. (2013) *Patent Trolls by the Numbers.* Santa Clara Law Digital Commons. Compiled by Susan Schneegans, UNESCO.

Google was included in this list for the first time in 2013 and Amazon in 2014, which is why the online store does not appear in Table 9.3, despite having spent US$ 6.6 billion on R&D in 2014. Intel's investment in R&D has more than doubled in the past 10 years, whereas Pfizer's investment is down from US$ 9.1 billion in 2012.

The technological ambitions of the new giants of information and communications technology (ICTs) can broadly be described as smoothing the interface between information technology and the physical world. Amazon has optimized the consumer experience by developing services like Prime and Pantry to meet consumer needs in almost real time. Amazon recently introduced a limited pilot of the Dash Button, an extension of Amazon Pantry that allows a user to re-order a household consumable by pressing a physical button. Google has made several acquisitions of products at the interface of computation and the physical world, including autonomous thermostats, and has developed the first operating system specifically for such low-power devices. Perhaps the most ambitious project is Google's self-driving car, which is scheduled for commercial release in the next five years. Conversely, Facebook is developing virtual reality technology based on their acquisition of Oculus Rift, an approach that will integrate people into the digital environment, rather than vice versa.

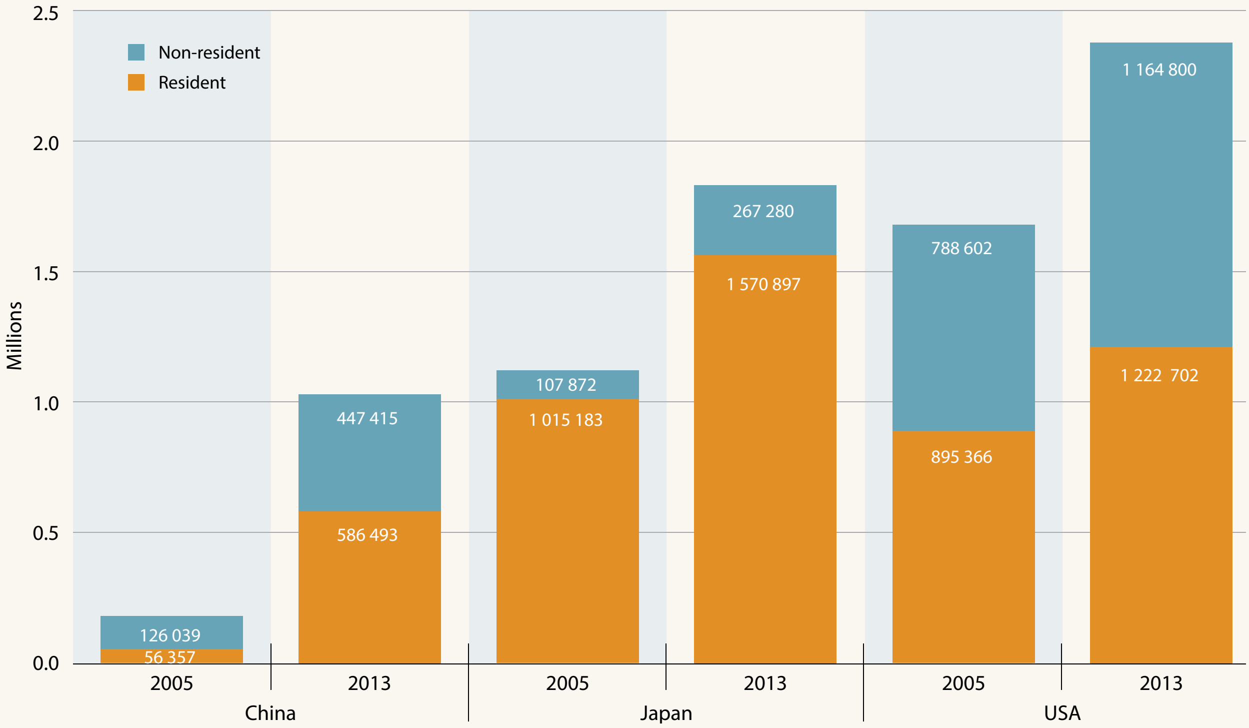
The small sensors that facilitate this connectivity are also being applied in industry and health care. Since it relies on service contracts for much of its revenue, General Electric is currently investing in sensor technology to collect more information about the performance of its aeroplane engines in flight. Meanwhile, in health care, a few new enterprises are experimenting with the use of data from personal activity trackers to manage chronic diseases like diabetes.

Massachusetts a hotspot for non-profit R&D

Private non-profit organizations account for about 3% of GERD in the USA. In the 2013 fiscal year, federal obligations to non-profits for R&D totalled about US$ 6.6 billion. Among non-profits, those in the State of Massachusetts received the greatest share of federal funding: 29% of the total in 2013, driven primarily by the cluster of research hospitals near Boston.

Figure 5.8: **Patents in force in the USA, 2005 and 2013**

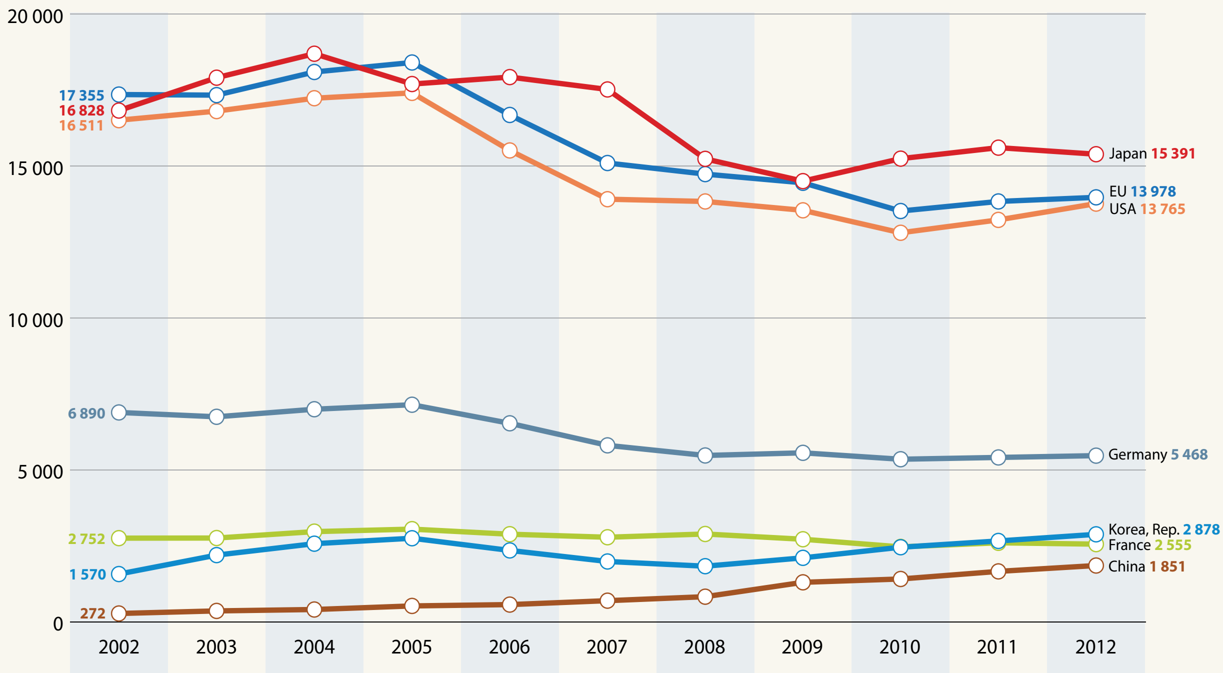
Other major economies are given for comparison



Source: WIPO statistics online, accessed on 27 August 2015; patents held by the primary patent office for each economy: China's State Intellectual Property Office, Japan Patent Office, European Patent Office, US Patent and Trademarks Office for the USA

Figure 5.9: **Triadic patents of the USA in the USPTO database, 2002–2012**

Number of triadic patents (nowcasting) for the world's largest economies for this indicator

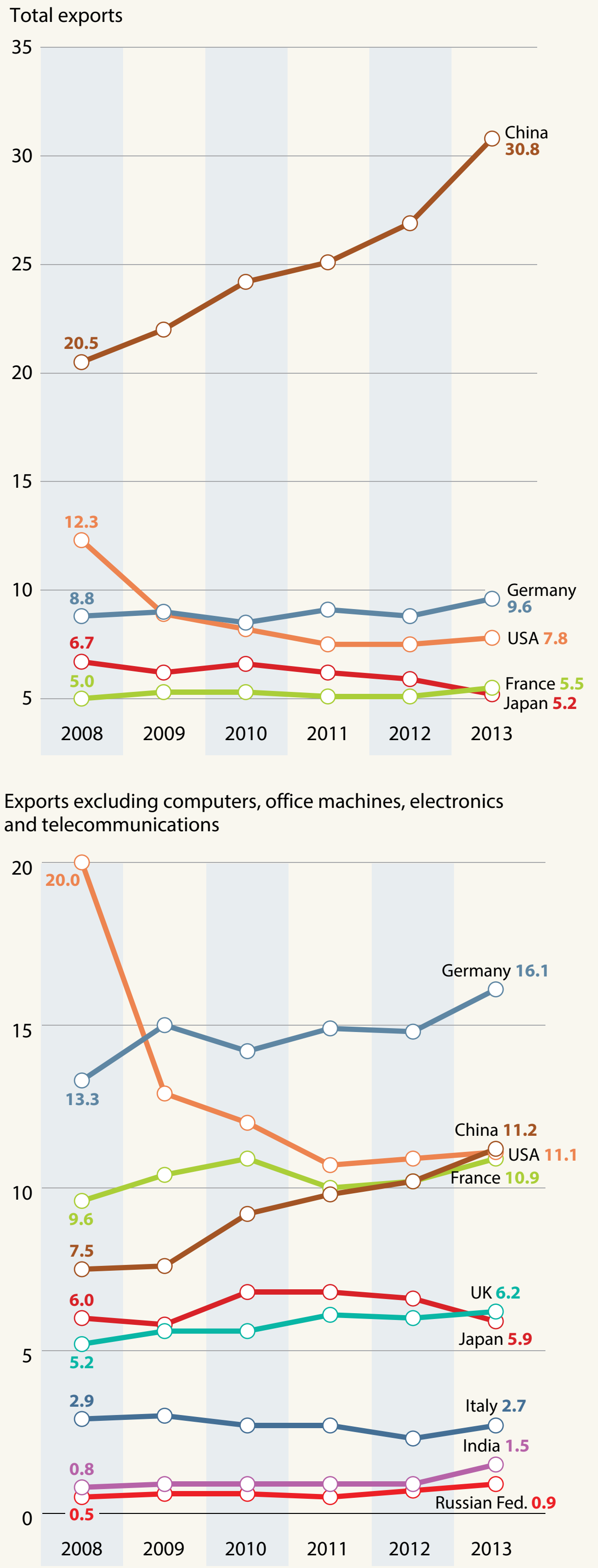


Note: Triadic patents are filed by the same inventor for the same invention in the USA, Europe and Japan.

Source: OECD Patent Statistics (database), August 2015

Figure 5.10: **High-tech exports from the USA as a world share, 2008–2013 (%)**

Other large exporters are given for comparison



Source: Comtrade database of United Nations Statistics Division, July 2014

Half of all federal obligations to non-profits are distributed within Massachusetts, California and the District of Columbia, three states which also happen to account for a sizeable share of the nation's R&D expenditure and science and engineering occupations (Figure 5.6). The institutions that receive the lion's share of funding are the national security-oriented MITRE Corp., research hospitals and cancer centres, Batelle Memorial Institute, the R&D generalist SRI International and RAND Corporation. Non-profits can also raise money for R&D from private sources, such as philanthropic donations (Box 5.4).

TRENDS IN EDUCATION

Common core standards to improve science teaching

To prepare for the projected growth in jobs in science, technology, engineering and mathematics in the coming years, the Department of Education has focused on improving the proficiency of students and teachers in these subjects. To that end, a group under the aegis of the National Governors Association created the Common Core State Standards in 2009 for proficiency in English and mathematics.

These are national standards, as opposed to state ones. The US education system is highly decentralized, however, so federal policy may not be fully implemented in practice. In anticipation of this, the Obama administration has created incentives like the US$ 4.3 billion Race to the Top, a competition for funding designed to encourage states to engage in educational reform.

Common Core Standards are highly controversial, as they require very difficult standardised testing, with tests produced by major academic publishing houses. It remains to be seen whether schools that embrace the Common Core Standards will prepare students any better for a career in science and engineering.

A drive to improve the quality of education

The America COMPETES Act is intended to bolster US competitiveness in science, technology, engineering and mathematics through education. It places strong emphasis on improving this type of education at all levels through teacher training. This has resulted in the creation of a STEM Master Teacher Corps. Additionally, the administration has formed a loose coalition of government and non-profit groups with an interest in teacher education called *100Kin10,* the explicit goal of which is to prepare 100 000 excellent teachers of these subjects and, in turn, one million qualified workers within 10 years.

The America COMPETES Act also mandates programmes to retain undergraduates majoring in S&T fields, with an emphasis on underrepresented minorities, such as African Americans, Latinos and Native Americans. In addition, it provides scientific institutions with funds to stimulate

Box 5.4: American billionaires driving more R&D

America's billionaires have increased their influence on R&D in both for-profit and non-profit contexts and are having a major impact on research priorities. Critics suggest that this influence is skewing research activities towards the narrow interests of wealthy, predominantly Caucasian patrons and the elite universities where most of these billionaires received their education.

Some projects do, indeed, focus explicitly on the personal interests of their patrons. Eric and Wendy Schmidt founded the Schmidt Ocean Institute after an inspiring diving trip in the Caribbean, for instance, and Lawrence Ellison founded the Ellison Medical Foundation after a series of salons held at his home that had been led by Nobel laureate Joshua Lederberg. Conversely, the Bill and Melinda Gates Foundation, perhaps the most high-profile philanthropic research organization of all, has consistently defied that trend by instead focusing on the diseases that most affect the world's poor.

Philanthropic and other privately funded R&D has a complex relationship with federal priority-setting. Some privately funded groups have stepped in when political will is weak. For example, executives from eBay, Google, and Facebook are funding the development of a space-based telescope to search for asteroids and meteors that threaten to strike Earth for far less money than a similar project would require at NASA. SpaceX, the private venture of Elon Musk, has achieved similar savings for the federal government by acting as a contractor. SpaceX has received more than US$ 5.5 billion in federal contracts from the US Air Force and NASA. It received a US$ 20 million subsidy from the State of Texas to build a launching facility to foster the state's economic development.

Other philanthropy-driven R&D priorities have become federal priorities, as well. Before President Obama announced his BRAIN initiative, Paul G. Allen and Fred Kavli had established privately funded brain institutes in Seattle in the State of Washington and at the three Universities of Yale, Columbia and California, with scientists at those institutes helping to develop the federal agenda.

Source: compiled by authors

student interest through informal education. It also prioritizes vocational training in advanced manufacturing at the secondary school and community college levels. Lastly, it requires that the White House Office of Science and Technology Policy draw up a strategic plan for science, technology, engineering and mathematics education every five years.

A drop in revenue for state universities

Since the recession of 2008–2009, public research universities have experienced a decline in state appropriations, federal research funds and other grants, while enrolment has increased. The result has been a major decline in the amount of funding per student at these universities, despite dramatic increases in tuition fees and deferrals of facility maintenance. The National Science Board predicted in 2012 that this cost-saving drive would have a lasting impact on the educational and research capacities of public research universities. (The pattern of growth in scientific publications does seem to have become more irregular since 2011, see Figure 5.11). This prospect is particularly troubling because demand for public education is rising fastest among historically disadvantaged groups who would otherwise choose two-year degree programmes at for-profit institutions; public universities provide educational opportunities in science and engineering that their for-profit competitors do not (National Science Board, 2012).

Universities have responded to the constrained funding environment by looking for new ways to diversify revenue and decrease costs. This includes seeking new sources of funding from industry, relying heavily on temporary contract or adjunct workers for both teaching and research and the adoption of new teaching technologies that allow bigger class sizes.

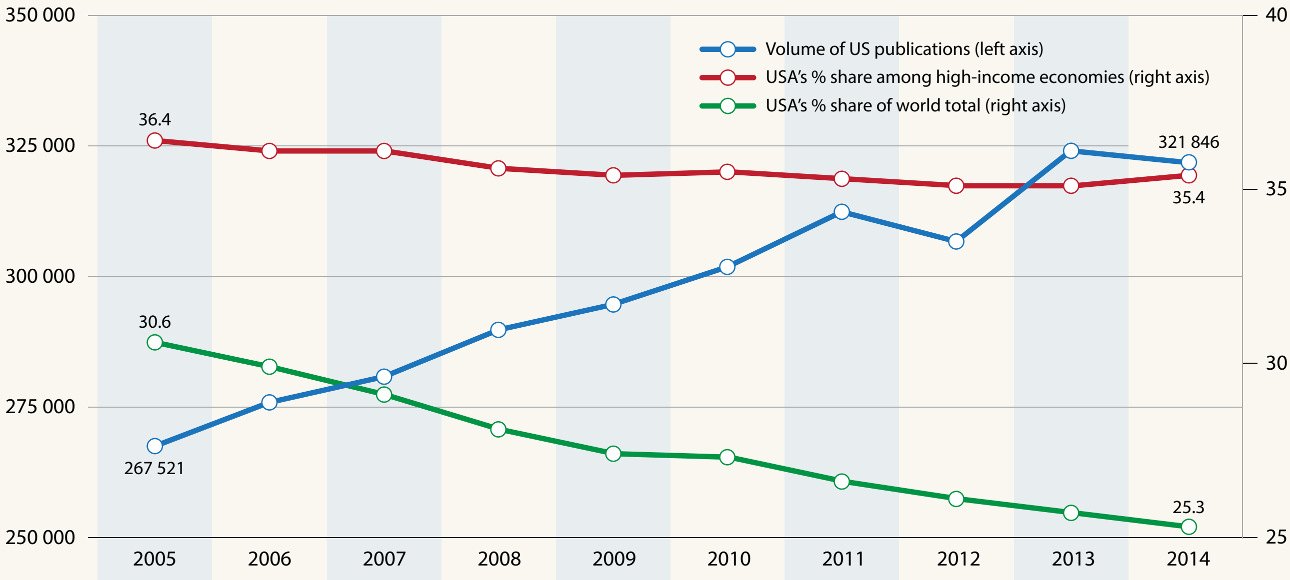
Too many researchers competing for academic posts

In the latter half of the 20th century, scientific departments at US universities went through a growth phase. Each investigator would train several people who could then reasonably expect to obtain an academic research position themselves. Recently, science departments have stopped expanding. As a result, the pipeline has dramatically narrowed at the postdoctoral phase, creating a bottleneck that effectively stalls the career of many researchers.

A 2015 National Academy of Sciences report suggests that, as tenure-track positions become scarcer, academic postdoctoral fellowships are being extended. In parallel, the fraction of graduates who pursue a fellowship before obtaining their first faculty position is increasing, a practice that is spreading to new fields. As a result, the number of postdoctoral researchers climbed by 150% between 2000 and 2012. Although postdoctoral fellowships were originally conceived as advanced research training, in practice, evidence suggests

Figure 5.11: **Scientific publication trends in the USA, 2005–2014**

The USA has maintained its share of publications among high-income economies



1.32
Average citation rate for US publications, 2008–2012; the OECD average is 1.08

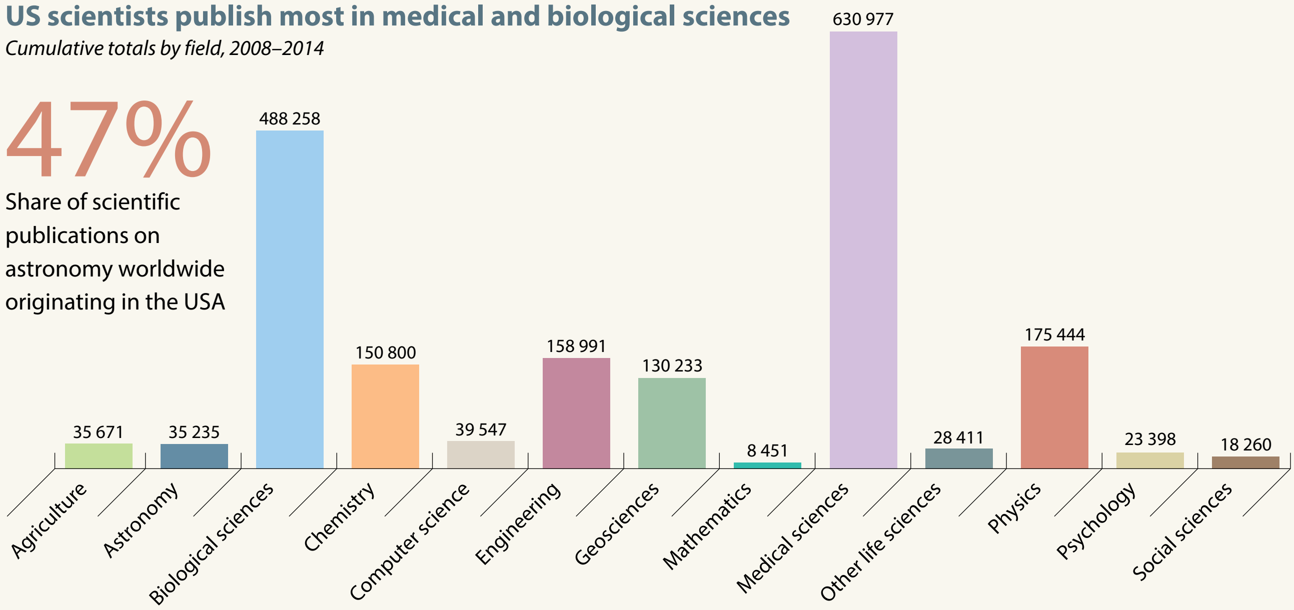
14.7%
Share of US papers among 10% most cited papers, 2008–2012; the OECD average is 11.1%

34.8%
Share of US papers with foreign co-authors, 2008–2014; the OECD average is 29.4%

US scientists publish most in medical and biological sciences

Cumulative totals by field, 2008–2014

47%
Share of scientific publications on astronomy worldwide originating in the USA



Note: The totals exclude 175 543 unclassified articles.

The USA's main partner is China, followed closely by the UK, Germany and Canada

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
USA	China (119 594)	UK (100 537)	Germany (94 322)	Canada (85 069)	France (62 636)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

that not all postdoctoral fellowships provide consistent and thorough mentoring and professional development. Often, hopeful academics will stall professionally in postdoctoral fellowships while providing high-quality research for low pay on indefinite terms.

Open innovation: a marriage of reason

Realizing that it had a lot of gain from encouraging the adoption of technologies developed with federal grant money, Congress passed the Bayh Dole Act in 1980. The act allowed universities to retain intellectual property rights from federally funded R&D and launched a trend in the university system towards the patenting and licencing of new technology.

As a result, some universities have become foci of innovation, where small start-ups developed from on-campus research add value and, usually, partner with a larger established industrial partner to bring its product(s) to market. Having observed the success of these universities in seeding local innovation ecosystems, a growing number of universities are developing internal infrastructure like technology transfer offices, to support start-ups based on research, and incubators for faculty inventors that are designed to support embryonic companies and their technologies (Atkinson and Pelfrey, 2010). Technology transfer supports the university mission in disseminating ideas and solutions that can be put into practice. It also supports job growth in their local economies and increases ties to industry that form the basis for sponsored research. However, owing to its unpredictable nature, technology transfer is not a reliable supplement to the university's revenue compared to other sources of revenue, such as federal grants and tuition.

From the industrial perspective, many companies in technology-heavy industries are finding that partnering with universities is a more effective use of their R&D investment than developing technologies internally (Enkel, *et al*., 2009). By sponsoring university research, they benefit from the broad expertise and collaborative environment within academic departments. Although industry-sponsored research accounts for only 5% of academic R&D, leading universities are increasingly relying on research dollars from industry as alternatives to federal and state dollars. Incentives are not always directly aligned on sponsored research, however. The career of academic researchers is dependent on publishing their results, whereas industrial partners may prefer not to publish to prevent competitors from benefiting from their investment (see also Chapter 2).

An 8% rise in foreign students since 2013

In the 2013/2014 academic year, over 886 000 international students and their families living in the USA supported 340 000 jobs and contributed US$ 26.8 billion to the US economy, according to a 2014 report by the National Association of Foreign Student Advisers.

The number of US citizens studying overseas was much lower, just under 274 000. The top five destinations for US students were the UK (12.6%), Italy (10.8%), Spain (9.7%), France (6.3%) and China (5.4%). These statistics belie the sheer numbers of students enrolled outside the country of their citizenship: 4.1 million in 2013, 53% of whom came from China, India and the Republic of Korea (see also Chapter 2).

The top five foreign student populations in the USA in 2014 were from China (28%), India (12%) and the Republic of Korea (*circa* 8%), Saudi Arabia (*circa* 6%) and Canada (*circa* 3%), according to the July 2014 quarterly review of the Student and Exchange Visitor Information System published by US Immigration and Customs Enforcement (ICE). Some 966 333 foreign students were following a full-time academic or vocational programme at a certified tertiary institution (F-1 and M-1 visas).[9] According to ICE, the numbers of F-1 and M-1 visa-holders increased by 8% from 2013 to 2014. An additional 233 000 students were J-1 visa holders.

More than half of the F-1 and M-1 visa students were men (56%), according to statistics collected by ICE. Almost one in four of the women (58%) were from Eastern Europe and three-quarters (77%) of the men from Western Asia. A little less than half of students with this type of visa had chosen California as their destination, followed by New York and Texas.

The bulk of these students are pursuing degrees in the following fields: business, management and marketing; engineering; computer and related sciences; and education-related studies. Among those studying science, technology, engineering or mathematics, three-quarters (75%) had opted for engineering, computer and information sciences and support services, or biological and biomedical sciences.

In 2012, the USA hosted 49% of the world's international doctoral students in science and engineering (See Figure 2.12). The National Science Foundation's 2013 *Survey of Earned Doctorates* compared doctoral degrees awarded to US citizens with those awarded to students with permanent residence and temporary visa-holders. The study found that temporary visa-holders earned 28% of the doctoral degrees awarded in the life sciences, 43% of those in the physical sciences, 55% in engineering, 10% in education, 14% in humanities, and 33% in non-science and engineering fields. These percentages have increased slightly for all fields since 2008.

9. J-1 visas are conferred on foreign nationals selected by a Department of State-designated programme to participate in an exchange visitor programme.

More foreign students being wooed back home

Historically, a large majority of trainees from overseas who came to the USA have stayed on indefinitely. As the countries of origin develop increasingly sophisticated R&D sectors, students and trainees are seeing more opportunities open up at home. As a result, the rate of return migration among foreign students and postdoctoral scholars is rising. Twenty years ago, around one in 10 Chinese doctoral graduates returned to China after completing their degree but the current rate is closer to 20% and the trend is gaining momentum (see also Box 23.2).

The drivers of this trend are a push–pull phenomenon in which the US research environment seems increasingly competitive, even as foreign enterprises are offering skilled workers more opportunities. For instance, the scarcity of visas for skilled workers creates tough competition for those wishing to work in sophisticated US industries; in 2014, the lottery for these visas closed after just one week because it was oversubscribed. US business executives are strongly in favour of increasing the number of visas for skilled workers, particularly in the software industry. At the same time, countries such as China, India and Singapore are investing heavily in building world-class research facilities, a potent lure for US-trained foreign students to return home.

SCIENCE, TECHNOLOGY AND THE PUBLIC

Americans positive about science

Several recent surveys have found that Americans' attitudes towards science are generally positive and optimistic (Pew, 2015). They value scientific research (90% support maintaining or increasing research funding) and have high confidence in scientific leaders. In general, they appreciate the contributions of science to society and believe that scientific and engineering work is a worthy enterprise: 85% consider that the benefits of scientific research outweigh or match the harm it can do. In particular, they believe science has had a positive impact on medical treatments, food safety and environmental conservation. Furthermore, the great majority of Americans see investment in engineering, technology and research as paying off in the long term. Most Americans report being generally interested in new scientific discoveries. More than half have visited a zoo, aquarium, natural history or science museum in 2012.

Public sceptical of some scientific issues

The biggest differences of opinion between the general public and the scientific community concern acceptance of genetically modified foods (37% of the public versus 88% of scientists consider them generally safe) and animal research (47% of the public versus 89% of scientists in favour). There is a comparably large scepticism about whether humans are responsible for global climate change: 50% of the public agrees with this statement, compared to 87% of scientists.

Americans are less concerned about climate change than residents of other countries and more likely to attribute observed trends to non-human causes. Addressing the causes of climate change is not a high policy priority for most Americans. However, momentum may be building in this area, as evidenced by the People's Climate March 2015 in New York City, which attracted about 400 000 participants from civil society.

In general, Americans view nuclear energy more favorably than residents of other countries. Support for both oil and nuclear power has gradually rebounded after high-profile accidents in those industries in the Gulf of Mexico and Japan, although support for nuclear energy production has not completely recovered.

One point on which both the general public and scientists agree, according to a survey of the public and the American Association for the Advancement of Science, is that science teaching at the primary level in the USA lags behind that of other countries, despite US science being highly regarded abroad.

Public's factual grasp of science is tenuous

In spite of a broad enthusiasm for science and discovery, the American public's factual grasp of science shows room for improvement. Respondents to a factual questionnaire scored an average of 5.8 correct answers to nine questions, which is comparable to results from European countries. These scores have been stable over time.

In addition, the way in which a question is asked may affect a person's answer. For instance, only 48% of survey respondents agreed with the statement that 'human beings, as we know them today, developed from earlier species of animals' but 72% agreed with an identical statement that first specified 'According to the theory of evolution…'. Likewise, 39% of Americans agreed that 'the Universe began with a huge explosion' but 60% agreed with the statement that 'According to astronomers, the Universe began with a huge explosion.'

Public consulting open access scientific literature

The America COMPETES Act established the goal of making all unclassified research results produced at least partly with federal funding publicly available. By the time the act was passed in 2007, a similar requirement was already in the pipeline at the NIH requiring funded investigators to submit accepted manuscripts to PubMed Central within 12 months of publication. PubMed Central is a free full-text archive of literature from biomedical and life science journals at the NIH's National Library of Medicine.

The 12-month embargo has successfully protected the business models of scientific journals, since the number of publications has risen since the policy entered into effect and has made a wealth of information available to the public. Estimates suggest that PubMed Central receives 500 000 unique visits every weekday, the average user accessing two articles, and that 40% of users are members of the general public, rather than from industry or academia.

The government generates about 140 000 datasets[10] in a host of areas. Each of these datasets is a potential application for a mobile phone or could be cross-referenced with other datasets to reveal new insights. Innovative businesses have used these data as a platform for the provision of useful services. For example, home price estimates on Realtor.com® are based on open-source data on housing prices from the Census Bureau. Bankrank.org provides information on banks based on data from the Consumer Financial Protection Bureau. Other applications are built on the Global Positioning System or the Federal Aviation Administration. President Obama has created the position of Chief Data Scientist to promote the use of these datasets, with Silicon Valley veteran DJ Patil the first person to serve in this office.

TRENDS IN SCIENCE DIPLOMACY

An agreement with China on climate change

Consistent with the president's overarching priorities, the most important goal of science diplomacy at the moment and in the near future will be to address climate change. His *Climate Action Plan* (2013) articulates both a domestic and international policy agenda aimed at quickly and effectively reducing greenhouse emissions. To that end, the administration has entered into a variety of bilateral and multilateral agreements and will be participating in negotiations at the United Nations Climate Change Conference in Paris in November 2015 for a universal legally binding agreement. In the run-up to the conference, the USA has provided developing countries with technical assistance in preparing their Intended Nationally Determined Contributions.

During a visit to China in November 2014, the USA agreed to reduce its own carbon emissions by 26–28% over 2005 levels by 2025. In parallel, the US and Chinese presidents issued a Joint Announcement on Climate. The details of the agreement had been ironed out by the USA–China Clean Energy Research Center. This virtual centre was established in November 2009 by President Obama and President Hu Jintao and endowed with US$ 150 million. The joint workplan foresees public–private partnerships in the areas of clean coal technology, clean vehicles, energy efficiency and energy and water.

An historic agreement with Iran

Another major diplomatic success has been the negotiation of a nuclear agreement with Iran jointly with the other four permanent members of the United Nations Security Council and Germany. The agreement signed in July 2015 is highly technical. In return for the lifting of sanctions, the Iranians have made a number of concessions with regard to their nuclear programme. The agreement was endorsed by the United Nations Security Council within a week of adoption.

Building diplomacy through science

Scientific collaboration is often the most durable type of peace-building programme, owing to the high level of personal investment. For instance, the Middle East Research Cooperation programme run by the US Agency for International Development (USAID), which establishes bilateral or trilateral scientific collaboration with Arab and Israeli partners, has operated without interruption since its establishment in 1981 as part of the 1978 Camp David Accords, in spite of periods of violent conflict in the Middle East. In a similar spirit of peace-building, individual scientists in the USA have been working with Cuban colleagues for over half a century, despite the embargo. The restoration of US–Cuban diplomatic relations in 2015 should lead to new export rules for donated scientific equipment that will help to modernize Cuban laboratories.

Universities are also a major contributor to science diplomacy through international scientific collaboration. In the past decade, a number of universities have set up satellite campuses abroad that focus specifically on science and technology, including the University of California (San Diego), the University of Texas (Austin), Carnegie Mellon University and Cornell University. A School of Medicine is due to open at Nazarbayev University in 2015, in partnership with the University of Pittsburgh; another fruit of this US–Kazakh partnership is the *Central Asian Journal of Global Health*, which first appeared in 2012 (see Box 14.3). For its part, the Massachusetts Institute of Technology has helped to establish the Skolkovo Institute of Science and Technology in the Russian Federation (see Box 13.1).

Other projects involving the Russian Federation have stalled or lost momentum. For instance, as diplomatic tensions grew between the USA and the Russian Federation in 2012, Bilateral Presidential Commission meetings bringing together scientists and innovators from the two countries were quietly suspended. Projects such as the USA–Russia Innovation corridor have also been put on hold. The Russian Federation has also enacted a number of policies since 2012 that have

10. These datasets are available online at www.data.gov.

had an adverse effect on foreign scientific collaboration, including a law on undesirable organizations. The MacArthur Foundation recently pulled out of the Russian Federation after being declared an undesirable organization.

For its part, the USA has introduced new restrictions on Russian scientists working in the USA in sensitive industries but, for now, the longstanding collaboration in human space flight is proceeding as usual (see Chapter 13).

A focus on Africa in health and energy

The Ebola epidemic in 2014 highlighted the challenge of mobilizing funds, equipment and human resources to manage a rapidly evolving health crisis. In 2015, the USA decided to invest US$ 1 billion over the next five years in preventing, detecting and responding to future infectious disease outbreaks in 17 countries,[11] within its Global Health Security Agenda. More than half of this investment will focus on Africa. The USA is also partnering with the African Union Commission for the establishment of African Centers for Disease Control and Prevention. It is also supporting the development of national public health institutes.

The USA and Kenya signed a Cooperative Threat Reduction agreement during President Obama's visit to Kenya in July 2015. The aim is to enhance biological safety and security through 'real-time biosurveillance, rapid disease reporting, research and training related to potential biological threats, whether posed by naturally occurring diseases, deliberate biological attacks or the unintentional release of biological pathogens and toxins.'

In 2014, USAID launched the Emerging Pandemic Threats 2 Program with more than 20 countries in Africa and Asia to help 'detect viruses with pandemic potential, improve laboratory capacity to support surveillance, respond in an appropriate and timely manner, strengthen national and local response capacities and educate at-risk populations on how to prevent exposure to these dangerous pathogens.'

A year later, President Obama launched Power Africa, which is also being spearheaded by USAID. Rather than being an aid programme, Power Africa provides incentives to foster private investment in the development of infrastructure in Africa. In 2015, Power Africa partnered with the United States African Development Foundation and General Electric, for instance, to provide African entrepreneurs with small grants to develop innovative, off-the-grid energy projects in Nigeria (Nixon, 2015).

CONCLUSION

The future looks brighter for business than for basic research

In the USA, the federal government specializes in supporting basic research, leaving industry to take the lead in applied research and technological development. In the past five years, federal spending on R&D has dipped as a consequence of austerity and changing priorities. Industry spending, on the other hand, has picked up. The result is that R&D spending has flagged only somewhat over the past five years before returning to modest growth.

Business has generally maintained or augmented its R&D commitment over the past five years, particularly in newer high-opportunity sectors. R&D tends to be considered a long-term investment in the USA that is essential to fuel innovation and build resilience in times of uncertainty.

Although most R&D spending enjoys broad bipartisan support, public-interest science stands to suffer the most from the current austerity and political targeting.

The federal government has been able to wield some influence through partnerships with industry and non-profit organizations in the field of innovation, in particular. Examples are the Advanced Manufacturing Partnership, the BRAIN Initiative and the more recent Climate Pledge. The federal government has also fostered greater transparency and made government data available to potential innovators. Regulatory reforms offer a promising new era in precision medicine and drug development.

The USA has also maintained its commitment to science and engineering education and job training. The stimulus package adopted in 2009 to conjugate the financial crisis provided a one-time opportunity for the federal government to foster high-tech job growth at a time of burgeoning demand for skilled workers. Only time will tell if this massive injection of funds in education and training will pay off. Within universities meanwhile, the pipeline of trainees has been squeezed by the austerity drive, resulting in a build-up of postdoctoral fellows and greater competition for funding. Thanks to a heavy investment in technology transfer, leading universities and research institutes are making their ivory tower more porous to their surrounding communities in the hope of seeding robust local knowledge economies.

What does the future look like for US science? Indications are that opportunities in federally funded basic research are likely to stagnate. Conversely, the future looks bright for innovation and development in the business enterprise sector.

11. The 17 partners are (in Africa): Burkina Faso, Cameroon, Cote d'Ivoire, Ethiopia, Guinea, Kenya, Liberia, Mali, Senegal, Sierra Leone, Tanzania and Uganda; (in Asia): Bangladesh, India, Indonesia, Pakistan and Viet Nam.

KEY TARGETS FOR THE USA

- Raise GERD to 3% of GDP by the end of 2016;
- Prepare 100 000 excellent teachers of science, technology, engineering and mathematics and, in turn, one million qualified workers in the ten years to 2021, through a loose coalition of government and non-profit groups with an interest in teacher education dubbed *100Kin10*;
- Reduce the USA's carbon emission by 26–28% over 2005 levels by 2025;
- Reduce the carbon emissions of the State of California by 40% over 1990 levels by 2030.

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In the absence of robust public policy to support and entrench STI in the national development process, it is researchers themselves who are devising innovative means of driving STI.

Harold Ramkissoon and **Ishenkumba A. Kahwa**

A student prepares a tooth to receive a dental filling, 'observed' by a simulator software which can detect any incisions and compare them to an optimal one. Among the onlookers are the Hon. Portia Simpson Miller, Prime Minister of Jamaica, and Prof. Archibald McDonald, Principal of the Mona Campus of the University of the West Indies.
Photo: © University of the West Indies, Mona Campus

6 · Caricom

Antigua and Barbuda, Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Montserrat, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Suriname, Trinidad and Tobago

Harold Ramkissoon and Ishenkumba A. Kahwa

INTRODUCTION

Low growth and high debt

Most members of the Caribbean Common Market (CARICOM) are highly indebted[1] (Table 6.1), as they struggle to emerge from the global recession triggered in September 2008, which stressed their banking system and led to the failure of a major regional insurance[2] company in 2009. After meeting their debt obligations, there is little left for the state to support socio-economic imperatives. Consequently, the 2010–2014 period can best be described as one of slow growth. GDP progressed by about 1% on average over this period, although growth climbed to 2.3% in 2013 and growth of 3% is projected for 2014 (Figure 6.1).

Apart from natural resource-rich Trinidad and Tobago, which has been able to weather the economic storm thus far, thanks to high commodity prices, unemployment remains high in the region. Both Grenada and Barbados have had delicate conversations with the International Monetary Fund (IMF), while Jamaica has signed an agreement with the IMF leading to some painful adjustments. The majority of countries are dependent on tourism but, as Table 6.1 shows, remittances from the region's diaspora are quite significant contributors to many national incomes. In Haiti, remittances even account for about one-fifth of GDP.

1. The ratio of public debt to GDP rose by about 15 percentage points in the Caribbean between 2008 and 2010 (IMF, 2013).

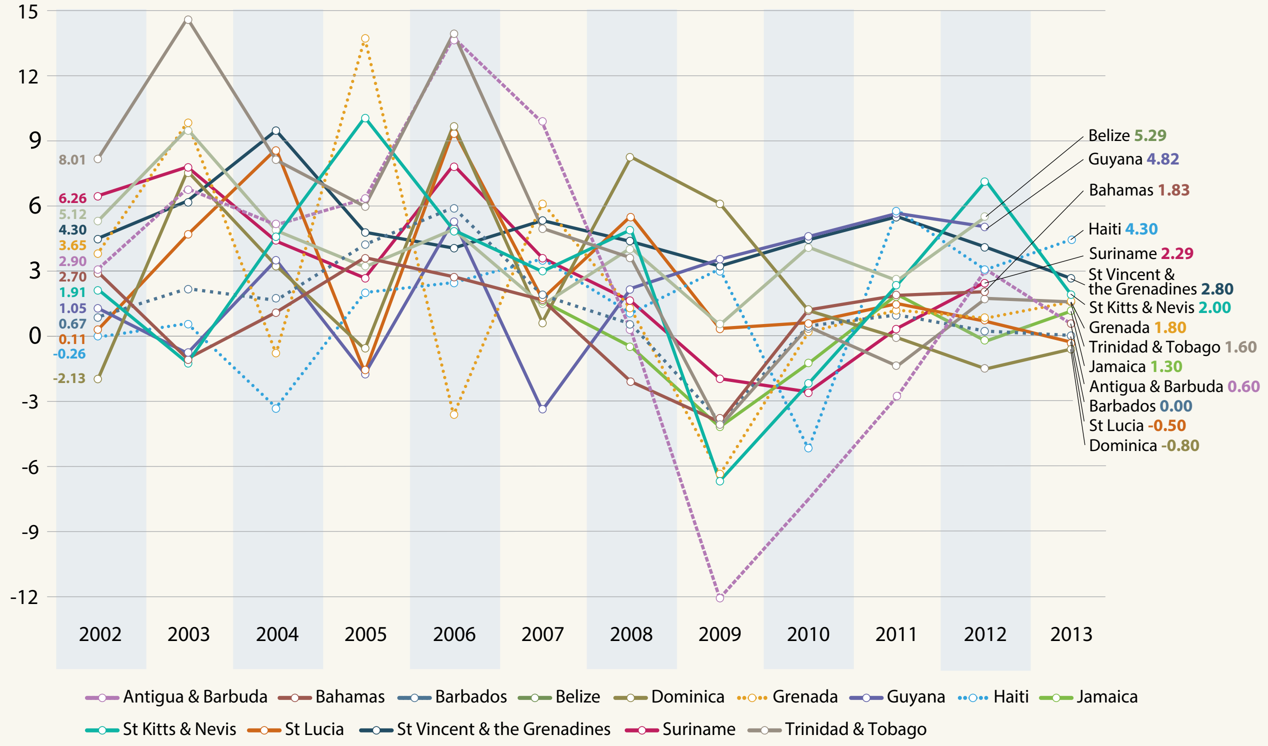
2. The region lost about 3.5% of GDP after the failure of the CL Financial Group in January 2009; this group of insurance companies had invested in real estate and other vulnerable assets in a weak regulatory environment. The group was active in all the CARICOM countries but Haiti and Jamaica. It was based in Trinidad & Tobago, where GDP shrank by as much as 12% (IMF, 2013).

Table 6.1: **Socio-economic indicators for CARICOM countries, 2014 or closest year**

	Population, 2014 ('000s)	Population growth, 2014 (annual %)	GDP per capita, 2013 (current PPP$)	Unemploy-ment rate, 2013 (%)	Inflation, consumer prices, 2013 (%)	Debt to GDP ratio, 2012 (%)	Remittances, 2013 (US$ millions)	Key sectors	Internet access, 2013 (%)	Mobile phone subscriptions, 2013 (%)
Antigua & Barbuda	91	1.0	20 977	–	1.1	97.8	21	Tourism	63.4	127.1
Bahamas	383	1.4	23 102	13.6	0.4	52.6	–	Tourism	72.0	76.1
Barbados	286	0.5	15 566	12.2	1.80	70.4	82	Tourism	75.0	108.1
Belize	340	2.3	8 442	14.6	0.7	81.0	74	Goods export (agriproducts and oil)	31.7	52.9
Dominica	72	0.5	10 030	–	0.0	72.3	24	Tourism	59.0	130.0
Grenada	106	0.4	11 498	–	0.0	105.4	30	Tourism	35.0	125.6
Guyana	804	0.5	6 551	11.1	1.8	60.4	328	Goods export and tourism	33.0	69.4
Haiti	10 461	1.4	1 703	7.0	5.9	–	1 780	Agriculture	10.6	69.4
Jamaica	2 799	0.5	8 890	15.0	9.3	143.3	2 161	Goods export and tourism	37.8	100.4
Montserrat	5	–	–	–	–	–	–	Tourism	–	–
St Kitts & Nevis	55	1.1	20 929	–	0.7	144.9	51	Tourism	80.0	142.1
St Lucia	184	0.7	10 560	–	1.5	78.7	30	Tourism	35.2	116.3
St Vincent & Grenadines	109	0.0	10 663	–	0.8	68.3	32	Tourism	52.0	114.6
Suriname	544	0.9	16 266	7.8	1.9	18.6	7	Goods export (energy, bauxite/ alumina) and tourism	37.4	127.3
Trinidad & Tobago	1 344	0.2	30 349	5.8	5.2	35.7	126^{-2}	Goods export (energy)	63.8	144.9

Source: For population data: UN Department of Economic and Social Affairs (2013) *World Population Prospects: 2012 Revision;* for GDP and related data: World Bank's World Development Indicators, February 2015; for government debt: World Bank's World Development Indicators and IMF (2013); for internet and mobile phone subscriptions: International Telecommunications Union. IMF (2013); for remittances: World Bank's World Development Indicators, February 2015; for type of economy: ECLAC.

Figure 6.1: **Economic growth in CARICOM countries, 2002–2013** (%)



Source: World Bank's World Development Indicators, January 2015

Despite financial constraints, there has been considerable investment in information and communication technologies (ICTs) in recent years. In Suriname, for instance, internet connectivity progressed from 21% to 37% between 2008 and 2013 and, in Trinidad and Tobago, from 35% to 64%. By 2013, almost three-quarters of the inhabitants of Barbados and Bahamas had access. Mobile phone subscriptions have grown at an even faster rate, including in Haiti where internet connectivity has stagnated at less than 10%. These trends offer new opportunities for businesses and are helping scientists to develop greater international and intraregional collaboration.

Vulnerable tourism-based economies

The region's fragile tourism-based economy has not diversified and remains vulnerable to the vagaries of Mother Nature (Figure 6.2). For example, winds that were well beneath hurricane strength took a toll on the small economies of St Lucia, Dominica and St Vincent and the Grenadines in December 2013. In 2012, two hurricanes struck Haiti just as its economy was beginning to recover from the devastating earthquake in January 2010 which had destroyed much of the capital city, Port-au-Prince, killed more than 230 000 people and left 1.5 million homeless. In 2014, more than 60 000 people were still living in camps; much of donor aid for rehousing has been used to build temporary shelters which are only designed to last 3–5 years (Caroit, 2015).

As seen in Figure 6.3, most CARICOM countries have at least a 10% chance of being struck by a hurricane each year and even moderate storms can reduce growth by about 0.5% of GDP, according to the IMF (2013).

The region would be hard-pressed to deal with a major meteorological disaster, which is why it should be taking climate change adaption more seriously. This is all the more urgent in that the Caribbean is both the most tourist-intensive region in the world and set to become the most at-risk tourist destination between 2025 and 2050, according to the World Travel and Tourism Council. Headquartered in Belize, the Caribbean Community Climate Change Centre (CCCCC) has received a mandate from CARICOM to[3]:

- Mainstream climate change adaptation strategies into the sustainable development agendas of CARICOM states;
- Promote the implementation of specific adaptation measures to address key vulnerabilities in the region;
- Promote actions to reduce greenhouse gas emissions through fossil fuel reduction and conservation, and switching to renewable and cleaner energy sources;

3. See: www.caribbeanclimate.bz/ongoing-projects/2009-2021-regional-planning-for-climate-compatible-development-in-the-region.html

- Encourage action to reduce the vulnerability of natural and human systems in CARICOM countries to the impact of a changing climate;
- Promote action to derive social, economic and environmental benefits through the prudent management of standing forests in CARICOM countries.

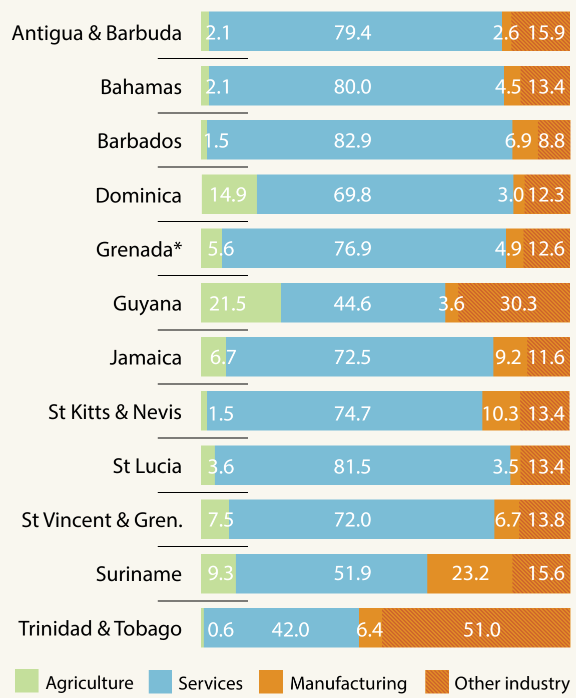
The CCCCC has produced an implementation plan for 2011–2021 and carried out work to assess and build capacity in climate change mitigation and resilient development strategies. This work has been supported by the region's specialists, who have produced models for climate change and mitigation processes in Caribbean states and who play a major advisory role to the divisions in ministries responsible for climate change, such as Jamaica's appropriately expanded Ministry of Water, Land, Environment and Climate Change[4].

Meanwhile, high energy costs impact negatively on economic competitiveness and the cost of living (Figure 6.4). In 2008, over US$ 14 billion was spent on importing fossil fuels, which are estimated to provide over 90% of energy consumed in CARICOM countries. The machinery needed to generate fossil-fuel-based electricity is also obsolete, inefficient and expensive to run. Conscious of this vulnerability, CARICOM has developed an Energy Policy (CARICOM, 2013), approved in 2013, and an accompanying *CARICOM Sustainable Energy Roadmap and Strategy* (C-SERMS). Under the policy, renewable energy sources are to contribute 20% to the total electricity generation mix in member states by 2017, 28% by 2022 and 47% by 2027. A similar policy instrument is being developed for the transportation sector.

Stakeholders participated in a resource mobilization forum for the first phase of C-SERMS in July 2013. The forum was hosted by the CARICOM Secretariat, with support from the Inter-American Development Bank (IADB) and the German Agency for International Cooperation (GIZ). The IADB has since provided the University of the West Indies (UWI) with a grant of over US$ 600 000 to develop capacity in sustainable energy technologies across the region. One area of interest is the utilization of ICTs in managing energy and training in sustainable energy technologies, with an emphasis on enhancing the involvement of women. The participation of energy giants such as General Electric, Phillips and the Scottish Development Corporation augurs well for technology transfer. The region has considerable potential for hydroelectric, geothermal, wind and solar energy which,

4. See www.mwh.gov.jm

Figure 6.2: **GDP by economic sector in the CARICOM countries, 2012**

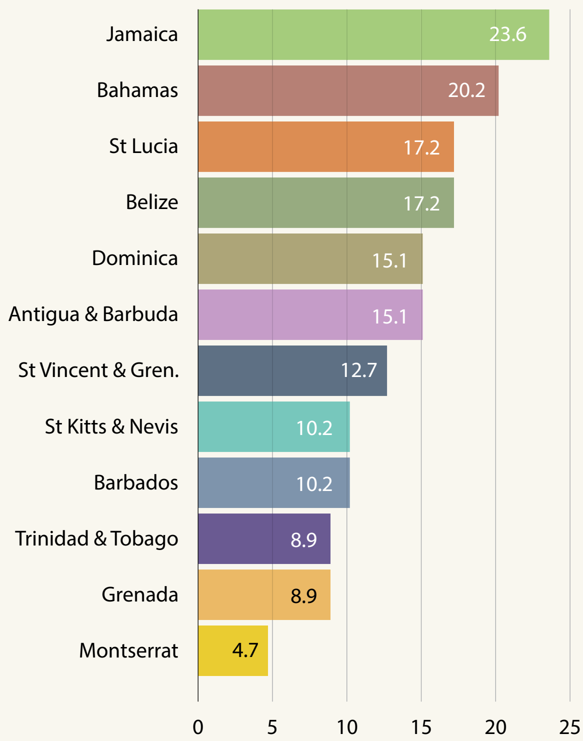


*For Grenada, data are for 2011.

Note: Data are unavailable for Haiti and Montserrat.

Source: World Bank; World Development Indicators, September 2014

Figure 6.3: **Probability of a hurricane striking Caribbean countries in a given year, 2012 (%)**

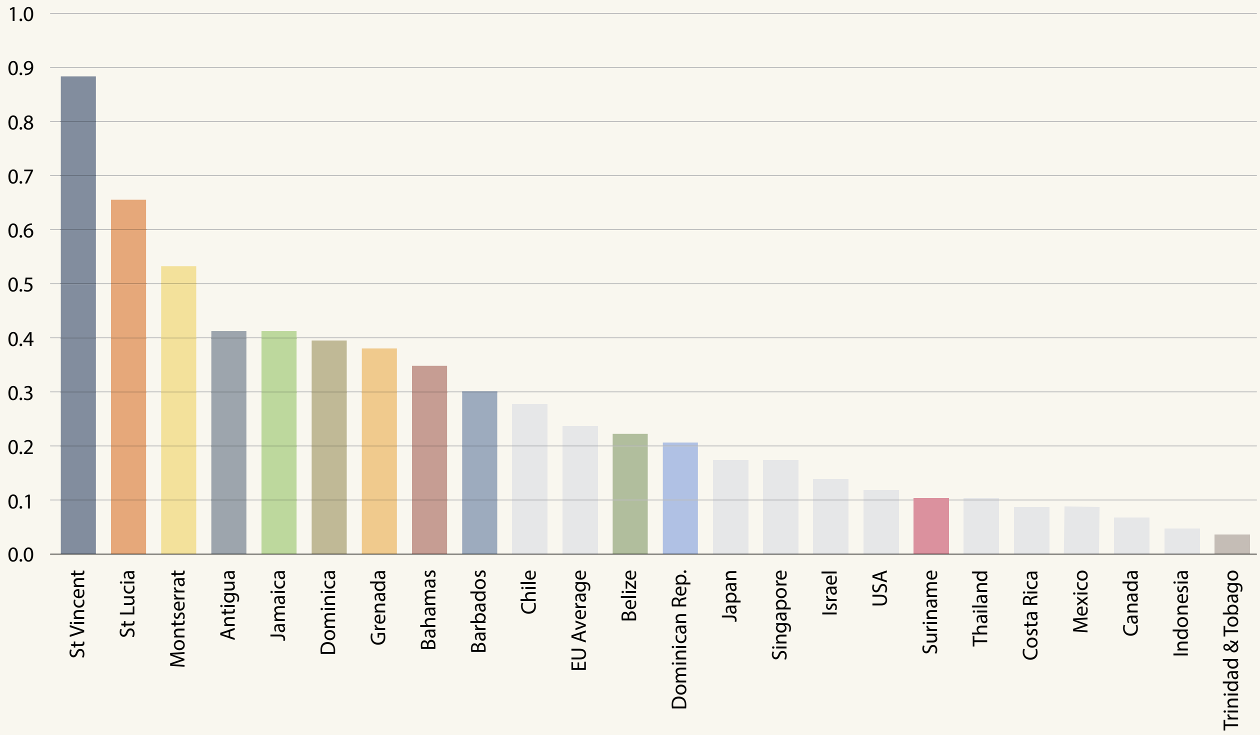


Source: IMF (2013)

Chapter 6

Figure 6.4: **Electricity costs for the CARICOM countries, 2011**

Household tariffs per kWh in US$, other countries and regions are given for comparison



Source: IMF (2013)

once significantly exploited (as opposed to sporadically, at present), could make a huge difference to the energy resilience of CARICOM countries. Some of these resources are being exploited to a limited extent. One of the problems with electricity generation using petroleum sources is that the region's machinery is obsolete, inefficient and expensive to run. To deal with this problem, Jamaica has approved construction of new gas-fired electricity generation plants.

The efforts of CARICOM countries to adopt sustainable energy technologies are contributing to implementation of the Programme of Action for the Sustainable Development of Small Island Developing States. First adopted[5] in Barbados in 1994, this programme was updated in Mauritius in 2005 then again in Samoa in 2014.

Strength in numbers: a need to develop regionalism

The Caribbean is in danger of being left behind, unless it can adapt to an increasingly knowledge-driven global economy that is being shaped by convergent phenomena. The first of these phenomena is the weak post-crisis recovery of developed countries and the slowdown in growth of developing countries, which obliges Caribbean economies to reduce their dependence on traditional markets and sources of foreign capital. The second phenomenon is the fluidification of markets, driven by progress in ICTs, manufacturing and automation, as well as by the lowering of trade barriers and transport costs; this is encouraging corporations around the world to spread their production capacity across different locations in order to create global value chains: the United Nations Conference on Trade and Development estimates that 80% of the world's exports of goods and services now occur through trade among multinational enterprises. This, in turn, has spawned a fourth phenomenon, the creation of megamarkets, such as the proposed regional free-trade agreement known as the Trans-Pacific Partnership, involving countries from North and Latin America, Asia and the South Pacific[6] (CARICOM, 2014).

Where does the Caribbean fit into this new global picture? As Ralph Consalves, Prime Minister of Saint Vincent and the Grenadines and former Chair of CARICOM, put it at CARICOM's 40th anniversary in 2013, 'it is evident to all responsible persons of discernment that our region would find it more difficult by far to address its immense current and prospective challenges, unless its governments and peoples embrace strongly a more mature, more profound regionalism'.

5. See www.unesco.org/new/en/natural-sciences/priority-areas/sids

6. The countries participating in negotiations thus far have been Australia, Brunei Darussalam, Canada, Chile, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore, USA and Viet Nam.

The *Strategic Plan for the Caribbean Community: 2015–2019* is CARICOM's answer to the phenomena described above (CARICOM, 2014). The first of its kind in the region, the plan sets out to reposition the Caribbean in an increasingly volatile global economy. The overarching objective is twofold: to stimulate the productive capability of domestic firms and correct the current mismatch between training and the specialized knowledge and skills required by the market, in order to drive growth and combat rising levels of unemployment among the young, in particular. The plan outlines strategies for nurturing innovation and creativity, entrepreneurship, digital literacy and inclusiveness and for making optimum use of available resources.

A central aim is to reinforce the Caribbean's socio-economic, technological and environmental resilience. With the exception of Guyana, Suriname and Trinidad and Tobago, which have significant hydrocarbon or mineral reserves, most states are small with too limited natural resources to support rapid economic development. They will thus need to look elsewhere for wealth creation. The two key enablers identified by the plan for improving the Caribbean's resilience are a common foreign policy, in order to mobilize resources effectively, and R&D and innovation. The plan proposes using advocacy to mobilize funding for business R&D from state and private sources, creating an enabling legislative environment for R&D and innovation, identifying opportunities for co-operation and devising national school-based programmes that drive, enable and reward R&D and innovation.

The strategy focuses on the following areas to drive economic growth:

- Creative, manufacturing and service industries, with a special focus on tourism initially;
- Natural resource and value-added products, promoting the integration of production;
- Agriculture and fisheries and export development, to reduce dependence on food imports and foster sustainable fisheries by improving co-operative management and conservation and the development of aquaculture;
- Resource mobilization;
- ICTs;
- Air/Maritime transport infrastructure and services, to facilitate the mobility of goods and services and foster global competitiveness;
- Energy efficiency, diversification and cost reduction, including the development of alternative energy to meet CARICOM's target of 20% renewable sources by 2017, by facilitating public–private partnerships, in line with the *CARICOM Energy Policy* of 2013 and its companion *CARICOM Sustainable Energy Roadmap and Strategy* (C-SERMS).

TRENDS IN STI GOVERNANCE

CARICOM plan mirrors national aspirations

Elections are constitutionally due for eight CARICOM countries in 2015 and the remainder between 2016 and 2019. If election results do not derail the *Strategic Plan for the Caribbean Community: 2015–2019* and it is fully implemented, it should provide a good framework for developing STI in the region.

The important point here is that the collective aspirations captured in the *Strategic Plan* to 2019 are similar to those of major national plans. For example, Trinidad and Tobago's *Vision 2020* (2002), Jamaica's *Vision 2030* (2009) and the *Strategic Plan* of Barbados for 2005–2025 all share a common aspiration to achieve socio-economic development, security, resilience to environmental shocks and an engagement in STI to improve the standard of living. Like the *Strategic Plan for the Caribbean Community,* these national plans accord central importance to STI in realizing these aspirations.

The United Nations Development Assistance Facility (UNDAF) programme has complemented these efforts. There are five national UNDAF programmes for each of Jamaica, Trinidad and Tobago, Guyana, Belize and Suriname, as well as a subregional one for Barbados and the smaller CARICOM members grouped within the Organization of Eastern Caribbean States (Kahwa *et al*., 2014). The UNDAF programmes have used national strategic planning documents to develop action plans aligned with national priorities, via a consultative process at national levels.

Antigua and Barbuda, the Bahamas, Belize, Jamaica, St Lucia, Guyana and Trinidad and Tobago have all either articulated their S&T policies or identified and targeted specific priority areas, such as ICTs. In these countries, there is either a national commission or a ministry/department responsible for science and technology, with Belize[7] also having a Prime Minister's Council of Science Advisors (Table 6.2).

Some countries have developed a roadmap for STI, like Jamaica. Its roadmap builds on the national consensus of *Jamaica Vision 2030* and places STI at the centre of national development efforts. This roadmap was triggered by the need, identified by Jamaica's public sector reform, for operational consolidation of government and other publicly supported R&D institutions, in order to achieve efficiency gains and accelerate innovation to pave the way to developed country status by 2030.

An urgent need to map research and innovation

As recognized by the *Strategic Plan for the Caribbean Community: 2015–2019, Jamaica's Roadmap for Science, Technology and Innovation* and a report commissioned by the

7. See: www.pribelize.org/PM-CSA-Web/PM-CSA-Statement-Members.pdf

Table 6.2: **Overview of STI governance in CARICOM countries, 2015**

	Body responsible for STI policy	Additional relevant bodies	Strategic planning document (year of adoption)	Main objective of planning document	National award (year) and body responsible	STI policy (year of adoption)	R&D priorities of STI policy	STI action/ implementation plan
Antigua & Barbuda	Ministry of Education, Science & Technology							
Suriname	Ministry of Labour & Technology Development							
Dominica	Ministry of information, Science, Telecommunications & Technology	National Science & Technology Council						
Bahamas	Ministry of Education, Science & Technology	Bahamas Environment, Science & Technology Commission	National Development Plan Vision 2040 (under development)					
Grenada	Ministry of Communications, Works, Physical Development, Public Utilities & ICT	National Science & Technology Council	*National Strategic Development Plan* (2007)	National transformation through innovation, creativity and enterprise				
St Vincent & Grenadines	Ministry of Foreign Affairs, Foreign Trade & Information Technology	National Centre of Technological Innovation Inc.	*National Economic & Social Development Plan 2013– 2025* (2013)	Improving the quality of life for all				
Barbados	Ministry of Education, Science, Technology and Innovation	National Council for Science and Technology	*Strategic Plan, 2006–2025*	A fully developed society that is socially just and globally competitive	National Innovation Competition (2003), National Council for Science & Technology			
St Lucia	Ministry of Sustainable Development, Energy, Science and Technology	National Science and Technology Council	National vision under preparation	Job creation through 'live local – work local' and tourism development	Prime Minister's Award for Innovation, Chamber of Commerce, Industry & Agriculture	Under preparation		
Belize	Ministry of Energy, Science and Technology and Public Utilities	Prime Minister's Council of Science Policy	*Horizon 2030 Vision* (2010-2030)	Resilience, sustainable development and high quality of life for all		Yes, 2012	Energy and capacity-building in STI	
Guyana	Office of the President	National Science Research Council	*National Development Strategy* (1997)	Enhance national capacity to undertake development programmes		Yes, 2014	Support development programming in diverse sectors	
Trinidad & Tobago	Ministry of Science, technology and Higher Education	National Institute of Higher Education, Research, Science & Technology	*Vision 2020* (2002)	Developed country status by 2020	Prime Minister's Awards For Scientific Ingenuity (2000)	Yes, 2000	Enhancing industrial competitiveness & human development	
Jamaica	Ministry of Science, Technology, Energy and Mining	National Commission for Science & Technology	*Vision 2030* (2009)	Developed country status by 2030	National Innovation Awards (2005), Scientific Research Council	Yes, 1960	Effective exploitation of natural resources	STI roadmap (2012)

Source: compiled by authors

UNESCO Kingston Office (Kahwa *et al*., 2014), STI policy in the region is desperately in need of:

- Systematic STI data collection and scientometric analysis to inform policy-making;
- Evidence-driven decision-making, STI policy development and implementation;
- Mapping existing STI policies, related legal frameworks and the impact of these on all national and regional economic sectors.

In November 2013, UNESCO launched *Mapping Research and Innovation in Botswana*, the first in a series which profiles STI in individual countries, via data and sectorial analyses, combined with an inventory of relevant institutions, the existing legal framework and national policy instruments (UNESCO, 2013). By providing an in-depth situation analysis, these mapping exercises help countries devise evidence-based strategies to correct structural weaknesses and improve the monitoring of their national innovation system. This type of mapping exercise is just what the Caribbean needs. Without a similar rigorous understanding of the status and potential of STI in their countries, Caribbean governments will be advancing in a haze. According to Kahwa *et al*. (2014), the current poor understanding of the Caribbean STI environment is compounded by weaknesses in institutional research capacity and the inadequate collection, analysis and storage of key data, including for performance indicators.

Lack of STI data: a persistent problem

As far back as 2003, the Subregional Office for the Caribbean of the United Nations' Economic Commission for Latin America and the Caribbean (ECLAC) noted the persistent paucity of STI indicators for the Caribbean and the negative impact this was exerting on policy development, economic planning and the ability of Caribbean states to assess and deal effectively with challenges requiring innovative application of STI. The same year, ECLAC addressed the STI indicators gap by developing a *Manual for the Compilation of Science and Technology Indicators in the Caribbean*[8].

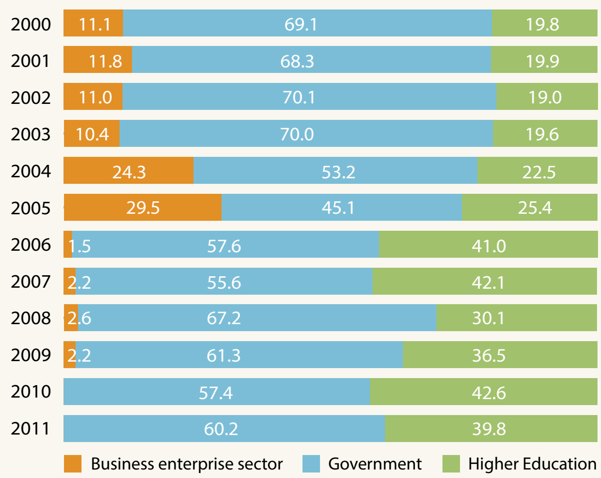
The UNESCO Institute for Statistics has also published several guides for developing countries, most recently the *Guide to Conducting an R&D Survey for Countries Starting to Measure R&D*[9] (2014). In 2011, the UNESCO Institute for Statistics ran a training workshop in Grenada to help CARICOM countries respond to STI data surveys while respecting international standards. Despite the efforts by UNESCO and ECLAC, Trinidad and Tobago was still the only CARICOM country providing data on R&D in 2014.

According to ECLAC, the collection and analysis of STI performance indicators remains a challenge for the Caribbean, despite the existence of relevant bodies, as this task is often not included in their mandate. These bodies include the:

- Scientific Research Council of Jamaica (est. 1960), an agency of the Ministry of Industry, Technology, Energy and Commerce, which has a subsidiary called Marketech Limited and a subdivision, the Food Technology Institute;
- Caribbean Industrial Research Institute in Trinidad and Tobago (est. 1970);
- Institute of Applied Science and Technology (formerly the National Scientific Research Centre) in Guyana (est. 1977), which 'is currently being resuscitated after a long period of decline,' according to its website.

It is not clear why Trinidad and Tobago is the only CARICOM country reporting R&D data but weaknesses in data collection may be at play. In Jamaica, the UWI has formed a partnership with the Jamaica Manufacturers' Association to determine the nature and level of R&D activity, as well as unmet needs, in the manufacturing sector, at least. Data-gathering got under way in 2014. It is planned to extend the study to Trinidad and Tobago, where recent reports on industrial R&D activity are not encouraging. According to the data, industrial R&D has declined markedly in recent years (Figure 6.5). This may have something to do with the drop in R&D activity in the sugar sector.

Figure 6.5: **GERD by sector of performance in Trinidad and Tobago, 2000–2011**



Source: UNESCO Institute for Statistics

8. See: www.cepal.org/publicaciones/xml/3/13853/G0753.pdf

9. see: www.uis.unesco.org/ScienceTechnology/Pages/guide-to-conducting-rd-surveys.aspx

Chronic underinvestment in R&D

The sluggish economic growth in the Caribbean in recent years has done little to boost STI, or deepen its engagement in solving economic challenges. Even the more affluent Trinidad and Tobago spent just 0.05% of GDP on research and development (R&D) in 2012.

Underinvestment in R&D is nothing new, however. As long ago as 2004, the Vice-Chancellor of the University of the West Indies, Prof. E. Nigel Harris, lamented in his inaugural address that, 'if we do not invest in science and technology, we shall not cross the ramparts in the field of sustainable development and even run the risk of perishing in the trenches of under-development'. At the time, Trinidad and Tobago was enjoying comfortable economic growth of 8% per year, which even peaked two years later at nearly 14%; despite this, the country devoted just 0.11% of GDP to R&D in 2004 and even less (0.06%) in 2006. Thus, poor economic performance alone cannot explain the extremely low commitment to STI by CARICOM governments.

A need for a more vibrant research culture

One of the greatest challenges facing the CARICOM countries is the need to develop a more vibrant and pervasive research culture. While there are certainly pockets of excellence, more people need to be encouraged to follow their passion for research. Scientists themselves need to make the quantum leap from doing good science to doing great science.

Despite limited funding, the Caribbean Academy of Sciences (est.1988) does its best to give CARICOM scientists international exposure by organizing biennial conferences to showcase research undertaken in the region. It also works closely with like-minded bodies, such as the InterAmerican Network of Academies of Sciences and the InterAcademy Panel.

The intergovernmental Caribbean Council for Science and Technology also does what it can to support the region's scientists but it continues to be plagued by the 'operational difficulties' identified in 2007 (Mokhele, 2007). The human and financial resources needed to achieve the council's objectives have not materialized.

An encouraging development is the revival of national innovation awards where contestants compete for prizes and the attention of investors, venture capital and opportunities for further product development by academic researchers and other interested parties. These contests have taken place[10] in Jamaica, Barbados and Trinidad and Tobago. The competitions are taken seriously by innovators and the exposure and prize money – between about US$ 2 500 and US$ 20 000 in Jamaica, depending on available funds – seem to be a good incentive. Senior leaders often hand out the awards at elegant galas.

To develop excellence, focus on the young

The World Academy of Sciences (TWAS) has a regional office for Latin America and the Caribbean which awards five annual prizes to the top senior scientist in the region. The Caribbean is yet to make an appearance on winner's row. TWAS also identifies the region's top five young scientists each year; to date, only one from the Caribbean has been so honoured. There is thus still some way to travel on the road to excellence.

What is critical at this juncture is to focus on our young researchers. St Lucia's Ministry of Youth Development and Sports has understood this. It runs a National Youth Awards Scheme which includes an award to an Outstanding Youth in Innovation and Technology.

Young researchers have also become a priority for two of the Caribbean's four regional organizations, the Caribbean Science Foundation and Cariscience.

Cariscience is a network of scientists set up in 1999 as an NGO affiliated to UNESCO. Cariscience remains the workhorse of the region. In the past four years, it has hosted several conferences for young scientists and a series of public lectures and summer schools for pre-university students in frontier areas such as genetics and nanoscience. In 2014, Cariscience pushed back its boundaries by running a training workshop on Technopreneurship for the Caribbean in Tobago, with the International Science, Technology and Innovation Centre for South–South Cooperation (ISTIC[11]) in Malaysia as its strategic partner. Of note is that the keynote speech was delivered by Dr Keith Mitchell, Prime Minister of Grenada, who is also the prime minister responsible for science and technology (S&T) within CARICOM.

The Caribbean Science Foundation dates from 2010. It has chosen the novel path of becoming a private company[12] with its attendant Board of Directors. In its young existence, it has already launched two programmes, both of which focus on introducing talented students to innovation and problem-solving.

The first of these is the Student Programme for Innovation in Science and Engineering (SPISE), which runs an intensive annual four-week summer school for gifted Caribbean secondary school pupils with an interest in science and engineering. The programme was introduced in 2012 and has enjoyed a noticeable measure of success.

10. In Barbados, the National Innovation Competition (est. 2003) is run by the National Council for Science and Technology. In Jamaica, the Scientific Research Council manages the National Innovation Awards for Science and Technology, established in 2005.

11. ISTIC was founded in 2008 and operates under the auspices of UNESCO.

12. It was originally intended for the Caribbean Science Foundation to focus largely on fostering university–industry linkages. However, most industries in CARICOM countries do not have an R&D unit or even invest in R&D. Economies remain primarily mercantile. To change this culture will take time, which is why the foundation is meanwhile focusing on youth.

The second programme is the Sagicor Visionaries Challenge, sponsored jointly by the Caribbean Science Foundation, Sagicor Life Inc., a Caribbean company offering financial services, and the Caribbean Examinations Council. The Sagicor Visionaries Challenge runs stimulating workshops in secondary schools for pupils and their teachers to brainstorm ideas for innovation and ways of improving the teaching of science subjects and mathematics. The aim is to encourage pupils to develop effective, innovative and sustainable solutions to the challenges facing them. The scheme includes mentorship and the organization of competitions.

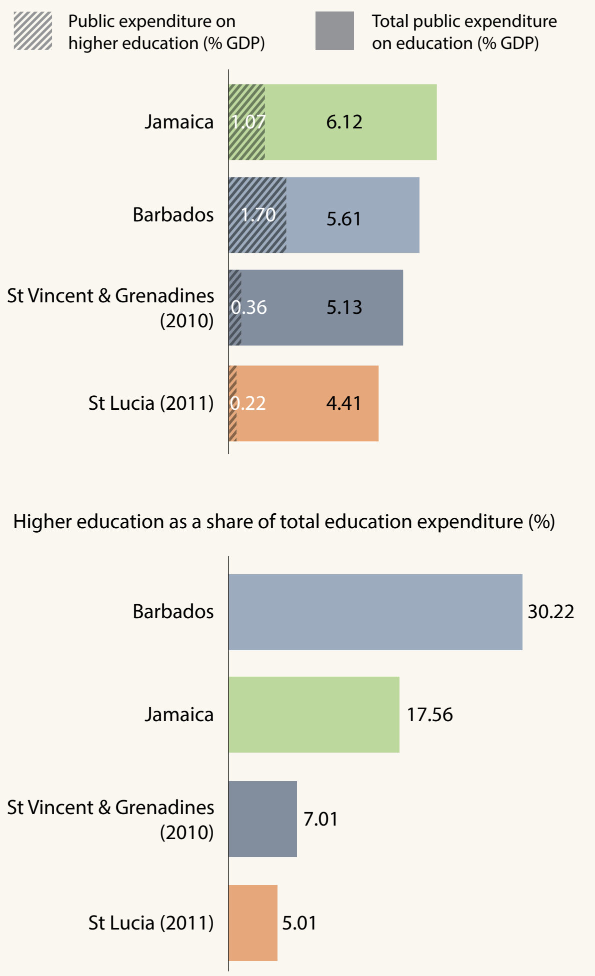
Better co-ordination should avoid duplication

While four regional organizations seem an adequate number to serve a population of about seven million, there has not generally been any co-ordination of activities up to now, even though this would avoid duplication and enhance co-operation. This led Dr Keith Mitchell to launch the CARICOM Science, Technology and Innovation Committee in January 2014. The committee has a mandate to work with existing regional bodies rather than competing with them; its objectives are to:

- identify and prioritize areas of interest in science and engineering for regional development;
- formulate projects;
- work closely with all regional bodies that will be implementing the projects;
- help raise project funding; and
- advise the prime minister responsible for S&T within CARICOM.

There are currently six committee members, plus a representative of the diaspora from the Massachusetts Institute of Technology in the USA. The committee is planning to hold a high-level ministerial meeting in 2015.

Figure 6.6: **Public expenditure on education, 2012 or closest year**



Source: UNESCO Institute for Statistics

TRENDS IN HIGHER EDUCATION

A wavering commitment to higher education

The CARICOM countries spend 4–6% of GDP on education, according to available data (Figure 6.6). Those with universities to support tend to spend more than those which do not. This level of expenditure is similar to that of Brazil (5.8%), France (5.7%), Germany (5.1%) and South Africa (6.6%).

Expenditure on higher education has become a controversial topic; it is argued that it is expensive and consumes a large proportion of the education budget (18% in Jamaica and 30% in Barbados), at the expense of early childhood and secondary-level education. In rebalancing its own education expenditure, the Jamaican government has slashed its support for UWI, which has reacted by generating over 60% of its income in the 2013/2014 academic year. Barbados is heading in the same direction, despite internal opposition, and Trinidad and Tobago is expected to follow suit.

Mona Campus: a success story

Of UWI's four campuses, the Mona Campus in Jamaica has demonstrated the greatest resilience; it is leading the way in putting innovative funding mechanisms in place for tertiary education: in 1999/2000, the 17 contributing Caribbean governments covered nearly 65% of the campus's income; by 2009/2010, this share had dwindled to 50% and by 2013/2014 to 34%. The Mona Campus has developed cost containment measures and new revenue streams based on supplementary tuition fees for high-demand teaching programmes such as medicine (since 2006), law (2009) and engineering (2012), as well as some commercial activities such as business process outsourcing and fees earned from service provision.

The campus has been able to devote 4.3% of its income to student support, over 75% of which goes to needy medical students. The campus is spending 6–8% of annual income on R&D. While this is modest compared to North American universities which spent 18–27% of their income on R&D, it should spearhead Jamaica's efforts to develop an effective national innovation system. The creation of a resource mobilization unit, the Mona Office of Research and Innovation, should help the campus to go after external grant funding and commercialize innovation from its R&D programme. Mona Campus has also engaged in public–private partnerships to deal with infrastructural challenges – the recent construction of student accommodation and the development of potable water resources are good examples. This has made the campus a more viable and competitive institution than it was a decade ago, a veritable success story.

Women marginalized as they climb the career ladder

One issue which continues to bedevil the region is the disproportionately small number of women rising to the highest echelons of academia. This phenomenon is quite evident at the University of the West Indies, where the share of women diminishes as staff move up the career ladder from low academic ranks such as lecturer, where they are the majority, to senior lecturer and professor, where they are in a small minority (Figure 6.7). This imbalance in academic progress may be resolved by giving female academic staff members ample time to focus on research. The important thing here is to recognize that there is a problem, so that the causes of this imbalance can be determined and the situation rectified.

TRENDS IN SCIENTIFIC PRODUCTIVITY

Grenada's scientific output progressing fast

For years, Jamaica, Trinidad and Tobago and Barbados have dominated scientific publishing, owing to the presence on their soil of campuses of the University of the West Indies (Figures 8 and 9). Today, however, UWI's dominance has been eroded somewhat by the impressive rise in refereed publications from Grenada. Much of this is due to St George's University, which contributes about 94% of Grenada's publications. Whereas, in 2005, Grenada produced just six articles in international journals covered by the Thomson Reuters Web of Science database, this number had risen to 77 by 2012. With this dramatic rise in output, Granada has overtaken Barbados and Guyana to become the number three producer in the Caribbean of the most internationally respected publications, behind Jamaica and Trindidad and Tobago. When publications per 100 000 inhabitants are considered (Figure 6.9), the high productivity of Grenada becomes evident. It is indeed a remarkable success story that a Caribbean country without a prior research pedigree should have made such impressive strides on the global stage.

The development of St George's University in Grenada over the past decade has been spectacular. The university was founded in 1976 by an act of parliament as an offshore medical training school, before introducing graduate and undergraduate programmes in 1993. In spite of being located in a small island country (Grenada) without a prior research pedigree, St George's University has morphed into a promising research centre in little over a decade.

The trend in Grenada should be encouraging to the Bahamas and St Kitts and Nevis, where output is also climbing steadily. The Bahamas published just five papers in 2006 but 23 in 2013. Much of this output is coming from the College of the Bahamas but there are other contributing institutions. St Kitts and Nevis can count on Ross University for veterinary medicine and related disciplines; it produced a single paper in 2005 but 15 in 2013.

Publications in the area of health are emanating from both university medical schools and hospitals, as well as government ministries and research centres (Box 6.1). By contrast, little output has materialized from agricultural research centres since 2005. In most CARICOM countries, agriculture accounts for less than 4% of GDP (Figure 6.2). The notable exceptions are Suriname (9%), Dominica (15%) and, above all, Guyana (22%) but, even here, articles on relevant topics are few and far between. Such low investment and output in agricultural R&D could be a threat to food security in a region that is still a net importer of foodstuffs.

While research output from non-academic, non-health related R&D centres is not high, these entities provide critical services. The Scientific Research Council in Jamaica is active in wastewater management and provides information services on topics that include renewable energy, education, industrial support services and the development of natural products from endemic plants. The Caribbean Industrial Research Institute in Trinidad and Tobago facilitates climate change research and provides industrial support for R&D related to food security, as well as equipment testing and calibration for major industries[13]. The Bureaux of Standards in St Lucia[14] and St Vincent and Grenadines develop and manage standards and ensure product quality control and compliance, including environmental monitoring.

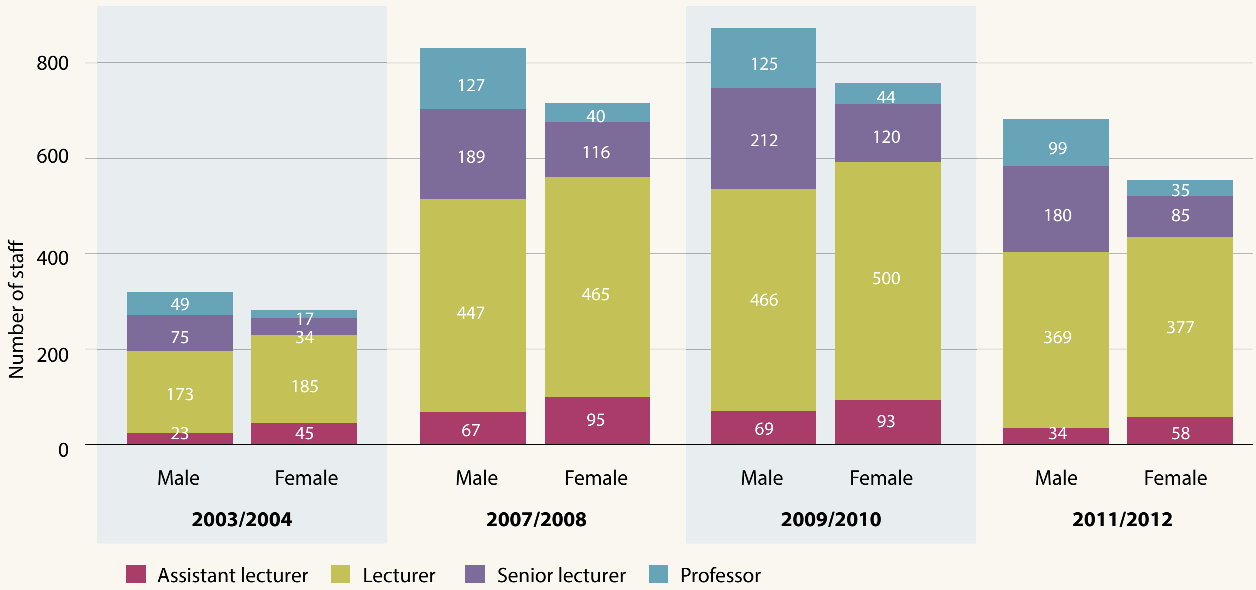
Another challenge is the low level of intraregional collaboration. US researchers are the primary collaborators for the CARICOM countries. Over 80% of articles from Grenada are co-authored with the USA and nearly 20% with Iranian collaborators. The highest level of intraregional collaboration is found in Jamaica, which counts Trinidad and Tobago as its number four collaborator. The CARICOM innovation framework should create a mechanism to encourage intraregional collaboration; UWI's Mona Campus has established a small grant scheme to support quality R&D proposals from such collaborators.

13. See: www.cariri.com

14. See: www.slbs.org.lc

Figure 6.7: **Gender breakdown of staff at University of the West Indies, 2009/2010 academic year**

By level of appointment



Source: UWI Official Statistics and communication from the Office of Planning

Box 6.1: **The Tropical Medicine Research Institute: an oasis in a public policy desert**

The Tropical Medicine Research Institute (TMRI) operates Caribbean-wide out of the University of the West Indies (UWI). It was born of the merger, in 1999, of the Tropical Metabolism Research Unit and Sickle Cell Research Unit* at UWI's Mona Campus in Jamaica.

The new institute fleshed out its mandate by adding a new entity, the Epidemiology Research Unit (ERU), and by taking under its wing the Chronic Disease Research Centre (CDRC) at the UWI's Cave Hill Campus in Barbados.

The Tropical Medicine Research Institute's long-term research projects are relatively well-funded, thanks to the competitive funding obtained by staff from a variety of agencies over the past decade, such as the: National Institutes of Health (USA), National Health Fund (Jamaica), Caribbean Health Research Council (now the Caribbean Public Health Agency), The Wellcome Trust, European Commission, Grand Challenges, Canada and Chase Fund (Jamaica).

All the articles published by TMRI since 2000 have been funded by these agencies. Productivity peaked at 38 articles in 2011 before falling back to 15 in 2014, the same level as in 2006. Although there are relatively few publications, these are of an excellent quality, as indicated by regular contributions to high-impact journals such as *Science*, *Nature* and the *Lancet*. The total number of TMRI's refereed publications is actually about three times that found in elite journals covered by the Thomson Reuters database, so there is potential for productivity in high-impact journals to increase dramatically.

The departure of two senior researchers has affected productivity. However, TMRI has invested in staff mentorship and is increasing cross-institute collaboration, while still attracting significant funding; this recipe seems set to reverse the negative impact of the senior researchers' departure.

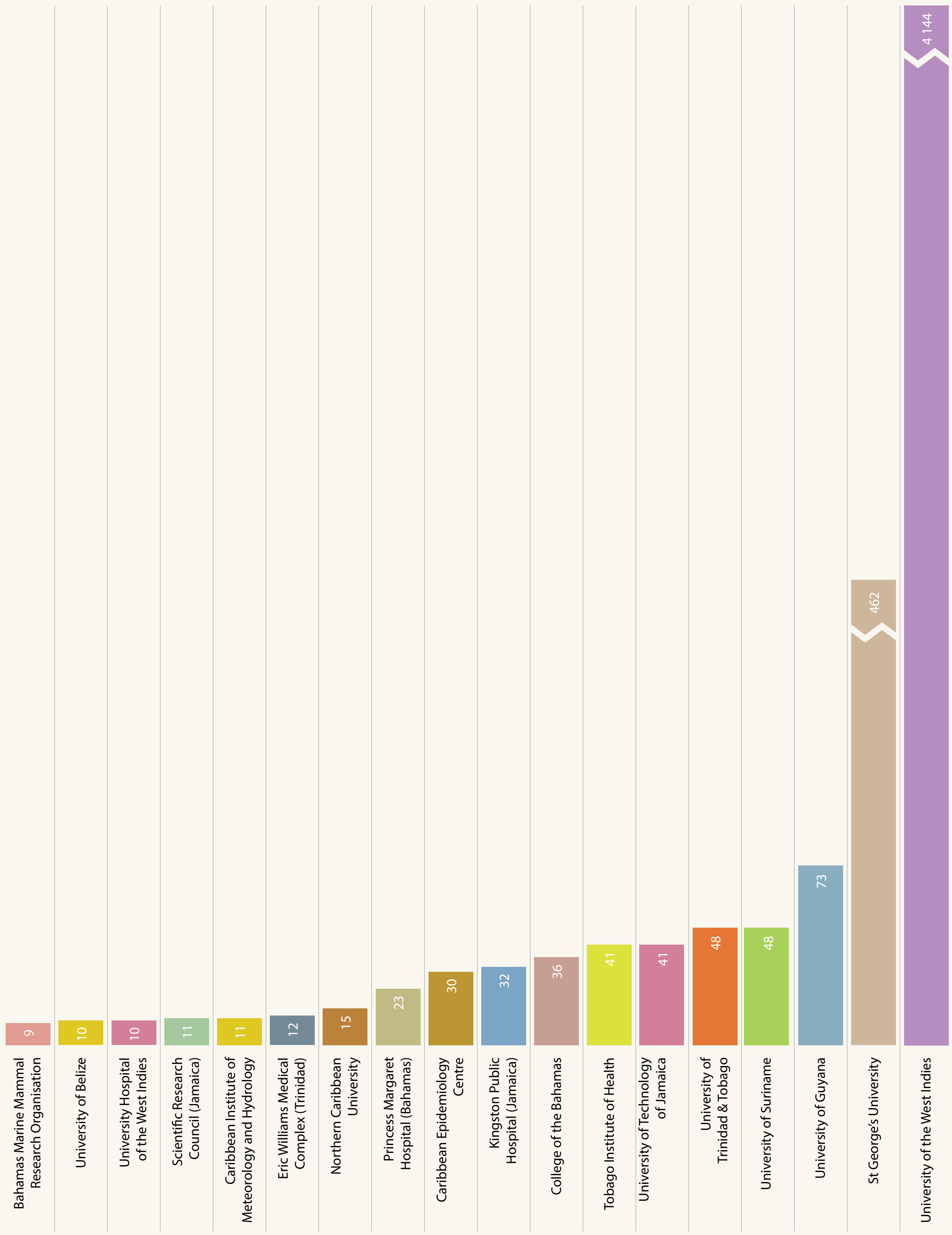
The Tropical Medicine Research Institute has built a research culture of a high standard by offering mentorship opportunities to young promising researchers (through postdoctoral positions) and competent support staff, such as research nurses, physicians, statisticians and equipment technologists. Very stringent recruitment and career advancement processes are also in place.

Clearly, the institute is an oasis of success in the desert that is Caribbean STI policy. The institute has managed to detach itself from the poor national research environment to create a competitive research programme on the global stage. Other R&D entities have not been so savvy; they will be held back as long as they continue to place all their eggs in the basket of non-functional or non-existent national R&D policy frameworks.

Source: authors

**Up until 1999, the Sickle Cell Research Unit had been funded by the British Medical Research Council (BMRC). The Tropical Metabolism Research Unit had been part of UWI since 1970, when it was transferred from the BMRC.*

Figure 6.8: **Refereed articles by Caribbean scientists, by institution, 2001–2013**



Source: Thomson Reuters Web of Science, Science Citation Index Expanded

Box 6.2: **Bio-Tech R&D Institute Ltd: adding value to local medicinal plants**

The Bio-Tech R&D Institute Ltd is a private R&D company founded by Dr Henry Lowe in 2010 with the ambition of becoming a premier biotechnology company in Jamaica and the wider Caribbean. The main research focus is on isolating pure compounds for the development of candidates for the treatment of cancer, HIV/AIDS, diabetes and other chronic diseases.

The company's research has led to the discovery and validation of several Jamaican medicinal plants and their products. These include *Tillandsia recurvata* (Old Man's Beard or Ball Moss), *Guaiacum officinale (Lignum vitae)* and *Vernonia* species. In February 2012, it began marketing seven nutraceutical products and a line of herbal teas in Jamaica. These discoveries have spawned several publications, including six in the journals covered by Thomson Reuters' database and as many patents.* The company's formulations for nutraceutical products are produced to the highest standards in a facility approved by the US Food and Drug Administration.

In October 2014, Dr Lowe and his team published a paper in the European Journal of Medicinal Plants after discovering that proprietary extracts from the Jamaican variety of Guinea Hen Weed inhibited the survival of the HIV virus. Dr Lowe told the Jamaican Observer at the time that these findings, if confirmed, might also impact the treatment of other viral diseases, such as Chikungunya and Ebola. In late 2014, he attracted international attention when he launched a company (Medicanja) to research and exploit marijuana plant varieties for potentially profitable medical applications.

The Bio-Tech R&D Institute Ltd employs about a dozen enthusiastic young PhD-holders and master's graduates, who have been able to engage in effective collaboration with established laboratories locally and overseas, especially at UWI and the University of Maryland (USA). The company has deepened its collaboration with the UWI, where it is establishing a state-of-the-art R&D facility and lending its entrepreneurial skill to the commercialization of UWI's suite of intellectual property.

Initially, the Bio-Tech R&D Institute Ltd received financial support from the Environmental Health Foundation, a not-for-profit company founded by Henry Lowe, but the BTI now lives off income from sales of its own products. No government funding flows to BTI.

BRDI has achieved remarkable success in its first five years of existence. Henry Lowe himself was awarded the National Medal for Science and Technology in 2014 by the Government of Jamaica.

This success story shows that an entrepreneur with a vision can provide a country and a region with desperately needed R&D leadership, even in the absence of effective public policy. There is hope that public policy will evolve in the near future, now that BRDI's achievements have attracted the attention of the senior political leadership.

Source: authors
**see: http://patents.justia.com/inventor/henry-lowe; www.ehfjamaica.com/pages/bio-tech-rd-institute-limited*

Private R&D companies emerging

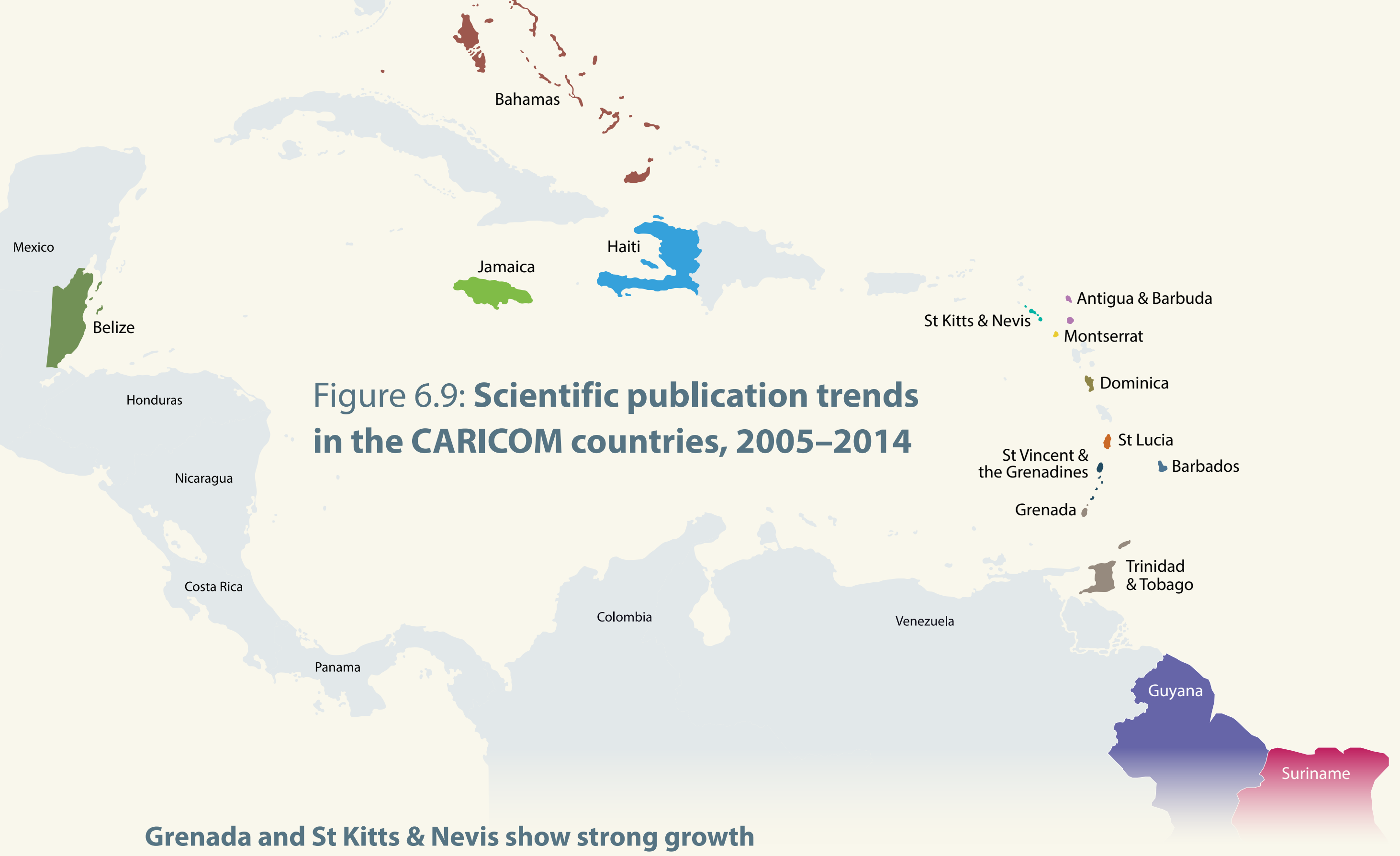
Private indigenous research companies are also emerging, such as the Bio-tech R&D Institute (Box 6.2). Cariscience has admitted the institute as a member at a time when some university departments are finding it a challenge to meet the criteria for membership. This is an important development in the science landscape, for it means that high quality research is no longer the preserve of universities, government laboratories and foreign outfits.

'Invented by the UWI'

Jamaica, Trinidad and Tobago and Barbados all register some patenting activity. Jamaica has a small but growing cadre of local inventers seeking patent ownership through the local Jamaica Intellectual Property Office. One known local invention which has been commercialized is a collection of three patents on UWI's Cardiac Surgery Simulator Technology,[15] which has been licensed to a US company after extensive field trials at leading US cardiac surgery schools. The cardiac surgery simulator, which uses a combination of specially harvested porcine (pig) hearts and a computer controlled electromechanical pumping system to simulate a pumping heart, gives students a much better feel for real surgical circumstances. Each unit manufactured will bear the label 'Invented by the UWI', which should help improve the techno-savvy image of the region.

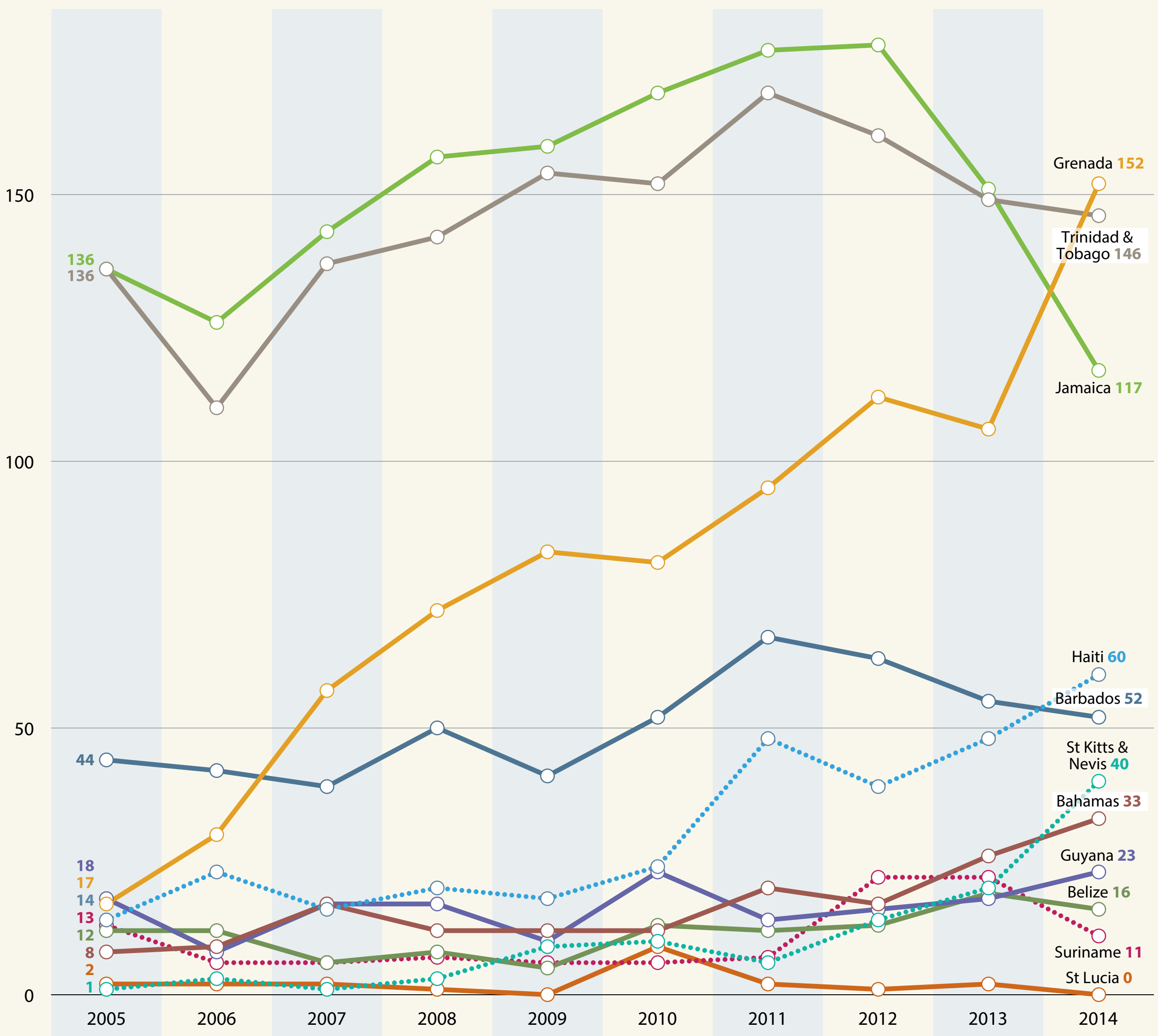
15. US Patent numbers: 8 597 874; 8 129 102; and 7 709 815: www.uspto.gov

Figure 6.9: **Scientific publication trends in the CARICOM countries, 2005–2014**



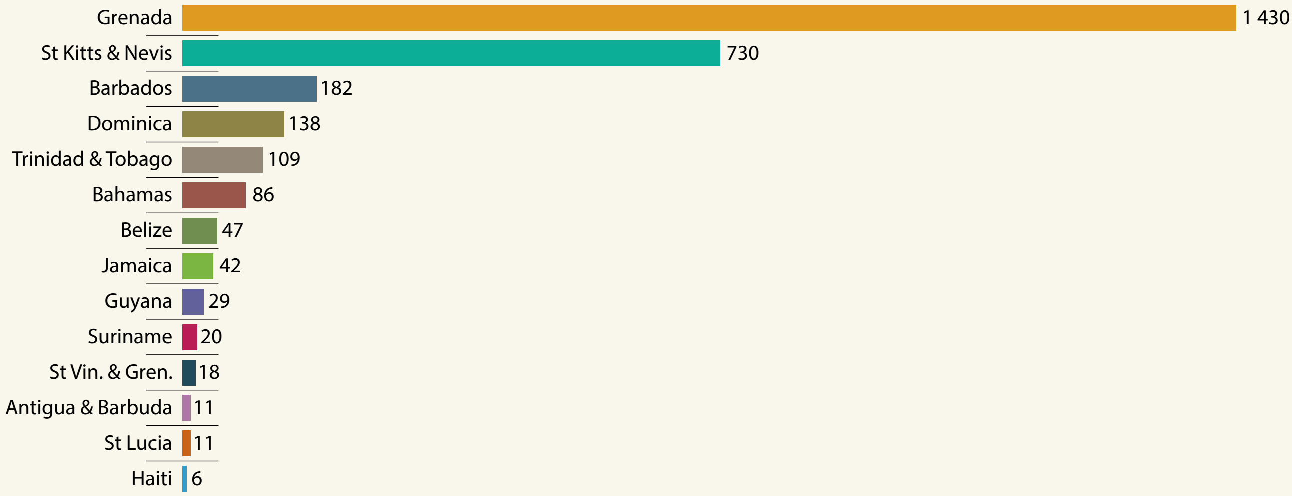
Grenada and St Kitts & Nevis show strong growth

Countries with more than 15 publications between 2008 and 2014



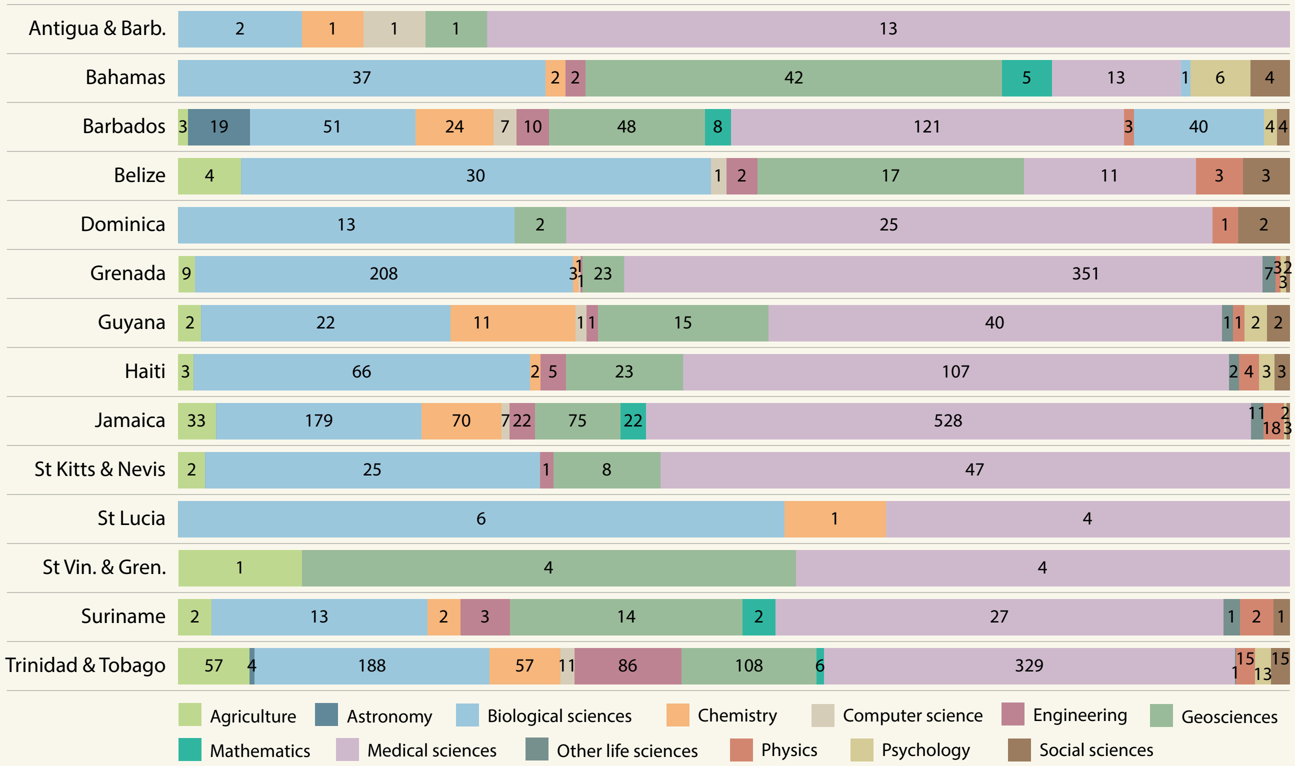
Grenada has the most intensive output

Scientific publications per million inhabitants in 2014



CARICOM countries publish most in health, led by Grenada and Jamaica

Cumulative totals, 2008-2014



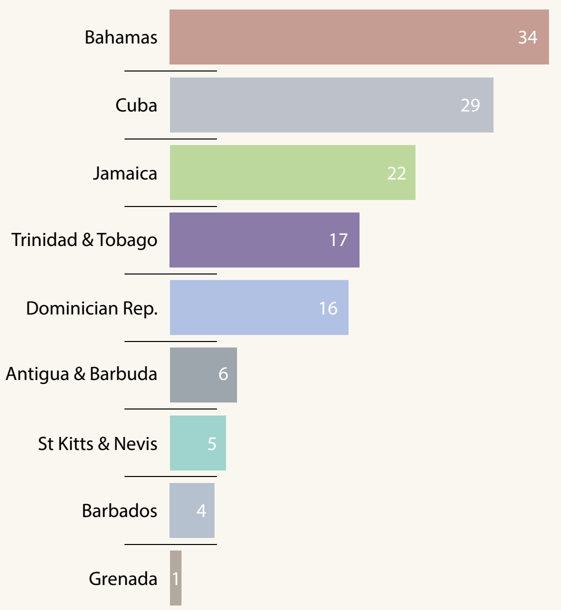
Jamaica and Trinidad & Tobago are close partners

Main partners for seven most prolific CARICOM countries, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Bahamas	USA (97)	Canada (37)	UK (34)	Germany (8)	Australia (6)
Barbados	USA (139)	UK (118)	Canada (86)	Germany (48)	Belgium/ Japan (43)
Grenada	USA (532)	Iran (91)	UK (77)	Poland (63)	Turkey (46)
Guyana	USA (45)	Canada (20)	UK (13)	France (12)	Netherlands (8)
Haiti	USA (208)	France (38)	UK (18)	South Africa (14)	Canada (13)
Jamaica	USA (282)	UK (116)	Canada (77)	Trinidad & Tobago (43)	South Africa (28)
Trinidad & Tobago	USA (251)	UK (183)	Canada (95)	India (63)	Jamaica (43)

Source: Thomson Reuters Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

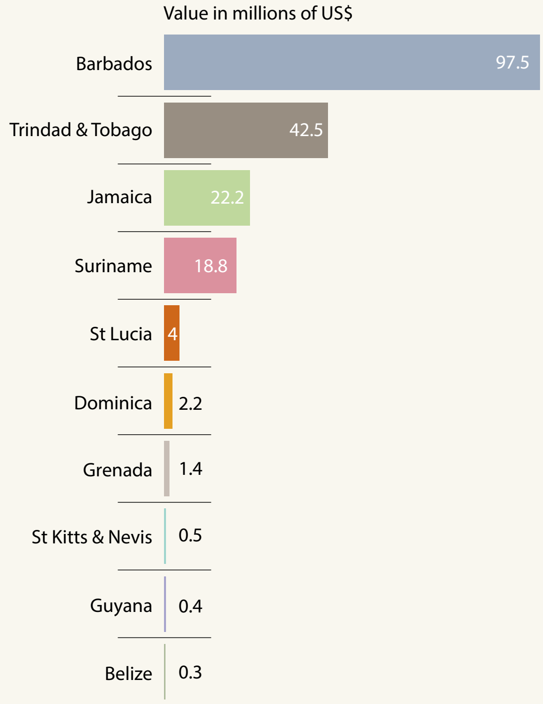
Figure 6.10: **USPTO patents granted to Caribbean countries, 2008-2013**



Note: Many patents are assigned to Barbados by companies but the inventors of these patents tend to have an address in the USA, so the patent is not attributed to Barbados.

Source: USPTO

Figure 6.11: **High-tech exports by CARICOM countries, 2008–2013**



Source: Comtrade database of United Nations Statistics Division

The US Patents and Trademark Office (USPTO) lists 134 patents from CARICOM countries over the period 2008–2013, the top contributors being the Bahamas (34), Jamaica (22) and Trinidad and Tobago (17). See Figure 6.10.

A handful of countries have high-tech exports

High-tech exports from the Caribbean are modest and sporadic (Figure 6.11). It is interesting to note, however, that Barbados not only holds a sizeable share of Caribbean patents but also has the greatest value of high-tech exports, which rose from US$ 5.5 million in 2008 to stabilize at US$ 18–21 million over 2010–2013.

Nearly eight out of ten Barbados exports over 2008–2013 concerned either scientific instruments (US$ 42.2 million) or chemistry (US$ 33.2 million excluding pharmaceuticals). Less revenue was earned from exports of electronics and telecommunications (US$ 6.8 million) and computers and office machines (US$ 7.8 million). Whereas Trinidad and Tobago led the region for high-tech exports in 2008 (US$ 36.2 million), these had plummeted to US$ 3.5 million by the following year. Jamaica's revenue has also dipped since 2008. By contrast, Suriname managed to increase its export earnings slightly over the same period.

CONCLUSION

Time for a detailed mapping exercise

The small CARICOM countries are vulnerable to a variety of environmental and economic shocks. Up until now, they have not managed to put in place and implement effective policy frameworks to propel STI. Consequently, important challenges in the region related to energy, water and food security, sustainable tourism, climate change and poverty reduction are not getting the level of input from the scientific enterprise required to make a difference.

What is encouraging is that CARICOM has promulgated a long-term development strategy for the region, the *Strategic Plan for the Caribbean Community: 2015–2019*. Moreover, engaging with STI is a pivot for this plan's success, as indeed it does in several national planning documents, such as *Vision 2020* in Trinidad and Tobago, *Jamaica Vision 2030* and the *Barbados Strategic Plan 2005–2025*. What is now required are policies that break with the implementation deficits of the past and effectively employ STI to accelerate the development process.

It is heartening to note that, in spite of a lack of effective STI policy frameworks and wavering public support for tertiary education, there are some bright spots on the horizon:

- Grenada has emerged over the past decade as a strong contributor to STI in the region, thanks largely to the growing productivity of St George's University;
- the UWI Mona Campus has managed to reduce its dependence on dwindling government funding by generating income streams of its own;
- the Tropical Medicine Research Institute at UWI continues to publish high-quality papers in top journals on the global stage; and
- a small new local private R&D company, the Bio-tech R&D Institute Limited, has muscled its way in just five years onto the global scene with papers, patents and commercial products, the sales from which are now generating a profit.

As pointed out by Kahwa (2003) a decade ago and echoed by the recent success stories above, in the absence of robust public policy to support and entrench STI in the national development process, it is researchers themselves who are devising innovative means of driving STI. It is high time that the region embarked on a detailed STI policy mapping exercise, in order to get a clear picture of the current situation.

Only then will countries be able to design evidence-based policies which propose credible strategies for raising investment in R&D, for instance. The findings of the situation analysis can be used to mobilize resources and strategic support for STI, to cultivate industrial participation in R&D by aligning efforts with industry needs, to reform or phase out underperforming public R&D institutions, to explore more politically and socially palatable means of raising funding for R&D, to align international and multilateral aid/borrowing on relevant R&D opportunities and to develop protocols for measuring and rewarding institutional and individual achievements in R&D. This cannot be too difficult a task when the leadership of the region is so highly educated.

KEY TARGETS FOR THE CARICOM COUNTRIES

- Raise the share of renewable energy sources in the electricity generation mix in CARICOM member states to 20% by 2017, 28% by 2022 and 47% by 2027;
- Raise the share of intra-CARICOM trade above the current share of 13–16% of intraregional trade by 2019.

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A variety of policy instruments have been introduced to make endogenous research more responsive to the needs of the productive system and society at large. This is now beginning to bear fruit in some countries.

Guillermo A. Lemarchand

A young man from the Achuar Territory in Ecuador holds up a frog. There is a growing research focus on pharmacology, biodiversity and the sustainable management of natural resources in Latin America.
Photo: © *James Morgan/ Panos*

7 · Latin America

Argentina, Plurinational State of Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, Bolivarian Republic of Venezuela

Guillermo A. Lemarchand

INTRODUCTION

Development slowing after a buoyant decade

Latin America consists essentially of middle-income economies[1] with very high (Argentina, Chile, Uruguay and Venezuela), high or medium levels of development. Chile has the highest GDP per capita and Honduras the lowest. Within countries, inequality is among the highest in the world, even though there has been some improvement in the past decade. According to the United Nations Economic Commission for Latin America (ECLAC), the four countries with the lowest levels of poverty are, Honduras, Brazil, Dominican Republic and Colombia (on Brazil, see Chapter 8).

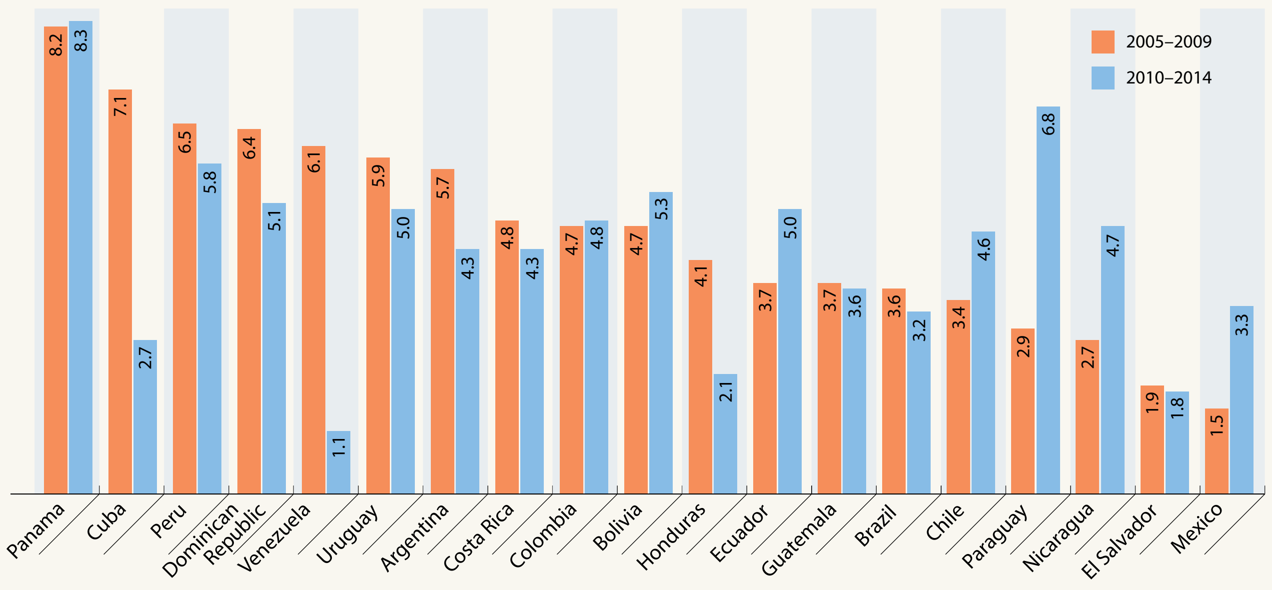
The Latin American economy grew by just 1.1% in 2014, meaning that GDP per capita actually stagnated. Preliminary figures for the first quarter of 2015 suggest an ongoing slowdown in activity since the decade-long commodities boom wound down in 2010 (see also Figure 7.1); some of the region's larger economies could even experience a contraction. While the region is expected to grow by about 0.5% on average in 2015, this masks a fairly wide variation: although South America is set to contract by 0.4%, Central American economies and Mexico are likely to expand by 2.7% (ECLAC, 2015a).

Prospects for Central America have improved, thanks to the healthy economic growth of their biggest trading partner, the USA (see Chapter 5), and lower oil prices since mid-2014. Moreover, declining prices for raw materials since the end of the commodities boom in 2010 should give countries in Central America and the Caribbean which are net importers of these products some breathing space. The Mexican economy is also dependent on North America's performance and is, thus, looking more dynamic. Present reforms in Latin America within the energy and telecommunications sectors, in particular, are expected to push up growth rates in the medium term. Meanwhile, growth forecasts are being revised downwards for those countries of South America that export raw materials. GDP is most dependent on this type of export in Venezuela, followed by Ecuador and Bolivia then Chile and Colombia.

The Andean countries of Chile, Colombia and Peru are in a comparatively enviable position but this may be short-lived, since their growth is expected to falter. Paraguay is also showing strong growth, as it recovers from a severe drought in 2012, whereas Uruguay's economy is growing at a more moderate rate.

1. Argentina and the Bolivarian Republic of Venezuela have had high inflation rates for the past few years. However, the 'official' exchange rate has remained flat, a factor which might generate some distortions in the real GDP per capita values expressed in US dollars. For a discussion of this issue, see ECLAC (2015a).

Figure 7.1: **Trends in GDP growth in Latin America, 2005–2009 and 2010–2014**



Note: Data for Cuba cover 2005–2009 and 2010–2013.

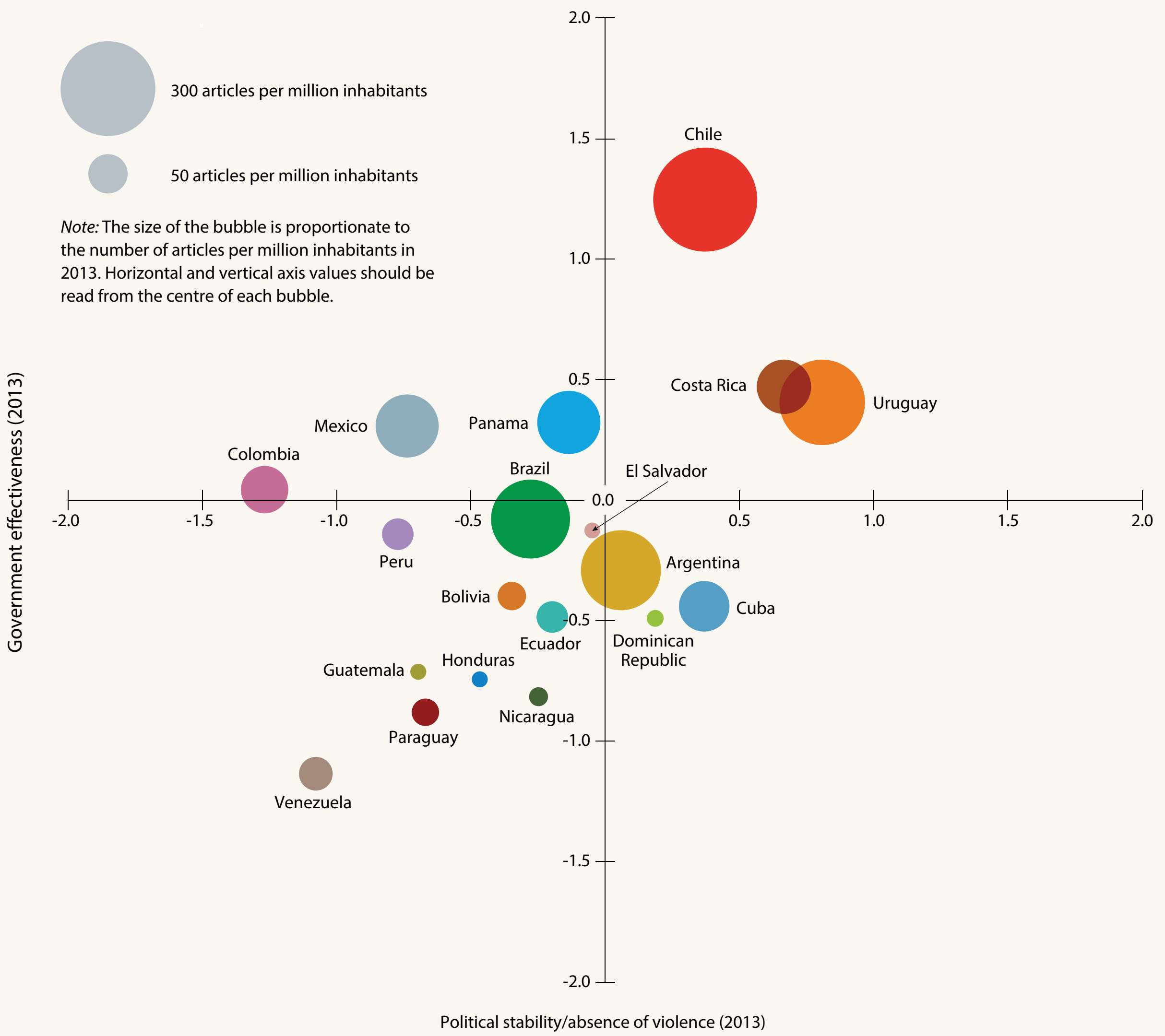
Source: World Bank's World Development Indicators, September 2015

In Venezuela, the collapse of the Brent crude price since mid-2014 has complicated an already difficult political situation but the economy is still performing vigorously. Argentina, meanwhile, is facing a debt crisis that has pitched it against private creditors in the USA; it showed almost zero growth in 2014 and this indicator may slip further in 2015. The combination of numerous administrative barriers and successive fiscal and monetary policies designed to stimulate household and business spending have engaged both Argentina and Venezuela in a spiral of high inflation levels and low foreign reserves.

On the political front, there has been some turbulence. A corruption scandal involving the Brazilian oil company Petrobras has taken a political turn (see Chapter 8). In Guatemala, President Pérez Molina resigned in September 2015 to face charges of fraud after months of street protests; such a development would have been inconceivable a few decades ago, suggesting that the rule of law has gained traction in Guatemala. The normalization of bilateral relations with the USA in 2015 should give Cuban science a considerable boost. Meanwhile, political tensions persist in Venezuela, the only country in the region to have seen its scientific publications decline between 2005 and 2014 (by 28%).

Political stability, the absence of violence, government effectiveness and the control of corruption are all vital to achieve long-term development goals and improve a country's scientific and technological performance. However, only Chile, Costa Rica and Uruguay currently have positive values for all of these governance indicators. Colombia,

Figure 7.2: **Relation between governance indicators and scientific productivity in Latin America, 2013**



Source: author, based on World Bank's Worldwide Governance Indicators; United Nations Statistics Division; and Thomson Reuters' Science Citation Index Extended

Mexico and Panama can boast of government effectiveness but not of political stability, owing to internal conflicts. Argentina, Cuba and the Dominican Republic all have positive values for political stability but are less effective when it comes to policy implementation. The remainder of countries have negative values for both indicators. It is interesting to note the high correlation between good governance and scientific productivity (Figure 7.2).

A regional union modelled on the EU

At the regional level, one of the most momentous developments in recent years has been the creation of the Union of South American Nations (UNASUR). The treaty was approved in May 2008 and entered into force in March 2011; the South American Council of Science, Technology and Innovation (COSUCTI) was established a year later within UNASUR to foster scientific co-operation.

The new regional body is modelled on the European Union (EU) and, thus, embraces the principle of the freedom of movement of people, goods, capital and services. UNASUR's 12 members[2] have plans to establish a common currency and parliament (in Cochabamba, Bolivia) and are discussing the idea of standardizing university degrees. UNASUR's headquarters are located in Quito (Ecuador) and its Bank of the South in Caracas (Venezuela). Rather than creating other new institutions, UNASUR plans to rely on existing trade blocs like the Common Market for the South (MERCOSUR) and the Andean Community.

High-tech exports drive growth in very few countries

The sectorial distribution of FDI in Latin America follows a very distinct pattern. In 2014, 18% of the region's technology-oriented FDI focused on low-tech projects, 22% on medium–low, 56% on medium–high and only 4% on high-tech projects. Investment in high technology tends to be destined for Brazil and Mexico, where much of it is captured by the automotive sector. At the other extreme, this type of technology accounts for less than 40% of FDI flows to Colombia, Panama and Peru. In Bolivia, the commodities sector receives the lion's share, especially the mining industry. In Central America and the Dominican Republic, where non-renewable natural resources are scarce and investment in *maquiladoras*[3] is not very capital-intensive, most investment goes to the services sector, which in the case of the Dominican Republic includes a competitive tourism sector. Ecuador, Colombia and especially Brazil have a more balanced distribution of FDI (ECLAC, 2015b).

2. Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay and Venezuela

3. A *maquiladora* is an export-processing zone where factories are exonerated from custom duties to enable them to assemble and transform goods using imported components, many of which are then re-exported.

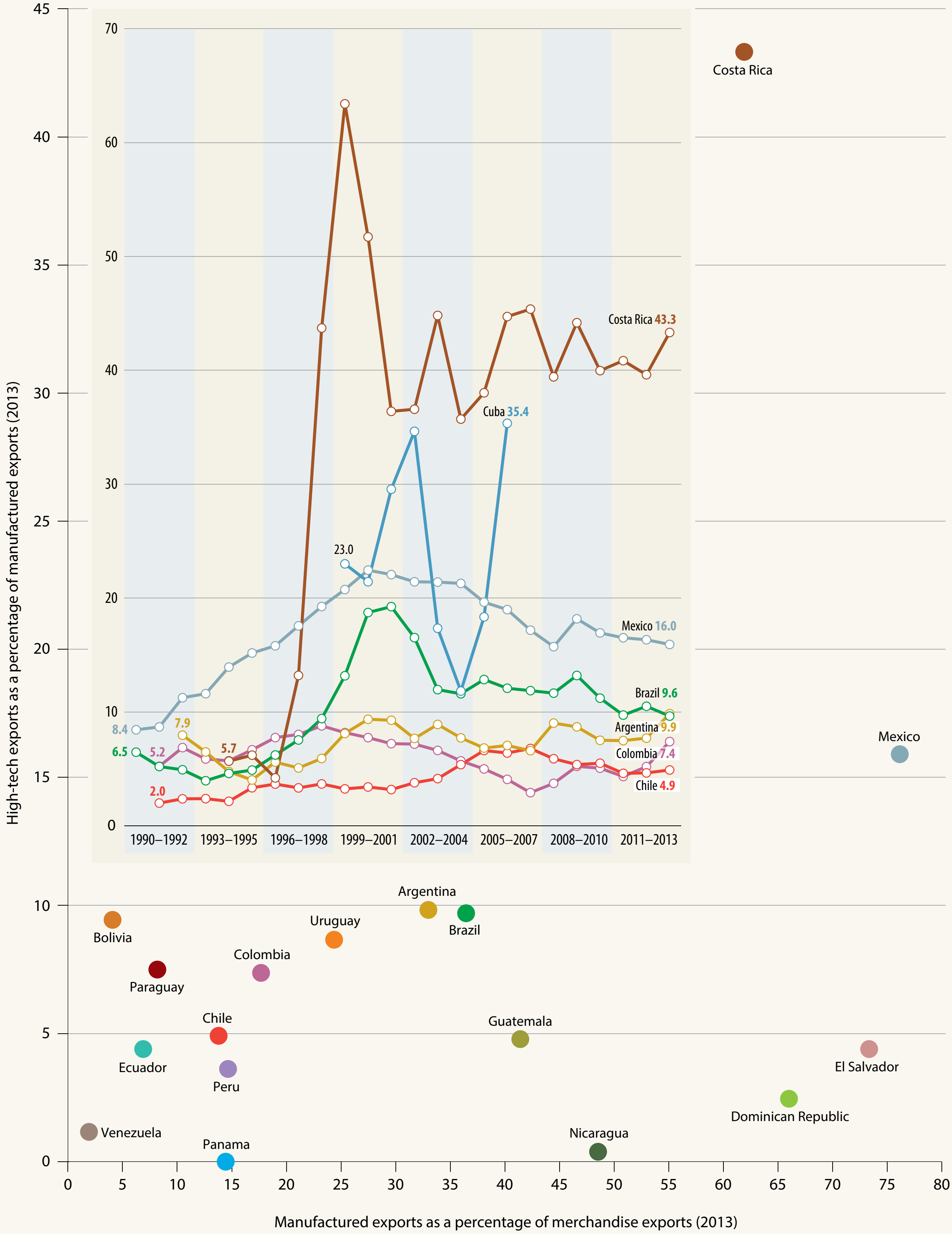
The majority of Latin American economies specialize in low technology, however, not only in terms of the content of their manufactured goods but also insofar as firms investing in an industry tend to operate at a considerable distance from the technological frontier. In addition to involving more innovation, the production and export of medium- or high-tech goods requires a higher level of physical and human capital than low-tech products or those based on natural resources.

In recent decades, the region has experienced mixed fortunes in incorporating technology into its exports. Mexico and, to a lesser extent, Central America, have achieved a radical transformation from commodities to medium- and high-tech manufactured products, thanks to special import regimes and export-oriented manufacturing. By contrast, the technological content of South American exports has not changed. This is because, on the whole, Latin America specializes in primary production.

Only in Costa Rica and, to a lesser degree, Mexico, do certain high-tech exports drive economic growth to an extent comparable with developing European economies (Figure 7.3). Moreover, there has been a decline in the high-tech component of manufactured exports from Mexico (and Brazil) since 2000. In Costa Rica, the large share of high-tech exports can be explained by the arrival of Intel, Hewlett–Packard and IBM in the late 1990s; this drove high-tech goods to a peak of 63% of manufactured exports before their share stabilized at around 45%, according to the *UNESCO Science Report 2010*. In April 2014, Intel announced that it would be relocating its microchip assembly plant in Costa Rica to Malaysia. Intel is estimated to have brought in 11% of net FDI inflows in 2000–2012 and represented 20% of Costa Rican exports in recent years. The cost to Costa Rica of the closure of Intel's production facility has been estimated at 0.3–0.4% of GDP over a 12-month period. The closure may reflect the highly competitive market for microchip assembly or the declining demand for personal computers worldwide. Although Intel wound up its assembly operations in Costa Rica with the loss of 1 500 jobs in 2014, it also added about 250 high-value jobs to the company's R&D group based in Costa Rica (Moran, 2014). Meanwhile, Hewlett Packard announced in 2013 that it would be moving 400 jobs in ICT services from its Costa Rican operations to Bangalore in India but that it would be remaining in Costa Rica.

A recent comparison with Southeast Asia has shown that the unfavourable conditions for trade in Latin America, such as time-consuming administrative procedures for exports, have discouraged export-intensive firms in the region from deeply integrating global supply chains (Ueki, 2015). Trade costs are also negatively affecting the development of internationally competitive manufacturing industries in Latin America.

Figure 7.3: **Technological intensity of Latin American exports, 2013**



Source: author, based on raw data from the World Bank accessed in July 2015

TRENDS IN STI POLICY AND GOVERNANCE

A growing public policy focus on R&D

Over the past decade, several Latin American countries have given their scientific institutions more political weight. Honduras, for example, has passed a law (2013) and related decree (2014) creating a national innovation system composed of the National Secretariat for Science, Technology and Innovation (SENACIT) and the Honduran Institute of Science, Technology and Innovation (IHCIETI), among other bodies, including a national foundation for funding STI. In 2009, Colombia passed a law defining the attributes and mandates of each individual institution within its entire national innovation system. In so doing, it followed in the footsteps of Panama (2007), Venezuela (2005), Peru (2004), Mexico (2002) and Argentina (2001).

In some cases, these new legal frameworks require that STI policies be approved by interministerial councils like the Scientific–Technological Cabinet (GACTEC) in Argentina. In other cases, STI policies may be approved by more eclectic councils bringing together the president, secretaries of state, academies of sciences and representatives of the private sector, as in the case of the Council for Scientific Research, Technological Development and Innovation (CGICDTI)[4] in Mexico. The most complex and sophisticated institutional ecosystems are found in the larger, richer economies of Argentina, Brazil, Chile and Mexico.[5]

Argentina, Brazil and Costa Rica all have Ministries of Science, Technology and Innovation. In Cuba, the Dominican Republic and Venezuela, on the other hand, the science ministry shares its mandate with higher education or the environment. Chile has a National Innovation Council and Uruguay a Ministerial Cabinet for Innovation. Several countries still have National Science and Technology Councils with policy planning attributes, as in Mexico and in Peru. Other countries have national secretaries of science and technology, such as Panama and Ecuador. In March 2013, Ecuador also created a National Council for Science and Technology (see p. 203). Some have administrative departments responsible for science and technology, like Colombia's Administrative Department for Science, Technology and Innovation (Colciencias).

A variety of sophisticated funding schemes for R&D

Over the past decade, many countries have formulated strategic plans and designed a variety of new policy instruments, including fiscal incentives, to foster innovation in the public and/or private sectors (Lemarchand, 2010; CEPAL, 2014; IDB, 2014). In Colombia, for instance, 10% of the revenue from the General Royalties System Fund (est. 2011) goes towards STI. In Peru, 25% of the royalties from the exploitation of various natural resources are allocated to the regional government where the mining took place through what are known as Canon funds (est. 2001); of these royalties, 20% is earmarked exclusively for public investment in academic research that promotes regional development through science and engineering. In Peru, 5% of the royalties from mining are allocated to universities by law (2004). A similar law adopted by Chile in 2005 allocates 20% of mining revenue to an innovation fund (IDB, 2014).

The most traditional mechanisms for promoting scientific research in Latin America are competitive grants and centres of excellence. Competitive funds may target infrastructure and the equipping of laboratories, take the form of travel grants, research grants, technological development grants or financial incentives that reward a researcher's scientific productivity. Argentina's Incentive Programme for University Teachers who conduct scientific research and the National System of Researchers (SNI) in Mexico[6] have played a fundamental role in expanding academic research. Two examples of centres of excellence are the *Programa Iniciativa Científica Milenio* in Chile and the *Centro de Excelencia en Genómica* in Colombia.

Over the past two decades, most Latin American countries have created specific funds for competitive research and innovation.[7] Most of these funds originated from a series of national loans provided by the Inter-American Development Bank (IDB). The IDB wields considerable influence over the design of national research and innovation policies by proposing specific terms of reference for how these loans should be allocated: as competitive grants, credits, scholarships, for public–private partnerships, new evaluation and assessment procedures, etc.

Cuba adopted this competitive funding model in 2014 with the creation of the Financial Science and Innovation Fund (FONCI), which promotes research and innovation in the public and business enterprise sector. This is a major breakthrough for Cuba, considering that, up until now, the bulk of the research budget for all R&D institutions, personnel and research projects has come from the public purse.

4. Consejo General de Investigación Científica, Desarrollo Tecnológico e Innovación

5. The complete organizational charts of all Latin American and Caribbean countries can be found at UNESCO's Global Observatory of STI Policy Instruments (GO→SPIN), which developed a prototype in 2010 for monitoring these national innovation systems. See: http://spin.unesco.org.uy

6. respectively the Programa de Incentivo a Docentes Investigadores (Argentina) and Sistema Nacional de Investigadores (Mexico); both programmes established a financial incentive for university teachers, according to their annual scientific productivity and their category of researcher

7. Examples are the Fondo para la Investigación Científica y Tecnológica (FONCYT) and Fondo Tecnológico Argentino (FONTAR, Argentina), Fondo de Fomento al Desarrollo Científico y Tecnológico (FONDEF, Chile), Fondo de Riesgo para la Investigación (FORINVES, Costa Rica), Fondo Financiero de Ciencia e Innovación (FONCI, Cuba), Fondo de Apoyo a la Ciencia y Tecnología (FACYT, Guatemala), Fondo Nacional de Ciencia y Tecnología (FONACYT, Paraguay), Fondo para la Innovación, Ciencia y Tecnología (FINCYT, Peru) and the Agencia Nacional de Investigación e Innovación (ANII, Uruguay)

A shift towards sectorial funding of R&D

Brazil established 14 sectorial funds between 1999 and 2002 to channel taxes[8] levied on specific state-owned companies towards fostering industrial development in key industries and services such as oil and gas, energy, space or information technology. Argentina, Mexico and Uruguay have all reoriented their policies towards this type of vertical funding, as opposed to horizontal funding which tends not to prioritize fields. Mexico adopted 11 sectorial funds in 2003 and a 12th for sustainability research in 2008. Other examples are Argentina's Sectorial Fund (FONARSEC, est. 2009) and the fund for software (FONSOFT, est. 2004), as well as the Innovagro Sectorial Fund for the Uruguayan agro-industry (est. 2008).

Brazil launched its own Inova-Agro programme in mid-2013. Inova-Agro has since become the main tool for channelling funding to the agribusiness sector disbursed by the National Bank for Economic and Social Development (BNDES), since it accounts for over 80% of the total of *circa* US$ 27 million; more than four-fifths of Inova-Agro funding targets livestock, fisheries and aquaculture.

Sectorial funds are one illustration of the diversity of sophisticated policy instruments (Table 7.1) promoting research and innovation in Latin America, even if these instruments have proved more effective in some countries than others. All countries face the same challenges, however. For one thing, there is a need to link endogenous research with innovation in the productive sector – this problem was already highlighted in the *UNESCO Science Report 2010* and stems from the lack of long-term industrial policies (over decades) to promote private-sector innovation. There is also a need to design and develop more effective policy instruments to connect the demand and supply sides of national innovation systems. In addition, there is a weak culture of evaluation and oversight for scientific programmes and projects in most Latin American countries; only Argentina and Brazil can boast of having institutions that conduct strategic foresight studies, the Centre of Management and Strategic Studies (CGEE) in Brazil and the new Interdisciplinary Centre for Studies in Science, Technology and Innovation (CIECTI)[9] in Argentina, which opened in April 2015.

8. For details, see the *UNESCO Science Report 2010.*

9. Centro de Gestão e Estudos Estratégicos (Brazil) and Centro Interdisciplinario de Estudios de Ciencia, Tecnología e Innovación (Argentina)

Table 7.1: **Inventory of operational STI policy instruments in Latin America, 2010–2015**

Country	Number of operational policy instruments by objective												
	a	b	c	d	e	f	g	h	i	j	k	l	m
Argentina	22	9	25	2	32	15	5	4	5	14	12	10	38
Bolivia	2	1	1	1	8	1	1	1	4		3	1	5
Brazil	15	10	31	6	6	15	5	5		5	8	4	27
Chile	25	12	25	6	24	17	7			6	14	6	37
Colombia	6	1	2	1	10	1		1	3	2	2	1	6
Costa Rica	2	2	10	2	23	4	3				4	4	4
Cuba					5						1		
Dominican Rep.					1								
Ecuador			5		4	2	2		4	1	1		4
El Salvador		4	2		5		9	1			6		2
Guatemala	3		6		6		2				1		4
Honduras	1		1		1		2						1
Mexico	16	9	13	5	6	14	6		3	4	6	5	19
Nicaragua	1		1									1	
Panama	5	2	14		6		3			1	1	1	4
Paraguay	8	1	6		5	4	1			3	2	5	3
Peru	10	7	12	1	6	3	5		1		1	2	6
Uruguay	13	3	11	1	13	9	2	3		3	8	4	14
Venezuela	5	1	3	2	7						2	1	2

Source: compiled by author on the basis of operational policy instruments collected by UNESCO's Montevideo office (http://spin.unesco.org.uy) and categorized using the new GO➞SPIN methodology: see UNESCO (2014) *Proposed Standard Practice for Surveys on Science, Engineering, Technology and Innovation (SETI) Policy Instruments, SETI Governing Bodies, SETI Legal Framework and Policies*

Policy instruments to:

a. strengthen production of new endogenous scientific knowledge;

b. strengthen the infrastructure of public and private research laboratories;

c. build capacity in research, innovation and strategic planning;

d. strengthen gender equality in research and innovation;

e. strengthen the social appropriation of scientific knowledge and new technologies;

f. develop strategic S&T areas;

g. strengthen science education from primary to postgraduate levels;

h. develop green technologies and technologies fostering social inclusion;

i. promote indigenous knowledge systems;

j. strengthen co-ordination, networking and integration processes in the research and innovation eco-system to promote synergies among the government, university and productive sectors;

k. strengthen the quality of technology foresight studies to: assess the potential of high-value markets; develop business plans for high-tech companies; construct and analyse long-term scenarios; and provide consulting services and strategic intelligence;

l. strengthen regional and international co-operation, networking and promotion of science and technology;

m. promote start-ups in high-tech fields and new niche products and services with high added value.

TRENDS IN HUMAN RESOURCES

Spending on tertiary education high

Many Latin American governments devote more than 1% of GDP to higher education (Figure 7.4), a level typical of developed countries. Moreover, in Chile and Colombia, there has been strong growth in both expenditure per student and in university enrolment since 2008.

Both the number of university graduates and tertiary institutions have been expanding steadily for decades. According to the UNESCO Institute for Statistics, more than 2 million bachelor's or equivalent degrees were awarded in Latin America in 2012, a 48% increase over 2004. Most of the graduates were women.[10] The rise in PhD degrees has been almost as spectacular: 44% since 2008 (23 556 in 2012). The share of PhD-holders in the general population in the more advanced countries of Latin America compares well with the figures for China, India, the Russian Federation and South Africa but not with the most developed countries (Figure 7.4).

Six out of ten graduates at the bachelor's level specialize in social sciences (Figure 7.4), compared to only about one in seven for engineering and technology. This trend contrasts starkly with that in emerging economies such as China, the Republic of Korea or Singapore, where the great majority of graduates study engineering and technology. In 1999, there was an equal share of PhD students studying social sciences and natural and exact sciences in Latin America but the region has never recovered from the strong disaffection for the latter fields witnessed at the turn of the century (Figure 7.4).

High ratios of students living abroad

Among students from the region enrolled in tertiary study abroad, there were four times as many (132 806) living in North America or Western Europe as in Latin America (33 546) in 2013 (Figure 7.4). Although the more populous countries account for the majority of these international students, some smaller countries also have large contingents, such as Ecuadorians in the USA (Figure 7.4). The highest ratios (per national population) of students living in developed countries are to be found in Ecuador, Colombia, the Dominican Republic and Panama.

Some 3 900 students of Latin American origin were awarded PhDs in science or engineering in US universities between 2008 and 2011 (NSB, 2014). Although between one-third and half typically announce their intention to stay in the USA indefinitely, the number of PhDs and postdocs returning from study abroad can rival the number trained at home, as in the case of Panama.

10. The highest shares were found in Panama and Uruguay (66%), the Dominican Republic and Honduras (64%), Brazil (63%), Cuba (62%), Argentina (61%), El Salvador (60%), Colombia (57%), Chile (56%) and Mexico (54%).

Many Bolivians, Colombians, Ecuadorians and Peruvians choose to study in Latin America but outside their home country. Relative to population, Bolivia still figures high on the list but is this time joined by Nicaragua, Panama and Uruguay. Cuba is one of the most popular student destinations within Latin America; the UNESCO Institute for Statistics estimates that there are around 17 000 students from other Latin American countries living in Cuba, compared to 5 000 in Brazil and around 2 000 in each of Argentina and Chile.

Schemes to strengthen knowledge networks

In light of the shortage of engineers, geologists, oceanographers, meteorologists and other specialists, Argentina, Brazil and Chile have all introduced a series of financial incentives and scholarships to attract undergraduates to these strategic fields. They have also adopted new scholarship schemes to attract foreign nationals to PhD programmes. In 2013, the Mexican National Council for Science and Technology (CONACYT) and the Organization of American States jointly created a programme offering 500 scholarships over the next five years for postgraduate education in biology, chemistry, Earth sciences, engineering, mathematics and physics, in order to facilitate graduate student exchanges within the Americas.

Another milestone has been the founding of a research institute in collaboration with UNESCO's Abdus Salam International Centre for Theoretical Physics (ICTP), the São Paulo State University and the São Paulo Research Funding Agency: the ICTP–South American Institute for Basic Research, located within the State University of São Paulo. Between 2012 and 2015, this new institute organized 22 regional graduate schools, 23 regional workshops and 18 regional mini-schools.

In recent decades, several Latin American countries have sought to strengthen knowledge networks at home by reinforcing ties with the diaspora. Those proposing the greatest variety of student scholarships and training schemes are Argentina, Brazil, Chile and Mexico. In Argentina, the Raíces Programme (*raíces* meaning 'roots') became a state policy in 2008; this programme has repatriated around 1 200 highly qualified researchers since its creation in 2003, in parallel to promoting the creation of networks of Argentinean scientists in developed countries.

Other examples are the Mexican Talent Network (*Red de Talentos Mexicanos,* est. 2005), the Bilateral Forum on Higher Education, Innovation and Research involving Mexico and the USA (FOBESII, est. 2014), Chile Global and, in Brazil, Science without Borders (see Box 8.3). Colombia, Ecuador and Uruguay have also put in place well-funded initiatives. Some schemes favour the repatriation of scientists, with a set of sophisticated mechanisms for the co-ordination of these schemes with industrial and production development policies to ease the absorption of these highly skilled people into the domestic economy. Others promote short visits (2–3 months) by experts for the purposes of teaching graduate courses.

Figure 7.4: **Trends in higher education in Latin America, 1996–2013**

4.47%

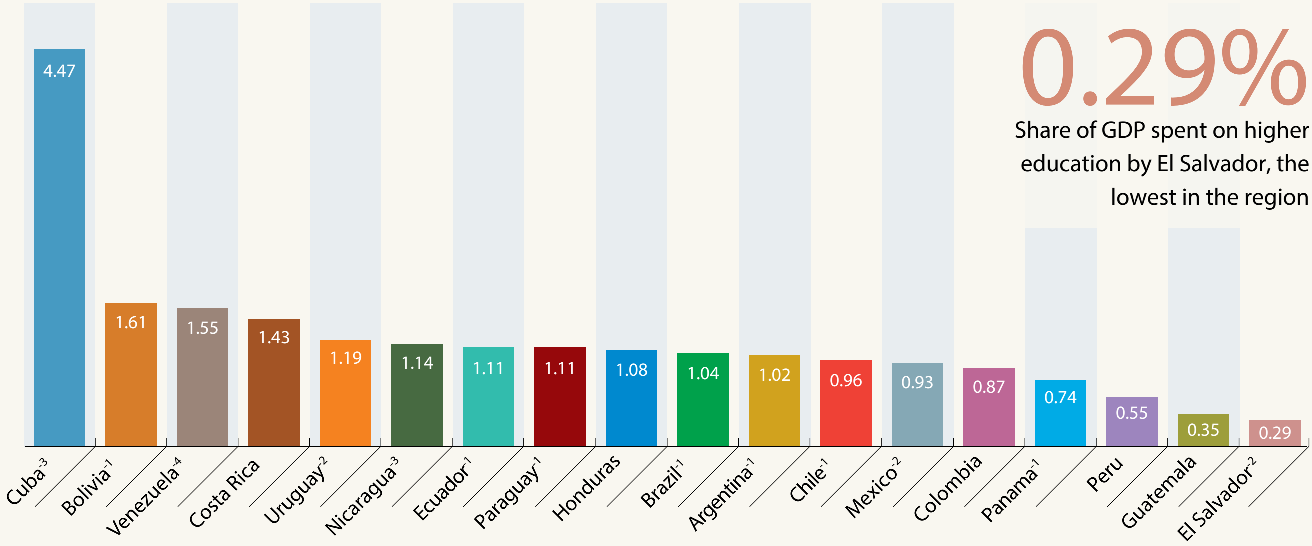
Share of GDP spent on higher education by Cuba, the highest in the region

0.29%

Share of GDP spent on higher education by El Salvador, the lowest in the region

Eleven countries devote more than 1% of GDP to higher education

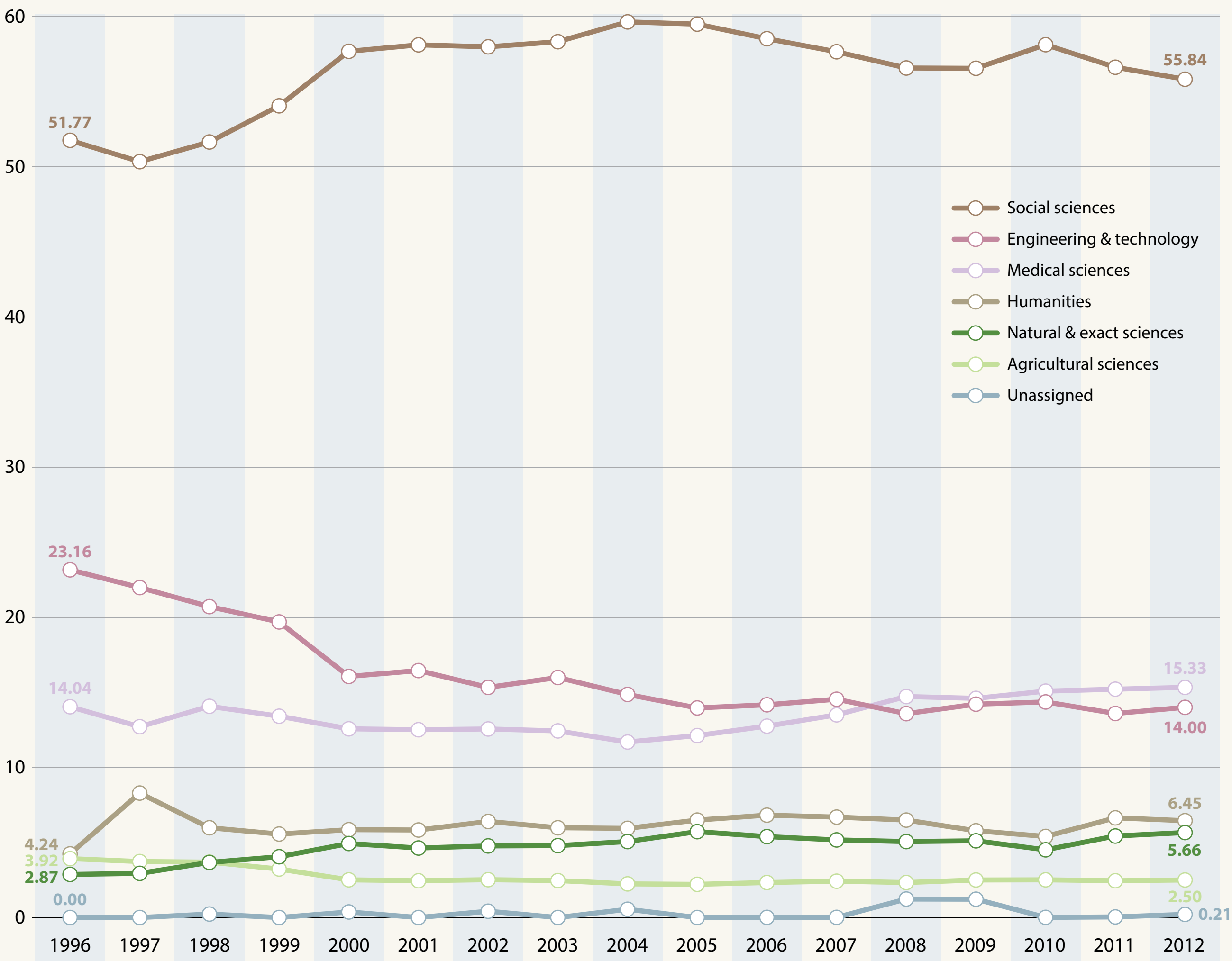
Expenditure on higher education as a share of GDP, 2013 or closest year (%)



+n/-n = data refer to *n* years before or after reference year

The great majority of first-degree graduates in Latin America study social sciences

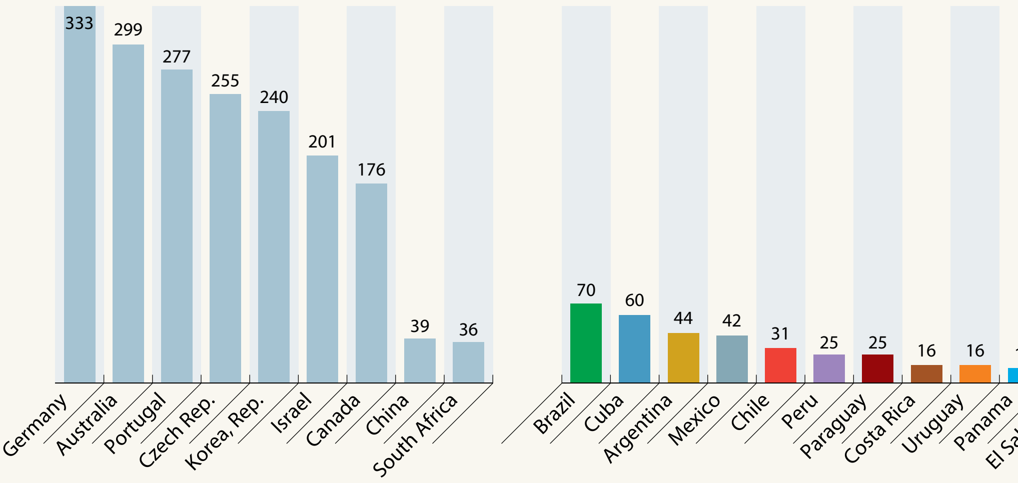
Distribution of bachelor's degrees by field of study, 1996–2012 (%)



Brazil has the most PhD graduates per million inhabitants in Latin America

PhD graduates per million inhabitants, 2012

Countries outside Latin America are given for comparison

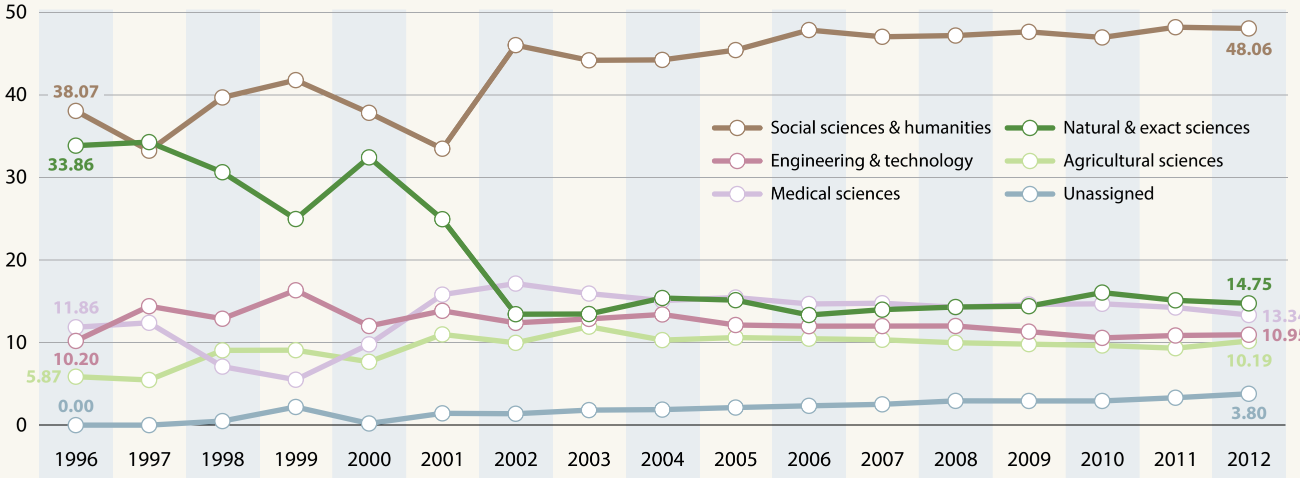


23 556

Number of doctorates awarded in Latin America and the Caribbean in 2012

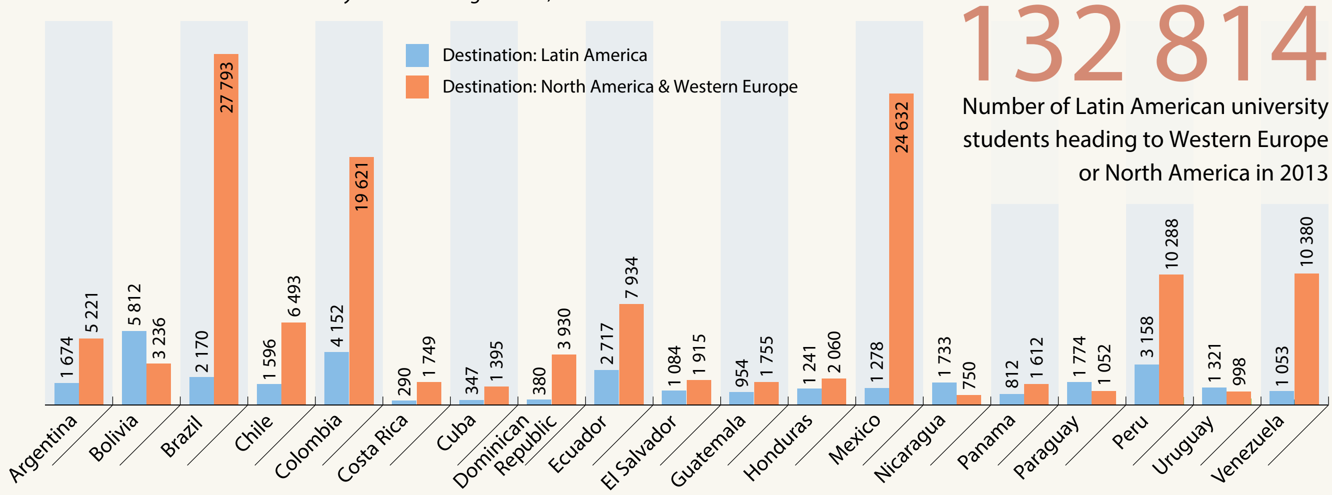
The share of PhD graduates in natural sciences has not recovered since this indicator plunged a decade ago

Distribution of PhDs in Latin America by field of study,1996–2012 (%)



Students head for Western Europe and North America more than other Latin American countries, with the exception of those from Bolivia, Nicaragua, Paraguay and Uruguay

Number of Latin American university students living abroad, 2013



132 814

Number of Latin American university students heading to Western Europe or North America in 2013

Source: For higher education spending and students living abroad: UNESCO Institute for Statistics: for graduates; RICYT database, July 2015; for PhD students per million inhabitants, estimations based on data from the UNESCO Institute for Statistics and United Nations Statistics Division

The Start-Up Chile programme (2010) takes a different approach. Its aim is to attract entrepreneurs from around the world in the hope that their presence in Chile will help transmit tacit entrepreneurial knowledge to local entrepreneurs in a way that would be impossible through traditional training and scholarship programmes (see also Box 7.1).

Most countries need more researchers

In the past few years, there has been a leap in the number of full-time equivalent (FTE) researchers in Costa Rica, Ecuador and Venezuela, whereas other countries have seen less vigorous growth (Figure 7.5). Latin American countries generally trail dynamic open economies for the number of researchers per million inhabitants, although the top two

Box 7.1: **Tenaris: a corporate university building industrial skills in-house**

Attracting and retaining talented scientists and engineers remains a big challenge for the industrial sector in Latin America. In the past two decades, top companies have been investing in the development of corporate universities around the world: Motorola, Mastercard, Toyota, Cisco, etc..

In 2005, Tenaris – a company of Argentinian origin – created the first corporate university in Latin America. Tenaris is a leading manufacturer of seamless steel pipes for the world's oil and gas industry, with facilities in nine countries* that employ over 27 000 people.

Tenaris University has based its global campus in Campana (2008), Argentina, and has three other training facilities in Brazil, Italy and Mexico. The university offers employees the choice between 450 e-learning and 750 classroom courses at its Industrial Schools (for company engineers), Schools of Finance and Administration, Commercial Management, Information Technology and its Schools of Technical Studies.

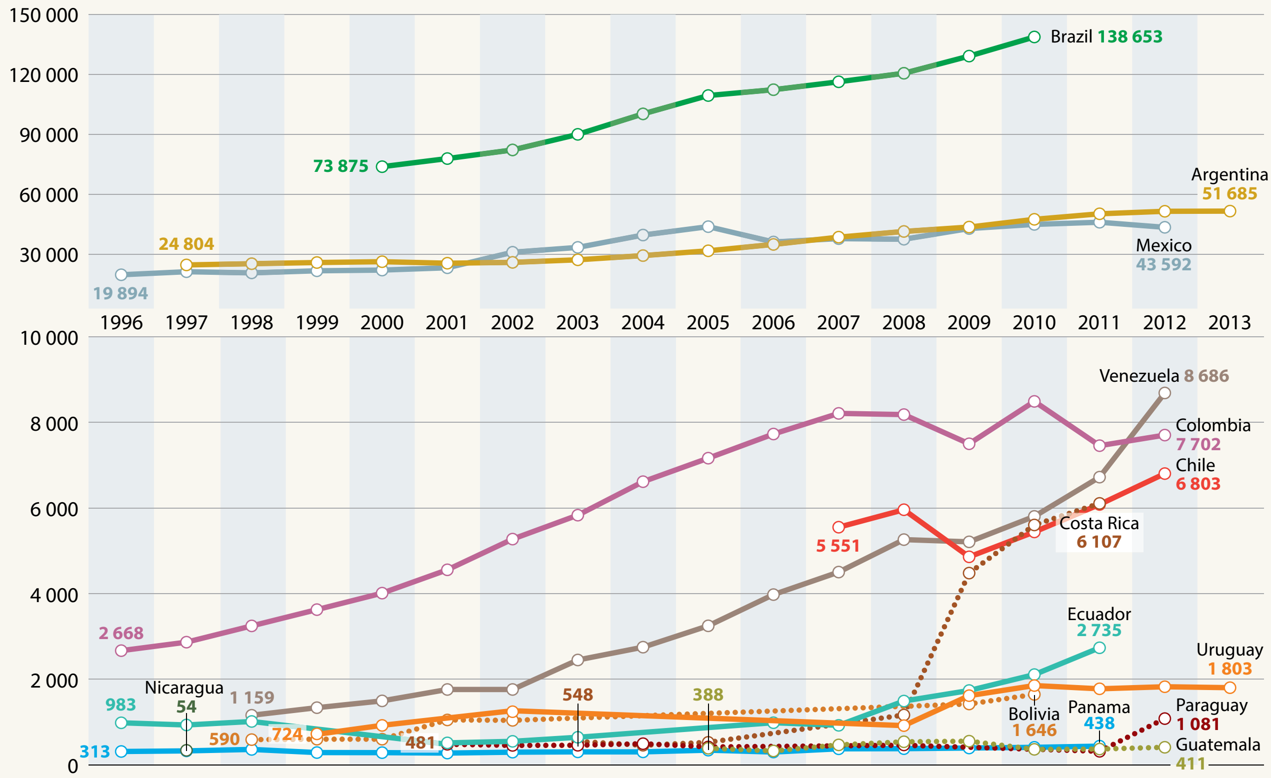
Internal experts recruited from within the company serve as the main body of instructors.

The company has compensated for the recent drop in global demand for its products by augmenting the number of hours employees spend in training. This way, employees should return to the factory floor with better skills once production picks up again.

*Argentina, Brazil, Canada, Colombia, Italy, Japan, Mexico, Romania and the USA

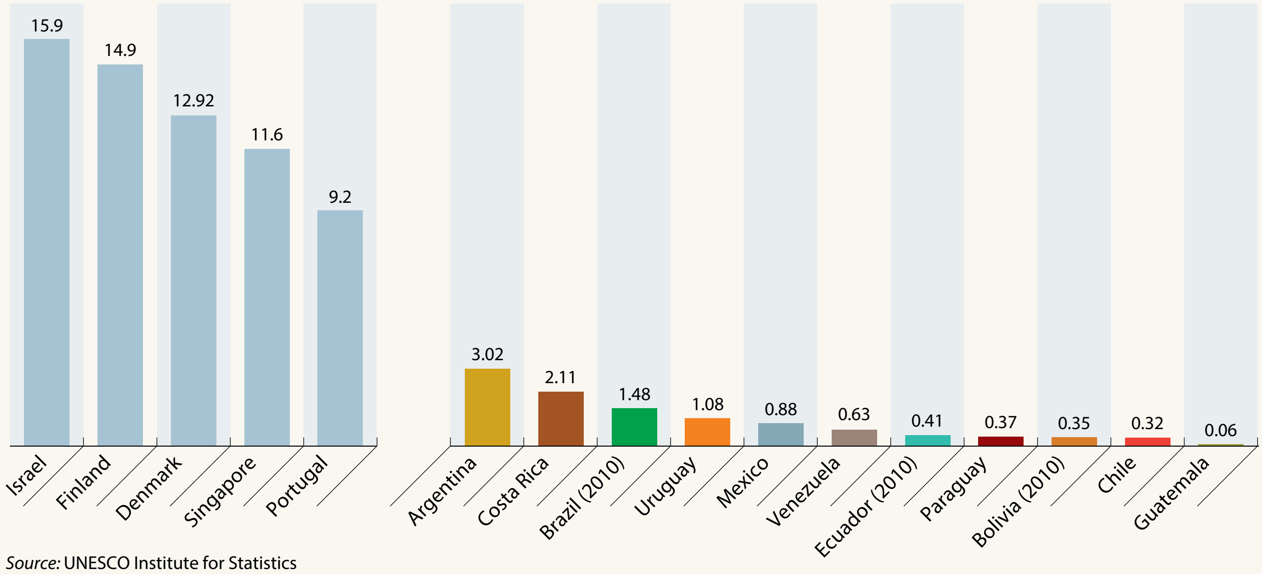
Source: compiled by author

Figure 7.5: **Researchers (FTE) in Latin America, 1996–2013**



Source: UNESCO Institute for Statistics

Figure 7.6: **Researchers (FTE) in Latin America per thousand labour force, 2012**
Countries outside Latin America are given for comparison



Source: UNESCO Institute for Statistics

countries – Argentina (1 256) and Costa Rica (1 289) – both have ratios above the world average: 1 083 (see Table 1.3).

Argentina still has the most full-time equivalent (FTE) researchers per thousand labour force. Argentina's ratio is even twice that of Brazil, 3.4 times that of Mexico and almost ten times that of Chile. This said, Argentina still has a great distance to travel to catch up to developed economies (Figure 7.6).

Latin America as a region nevertheless excels for other indicators, such as for the participation of women in research (Lemarchand, 2010, pp. 56–61). A recent study has shown that Latin America also has the highest rates of female entrepreneurship and a smaller gender gap in research than other regions (IDB, 2015; see also Chapter 3). This is hardly surprising, given the explicit policy instruments promoting women in science and engineering in Latin America. The most compelling of these are the Women and Science programme in Brazil and the Postgraduate Scholarship Programme for Indigenous Women in Mexico.

TRENDS IN R&D EXPENDITURE

Countries could invest more in R&D

In 2012, gross domestic expenditure on R&D (GERD) in Latin America and the Caribbean surpassed PPP$ 54 billion (in 2012 constant dollars),[11] a 1.70% increase over 2003. Just three countries concentrate 91% of GERD: Argentina, Brazil and Mexico. Brazil is the only country with an R&D effort of more than 1% of GDP (see Chapter 8 and Figure 7.7).

GERD has remained relatively constant in Latin America over the past few decades (Lemarchand, 2010, p. 35–37). Since 2006, R&D spending has grown moderately in Argentina, Brazil and Mexico but there is no evidence to suggest that either Chile or Colombia is making a determined push to raise its own R&D intensity. Among the smaller economies, Costa Rica and Uruguay have the highest level of investment in R&D, whereas GERD seems to fluctuate in Bolivia, Cuba, Ecuador and Panama.

The public sector remains the main source of funding, particularly in Argentina, Cuba, Mexico and Paraguay. Businesses in the region contribute about 40% of R&D funding, on average (Figure 7.7), with Brazil slightly surpassing this share (see Chapter 8). The public sector still carries out the bulk of research. Six countries receive a considerable share of research funding from abroad: Chile, El Salvador, Guatemala, Panama, Paraguay and Uruguay (Figure 7.7). In the case of Chile, the high share of GERD funded from abroad (18%) relates to the activity of a cluster of European and North American astronomical observatories; in Panama, the high share (21%) is due to the presence of the Smithsonian Institution.

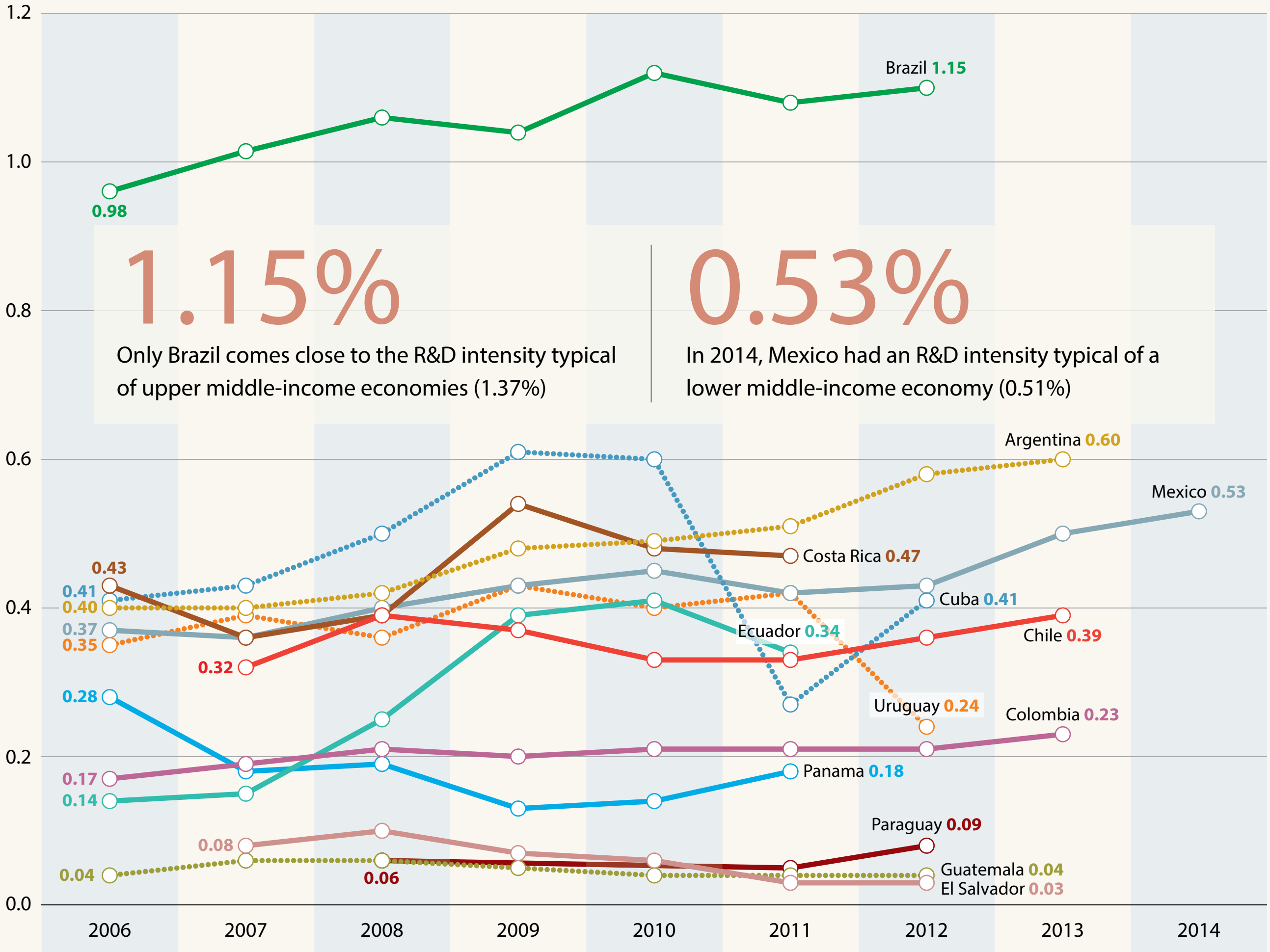
A breakdown of R&D expenditure by socio-economic objective is only available for a handful of countries. In 2012, Argentina and Chile allocated one-third of this expenditure to engineering and technology, a sizeable share for emerging economies. Both prioritized industrial and agricultural production and technology. Smaller countries prioritized agricultural production (Guatemala and Paraguay), human health (El Salvador, Guatemala and Paraguay), social structures (Ecuador), infrastructure, energy and the environment (Panama).

11. The original RICYT estimations were calculated using PPP current international dollars. In order to remove distortions caused by inflation, here, we have adjusted those values to constant PPP (2012) dollars.

Figure 7.7: **Trends in GERD in Latin America and the Caribbean, 2006–2014 (%)**

Few Latin American countries have seen a consistent rise in their R&D intensity over the past decade

GERD as a share of GDP, 2006–2014 (%)



1.15%

Only Brazil comes close to the R&D intensity typical of upper middle-income economies (1.37%)

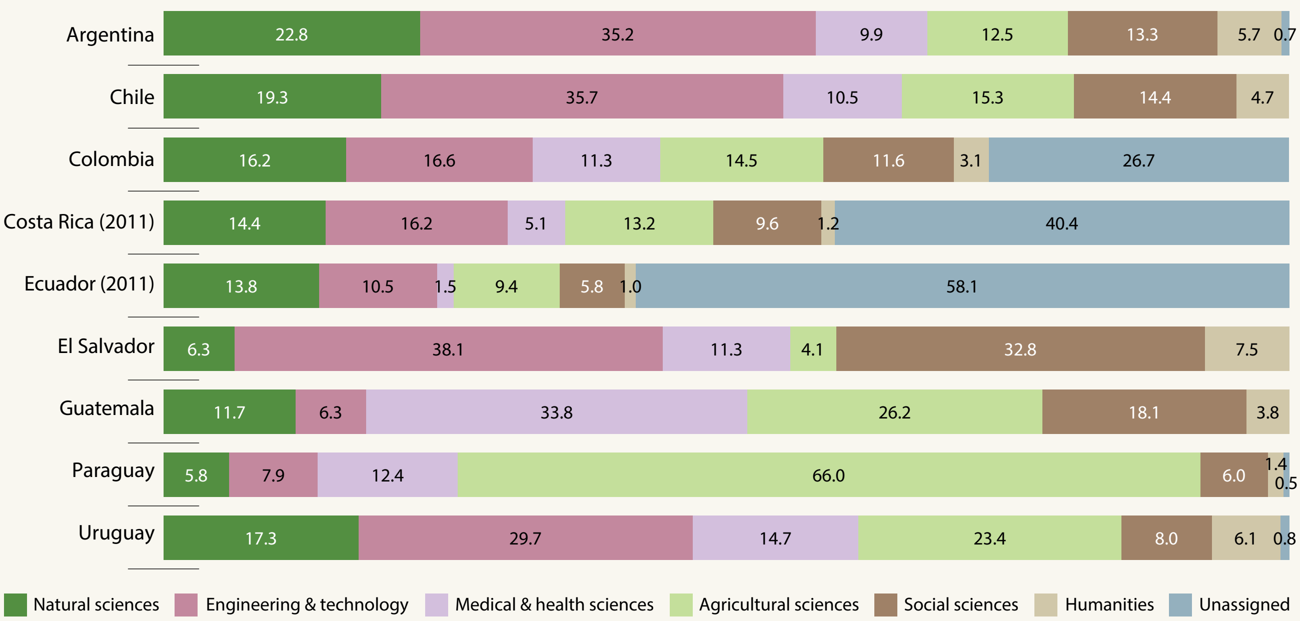
0.53%

In 2014, Mexico had an R&D intensity typical of a lower middle-income economy (0.51%)

Note: Data are unavailable for Honduras, Nicaragua, Peru and Veneuzela. Data are only available for Bolivia for 2009 (0.15%).

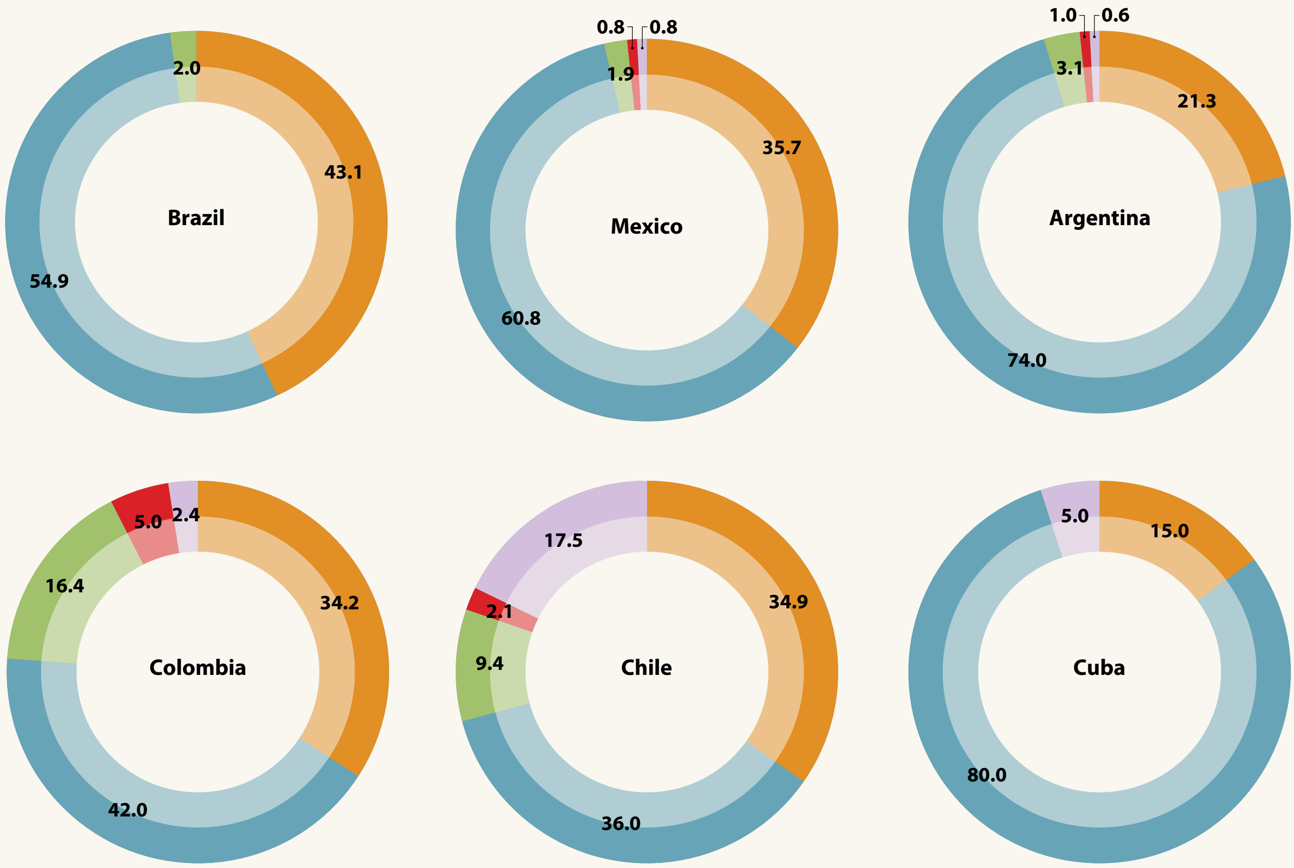
Agricultural sciences account for two-thirds of Paraguay's R&D expenditure

GERD by field of science, 2012 (%)

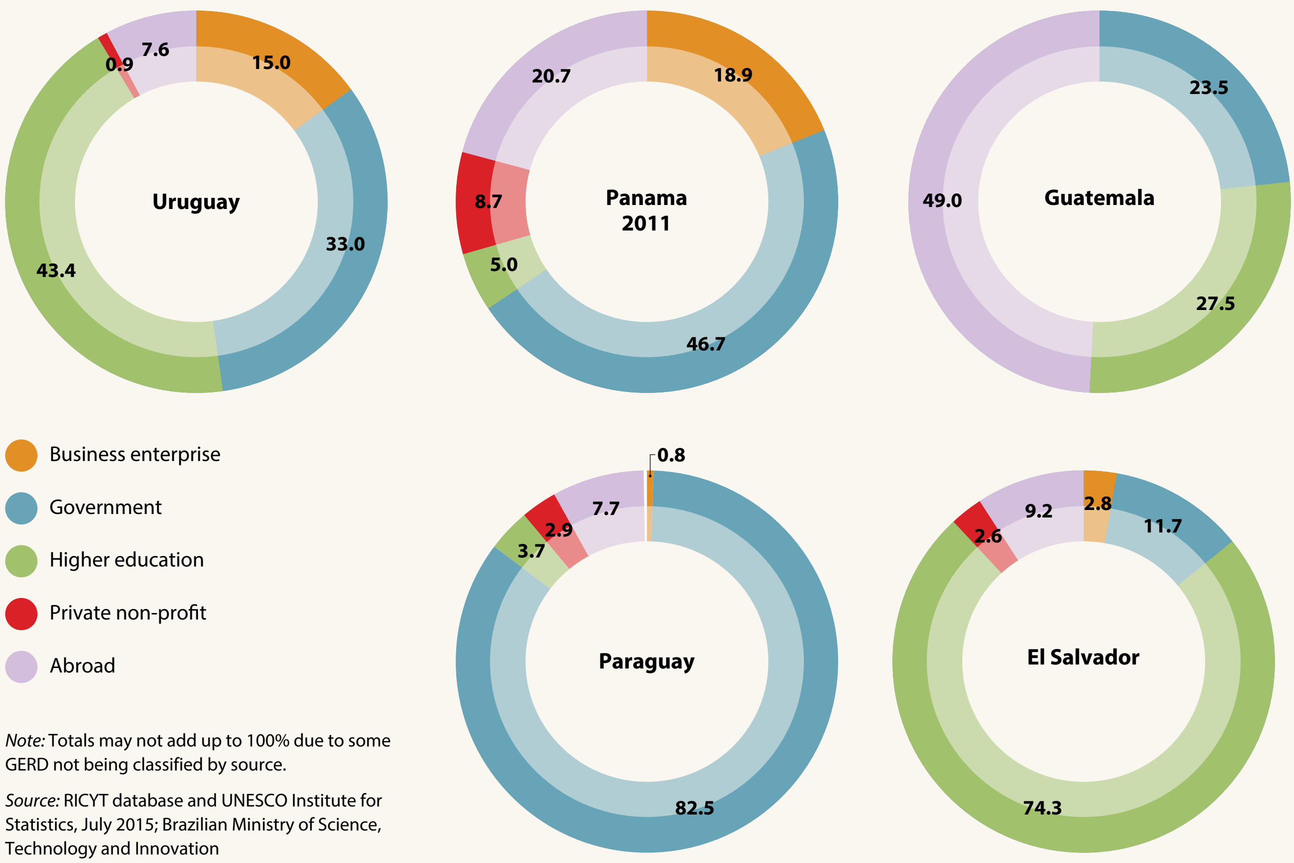


Brazil and Mexico have the highest share of business-funded R&D in Latin America

GERD by source of funds, 2012 (%), countries arranged in descending order of GERD by volume (PPP$)



Panama has the highest share of private non-profit-funded R&D, thanks largely to the presence of the Smithsonian Institution



Note: Totals may not add up to 100% due to some GERD not being classified by source.

Source: RICYT database and UNESCO Institute for Statistics, July 2015; Brazilian Ministry of Science, Technology and Innovation

TRENDS IN R&D OUTPUT

Publications rising, including those with foreign partners

The number of articles published by Latin American authors in mainstream scientific journals catalogued in the Science Citation Index Extended increased by 90% between 2005 and 2014, carrying the region's global share from 4.0% to 5.2%. Growth was fastest in Colombia (244%), Ecuador (152%), Peru (134%) and Brazil (118%) and more moderate in Argentina and Mexico (34% and 28% respectively). The overall volume of scientific Venezuelan publications actually declined by 28% (Figure 7.8).

Between 2008 and 2014, one-quarter (25%) of the region's publications focused on biological sciences, one-fifth (22%) on medical sciences, 10% on physics, 9% on chemistry and 8% each on agricultural sciences, engineering and geosciences. Of note is the relatively large share of Chilean articles in astronomy: 13% (Figure 7.8).

Despite the rise in the volume of Latin American publications, their impact on breakthrough international science remains modest. Central American papers are cited more than those from South America but this may be because the sheer volume of output from South America stifles these 'hot topics.'

It can be more telling to evaluate the impact of publications over decades rather than years. Hirsch (2005) has proposed the so-called *h*-index, which reveals the number of articles (*h*) from a given country that have received at least *h* citations. Between 1996 and 2014, the highest *h* indices were obtained by Brazil (379), Mexico (289), Argentina (273), Chile (233) and Colombia (169). Taking into account the full scientific production over this period, all Latin American countries (with the exception of Brazil, El Salvador and Mexico) rank better worldwide for their *h*-index than for the number of articles. Panama carries this trend to extremes: it ranks 103rd for the number of articles but 63rd in terms of its *h*-index.[12]

Since the early 1980s, scientific co-authorship among countries has been determined by the desire of individual scientists to give their work greater visibility (Lemarchand, 2012). This has led them to collaborate with bigger scientific networks (USA, EU, etc.). Formal co-operation agreements among countries or regions tend to have little influence over co-authorship behaviour.

Most Latin American countries have concluded a host of bilateral agreements or treaties with other economies within and beyond the region. When it comes to collaborative research, though, partners tend to be based in North America and Western Europe. Co-operation with the EU has even been stepped up since 2010 with the signing of the *Madrid Declaration* (Box 7.2).

Whereas Brazil has a copublication rate (28%) that is close to the G20 average and just under half of Mexican (45%) and Argentinian (46%) articles have foreign collaborators, this rate rises to more than 90% for the smaller countries (Figure 7.8); the latter have become so dependent on international copublishing that, in some cases, the most representative institution is based abroad.

12. The Smithsonian Institute for Tropical Research in Panama was responsible for 63% of Panama's scientific articles between 1970 and 2014. This may explain why Panama ranks so highly.

Box 7.2: Towards a common knowledge area for Europe and Latin America

Biregional scientific co-operation between Europe and Latin America and the Caribbean dates back to the early 1980s, when the former Commission of the European Communities and the Andean Group Secretariat signed an agreement for co-operation and established a joint commission to oversee its implementation. Later, Europe concluded similar agreements with the Central American countries and MERCOSUR.

The sixth summit between the European Union (EU) and Latin America and the Caribbean in 2010 identified new pathways for biregional co-operation in the *Madrid Declaration*, which emphasized partnership in the areas of innovation and technology for sustainable development and social inclusion.

The summit defined the long-term goal of achieving a common 'knowledge area' and agreed on a Joint Initiative for Research and Innovation. Some 17 countries are participating in a key project within this initiative entitled ALCUE Net, which runs from 2013 to 2017; this project has established a joint platform for policy-makers, research institutions and the private sector from both regions in four thematic areas: ICTs; the bio-economy; biodiversity and climate change; and renewable energies. A second project with joint calls (ERANet LAC) is implementing projects in these four areas. There were € 11 million available for the first call for project proposals (2014–2015) and a similar amount for the second call (2015–2016).

The partners are also carrying out a foresight exercise which is due to be concluded by November 2015, to build a common long-term vision for biregional co-operation.

Source: Carlos Aguirre-Bastos, National Secretariat for Science, Technology and Innovation (SENACYT), Panama

Figure 7.8: **Scientific publication trends in Latin America and the Caribbean, 2005–2014**

4.0%

Latin America and the Caribbean's world share of publications in 2005

5.2%

Latin America and the Caribbean's world share of publications in 2014

Strong growth in many countries

For the evolution in the volume of publications in Brazil, see Figure 8.9

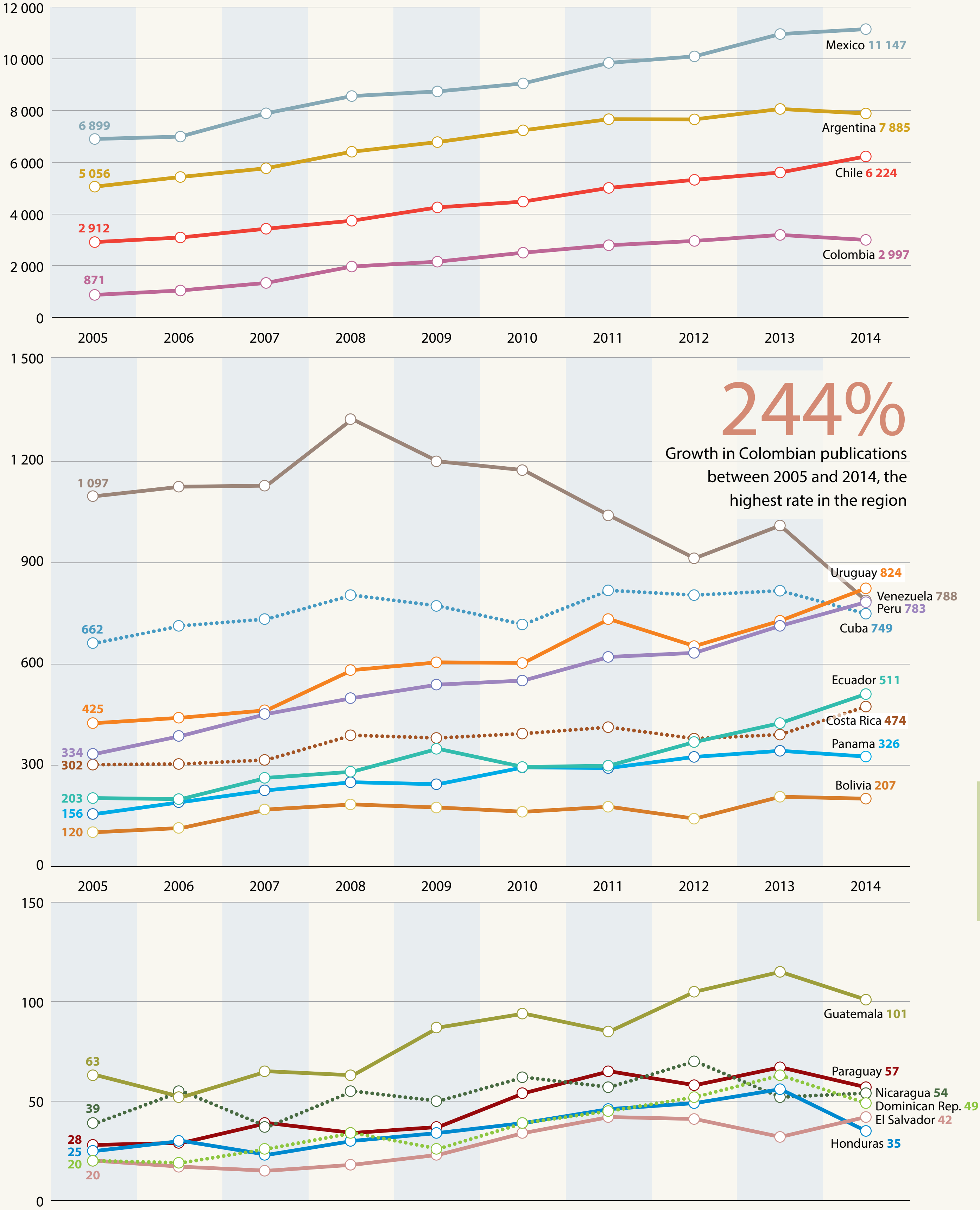
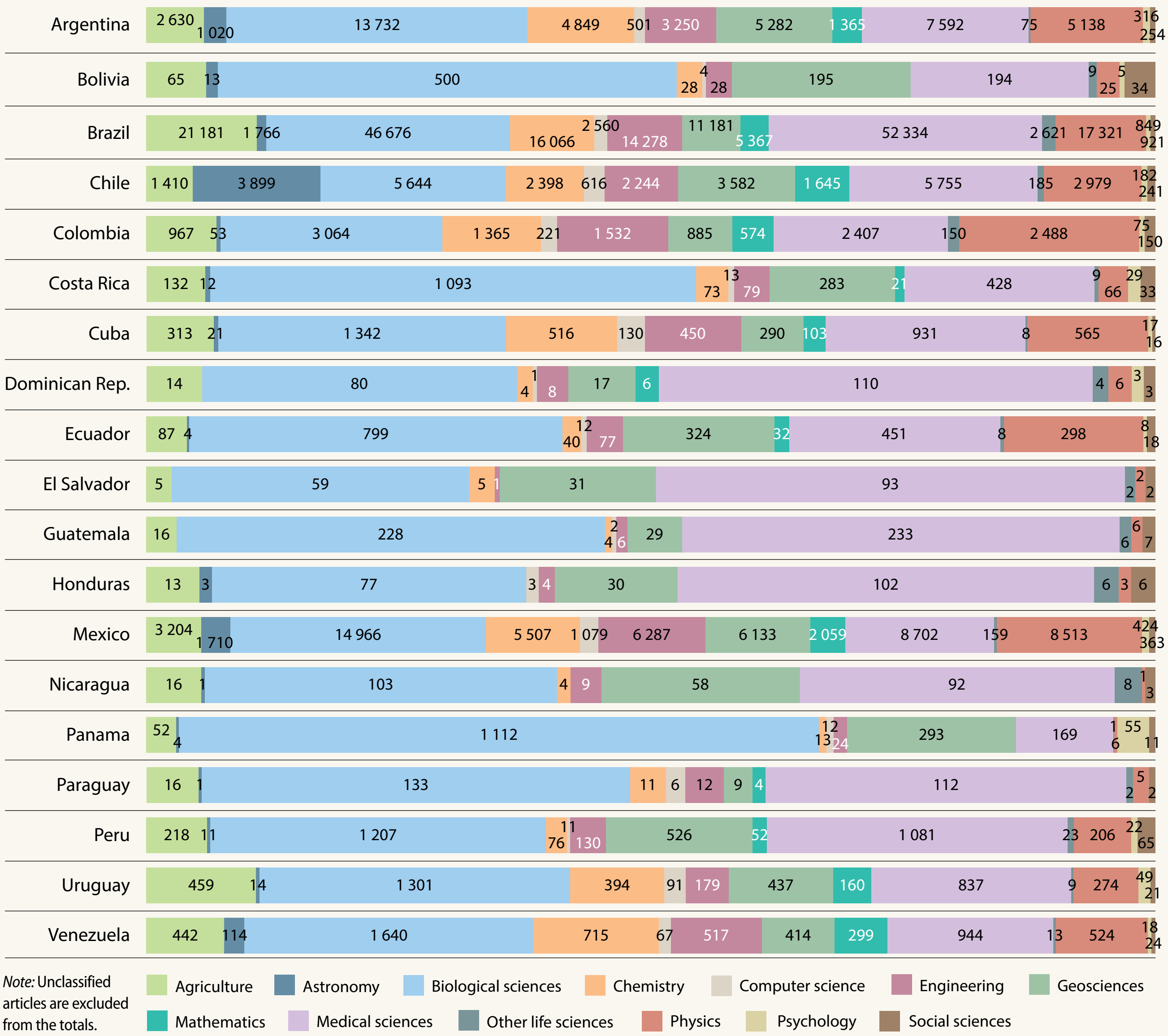


Figure 7.8 *(continued)*

Life sciences dominate research in Latin America and the Caribbean

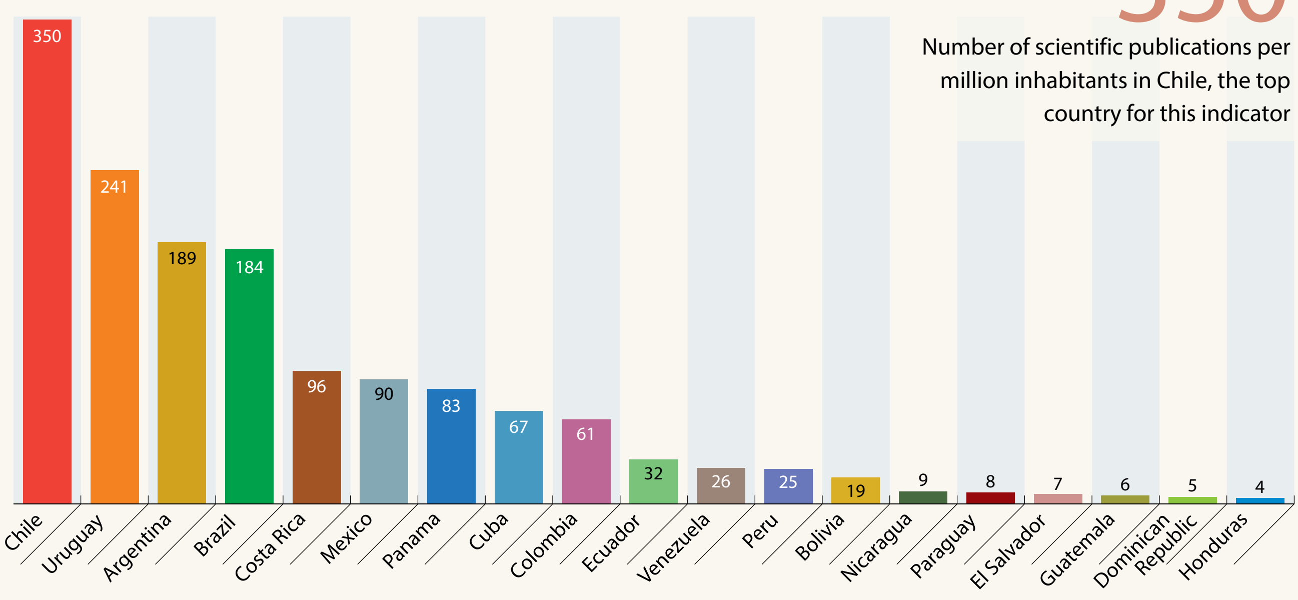
Cumulative totals by field, 2008–2014



Note: Unclassified articles are excluded from the totals.

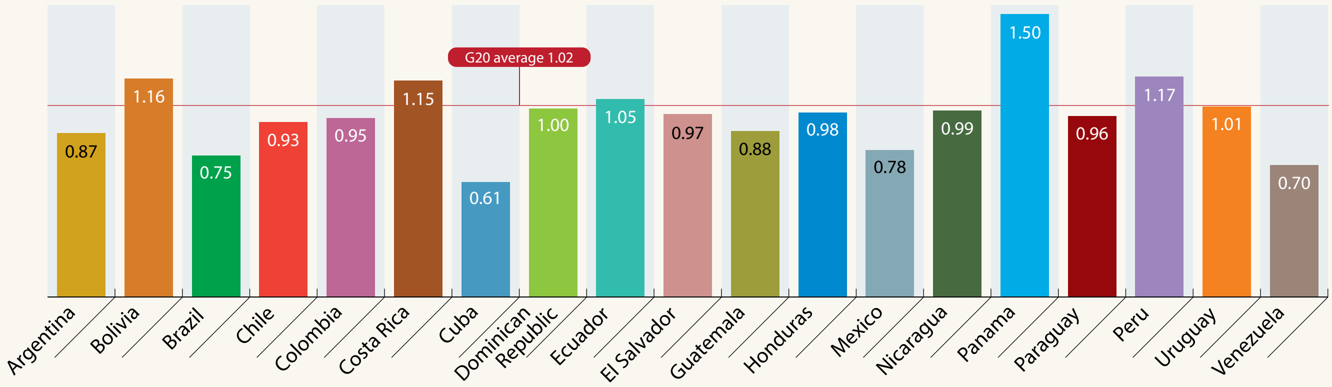
Chile has the highest publication intensity, followed by Uruguay

Publications per million inhabitants in 2014



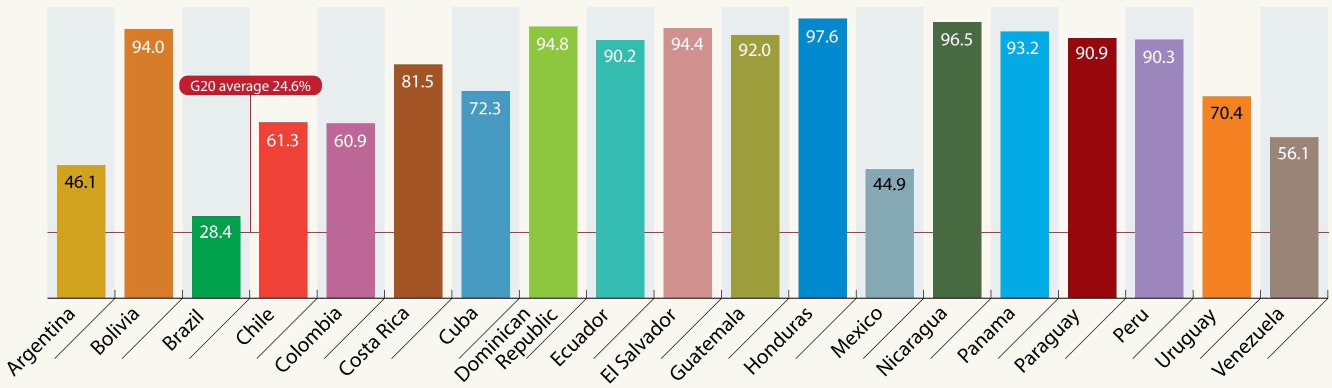
Countries with modest output have the highest average citation rate

Average citation rate for publications, 2008–2012



The majority of articles have foreign co-authors in all but Argentina, Brazil and Mexico

Share of papers with foreign co-authors, 2008–2014 (%)



The top partner for all but Cuba is the USA; Brazil is a key partner for most

Main foreign partners, 2008–2014

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Argentina	USA (8 000)	Spain (5 246)	Brazil (4 237)	Germany (3 285)	France (3 093)
Bolivia	USA (425)	Brazil (193)	France (192)	Spain (187)	UK (144)
Brazil	USA (24 964)	France (8 938)	UK (8 784)	Germany (8 054)	Spain (7 268)
Chile	USA (7 850)	Spain (4 475)	Germany (3 879)	France (3 562)	UK (3 443)
Colombia	USA (4 386)	Spain (3 220)	Brazil (2 555)	UK (1 943)	France (1 854)
Costa Rica	USA (1 169)	Spain (365)	Brazil (295)	Mexico (272)	France (260)
Cuba	Spain (1 235)	Mexico (806)	Brazil (771)	USA (412)	Germany (392)
Dominican Rep.	USA (168)	UK (52)	Mexico (49)	Spain (45)	Brazil (38)
Ecuador	USA (1 070)	Spain (492)	Brazil (490)	UK (475)	France (468)
El Salvador	USA (108)	Mexico (45)	Spain (38)	Guatemala (34)	Honduras (34)
Guatemala	USA (388)	Mexico (116)	Brazil (74)	UK (63)	Costa Rica (54)
Honduras	USA (179)	Mexico (58)	Brazil (42)	Argentina (41)	Colombia (40)
Mexico	USA (12 873)	Spain (6 793)	France (3 818)	UK (3 525)	Germany (3 345)
Nicaragua	USA (157)	Sweden (86)	Mexico (52)	Costa Rica (51)	Spain (48)
Panama	USA (1 155)	Germany (311)	UK (241)	Canada (195)	Brazil (188)
Paraguay	USA (142)	Brazil (113)	Argentina (88)	Spain (62)	Uruguay/Peru (36)
Peru	USA (2 035)	Brazil (719)	UK (646)	Spain (593)	France (527)
Uruguay	USA (854)	Brazil (740)	Argentina (722)	Spain (630)	France (365)
Venezuela	USA (1 417)	Spain (1 093)	France (525)	Mexico (519)	Brazil (506)

Note: Belize, Guyana and Suriname are covered in Chapter 6 on the CARICOM countries. See also Figure 8.9 devoted solely to Brazil.

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

For example, 50% of the articles published by at least one author from Paraguay between 2010 and 2014 and listed in the Science Citation Index Extended were co-published with the University of Buenos Aires and 31% with CONICET, both Argentinian institutions.

The most important copublication 'hub' for most Latin American countries is the USA, followed by Spain, Germany, the UK and France for the sheer number of copublications (Figure 7.8). Since the mid-1990s, intraregional co-authorship has quadrupled (Lemarchand, 2010, 2012). Over the past five years, all countries have published more than before with Latin American partners, with Brazil and Mexico often figuring among the closest collaborators (Figure 7.8).

In terms of publications per million inhabitants, Chile, Uruguay and Argentina have the highest ratios but, when it comes to articles per full-time equivalent (FTE) researcher, Panama (1.02) takes the lead, ahead of Chile (0.93), Uruguay (0.38),

Table 7.2: **Scientific articles on indigenous knowledge systems, 1990–2014**

Articles catalogued in the Science Citation Index Extended and Social Science Citation Index

	1990–2014		2010–2014	
	Articles on indigenous knowledge	Share of national production (%)	Articles on indigenous knowledge	Share of national production (%)
USA	1 008	0.02	482	0.03
Australia	571	0.08	397	0.17
Canada	428	0.04	246	0.08
UK	425	0.02	196	0.04
Latin America				
Brazil	101	0.02	65	0.04
Mexico	98	0.05	42	0.06
Argentina	39	0.03	26	0.06
Chile	33	0.05	14	0.05
Colombia	32	0.10	19	0.12
Bolivia	26	0.80	17	1.40
Peru	22	0.23	11	0.29
Venezuela	19	0.08	4	0.08
Costa Rica	12	0.18	7	0.31
Ecuador	7	0.14	6	0.28
Guatemala	6	0.36	4	0.66
Panama	5	0.09	2	0.09
Cuba	5	0.03	3	0.07
Honduras	4	0.55	–	–
Uruguay	3	0.03	2	0.05
Nicaragua	–	–	2	0.60

Source: Estimations by author on the basis of raw Web of Science data

Brazil (0.26), Mexico (0.26) and Argentina (0.19). The high ratios for Panama and Chile probably reflect the presence of the Smithsonian Institute of Tropical Research (of US origin) in Panama and that of European and North American astronomical observatories in Chile. In both cases, some of the articles attributed to authors residing in Chile or Panama were actually written by foreign researchers, who are not counted as local research staff.

A growing policy interest in indigenous knowledge systems

The first scientific papers exploring the relationship between academic science and indigenous knowledge systems appeared in the early 1990s, a few years before the World Conference on Science (1999) encouraged this interaction through its *Science Agenda*. However, just 4 380 articles on indigenous knowledge were listed in the Science Citation Index Extended and Social Science Citation Index between 1990 and 2014. The principal contributors were the USA, Australia, the UK and Canada (Table 7.2). Globally, indigenous knowledge thus appears to be playing a negligible role so far in the global research agenda, even though several Latin American countries have increased their shares since 2010.

Bolivia has the one of the highest ratios of articles on indigenous knowledge (1.4%) in the region and probably the world. After the election of President Evo Morales in 2006, Bolivia attempted to organize its entire national innovation system around the indigenous concept of *good living*. The Morales government's Programme for the Protection, Recovery and Systematisation of Local and Ancestral Knowledge for Social and Productive Development has drafted a Law for the Protection of Indigenous Knowledge. Other projects within this programme include a national policy on intellectual property; mechanisms to protect strategic intellectual property; the recording of incremental knowledge; and the recovery and spread of local knowledge and ethnic knowledge through ICTs and the aforementioned law (UNESCO, 2010). The 'recovery, protection and utilization of local knowledge and technical and ancestral knowledge' is a priority of the Vice-Minister of Science and Technology. In the *National Science and Technology Plan* (2013), local and ancestral knowledge are considered to be central elements of STI policy-building. Instruments have been set in motion within this framework, including the Law on Ancestral Traditional Bolivian Medicine (2013).

In recent years, other Latin American countries have developed policy instruments to protect indigenous knowledge systems and use them in STI policy-making (Box 7.3). UNASUR has, itself, considered the promotion of indigenous knowledge systems to be one of its priorities since 2010.

Relatively modest patenting

Patenting is relatively modest in Latin America. Between one and five out of every 100 firms in any given Latin American country hold a patent, compared to between 15 and 30 in European countries (WIPO, 2015). Patenting by Latin Americans in the main developed country markets is also very low, testifying to the absence of technology-based international competitiveness.

The best way to compare patenting rates at the international level is to use the data provided by the Patent Cooperation Treaty (PCT).[13] This system makes it possible to seek patent protection for an invention simultaneously in a wide range of countries by filing a single international patent. Two of the top 10 patenting offices of destinations worldwide are located in Latin America, those of Brazil and Mexico. Within Latin America, Chile counts the greatest number of patent applications per million inhabitants (187), which is consistent with the innovation policies promoted by the Chilean Corporation for the Promotion of Production (Corporación de Fomento de la Producción de Chile, CORFO) over the past decade (Navarro, 2014). Brazil, Mexico, Chile and Argentina have the most patent applications and grants (Figure 7.9).

The top five categories for global patent applications filed under the PCT are: electrical machinery, apparatus and energy; digital communication; computer technology; measurement; and medical technology. In 2013, the patents granted in these categories in Latin America represented around 1% of the number granted to high-income economies.

13. By 2014, the PCT counted 148 contracting states. Argentina, Bolivia, Paraguay, Uruguay and Venezuela are not contracting members (WIPO, 2015).

Box 7.3: A growing policy interest in indigenous knowledge in Latin America

Bolivia is not the only Latin American country to show an interest in mainstreaming indigenous knowledge in STI policies. Peru was one of the first to draw attention to the importance of indigenous knowledge and to protect it by law, through its Protection Regime for Traditional Knowledge (2002). Projects have since been launched to promote technology transfer to rural and native communities, such as the Technological Transfer and Extension Projects (PROTEC) in 2010 or the contest run by the National Council for Science and Technology and Technological Innovation (CONCYTEC) in 2012 called From Peru to the World: Quinoa, the Food of the Future.

Ecuador's Constitution of 2008 gives the National System of Science, Technology, Innovation and Ancestral Knowledge the mandate 'to recover, fortify and empower ancestral knowledge,' making Ecuador the only country in the region to codify references to ancestral knowledge and STI at the highest level of the state. The incorporation and promotion of ancestral knowledge are, consequently, reflected in programmes run by the Ministry of Higher Education, Science and Technology, including those on Research and Innovation in Knowledge Dialogue (2013) and Traditional Knowledge and Climate Change.

Among the general objectives of Colciencias in Colombia figure the promotion and reinforcement of 'intercultural research, in agreement with the indigenous peoples, their authorities and elders, being directed towards protecting cultural diversity, biodiversity, traditional knowledge and genetic resources.' Instruments have been developed to this end, such as *A Ciencia Cierta* (2013) and Ideas for Change (2012).

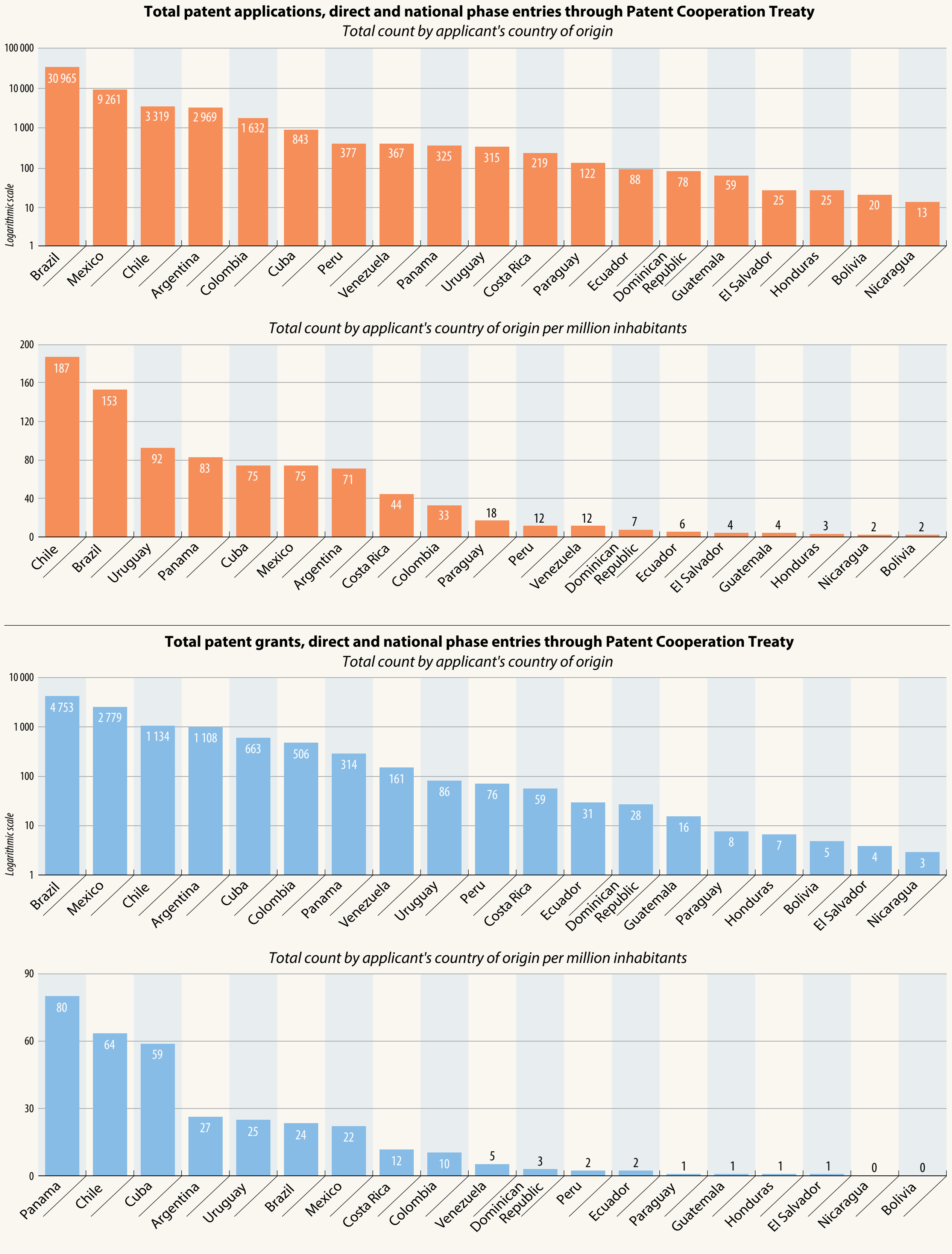
In 2013, the Mexican National Council for Science and Technology (CONACYT) stated that, within its strategic areas of growth, 'innovation will be oriented towards benefiting the less fortunate, with indigenous groups to receive special attention'. CONACYT subsequently announced a Call for Research into Indigenous and Intercultural Education and launched the Academic Strengthening Programme for Indigenous Peoples: Complementary Support for Scholarship-holding Indigenous Women. A third programme provides indigenous peoples with scholarships to pursue postgraduate study overseas.

Although indigenous knowledge is not highlighted in Argentina's national plan for STI entitled *Innovating Argentina 2020* (2013), a series of initiatives have been implemented to incorporate indigenous knowledge systems into innovation processes. Two examples are the projects on Rescuing Ancestral Technologies of Water, Land and Indigenous Farming Conservation as a Means of Adaptation to Climate Change (2009) and for the Industrialization of Fine Camelid Fibre for Social Inclusion (2013).

Last but not least, the Brazilian Ministry of Science and Technology plans to develop an approach to recording, protecting, promoting, diffusing and adding value to traditional knowledge that would not be centred exclusively on patents. In parallel, the Traditional Communities Programme – Science and Technology – is supplying indigenous villagers and communities with technology to make their lives easier.

Source: Ernesto Fernandez Polcuch and Alessandro Bello, UNESCO

Figure 7.9: **Patent applications and grants in Latin America, 2009–2013**



Source: Source: WIPO (2015)

There is a growing tendency among public research institutions to obtain patents in areas related to natural resources, such as mining and, above all, agriculture. This is true, for example of the Brazilian Agricultural Research Company (Embrapa) the National Institute for Agricultural Technology (INTA) in Argentina and the National Institute of Agricultural Research (INIA) in Uruguay.

The top four applicants in Latin America between 1995 and 2014 all came from Brazil: Whirlpool SA, a subsidiary of the Whirlpool Corporation in the USA (engines, pumps, turbines), with 304 applications; Petrobrás (basic material chemistry), with 131 applications; the Federal University of Minas Gerais in Brazil (pharmaceuticals), with 115 applications, and Embraco (engines, pumps, turbines), with 115 applications (WIPO, 2015).

The quest for innovation policies that work

Innovation surveys are becoming standard practice in several Latin American countries. Since the mid-1990s, no fewer than 60 innovations surveys have been conducted in 16 countries (Table 7.3). Argentina has conducted nine surveys, for instance, Chile eight, Mexico seven and Brazil and Colombia five each (see Chapter 8 on the outcome of Brazil's most recent innovation survey). In the region, small and medium-sized enterprises (SMEs) account for 99% of all firms and generate 40–80% of jobs (ECLAC, 2015a).

Whatever companies may say in innovation surveys, businesses contribute little to R&D. This is a pity, since local industry could exploit demand for innovation to strengthen its own competitiveness. Innovation capital measures a firm's capacity to innovate and disseminate this innovation. In Latin American countries, capital stock represents just 13% of the economy, on average, less than half the OECD average (30%). More than 40% of Latin American knowledge-based capital stock comes from tertiary education (5.6% of GDP), compared to only 10% (1.3% of GDP) from R&D, the core driver of innovation.

According to Crespi *et al.* (2014), the private return on innovation in Latin America depends on the type of innovation, being larger for product innovation than for process innovation (see also Chapter 2). The same is true of spillovers, suggesting that the wedge between the private and social return on innovation could be higher in the case of product innovation, something that could guide policy for this type of innovation. The study also shows that the typical multinational firms operating in Latin America are less prone to invest locally in R&D and, consequently, less likely to innovate. Crespi and Zuniga (2010) found that, in Argentina, Chile, Colombia, Costa Rica, Panama and Uruguay, firms that invested in knowledge were capable of introducing new technologies. Firms that innovated also had greater labour productivity than those that did not. Crespi *et al.* (2014) take into account the oft-observed fact that firms in developing countries rarely undertake formal R&D on the edge of the technology curve. Rather, these firms focus on the difficult processes of acquiring and absorbing new technologies efficiently. Other national and regional studies suggest that

Table 7.3: **Percentage of manufacturing firms in Latin America engaged in innovation**
Selected countries

	Year/Period	Share of manufacturing firms that engaged in in-house R&D (%)	Share of manufacturing firms that engaged in contracted-out (external) R&D (%)	Share of manufacturing firms that acquired machinery, equipment and software (%)	Share of manufacturing firms that acquired external knowledge (%)	Share of manufacturing firms that engaged in training (%)	Share of manufacturing firms that engaged in market innovation (%)	Total number of innovation surveys conducted in country
Argentina	2007	71.9	19.3	80.4	15.1	52.3	–	9
Brazil	2009–2011	17.3	7.1	84.9	15.6	62.8	33.7	5
Colombia	2009–2010	22.4	5.8	68.6	34.6	11.8	21.4	5
Costa Rica	2010–2011	76.2	28.3	82.6	38.9	81.2	–	4
Cuba	2003–2005	9.8	41.3	90.2	36.6	22.1	83.8	2
Ecuador	2009–2011	34.8	10.6	74.5	27.0	33.7	10.6	1
El Salvador	2010–2012	41.6	6.7	–	–	–	82.7	1
Mexico	2010–2011	42.9	14.5	35.4	2.6	12.5	11.4	7
Panama	2006–2008	11.4	4.7	32.2	8.5	10.0	–	3
Uruguay	2007–2009	38.7	4.3	78.2	14.5	50.2	–	5

Note: The following countries have also conducted a series of innovation surveys in the region: Chile (8), Dominican Republic (2), Guatemala (1), Paraguay (2), Peru (3) and Venezuela (2).

Source: UNESCO Institute for Statistics; see also Chapter 2 of the present report the major challenge facing the region will be to overcome the institutional weakness of the organizations responsible for co-ordinating research and innovation policies.[14]

Brazil and, to a lesser degree, Argentina, Chile and Mexico, have all made progress towards an integrated public innovation policy by creating sectorial funds and linking industrial policy to the fund's objectives in terms of innovation. However, in most of Latin America, STI policies are rarely indexed on skills and industrial policies tend to be limited and compartmentalized (CEPAL, 2014; Crespi and Dutrénit, 2014).

In Colombia, the government uses three main mechanisms to support business investment in R&D. Firstly, under the guidance of Colciencias and other relevant government bodies, the National Development Bank provides preferential credits at below-market interest rates for projects involving innovation. Secondly, a tax incentive scheme offers exemptions of up to 175% on investment made in R&D during the taxable period. Thirdly, various government agencies provide firms with subsidies for their activities related to research and innovation.

The Peruvian National Council for Science, Technology and Technological Innovation (CONCYTEC) has been directly linked to the Presidency of the Council of Ministers since 2011; its budget soared from US$ 6.3 million to around US$ 43 million between 2012 and 2014. In parallel, new policy instruments have been launched to reduce bottlenecks in the innovation system and increase business R&D, including a 30% tax deduction on related activities since 2013 and a fund to finance credit guarantees or risk-sharing mechanisms for business through the financial system.

Mexico introduced a stimulus programme for innovation in 2009 that has three elements: INNOVAPYME (for small and medium-sized enterprises), PROINNOVA (for new and potential technologies) and INNOVATEC (for large firms). The latter operates as a grant scheme with matching funds; in 2014, the public budget amounted to U$ 295 million. The Fund for Fostering Science, Technology and Innovation at Regional Level (FORDECYT) complements this stimulus programme; the fund focuses on problem-solving projects in different regions by fostering scientific research, technological development and high-impact innovative solutions, as well as specialized training.

Other schemes target sectors in which countries have a competitive edge but could still do better. Examples are the Agriculture Technology Fund in Peru (INCAGRO-FTA) and, in Chile, the Fishing Research Fund (FIP) and Agriculture Research Fund (FIA).

Adopted in 2012, *Innovative Argentina 2020* promotes synergy in the national innovation system through the creation of clusters in 'strategic socio-productive hubs' with a high socio-economic and technological impact. The new cluster of biorefineries is one example; it groups research in bio-energy, polymers and chemical compounds. Four pilot plants have been created under agreements between public research and education institutions in the productive sector. These plants will house applied research and be used for training experts in the field. This model builds on success stories from the 1970s, such as the creation of the Chemical Engineering Pilot Plant (PLAPIQUI) within a consortium involving the National University of the South, the National Council for Scientific and Technical Research (CONICET) and the Petrochemical Pole Bahía Blanca. PLAPIQUI now produces a wealth of patents, scientific papers and PhDs theses.

The private sector has become more proactive in pushing innovation up the public policy agenda. There are a number of business councils, including the Competitiveness and Innovation Council in Chile (est. 2006) and the Private Competitiveness Council in Colombia (est. 2007). Private firms also participate forcefully in the preparation of Peru's competitiveness agenda. In addition, the private sector participates in many councils, such as in the Scientific and Technological Advisory Forum in Mexico (est. 2002) or the Advisory Commission on High Technology Foundation (CAATEC) in Costa Rica.

In parallel, a number of Latin American cities are introducing tax incentives and other mechanisms to turn themselves into innovation hubs and are starting to invest heavily in technology and innovation. Examples are Buenos Aires and Bariloche (Argentina), Belo Horizonte and Recife (Brazil), Santiago (Chile), Medellin (Colombia), Guadalajara and Monterrey (Mexico) and Montevideo (Uruguay).

A conscious use of innovation for social inclusion

Research and innovation for social inclusion can be defined as a process and an outcome which generate benefits for the disenfranchised. In recent years, this field has generated a mass of theoretical and empirical research and policy instruments (Table 7.1, item h) [Thomas *et al.*, 2012; Crespi and Dutrénit, 2014; Dutrénit and Sutz, 2014]. Most of these studies have revealed the inadequacy of local STI agendas to meet the population's needs and identified the value of using available technologies to foster social inclusion.

In 2010, Uruguay approved the first *National Strategic Plan for Science, Technology and Innovation* (PENCTI) to recognize the importance of social inclusion. In Bolivia, Colombia, Ecuador and Peru, the diagnosis of pressing problems has been aligned with national, regional and/or sectorial needs.

14. See, for example, the OECD's *Reviews of Innovation Policy in Panama* (2015), *Colombia* (2014) and *Peru* (2013), as well as the OECD's regional studies of Chile and Mexico (2013a, 2013b), or UNCTAD studies on El Salvador and Dominican Republic (UNCTAD, 2011, 2012). For regional coverage, see Crespi and Dutrénit (2014) and IDB (2014) or, for Central America as a whole, Pérez *et al.* (2012).

In particular, there has been a desire to reorient STI, traditional knowledge and know-how towards the search for solutions to national and local problems, be they related to production, social or environmental ills. (See the article by Bortagaray and Gras in Dutrénit and Crespi, 2014.)

In Colombia, Ideas for Change (2012), a Colciencias programme, is turning innovative thinking into the source of practical solutions for the poor and excluded. This offers a fresh perspective and helps spread the word that technology and innovation are not only important for firms and research institutions but also for society at large (IDB, 2014). Similar policy instruments have been implemented in Brazil by the Agency for Funding Innovation Studies and Projects (FINEP), namely the Development and Diffusion of Technologies with a High Social Impact (Prosocial) and Housing Technologies (Habitare). In Mexico, two examples are the Sectorial Fund for Research and Development related to Water and the Sectorial Research Fund for Social Development. In Uruguay, the project for Educational Connectivity of Basic Computing for Online Learning (CEIBAL) has generated a surprisingly large number of innovative technical and social solutions beyond the original one learner, one notebook programme.

Meanwhile, Peru has subsumed technology transfer in poverty alleviation programmes; these schemes have met with relative success in strengthening production chains and conglomerates. Examples are the Innovation and Competitiveness Programme for Peruvian Agriculture, the INCAGRO Project; and the network of Technological Innovation Centres (CITEs) run by the Ministry of Production. The latter two projects were implemented independently from the national innovation system: whereas INCAGRO showed impressive results, CITEs required more funding to expand its coverage and upgrade the services it offers.

GROWTH AREAS FOR R&D

Argentina and Brazil seeking space autonomy

Several Latin American countries have dedicated space agencies (Table 7.4). Taken together, they invest more than US$ 500 million per year in space programmes. In the late 1980s and 1990s, Brazil invested almost US$ 1 billion in developing space infrastructure around the National Institute of Space Research (INPE), leading to the launch of the first scientific satellite built entirely in Brazil in 1993 (SCD-1). Argentina's first scientific satellite (SAC-B) was launched in 1996 to advance the study of solar physics and astrophysics. Both countries have now achieved the critical mass of skills and infrastructure required to dominate several space technologies. Both exhibit a determination to master the complete chain of space technologies, from material sciences, engineering design, remote sensing, aperture-synthetic radars, telecommunications and image processing to propulsion technologies.

ARSAT-1, the first communication satellite built entirely in Latin America, was placed in a geostationary orbit around the Earth in October 2014. It was constructed by INVAP, a public Argentinian company, at a cost of US$ 250 million. With this feat, Argentina has become one of only ten countries to possess this technology. This is the first of a constellation of three geosynchronous satellites that will serve Argentina and other countries in the region. ARSAT-2 was launched in September 2015 from French Guyana and ARSAT-3 is due to be launched in 2017.

A new generation of scientific satellites is ready to be launched. The SAOCOM 1 and 2 Earth observation series will use remote-sensing data that incorporate a synthetic aperture radar designed and built in Argentina. The joint Argentinian–Brazilian SABIA-MAR mission will be studying ocean ecosystems, carbon cycling, marine habitats mapping, coasts and coastal hazards, inland waters and fisheries. Also under development is the new SARE series designed to expand the active remote observation of Earth through the use of microwave and optical radars. Argentina is also developing new launching technologies through the TRONADOR I and II projects.

Time for sustainability science in Latin America

In 2009, sustainable development was recognized as a priority by a series of regional fora involving ministers and other high-ranking public authorities in Latin America (UNESCO, 2010). The decision-makers acknowledged that Latin America possessed certain characteristics that required a specific research agenda for regional co-operation focusing on sustainability science.

Latin America harbours many of the world's biodiversity hotspots and the globe's largest carbon sink on land. The region counts one-third of the world's freshwater reserves and 12% of its arable land. Several countries have high potential for the use and development of clean and renewable energy sources.

The subcontinent also has one the highest rates of biodiversity loss, owing to the conversion of natural ecosystems; conservation and sustainable management of natural ecosystems is also hampered by the expansion of the agricultural frontier and problems related to land tenure and accreditation of rural properties. The Caribbean and Central America are also highly vulnerable to tropical cyclones, in particular. Coastal and watershed ecosystems are being degraded, as urban sprawl raises pollution levels and fuels demand for resources and energy (UNESCO, 2010).

Scientists are concerned about the environmental impact of Nicaragua's plans to dig a canal linking the Atlantic and Pacific Oceans that would pass through Lake Nicaragua, Central America's key freshwater reservoir. In June 2013, Nicaragua's National Assembly passed a bill granting a 50-year concession to a private firm based in Hong Kong (China).

Table 7.4: **National space agencies and main national space technology suppliers in Latin America**

Country	Institution	English name	Founded	Specialization
Argentina	Comisión Nacional de Investigaciones Espaciales (CNIE)	National Commission for Space Research	1960–1991	Propulsion systems and rocket development; projects CONDOR I & II, capacity-building
Argentina	Comisión Nacional de Actividades Espaciales (CONAE)	National Space Activities Commission	1991	Design and planning of the space programme, operation of the Cordoba Space Centre, capacity-building. Design of satellites SAC-A, SAC-B, SAC-C, SAC-D/Aquarius, SAOCOM 1 & 2, SABIA-MAR, SARE and propulsion systems TRONADOR I & II
Argentina	INVAP	Public company in nuclear and space technologies	1976	Technology design and construction of the satellites SAC-A, SAC-B, SAC-C, SAC-D/Aquarius, SAOCOM 1 & 2, SABIA-MAR, SARE, ARSAT I, II & III
Bolivia	Agencia Boliviana Espacial (ABE)	Bolivian Space Agency	2012	*Tupak Katari* (2013), a communication satellite developed in China
Brazil	Comissão Nacional de Atividades Espaciais (CNAE)	National Commission of Space Activities	1963–1971	Space propulsion studies, several rocket launchings, remote sensing analysis, capacity-building
Brazil	Agência Espacial Brasileira (AEB)	Brazilian Space Agency	1994	Design and planning of the satellites CBERS (Sino-Brazilian Earth Resources Satellite), Amazônia-1 (2015), EQUARS, MIRAX, SCD1, SCD2
Brazil	Instituto Nacional de Pesquisas Espaciais (INPE)	National Institute of Space Research	1971	Construction and technological design of the satellites SCD-1, CBERS (see AEB), Amazônia-1 (2015), EQUARS, MIRAX, Satélite Cientifíco Lattes, Satélite GPM–Brasil, SARE, SABIA-MAIS
Colombia	Comisión Colombiana del Espacio (CCE)	Colombian Space Commission	2006	Planning for space applications
Costa Rica	Asociación Centroamericana de Aeronáutica y el Espacio (ACAE)	Central American Association for Aeronautics and Space	2010	Planning for space applications; design of a picosat satellite project (2016)
Mexico*	Agencia Espacial Mexicana (AEM)	Mexican Space Agency	2010	Planning for space research and applications
Peru	Agencia Espacial del Perú (CONIDA)	Space Agency of Peru	1974	Planning for space research and applications
Uruguay	Centro de Investigación y Difusión Aeronáutico-Espacial (CIDA-E)	Aeronautics and Space Research and Diffusion Centre	1975	Space research and popularization
Venezuela	Agencia Bolivariana para Actividades Espaciales (ABAE)	Bolivarian Agency for Space Activities	2008	Planning for space research and popularization

* In 1991, the National Autonomous University of Mexico (UNAM) started building scientific satellites. The first (UNAMSAT-1) was destroyed during the launch in 1996; UNAMSAT-B operated in orbit for one year.

Note: For details of the CBERS programme, see the chapter on Brazil in the *UNESCO Science Report 2010.*

Source: Compiled by author

As of August 2015, construction of the controversial shipping route had not yet commenced.

The complex nature of sustainable development, in which biogeophysical, economic and social processes tend to overlap, demands a transdisciplinary approach to implementing the regional research agenda (Lemarchand, 2010), combined with new financial schemes to support related R&D at the regional level and capacity-building in sustainability science (Komiyama *et al.,* 2011).

In the past two decades, the publication of scientific articles on topics related to sustainable development has grown 30% faster in Latin America than in the rest of the world. This trend underlines the growing interest in sustainability science in Latin America. However, there is currently a lack of graduate programmes in Latin America (and elsewhere) in sustainability science. In 2015, the United Nations University in Tokyo launched the world's first PhD programme in sustainability science. Universities in Latin America should also develop PhD programmes in this new interdisciplinary field.

Renewable energy could have a bright future

By early 2014, at least 19 Latin American countries had renewable energy policies and at least 14 had adopted relevant targets, mostly concerning electricity generation. Uruguay aims to generate 90% of its electricity from renewable sources by 2015. Despite having an average electrification rate of almost 95%, one of the highest among developing regions, access to energy remains a challenge: an estimated 24 million people living mainly in rural and remote areas still lack access to electricity in Latin America.

Most Latin American countries have adopted regulatory policies and fiscal incentives (Table 7.5) to drive the deployment of renewable energy. The use of public competitive bidding has gained momentum in recent years, with Brazil, El Salvador, Peru and Uruguay all issuing tenders in 2013 for more than 6.6 GW of renewable electric capacity. The more clement environment for renewable sources of energy is attracting new national and international investors.

The Brazilian government has nevertheless cut back its own commitment to energy research from 2.1% (2000) to 0.3% (2012). Renewable energy has been the primary victim of these cuts, including the bioethanol industry, as public investment has increasingly turned towards deep-sea oil and gas exploration off Brazil's southeast coast (Chapter 8).

The manufacture of 'green' technologies such as wind turbines is spreading across the region. However, differences in electricity market structures and regulations have so far hampered efforts to integrate regional electricity markets and the lack of transmission infrastructure has delayed some projects. The main obstacle is the impossibility of compensating for fluctuations in the supply of renewable energy from one country to another.

Nevertheless, the region is demonstrating unprecedented growth, with strong opportunities for further expansion. In 2014, Brazil ranked second worldwide for its hydropower capacity (89 GW) and biodiesel/ethanol fuel production, fifth for its solar water heating capacity (6.7 GW) and tenth for wind power (5.9 GW). Mexico is the world's fourth-biggest producer of geothermal power (1 GW). Both Chile and Mexico have boosted their own capacity in wind and solar energy and Uruguay has raised wind capacity per capita more than any other country. Other innovative applications are spreading, such as solar food-dryers in Mexico and Peru to process fruits and coffee. Long-term incentives for industry and technological development will be needed to guarantee that these schemes are implemented fully.

Strong growth in ICT usage...

The region uses about 5% of the world's public cloud services, less than its share of global GDP (8.3% in 2013, see Table 1.1). Nevertheless, estimated annual growth of 26.4% means that

Table 7.5: **Existing regulatory policies and fiscal incentives in Latin America for renewable energy, 2015**

Countries	Regulatory policies						Fiscal incentives and public financing				
	Feed-in tariff/ premium payment	Electric utility quota obligation/ Renewable portfolio standards	Net metering	Biofuels obligation/ mandate	Heat obligation/ mandate	Tendering	Capital subsidy, grant or rebate	Investment or tax production credits	Reduction in sales, energy, carbon, VAT or other taxes	Energy production payment	Public investment, loans or grants
Argentina	●		●	●		●	+	+	+	+	+
Brazil			●	●	●	●		+	+		+
Chile		●	●			●	+	+	+		+
Colombia			●	●				+	+		+
Costa Rica	●		●	●		●			+		
Dominican Rep.	●		●			●	+	+	+		+
Ecuador	●			●		●			+		+
El Salvador						●		+	+	+	+
Guatemala			●	●		●		+	+		
Honduras	●		●			●		+	+		
Mexico			●			●		+			+
Nicaragua	●								+		
Panama	●		●	●		●		+	+	+	
Paraguay				●					+		
Peru	●	●		●		●			+		+
Uruguay	●		●	●	●	●	+		+	+	+

Note: Data are unavailable for Bolivia, Cuba and Venezuela. VAT stands for value-added tax.

Source: REN21 (2015) *Renewables 2015: Global Status Report*, pp. 99–101. Renewable Energy Policy Network for the 21st Century: Paris these services will be adopted more quickly than in Western Europe. The strong growth forecast for cloud computing in Latin America is affirmed by the distribution of workloads among cloud data centres in the region, which is expected to grow from 0.7 million to 7.2 million workloads between 2011 and 2016, with a compound annual growth rate of 60% (ECLAC, 2015c).

However, firms in Latin America face several obstacles in adopting ICT technologies. They incur high fixed costs associated with purchasing and maintaining hardware and software and adapting it to production processes, owing to limited ICT literacy in the region (IDB, 2014). Another key problem affecting the dissemination of broadband service concerns the high rates charged for the service in relation to per-capita income. Whereas, in the EU, economy service rates are equivalent to around 0.1% of per-capita income, in Latin America, they range from 0.6% in Chile and Mexico to nearly 21% in Bolivia (CEPAL, 2015).

Over the past two decades, Costa Rica's technology sector has grown into one of Latin America's most dynamic industries. The main focus of the sector's more than 300 companies is on developing software for local and international markets. Costa Rican industry also plays an important role in manufacturing and high-tech exports, as we saw earlier, although the departure of Intel will affect this market.

Various sectorial funds and tax incentives have been designed for the software industry to improve the productivity and innovation capacity of SMEs. One successful example of competitive funds is the aforementioned FONSOFT in Argentina, another is PROSOFT in Mexico. Both funds have a diverse set of policy instruments to improve the quality of software production and foster linkages between academia and industry. These sectorial funds emphasize collaboration between public research institutions, technology transfer, extension services, export promotion and industrial development.

A study by the Inter-American Development Bank (BID, 2014) forecasts that, by 2025, Buenos Aires, Montevideo, San José, Córdoba and Santiago will be the five most important poles for the development of the ICT and software industries. By that time, business processing outsourcing is expected to employ 1.2 million people and generate sales of US$ 18.5 billion in Latin America.

... and in biotechnology

The impact of research and innovation on biotechnology in Latin America has been very well documented (Sorj *et al.* 2010, Gutman and Lavarello, 2013; RICYT, 2014). Although the bulk of progress in biotechnology has been circumscribed to a handful of research centres and corporations in developed countries, a number of public research institutions in Latin American countries have also contributed since the mid-1950s. However, the networks and nodes of these institutions are usually located in developed countries and the respective technologies are not automatically transferred. This state of affairs offers broad opportunities for local development.

Up until now, investment in biotechnology has been directed more towards higher education and creating skills in the public sector than towards R&D. This has created a fertile terrain for private firms wishing to recruit locally. As shown above, agriculture and health consume the bulk of investment in several countries. Some 25% of publications from the region concern biological sciences and 22% medical sciences (Figure 7.8). One of the most prolific institutions for patenting in pharmaceuticals is the Universidade Federal de Minas Gerais (Brazil) and, in agribusiness, one could cite Embrapa (Brazil), INTA (Argentina) and INIA (Uruguay).

A relatively modest number of enterprises specialize in technology transfer (Gutman and Lavarello, 2013; Bianchi, 2014). Figuring among the most innovative biotechnology firms in the region are: Grupo Sidus (Biosidus and Tecnoplant), Biogénesis-Bagó, Biobrás-Novo Nordik, Biomm, FK Biotecnología, BioManguinos, Vallée, Bio Innovation, Bios-Chile, Vecol and Orius.

According to the Brazilian National Confederation of Industry, the main areas for research within the Brazilian agricultural innovation system are biotechnology, bioreactors, plant- and animal- assisted reproduction, forest biotechnology, germplasm collection and conservation, plant resistance to biotic and abiotic stresses, genetically modified organisms and bioprospection. There are also a few examples of R&D contracts between public and private companies. Embrapa is carrying out research with all of the following, for instance: Monsanto (USA), BASF (Germany), DuPont (USA) and Syngenta (Switzerland). There are also R&D contracts in Brazil for seed production with non-profit organizations, such as Unipasto and Sul Pasto, and with foundations (Meridional, Triângulo, Cerrado, Bahia and Goiás).

The Biotech project is an interesting example of subregional co-operation designed to take better advantage of existing research skills to foster competitiveness in productive sectors within the MERCOSUR space.[15] The second phase, Biotech II, addresses regional projects in biotechnological innovation linked to human health (diagnosis, prevention and the development of vaccines against infectious diseases, cancer, type 2 diabetes and autoimmune diseases) and biomass production (traditional and non-traditional crops), biofuel elaboration processes and evaluation of its by-products. New criteria have been incorporated to respond to demand from participating consortia for a greater return on investment and the participation of more partners, such as from Europe.

15. See: www.biotecsur.org

COUNTRY PROFILES

UNESCO's Global Observatory of STI Policy Instruments (GO→SPIN) provides a complete description of the national innovation system for all 34 countries of Latin America and the Caribbean, with regular updates every six months.[16] Given the sheer size of the region, we summarize the most important developments since 2010 only for those countries with a population of more than 10 million. For a profile of Brazil, see Chapter 8.

ARGENTINA

Investment in STI has accelerated

Argentina has enjoyed a decade of strong growth (*circa* 6% per year until 2013) that was partly underpinned by high commodity prices. With the end of the cyclical commodities boom, however, rising subsidies and a strong currency, combined with unresolved issues from the country's 2001 debt crisis, have begun to affect trade. The Argentine economy grew by just 0.5% in 2014, as healthy public consumption (+2.8%) was offset by a 12.6% drop in imports and an 8.1% drop in exports (ECLAC, 2015a). Faced with an unemployment rate of 7.1% in the first quarter of 2015, Congress passed a bill cutting back employer contributions for micro-enterprises and payroll taxes for larger businesses that created jobs.

Between 2008 and 2013, research infrastructure expanded in Argentina as never before. Since 2007, the government has built more than 100 000 m^2 of new laboratories, with another 50 000 m^2 under construction in September 2015. Spending on R&D almost doubled between 2008 and 2013 and the number of researchers and publications progressed by 20% and 30% respectively (Figures 7.5, 7.6 and 7.8).

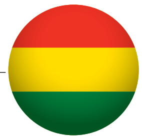
In 2012, the Ministry of Science, Technology and Productive Innovation (MINCYT) launched the *National Science, Technology and Innovation Plan: Innovative Argentina 2020*. The plan prioritizes the most scientifically underdeveloped regions by assigning 25% of all new posts at the National Scientific and Technological Research Council (CONICET) to these regions. The plan is organized in a matrix composed of six strategic areas (agro-industry; energy; environment and sustainable development; health; industry; and social development) and three general-purpose technologies: biotechnologies, nanotechnologies and ICTs.

The creation of the Argentine Sectorial Fund (FONARSEC) by MINCYT in 2009 accelerated the shift from horizontal to vertical policy instruments. Its mission is to establish public–private partnerships, in order to improve competitiveness in the following sectors: biotechnology, nanotechnology, ICTs, energy, health, agribusiness, social development, environment and climate change.

The establishment of the Interdisciplinary Centre for the Study of Science, Technology and Innovation (CIECTI) in 2015 should give MINCYT an enormous boost, as the ministry will henceforth be able to draw upon the findings of strategic studies and foresight exercises prepared by CIECTI when designing future policies.

More than one in ten FTE researchers in Argentina were involved in some form of international collaboration between 2007 and 2013, through a total of 1 137 research projects in other countries. In some cases, this collaboration involved Argentine researchers working with foreigners who had completed internships in Argentinian institutions as part of their postdoctoral training.

BOLIVIA



A focus on communitarian and productive research

Bolivia continues to show healthy growth: 5.4% in 2014, with projections of 4.5% in 2015 (ECLAC, 2015a). The government is promoting the industrialization of the hydrocarbons sector, as well as the extraction of natural gas and lithium, through the Investment Promotion Act (2014) and the Mining and Metallurgy Act (2014). Other projects include boosting exports of electricity to Argentina and Brazil (ECLAC, 2015a).

The government elected in 2005 has adopted a new communitarian productive model to ensure that surplus production serves the collective need, as part of the planned transition from capitalism to socialism. According to this model, the four strategic sectors capable of generating a surplus for Bolivians are identified as being hydrocarbons, mining, energy and environmental resources; rather than using this surplus to drive exports, the new model advocates using it to develop employment-generating sectors such as manufacturing, tourism, industry and agriculture.

Since 2010, the design of S&T policies has fallen under the supervision of the Ministry of Education. A series of programmes have been proposed within the *Institutional Strategic Plan 2010–2014*, including the Bolivian System of Scientific Information and Technology (SIBICYT) and the Bolivarian Innovation System. Within the plan, the Innovation, Research, Science and Technology Programme lays the groundwork for the following policy instruments:

- the conduct of communitarian and productive research at the country's public technical institutes;

16. See: http://spin.unesco.org.uy

- the creation of centres for research and innovation in textiles, leather, wood and camelids – Bolivia is thought to have the greatest number of llamas in the world;
- the development of research and innovation networks in biodiversity, food production and land and water management – some of these networks comprise more than 200 researchers from both public and private institutions distributed in various regional and national working groups; and
- the creation of a fund for STI.

CHILE

A desire to embrace the knowledge economy

Chile's economy grew by 1.9% in 2014, slowing markedly from 4.2% in 2013. An expansion of 2.5% is forecast in 2015, driven by a surge in public spending and positive developments in the external sector (ECLAC, 2015a). Chile is the major recipient of FDI in the region. In 2014 alone, it received more than US$ 22 billion. Chile has a higher proportion of private funding for education than any other OECD member country, with 40.1% of education spending coming from private sources (16.1% average for OECD countries). Chile was the highest scoring Latin American country in the PISA 2012 mathematics test but still 71 points behind the OECD average.

In Chile, it is the Office of the President of the Republic which leads the national innovation system, under the direct guidance of the National Innovation Council for Competitiveness (CNIC). The latter proposes general guidelines for the development of a *National Innovation Strategy*. The Interministerial Innovation Committee then evaluates these criteria before establishing short-, medium- and long-term national STI policies; it also monitors the implementation of the *National Innovation Strategy*.

The Ministries of Education and of the Economy play a leading role in the Interministerial Innovation Committee, their participation being channelled through the main public institutions with a focus on STI, namely, the National Commission for Scientific and Technological Research (CONICYT) and the *InnovaChile* wing of the Corporation for the Promotion of Production (CORFO). The latter[17] supports sectors with high-growth potential, through funding for SMEs and the nurturing of an early-stage seed capital industry.

The government's *Agenda for Productivity, Innovation & Economic Growth for 2014–2015* reflects the desire to move from an economy based on natural resources to one based on knowledge by diversifying the economy and supporting sectors with strong growth potential. CORFO is a key partner in this intiative.

By March 2012, the government had already modified its R&D tax credit framework to make it easier for firms to innovate. The reform abolished both the eligibility requirements for collaboration with external research centres and the requirement to invest at least 15% of the company's gross annual revenue in R&D. In a move questioned by some, the revenue from royalties levied on all mining operations was used to finance R&D cluster development in priority sectors.

In January 2015, President Michelle Bachelet established a Presidential Commission composed of 35 experts on the theme of Science for Chile. Their mandate is to elaborate a proposal as to how to foster STI and a broad scientific culture. They are considering the possibility of creating a Ministry of Science and Technology.

COLOMBIA

A greater focus on innovation

Colombia's economy grew by 4.6% in 2014. Growth projections for 2015 have been revised downwards, although they remain between 3.0% and 3.5% (ECLAC, 2015a). In June 2015, the government implemented a number of countercyclical policies known collectively as the *Productivity and Employment Stimulus Plan* to encourage investment and, thereby, limit the economic slowdown.

Colombia is preparing its entry into the OECD with the intention of adopting, adapting and implementing improved practices in a host of areas in relation to public governance, commerce, investment, fiscal issues, STI, environment, education and so on.

Colombia's innovation system is co-ordinated by the National Planning Department and the Colombian Institute for the Development of Science (Colciencias). In 2009, Colciencias was transformed into the Administrative Department for Science, Technology and Innovation with responsibility for formulating, co-ordinating, executing and implementing related public policies in line with the country's development plans and programmes.

In 2012, the government created *iNNpulsa Colombia* with the National Development Bank to support innovation and competitiveness, with a budget of US$ 138 million for the 2012–2013 period. Some 70% of Colciencias' Innovation Management Programme, on the other hand, was oriented towards micro-enterprises and SMEs (with a budget of US$ 20 million in 2013). Since 2009, Colciencias has been annually allocating US$ 0.5 million to support collaborative projects between firms and the academic sector. The General Royalties System Fund also now has a regional development focus as far as STI is concerned.

17. See www.english.corfo.cl

Between 2010 and 2014, Colciencias formulated a series of strategies for strengthening STI policies, such as *Vision 2025,* which seeks to position Colombia as one of the three most innovative countries in Latin America by 2025 and a world leader in biotechnology. The aim is for Colombia to be able to offer local, regional and global solutions to problems such as overpopulation and climate change, with a series of centres of excellence working on vector-transmitted diseases and the possibilities of interaction with other sectors: health, cosmetics, energy and farming.

Vision 2025 proposes generating 3 000 new PhDs, 1 000 annual patents and working with 11 000 companies by 2025. The programme will allocate US$ 678 million during 2011–2014, targeting researchers in the public and private sectors. In 2014, the government launched a Brain Repatriation Programme to woo 500 doctorate-holders from the diaspora over the next four years.

CUBA

Preparing incentives to attract investors

The Cuban economy grew by 1.3% in 2014 and is expected to expand by 4% in 2015. In 2014–2015, 11 priority sectors for attracting foreign capital were identified, including agrifood; general industry; renewable energy; tourism; oil and mining; construction; and the pharmaceutical and biotechnology industry (ECLAC, 2015a).

With the normalization of relations with the USA in 2015, Cuba is in the process of establishing a more attractive legal regime offering substantial fiscal incentives and guarantees for investors. Cuba is already one of the most popular destinations for Latin American university students (see p. 181).

Between 2008 and 2013, the number of Cuban scientific papers grew by 11%, even as GERD receded from 0.50% to 0.41% of GDP. In 2014, the government created the Financial Fund for Science and Innovation (FONCI) to enhance the socio-economic and environmental impact of science by boosting business innovation. This is a major breakthrough for Cuba, considering that, up until now, the bulk of R&D funding has come from the public purse.

DOMINICAN REPUBLIC

Growth restricted to economic 'enclaves'

Economic growth in the Dominican Republic has been high by regional standards, averaging 5.1% in the 12 years to 2013. However, this growth has not been accompanied by a significant reduction in poverty or inequality, contrary to trends in some other Latin American countries. Moreover, growth has been largely concentrated in what are sometimes described as economic 'enclaves' such as package tourism, export processing zones and mining, with little linkage to the broader economy.

Given the composition of sectors driving recent growth, it is not surprising that traditional indicators of industrial research intensity such as high-tech exports or patenting show little activity (Figures 7.3 and 7.9). Innovation surveys reported by UNCTAD (2012) show that the little firms invest in research comes mainly from their own treasury, suggesting weak public support and linkages with non-business actors.

Constitutional reforms adopted in January 2010 elevated the existing State Secretariat for Higher Education, Science and Technology to the rank of ministry. The Ministry for Higher Education, Science and Technology (MESCYT) has since been entrusted with developing national indicators of science and technology and with implementing a national programme to foster entrepreneurship. The ministry's *Strategic Plan for Science, Technology and Innovation 2008–2018* establishes research priorities in the following areas:

- Biotechnology;
- Basic sciences;
- Energy, with emphasis on renewable sources and biofuels;
- Software engineering and artificial intelligence;
- Innovation in processes, produce, goods and services;
- Environment and natural resources; and
- Health and food technology.

A number of key reforms recommended by UNCTAD's review of STI policy in the Dominican Republic would help coalesce public and private efforts in these priority sectors. These recommendations include a substantial increase in public investment in STI, fostering demand for STI through public procurement and the establishment of a formal status of researcher (UNCTAD, 2012).

ECUADOR

Investing in the knowledge economy of tomorrow

Ecuador's economy grew by 3.8% in 2014 but projections for 2015 have been revised downwards to 1.9%. The drop in the average price of Ecuadorian crude from US$ 96 a barrel in 2013 to US$ 84 in 2014 has meant that oil exports lost 5.7% of their value in 2014 even though their volume was up by 7% (ECLAC, 2015a).

Between 2008 and 2013, GERD tripled in PPP dollars, the number of researchers doubled (Figure 7.6) and scientific

Box 7.4: Ikiam: a university in the heart of the Amazon

The cities of Quito and Guayaquil group more than half of Ecuador's universities and polytechnics. Ikiam University (*ikiam* means 'forest' in Shuar) opened its doors in October 2014 in the heart of the Amazon. The first contingent of 150 students discovered a campus surrounded by 93 hectares of exceptional biodiversity; this protected territory will serve as an open-air laboratory for the students and researchers from Ikiam, who will be mainly studying pharmacology and the sustainable management of natural resources.

The aim is to turn Ikiam into Ecuador's first world-class university for teaching and research. All the professors hold a PhD and half are foreigners. The university offers levelling programmes to first-year students to overcome any shortcomings in their education up to the time of their admission.

In December 2013, an international workshop was organized in Misahuallí (Napo) to analyse Ikiam's future academic programme, as well as the university's organizational structure and research strategies. Ten Ecuadorian scientists participated, as well as 53 scientists from Australia, Belgium, Brazil, Canada, Germany, France, the Netherlands, South Africa, Spain, the UK, USA and Venezuela.

Source: www.conocimiento.gob.ec

output rose by 50% (Figure 7.8). In the past decade, public investment in education has quintupled from 0.85% (2001) to 4.36% (2012), one-quarter of which is devoted to higher education (1.16%). This steep rise in education funding is part of the government's wider strategy of developing a knowledge economy by reducing Ecuador's dependence on banana and oil revenue. A sweeping reform of higher education has been introduced to erect two of the pillars of any knowledge economy: quality training and research. In 2010, the Law on Higher Education established four flagship universities: Ikiam (Box 7.4), Yachay, the National University of Education and the University of the Arts. The law also introduced free education and a system of student scholarships to give a greater number of hopefuls the chance of a university education. In 2012, several private universities had to close because they did not respect the quality criteria defined by the law.

Flagship programmes put in place by the Secretariat for Higher Education, Science, Technology and Innovation (SENESCYT) include a sophisticated new system of scholarships for graduates to complete PhD programmes abroad and the construction of the City of Knowledge, modelled on similar cities in China, France, Japan, Republic of Korea and USA. Yachay (the word for knowledge in Quechua) is a planned city for technological innovation and knowledge-intensive businesses combining ideas, talent and state-of-the-art infrastructure. Together, these ingredients should be able to create a city that embodies the indigenous concept of *Buen Vivir* (good living). The city will be organized around five pillars of knowledge: life sciences, ICTs, nanoscience, energy and petro-chemistry. Yachay will host Ecuador's first University of Experimental Technological Research, which will be linked to public and private research institutes, technology transfer centres, high-tech companies and Ecuador's agricultural and agro-industrial communities, thereby becoming the first Latin American knowledge hub.

In 2013, legislation was passed certifying the status of scientific researcher and creating different categories of researchers. This normative step makes it possible to create special wages for researchers, according to their category of service.

GUATEMALA

A need to nurture its human capital

Guatemala's economy grew by 4.2% in real terms in 2014, up from 3.7% in 2013. Growth was driven by a surge in domestic demand among private consumers, in particular, along with low inflation, a rise in real wages and higher levels of bank lending to the private sector (ECLAC, 2015a).

Public spending on education has remained stable since 2006 at about 3% of GDP but only one-eighth of this goes to higher education, according to the UNESCO Institute for Statistics. Moreover, between 2008 and 2013, total expenditure on education slipped from 3.2% to 2.8% of GDP. Over this same period, GERD dropped by 40% (in PPP$) and the number of FTE researchers by 24%. Although scientific output increased by 20% (Figure 7.8), this progression is modest compared to that of other countries in the region. If we compare Guatemala with Malawi, a country with almost the same surface area and population, Guatemala's GDP is ten times that of Malawi but Malawi publishes almost three times the number of scientific articles. This suggests that Guatemala has fallen into the Sisyphus trap (see next section).

The National Council of Science and Technology (CONCYT) and State Secretariat for Science and Technology (SENACYT) now co-ordinate STI in Guatemala and are in charge of implementing policies in this area. In 2015, a National Plan for Science, Technology and Innovation to 2032 was under discussion to replace the existing plan. Guatemala disposes of a fairly wide range of funding mechanisms, including the Science and Technology Support Fund (FACYT), Science and Technology

Development Fund (FODECYT) and the Multiple Support to the National Plan Fund for Science and Technology (MULTICYT). These are complemented by the Technological Innovation Fund (FOINTEC) and the Science and Technology Emergency Activities Fund (AECYT). A grant from the Inter-American Development Bank in 2012–2013 has helped to operationalize these funds.

MEXICO

A 1% GERD/GDP target but no specific temporal horizon

Mexico, Latin America's second-largest economy after Brazil, grew by 2.1% in 2014 and is expected to do slightly better in 2015 (*circa* 2.4%), according to ECLAC. In 2014–2015, Mexico held intensive talks with EU countries with a view to opening negotiations on a new free trade agreement. According to the Mexican government, the aim is to update the agreement signed in 2000, in order to improve the access of Mexican goods and services to the European market, strengthen ties and create a transatlantic free trade area (ECLAC, 2015a).

Between 2008 and 2013, GERD (in PPP$) and scientific output progressed by 30% (Figure 7.8) and the number of FTE researchers by 20% (Figure 7.5). To improve the governance of the national innovation system, the government created the Office of Co-ordination of Science, Technology and Innovation in 2013 in the Office of the President. The same year, the National Council of Science and Technology (CONACYT) was ratified as the principal governing body for STI in Mexico.

The *National Development Plan 2013–2018* proposes making the development of STI the pillar of sustainable socio-economic growth. It also proposes a new Special Programme for Science, Technology and Innovation 2014–2018 to transform Mexico into a knowledge economy, with the normative target of reaching a 1% GERD/GDP target – but without any specific temporal horizon.

The number of doctoral programmes participating in the National Programme of Quality Postgraduate Studies increased from 427 to 527 between 2011 and 2013. In 2015, CONACYT supported around 59 000 postgraduate scholarship-holders. Mexico has been reorienting higher education programmes towards fostering entrepreneurial skills and an entrepreneurial culture. In 2014, the CONACYT Chairs Initiative planned to create 574 new positions for young researchers on a competitive basis and, in 2015, extended this programme to 225 additional new posts. Public support for research infrastructure increased tenfold between 2011 and 2013 from US$ 37 million to US$ 140 million.

As part of the drive to foster a knowledge economy, Mexico is creating or strengthening Technology Transfer Offices through its Sectorial Innovation Fund (FINNOVA) to encourage institutions that generate knowledge to establish linkages with the private sector through consulting, licensing and start-ups. In parallel, CONACYT has been stimulating business innovation through its Innovation Incentive Programme, which doubled its budget between 2009 and 2014 from US$ 223 million to US$ 500 million.

In 2013, Mexico proposed a new *National Climate Change Strategy* by raising the energy efficiency target by 5% for the national oil company, PEMEX, increasing the efficiency of transmission and distribution lines by 2% and the thermal efficiency of fuel oil-fired thermoelectric plants by 2%. The aim is to use endogenous research and a new sectorial fund known as CONACYT-SENER to reach these targets; the latter fund supports problem-solving in the areas of energy efficiency, renewable energy and 'clean and green' technologies.

To promote regional development, the government established the Institutional Fund for the Regional Development of Science, Technology and Innovation (FORDECYT) in 2009 to complement the existing Mixed Funds (FOMIX). FORDECYT receives both national (CONACYT) and state funds to promote R&D at the state and municipal levels. The new contribution ratio scheme for these two funding sources is respectively 3:1. The funds mobilized only amounted to US$ 14 million in 2013.

PERU

A new fund for innovation

The Peruvian economy grew by 2.4% in 2014 and is expected to progress by 3.6% in 2015, driven by a surge in mining output and, to a lesser extent, by higher public spending and the monetary stimulus created by lower interest rates and the increased availability of credit (ECLAC, 2015a).

GERD has been estimated at just 0.12% GDP (see the article by J. Kuramoto in Crespi and Dutrénit, 2014). Research and innovation policies in Peru are co-ordinated by the National Council of Science, Technology and Technological Innovation (CONCYTEC). Since 2013, CONCYTEC has been functioning in the orbit of the Presidency of the Council of Ministries. CONCYTEC's operational budget soared between 2012 and 2014 from US$ 6.3 million to US$ 110 million.

The *National Plan for Science, Technology and* Innovation 2006–2021 focuses on the following:

- Obtaining research results focused on the needs of the productive sector;
- Increasing the number of qualified researchers and professionals;
- Improving the quality of research centres;
- Rationalizing STI networking and system information; and

- Strengthening the governance of the national innovation system.

In 2013, the government created the Framework Fund for Innovation, Science and Technology (FOMITEC), allocating *circa* US$ 280 million for the design and implementation of financial and economic instruments fostering the development of research and innovation for competitiveness. The National Fund for Scientific and Technological Research and Technological Innovation (FONDECYT) received US$ 85 million in 2014, an increase over the previous year.

The government has introduced a scholarship programme for PhD candidates wishing to study abroad (*circa* US$ 20 million) and those planning to study at local universities (US$ 10 million).

VENEZUELA

Scientific output down

In 2014, the Venezuelan economy contracted by 4% with a double-digit inflation rate (ECLAC, 2015a). The number of FTE researchers increased by 65% between 2008 and 2013, the highest growth rate in the region. Scientific output has actually decreased by 28% over the past decade, however (Figure 7.8).

In 2010, a reform of the regulatory decree for the Organic Law for Science, Technology and Innovation (LOCTI) established that industrial and business sectors with higher revenues should pay a special tax to finance laboratories and research centres. The government prioritized a number of thematic areas to which these resources should be allocated: food and agriculture; energy; public safety; housing and urbanism; and public health. Plans for areas related to climate change and biological diversity have been developed and are being directed by the Ministry of the Environment.

After a series of ministerial reforms in 2015, the Popular Power Ministry for University Education, Science and Technology was made responsible for co-ordinating STI policy.

The online publication *Piel-Latinoamericana* reports that 1 100 out of the 1 800 doctors who graduated from medical school in Venezuela in 2013 have since left the country. Although precise numbers are unavailable, according to the President of the Venezuelan Academy of Physical, Mathematical and Natural Sciences, many researchers have emigrated in the past decade, most of them scientists and engineers, after becoming disillusioned with government policies. This is another example of the Sisyphus trap (see next section).

Table 7.6: **Institutions in Latin America and the Caribbean with the most scientific publications, 2010–2014**
Spanish-speaking countries of more than 10 million inhabitants

Argentina	CONICET (51.5%)	University of Buenos Aires (26.6%)	National University of La Plata (13.1%)	National University of Cordoba (8.3%)	National University of Mar del Plata (4.3%)
Bolivia	Major University of San Andres (25.2%)	Major University San Simon (10.7%)	Autonomous University Rene Moreno (2.6%)	National Historical Museum Noel Kempff Mercado (2.2%)	Bolivarian Catholic University San Pablo (1.5%)
Chile	University of Chile (25.4%)	Pontifical Catholic University of Chile (21.9%)	University of Conception (12.3%)	Pontifical Catholic University of Valparaiso (7.5%)	Austral University of Chile (6%)
Colombia	National University of Colombia (26.7%)	University of Antioquia (14.6%)	University of the Andes (11.9%)	University Valle (7.8%)	Pontifical University Javeriana (4.6%)
Cuba	University of Habana (23.4%)	Central University Marta Abreau las Villas (5.5%)	Genetic Engineering and Biotechnology Centre (5%)	University Oriente (4.9%)	Tropical Medicine Inst. Pedro Kouri (4%)
Dominican Republic	National University Pedro Henriquez Ureña (8%)	Santo Domingo Technological Institute (6%)	Ministry of Agriculture (4%)	Pontifical Catholic University Mother and Teacher (3%)	General Hospital Plaza Salud (3%)
Ecuador	San Francisco de Quito University (15.0%)	Pontifical Catholic University of Ecuador (11%)	Technical University of Loja (6.0%)	Polytechnic National School (5.4%)	University of Cuenca (3.7%)
Guatemala	University of the Valle (24.4%)	General Hospital San Juan de Dios (3.0%),	San Carlos University (2.5%)	Ministry of Public Health and Social Assistance (2.0%)	
Mexico	National Autonomous University of Mexico (26.2%)	National Polytechnic Institute of Mexico (17.3%)	Metropolitan Autonomous University of Mexico (5%)	Autonomous University of Puebla (2.1%)	Autonomous University of San Luis Potosi (2.9%)
Peru	University Cayetano Heredia (21.6%)	National University of San Marcos (10.3%)	Pontifical Catholic University of Peru (7.5%)	International Potato Centre (3.6%)	National Agrarian Univ. La Molina (2.5%)
Venezuela	Central University of Venezuela (23%)	IVIC (15.1%)	Simon Bolivar University (14.2%)	University of the Andes (13.3%)	Zulia University (11.1%)

Source: compiled by author from Thomson Reuters' Web of Science, Science Citation Index Expanded

CONCLUSION

Escaping the Sisyphus trap

According to ancient Greek mythology, Sisyphus was the craftiest of men but his chronic deceitfulness infuriated the gods, who ended up punishing him by compelling him to roll a boulder up a hill, only to watch it roll back down time and time again – forever. Francisco Sagasti (2004) made astute use of the Sisyphus metaphor to describe the recurrent difficulties developing countries face in creating endogenous research and innovation.

The history of STI policies in Latin America can be likened to the Sisyphus trap. Recurrent economic and political crises since the 1960s have had a direct impact on the design and performance of STI policies for both the supply and demand sides. The lack of continuity of long-term public policies and poor public governance in the majority of countries are largely to blame for the lack of appropriate STI policies in recent decades. How often has a new party or group come to power in a Latin American country and immediately set about putting a new set of rules and policies in place? Like Sisyphus, the national innovation system sees the original policy roll back down the hill, as the country takes a new policy direction. 'As the scientific and technological hills to climb will continue to proliferate – making Sisyphus' tasks even more daunting – it is also essential to devise ways of keeping the rock on the top of the hill…'(Sagasti, 2004).

Since the structural adjustments of the 1990s, a new generation of STI policy instruments has emerged that has profoundly transformed the institutional ecosystem, legal framework and incentives for research and innovation. In some countries, this has been beneficial. Why then has the gap between Latin America and the developed world not narrowed? This is because the region has failed to overcome the following challenges.

Firstly, Latin American economies do not focus on the type of manufacturing that lends itself to science-based innovation. Manufactured goods represent less than 30% of exports from most Latin American economies and, with the notable exception of Costa Rica and to a lesser extent Mexico, high-tech goods represent less than 10% of manufactured exports. With the exception of Brazil, GERD remains well below 1% and business contributes one-third, at best. These ratios have hardly changed for decades, even as many other developing countries have moved on. On average, R&D intensity in the private enterprise sector (expressed as a percentage of sales) is less than 0.4%, well below the averages for Europe (1.61%) or the OECD (1.89%) [IDB, 2014]. A recent Argentinian study showed that R&D expenditure as a percentage of sales over 2010–2012 amounted to just 0.16% for small firms, 0.15% for medium-sized firms and 0.28% for large firms (MINCYT, 2015). The stock of innovation capital is far lower in Latin America (13% of GDP) than in OECD countries (30% of GDP). Furthermore, in Latin America, this stock is mainly comprised of tertiary education, compared to R&D expenditure in the OECD countries (ECLAC, 2015c).

Secondly, the paltry investment in R&D partly reflects the insufficient number of researchers. Although the situation has improved in Argentina, Brazil, Chile, Costa Rica and Mexico, numbers remain low in relative terms. The shortage of trained personnel restricts innovation, especially that done in SMEs. Some 36% of companies operating in the formal economy struggle to find a properly trained workforce, compared to a global average of 21% per country and an OECD average of 15%. Latin American companies are three times more likely than South Asian firms and 13 times more likely than Asian–Pacific firms to face serious operational problems owing to a shortage of human capital (ECLAC, 2015b).

Thirdly, the education system is not geared to addressing the shortage of S&T personnel. Although the number of tertiary institutions and graduates has been rising, their numbers remain low in relative terms and insufficiently focused on science and engineering. The shares of bachelor's and PhD graduates against the major six fields of knowledge (Figure 7.4) show an important structural weakness. More than 60% of bachelor's graduates and 45% of PhDs obtained their corresponding degrees in social sciences and humanities. Moreover, only a small proportion of scientific researchers work in the business sector in Latin America (24%), compared to the OECD average (59%). In Argentina, Brazil, Chile, Colombia and Mexico, there is a lack of engineering graduates in the private sector.

Last but not least, patenting behaviour confirms that Latin American economies are not seeking technology-based competitiveness. The number of patents granted per million inhabitants between 2009 and 2013 was highest in Panama, Chile, Cuba and Argentina but generally very low across the region. Patent applications by Latin Americans over the same period in the top technological fields[18] accounted for just 1% of those filed in high-income economies in these same fields.

In the past decade, Argentina, Chile, Mexico and Uruguay have followed Brazil's example by initiating a shift from horizontal to vertical funding mechanisms like sectorial funds. In so doing, they have given a strategic boost to those economic sectors that require innovation to increase productivity, such as agriculture, energy and ICTs. In tandem, they are implementing specific policies and putting incentive mechanisms in place to foster strategic technologies such as biotechnologies, nanotechnologies, space technologies and biofuels. This strategy is beginning to pay off.

18. namely, electrical machinery, apparatus, energy, digital communication, computer technology, measurement and medical technology

A second group of countries are adopting a variety of funding mechanisms to foster greater endogenous research and innovation: Guatemala, Panama, Paraguay and Peru. Others are promoting competitiveness through specific programmes, such as the Dominican Republic and El Salvador.

In sum, in order to escape the Sisyphus trap, Latin American countries need to address the following challenges:

- Improve governance: political stability, government effectiveness, control of corruption;
- Design long-term public policies that extend beyond a single term of government;
- Involve a greater range of stakeholders in the formulation, co-ordination and harmonization of STI policies to connect the demand and supply sides of national innovation systems better;
- Promote regional integration mechanisms to share the costs of R&D, in order to be in a position to address the regional sustainability science agenda;
- Modify the organizational culture, in order to rationalize the institutional ecosystem responsible for formulating, monitoring and evaluating STI policies and policy instruments; and
- Create institutions to promote foresight and prospective studies to guide the decision-making process.

Step-by-step, Latin America has been consolidating its scientific research system and boosting its share in global publications, which rose from 4.9% to 5.2% between 2008 and 2014. A variety of policy instruments have been introduced to make endogenous R&D more responsive to the needs of the productive system and society at large. This is now beginning to bear fruit in some countries – but the road ahead remains long for Latin America.

KEY TARGETS FOR LATIN AMERICAN COUNTRIES

- Mexico's *National Development Plan 2013–2018* proposes raising GERD to 1% of GDP but gives no target year;
- Uruguay aims to generate 90% of its electricity from renewable sources by 2015.

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ACKNOWLEDGMENTS

Thanks go to Julia Tagueña Parga, Deputy-Director for Scientific Development at the National Council for Science and Technology (CONACYT) in Mexico and Alberto Majó Pineyrua, Secretary-General of the Iberoamerican Programme for Science and Technology for Development (CYTED) in Uruguay, for contributing information to the present chapter, and to their assistant Mónica Capdevielle. The author also expresses his gratitude to Carlos Aguirre-Bastos, Ernesto Fernandez Polcuch and Alessandro Bello for their contribution to the boxes.

Industry must embrace innovation to remain internationally competitive.

Renato Hyuda de Luna Pedrosa and **Hernan Chaimovich**

This laboratory uses desalination to convert ocean water into drinking water. It is situated in Bertioga, in the State of São Paulo.

Photo: © Paulo Whitaker/Reuters

8 · Brazil

Renato Hyuda de Luna Pedrosa and Hernan Chaimovich

INTRODUCTION

Economic downturn could jeopardize recent gains

Brazil's economy has experienced a severe downturn since 2011, after almost a decade of growth and a short-lived recovery from the 2008–2009 global financial crisis in 2010 (Figure 8.1). This economic slowdown has been triggered by weaker international commodities markets, on which Brazil is highly dependent, coupled with the perverse effects of economic policies designed to fuel consumption. The latter eventually caused government spending to overtake revenue by a large margin: in 2014, Brazil had a primary deficit of over 0.5% of GDP for the first time in 16 years; this deficit has helped to push annual inflation rates to over 6% since 2013. Brazil's economy stagnated in 2014 (0.1% of GDP growth) and the outlook is even worse for 2015, with the Ministry of Finance forecasting in April this year that the economy would contract by 0.9%.

Since her re-election in November 2014, President Dilma Roussef has overhauled national macro-economic policies. The new Minister of Finance, Joaquim Levy, has put in place, or proposed, a series of measures to cut spending and increase tax revenue, with the aim of obtaining a primary surplus of 1.2% in 2015.[1] Interest rates have been raised twice since the November election (to 12.75%) to try to curb inflation, which hit 8.1% for the 12-month period ending in March 2015. To make matters worse, the giant state-controlled oil company, Petrobrás, is currently fighting a crisis tied to poor management and a kick-back corruption scandal. The latter has taken a political turn, with the implication of several prominent political figures. At the end of April 2015, Petrobrás finally published its annual report for 2014, in which it acknowledged losses of over 50 billion reals (R$, *circa* US$ 15.7 billion), R$ 6 billion of which were related to the corruption scandal.

It is against this economic and political backdrop that Brazil is striving to maintain the momentum of reforms to its national innovation system, including innovation in social policies.

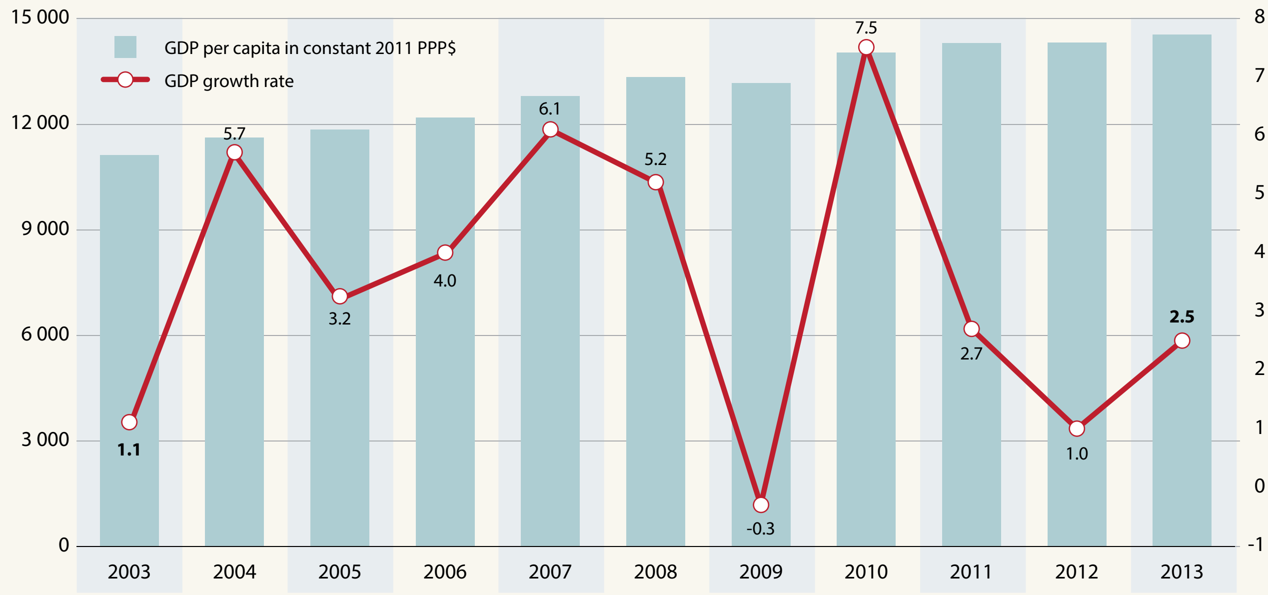
Social inclusion progressing more slowly

The downturn in the economy is starting to rub off on social inclusion, which had been one of Brazil's success stories, especially during the commodities boom up to 2010 when Brazil essentially managed to eliminate hunger and extreme poverty and, thereby, narrow the income gap. Between 2005 and 2013, unemployment rates fell from 9.3% to 5.9% of the population.

More recent data suggest that this growth cycle may already be at an end. According to the Social Panorama on Latin America published by the United Nations' Economic Commission for Latin America and the Caribbean (ECLAC, 2014a), Brazil reduced poverty rates by one-third between 2003 and 2008 but progress slowed from 2008 to 2012 and stagnated in 2013. Preliminary data even suggest that extreme poverty may

1. Given the difficulties in getting support from Congress for the fiscal policies proposed by Minister Levy, the target for primary surplus was reduced to 0.15% of GDP in July 2015. Recent forecasts put the contraction in GDP at 1.5% or more for 2015.

Figure 8.1: **GDP per capita and GDP growth rate for Brazil, 2003–2013**



Source: World Bank's World Development Indicators, May 2015

Chapter 8

have regained some ground, since it affected 5.9% of the population in 2013, compared to 5.4% a year earlier. Despite having managed to reduce poverty rates faster than the rest of Latin America, Brazil still trails the region's leaders for this indicator, namely Uruguay, Argentina and Chile (ECLAC, 2014a).

Brazilian labour productivity stagnating

Another recent study (ECLAC, 2014b) indicates that greater social spending by governments in Latin America has failed to translate into better labour productivity, contrary to what has been observed in high-income countries. The notable exception is Chile, which saw its labour productivity almost double between 1980 and 2010.

If we compare Brazil with other emerging economies, the Brazilian experience is akin to that of Russia and South Africa, where labour productivity has stagnated since 1980. China and India, on the other hand, have improved their own labour productivity remarkably over the past decade, in particular, albeit from a low starting point (Heston *et al.*, 2012).

Even the commodities boom between 2004 and 2010 did not make a difference. Part of the explanation for Brazil's poor performance even during this growth cycle lies in the fact that the bulk of economic growth over these years came from service industries; as this sector requires less skill, the average productivity of the employed actually dropped.

The government has enacted a range of policies which seek, indirectly, to raise labour productivity. The 2011–2020 *National Education Plan* provides incentives for developing basic and vocational education: new programmes established in 2011 finance the vocational training of low-skilled workers and offer scholarships for tertiary education. The dual reforms of the public pension and unemployment insurance systems in 2012, coupled with a reduction in the labour tax wedge, have been designed to encourage people to work in the formal economic sector, which is more amenable to innovation than the informal sector (OECD, 2014). However, there seem to be few, if any, substantial public policies designed specifically to help Brazilian enterprises catch up to their competitors on the frontier of technology. Since productivity levels are an indication of the rate of absorption and generation of innovation, Brazil's own low productivity levels suggest that it has not managed to harness innovation to economic growth.[2]

TRENDS IN STI GOVERNANCE

More flexible social organizations cutting the red tape

Brazil's public research institutes and universities follow rigid rules that tend to make them very difficult to manage. States may opt to develop their own research institutes and university systems but, as all laws and regulations are adopted at federal level, they all have to follow the same rules and regulations. Thus, they all come up against the same hurdles. These include extensive bureaucratic structures, an obligation to recruit staff, academic or otherwise, from among public servants, analogous career ladders and salary systems, an irregular flow of funds, overly complex procurement procedures and powerful unions in the civil service.

A structural alternative was developed in 1998, with the creation of social organizations. These private, non-profit entities manage public research facilities under contract to federal agencies. They have the autonomy to hire (or fire) staff, contract services, buy equipment, choose the topics and objectives of scientific or technological research and sign

2. The relationship between innovation and economic development, including productivity, has been at the centre of modern development economic theory and empirical studies. A good discussion may be found in Aghion and Howitt (1998).

Box 8.1: The Brazilian Institute for Pure and Applied Mathematics

The Institute for Pure and Applied Mathematics (IMPA) in Rio de Janeiro was set up in 1952 as part of Brazil's National Research Council (CNPq). From the outset, IMPA's mission was to carry out high-level mathematical research, train young researchers and disseminate mathematical knowledge in Brazilian society.

Since 1962, IMPA's graduate programme has awarded over 400 PhDs and twice as many master's degrees. About half of its student body comes from abroad, mainly other Latin American countries. The 50 faculty also include citizens of 14 different countries.

In 2000, IMPA obtained the status of social organization to allow for a more flexible and agile management of resources and to give greater autonomy in hiring researchers and in career development.

IMPA has since become involved in organizing the Brazilian Mathematics Olympiad for public schools and in training secondary school teachers.

In 2014, IMPA joined the exclusive group of institutions with a Fields Medallist on their staff, Ártur Avila, who had obtained his PhD from IMPA in 2001 and has been a permanent faculty member since 2009. Avila is the only Fields Medallist to date to have had been entirely educated in a developing country.

IMPA and the Brazilian Mathematical Society are organizing the International Congress of Mathematicians in 2018.

Source: www.icm2018.org

Box 8.2: The Brazilian Centre for Research in Energy and Materials

The National Centre for Research in Energy and Materials (CNPEM) is the oldest social organization in Brazil. It runs national laboratories in the areas of biosciences, nanotechnology and bioethanol.

It also runs the only Latin American synchrotron light source, which has been operational since the late 1990s. The light source and beamline were designed and installed using technology developed at the centre itself (see photo, p. 210).

CNPEM is currently engaged in the development and construction of a new internationally competitive synchrotron called Sirius. It will have up to 40 beamlines and will be one of the world's first fourth-generation synchrotrons. This US$ 585 million project will be the largest infrastructure for science and technology ever built in Brazil. It will be used for Latin American R&D projects stemming from academia, research institutes and private and public companies.

Typical industrial applications of this equipment will include developing ways to break down asphaltenes to allow the pumping of high viscosity oil; explaining the elementary process of catalysis in the production of hydrogen from ethanol; understanding the interaction between plants and pathogens to control citrus diseases; and analysing the molecular process that catalyses cellulose hydrolysis in the production of second-generation ethanol.

This endeavour has been made possible by CNPEM's structure as a social organization, a status that confers autonomy in project management.

Source: authors

R&D contracts with private companies. The flexibility accorded to these social organizations and their management style have made them a success story in Brazilian science. Today, there are six such organizations:

- the Institute for Pure and Applied Mathematics (IMPA, Box 8.1);
- the Institute for the Sustainable Development of the Amazon Forest (IDSM);
- the National Centre for Research in Energy and Materials (CNPEM, Box 8.2);
- the Centre for Management and Strategic Studies (CGEE);
- the National Teaching and Research Network (RNP); and
- the most recent addition, the Brazilian Research and Industrial Innovation Enterprise (Embrapii), established by the federal government in late 2013 to stimulate innovation through a system of calls for proposals; only institutions and enterprises deemed eligible may respond to these calls, thus speeding up the whole process and offering applicants a greater chance of success; Embrapii is due to be assessed in late 2015.

In the late 1990s, as economic reforms took hold, legislation was adopted to stimulate private R&D. Arguably the most important milestone was the National Law on Innovation. Soon after its approval in 2006, the Ministry of Science, Technology and Innovation published a *Plan of Action for Science, Technology and Innovation* (MoSTI, 2007) establishing four main targets to be attained by 2010, as described in the *UNESCO Science Report 2010*:

- Raise gross domestic expenditure on R&D (GERD) from 1.02% to 1.50% of GDP;
- Raise business expenditure on R&D from 0.51% to 0.65% of GDP;
- Increase the number of scholarships (all levels) granted by the two federal agencies, the National Research Council (CNPq) and the Foundation for Co-ordinating Capacity-building of Personnel in Higher Education (Capes), from 100 000 to 150 000; and
- Foster S&T for social development by establishing 400 vocational and 600 new distance-learning centres, by expanding the Mathematics Olympiad to 21 million participants and by granting 10 000 scholarships at the secondary level.

By 2012, GERD stood at 1.15% of GDP and business expenditure on R&D at 0.52% of GDP. Neither of these targets has thus been reached. Concerning tertiary scholarships, CNPq and Capes easily reached the target for PhDs (31 000 by 2010 and 42 000 by 2013) but fell short of reaching the target for tertiary scholarships as a whole (141 000 by 2010). The target of the *National Plan for Graduate Education 2005–2010* was for 16 000 PhDs to be granted by the end of the plan period. Since the actual number of PhDs granted stood at 11 300 in 2010 and less than 14 000 in 2013, this target has not been reached either, despite the fact that almost 42 000 federal PhD scholarships were granted in 2013.

On the other hand, the targets related to fostering a popular science culture have been partly reached. For instance, in 2010, over 19 million students took part in the Brazilian Mathematics Olympiad for Public Schools, up from 14 million in 2006. However, since then, the number of participants has tended to stagnate. Up until 2011, it was looking as if the targets for distance learning and vocational education might be reached but there has been little progress since.

The Fourth[3] National Conference on Science and Technology (2010) laid the groundwork for the *National Plan for Graduate Education 2010–2015* and established guidelines orienting R&D towards reducing regional and social inequalities; exploiting the country's natural capital in a sustainable manner; raising the added value in manufacturing and exports through innovation; and strengthening the international role of Brazil.

The proposals put forward at the Fourth Conference on Science and Technology were presented in a *Blue Book* which served as the basis for the elaboration of targets within a four-year plan dubbed *Brasil Maior* (Larger Brazil). The launch of this plan coincided with the arrival of the Roussef administration in January 2011. Targets of *Brasil Maior* to 2014 include:

- increasing the level of fixed capital investment from 19.5% in 2010 to 22.4% of GDP;
- raising business expenditure on R&D from 0.57% in 2010 to 0.90% of GDP;
- augmenting the share of the labour force that has completed secondary education from 54% to 65%;
- raising the share of knowledge-intensive businesses from 30.1% to 31.5% of the total;
- increasing the number of innovative small and medium-sized enterprises (SMEs) from 37 000 to 58 000;
- diversifying exports and increasing the country's share in world trade from 1.36% to 1.60%; and
- expanding access to fixed broadband internet from 14 million to 40 million households.

The only tangible progress so far concerns the last target. By December 2014, almost 24 million households (36.5%) had fixed broadband internet access. Investment in fixed capital has actually declined to 17.2% of GDP (2014), business expenditure has fallen back to 0.52% of GDP (2012) and the Brazilian share of world exports has receded to 1.2% (2014); in parallel, Brazil has dropped three places to 25th worldwide for the absolute amount of exports. The number of young adults completing secondary education has not risen, nor has their participation in the job market. We shall be examining the reasons for these trends in the following pages.

Another programme that has nothing to do with *Brasil Maior* has been attracting the most attention from the authorities and receiving a generous portion of federal funds for R&D. Science Without Borders was launched in 2011 with the aim of sending 100 000 university students abroad by the end of 2015 (Box 8.3).

3. The first was held in 1985 after the return to civilian government, in order to establish the mandate of the new Ministry of Science and Technology. The second conference took place in 2001. The third, in 2005, laid the groundwork for the *Plan of Action for Science, Technology and Innovation* (2007).

TRENDS IN HIGHER EDUCATION

Private enrolment slowing after years of rapid growth

Higher education has experienced very fast growth rates since the launch of the economic stabilization programme in the second half of the 1990s. Growth has been most visible in undergraduate enrolment, where the student body has swelled by an extra 1.5 million students since 2008. About three-quarters of undergraduates (7.3 million in 2013) are enrolled in private institutions. The latter tend to be mostly teaching institutions, with a few exceptions, such as the network of Catholic universities and a handful of non-profit institutions teaching economics and administration like the Getulio Vargas Foundation. About half of the growth in private tertiary education can be attributed to distance learning programmes, a new trend in Brazilian higher education.

Federal subsidies financed some two million student loans in 2014. Despite this assistance, growth in enrolment in private tertiary institutions appears to be tailing off, perhaps as consequence of the economic slowdown and a lesser willingness to contract debt. Only 1.2 million loans had been renewed up to March 2015, a month after the start of the new academic year. Whereas students took out 730 000 new loans in 2014, the Ministry of Education expects this figure to drop to 250 000 in 2015.

In the public sector, the Restructuring and Expansion of Federal Universities Programme (Reuni)[4] resulted in the number of public universities and polytechnics growing by about 25% and student numbers by 80% (from 640 000 to 1 140 000) between 2007 and 2013. Graduate education also flourished in public universities, where the number of PhD degrees granted between 2008 and 2012 rose by 30% (Figure 8.2).

The quality of education matters more than the duration

Raising labour productivity requires increasing capital investment and/or the adoption of new technologies. Creating, developing and incorporating new technologies requires a skilled labour force, including training in the sciences for those more closely involved in the innovation process. Even in the case of the services sector, which now generates about 70% of Brazilian GDP, a better-educated labour force will result in significant productivity gains.

It is thus of strategic importance for Brazil to raise the educational level of the average adult. The quality of education seems to be very low, judging from the OECD's Programme for International Student Assessment (PISA). In the 2012 PISA exams, the average 15-year old Brazilian scored roughly one standard deviation (100 points) below the OECD

4. See: http://reuni.mec.gov.br/

Box 8.3: **Science without Borders**

Science without Borders is a joint initiative of the Ministry of Science, Technology and Innovation and the Ministry of Education, through their respective funding agencies, the CNPq and Capes.

The programme was announced in early 2011 and began sending its first students abroad in August the same year.

By the end of 2014, it had sent more than 70 000 students abroad, mainly to Europe, the USA and Canada. More than 80% of these students are undergraduates who stay for up to a year at a foreign university.

Students enrolled in PhD programmes in Brazil are also entitled to spend up to a year furthering their research at an institution abroad.

Other target groups include students enrolled in full PhD programmes abroad and postdocs, as well as small numbers of visiting faculty and young faculty members. Researchers employed by private companies may also apply for specialized training abroad.

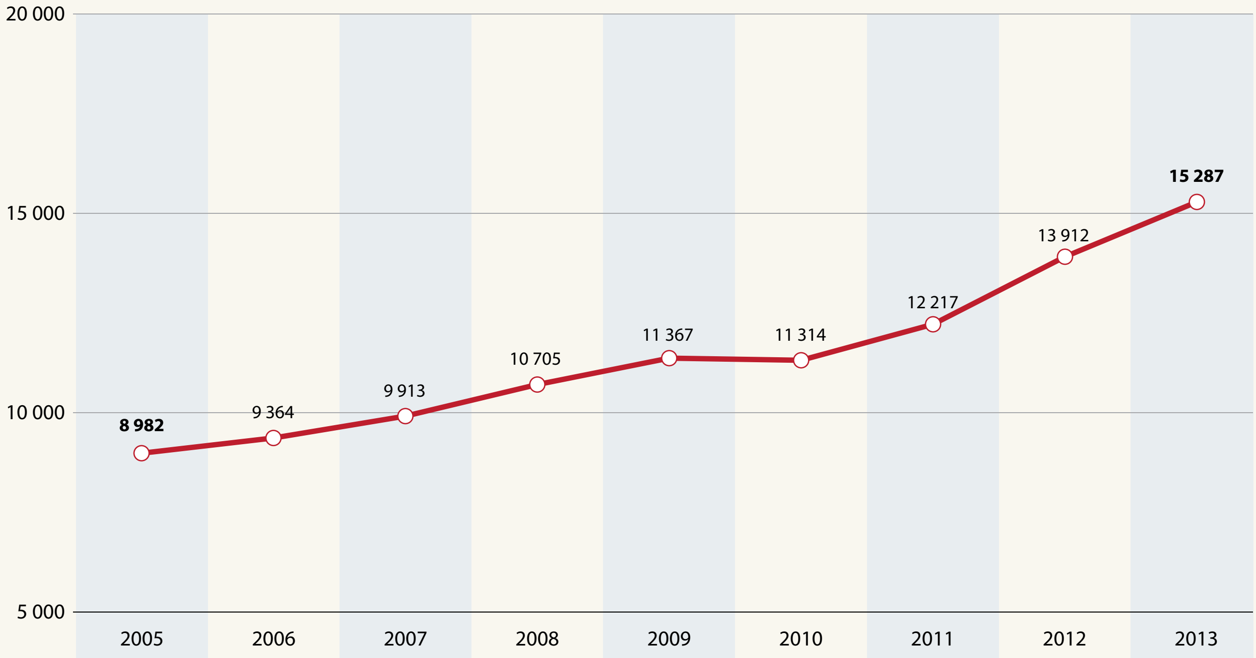
The programme also seeks to attract young researchers from abroad who might wish to settle in Brazil or establish partnerships with Brazilian researchers in the programme's priority areas, namely:

- Engineering;
- Pure and natural sciences;
- Health and biomedical sciences;
- ICTs;
- Aerospace;
- Pharmaceuticals;
- Sustainable agricultural production;
- Oil, gas and coal;
- Renewable energy;
- Biotechnology;
- Nanotechnology and new materials;
- Technology for the prevention and mitigation of natural disasters;
- Biodiversity and bioprospection;
- Marine sciences;
- Minerals;
- New technologies for constructive engineering; and
- Training of technical personnel.

The impact of this experience on the Brazilian higher education and research systems has not yet been evaluated. In September 2015, it was decided not to extend Science without Borders beyond 2015.

Source: authors

Figure 8.2: **PhD degrees obtained in Brazil, 2005–2013**



Source: Capes; Ministry of Education; InCites average in mathematics, despite Brazilian youth having recorded the biggest gains in mathematics of any country between 2003 and 2012.[5] Brazilian teenagers also scored relatively poorly in reading and science.

A recent study which used international learning outcome assessments and economic data for a large sample of countries over four decades (1960–2000) has concluded that it is not the number of years of formal education that matters for economic growth but how well that education has developed the requisite skills (Hanusheck and Woessmann, 2012). Using the PISA score as a proxy for the skills of the young adult population, the authors conclude that, for each 100 points, the average yearly rate of economic growth per capita increases by about 2 percentage points.

Brazil has just enacted a new National Law on Education establishing targets to 2024. One of these is to attain a PISA score of 473 points by 2024. If the recent past is any indication, that target may remain elusive: from 2000 to 2012, the score of Brazilian participants rose by about two points a year, on average, for mathematics, science and reading; at this rate, Brazil will not attain 473 points until 2050.

Quality is not the only aspect of basic education that should be attracting the attention of policy-makers: the number of secondary-school graduates has stagnated since the early 2000s at about 1.8 million a year, despite efforts to expand access. This means that only half of the target population is graduating from secondary school, a trend which limits the further expansion of higher education. Many of the 2.7 million students admitted to university in 2013 were older people coming back to study for a degree, a source of demand that is unlikely to evolve much further. Even the relatively small fraction of the population that is able to complete a university degree (currently about 15% of the young adult population) is not developing high-level skills and content-related knowledge, as evidenced by the results of the National System of Assessment of Higher Education (Pedrosa *et al,* 2013).

One federal initiative to expand qualified labour is Pronatec, a programme launched in 2011 for technical and vocational secondary-level education. According to government data, over 8 million people have already benefitted from the programme. This impressive picture is somewhat clouded by the growing claims from independent observers that most of the teenagers trained under the programme have not acquired many new skills and that much of the money might have been better spent elsewhere. A major criticism has been that most of the money went to private schools that had very little experience of vocational education.

5. See: www.oecd.org/pisa/keyfindings/PISA-2012-results-brazil.pdf

TRENDS IN R&D

R&D expenditure targets remain elusive

Brazil's economic boom between 2004 and 2012 translated into higher government and business spending on R&D. Gross domestic expenditure on R&D (GERD) almost doubled to PPP$ 35.5 billion (in 2011 dollars, Figure 8.3). Most of this growth occurred between 2004 and 2010, when GERD climbed from 0.97% to 1.16% of GDP. Since 2010, the government sector alone has been driving up R&D intensity, since the non-government contribution has actually declined from 0.57% to 0.52% of GDP (2012). Preliminary figures for 2013 indicate slight growth in government spending and a constant contribution from the business sector (relative to GDP). Business R&D expenditure is likely to contract from 2015 onwards until the economy shows signs of recovery. Even the most optimistic analysts do not expect this to happen before 2016. Fixed capital investment in Brazil is expected to decline further in 2015, especially in the manufacturing sector. This trend will certainly affect R&D expenditure by industry. The Petrobrás crisis is expected to have a major impact on investment in R&D, since it alone has accounted for about 10% of the country's annual fixed capital investment in recent years. The recently announced cuts to the federal budget and other austerity measures should also affect government spending on R&D.

Brazil's GERD/GDP ratio remains well below that of both advanced economies and such dynamic emerging market economies as China and, especially, the Republic of Korea (see Chapters 23 and 25). At the same time, it is quite comparable to the more stagnant developed economies such as Italy or Spain and other major emerging markets like the Russian Federation (see Chapter 13). It is also well ahead of most other Latin American countries (Figure 8.4).

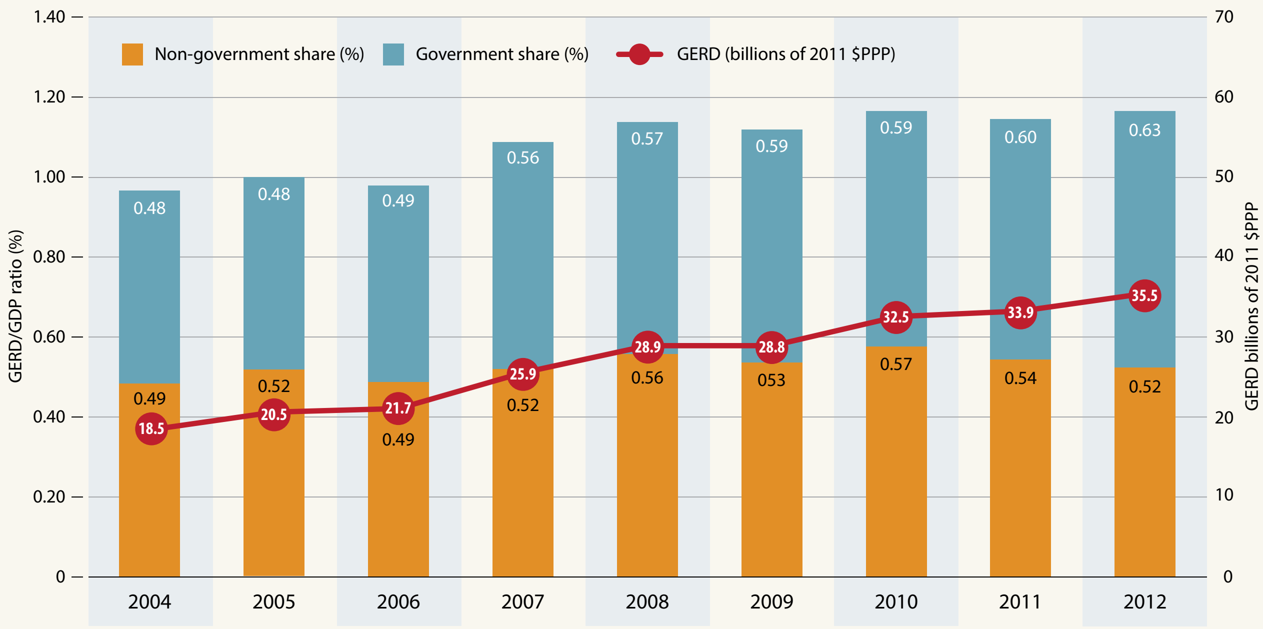
The gap between Brazil and advanced economies is much greater when it comes to human resources in R&D (Figure 8.5). Also striking is the sharp decline in the share of research personnel employed by the business sector in recent years (Figure 8.6). This is contrary to the trend observed in most developed and major emerging countries; it partly reflects the expansion of R&D in higher education and partly the anaemic growth of business sector R&D highlighted above.

Private firms are spending less on R&D

Almost all of non-government expenditure on R&D comes from private firms (private universities performing only a fraction of it). Since 2010, this expenditure has been declining as share of GDP (Figure 8.3); it has shrunk from 49% to 45% (2012) of total expenditure and even to 42% in 2013, according to preliminary government data. This trend is likely to last for some time. The business sector will, thus, have no chance of devoting 0.90% of GDP to R&D by 2014.

Figure 8.3: **GERD in Brazil by funding sector, 2004–2012**

In 2011 PPP$ billions and percentage share of GDP

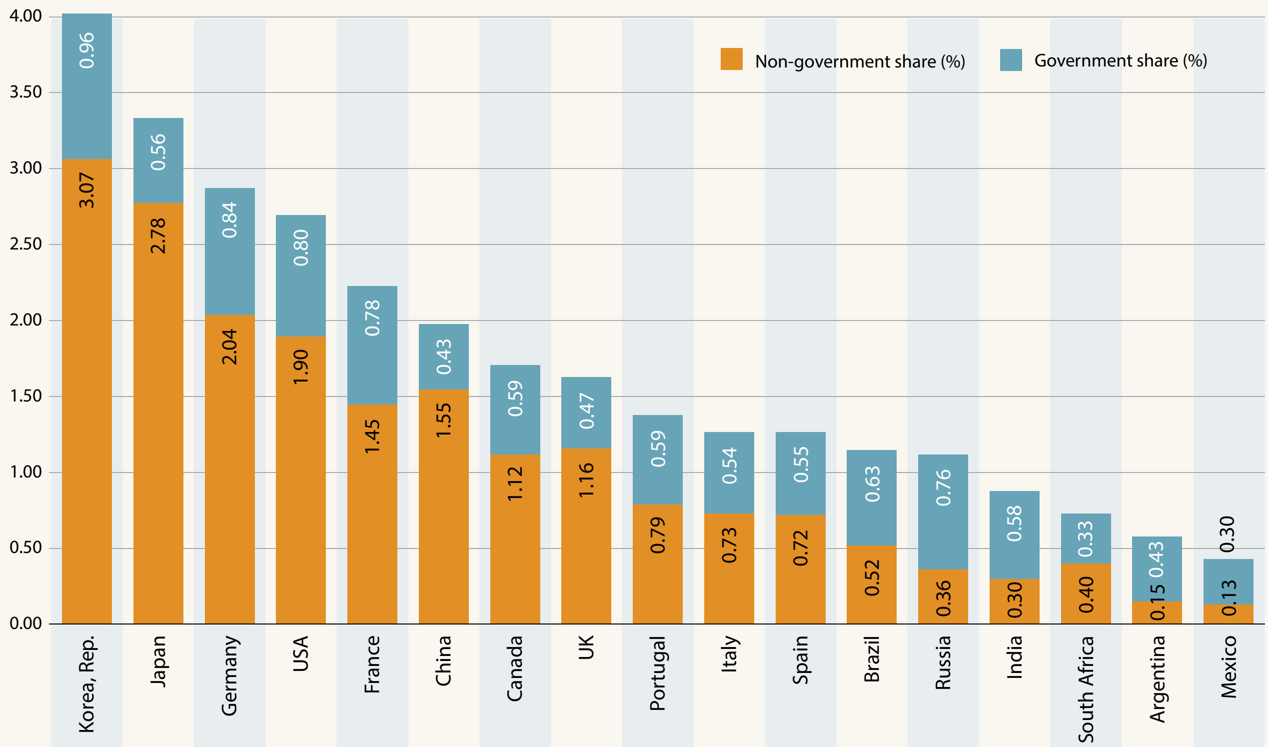


Note: The great majority of non-government funding comes from business enterprises. Private universities accounted for just 0.02–0.03% of GERD between 2004 and 2012. Figures 8.3 and 8.4 are based on updated GDP data for Brazil available as of September 2015 and may thus not match other indicators indexed on GDP reported elsewhere in the present report.

Source: Brazilian Ministry of Science, Technology and Innovation

Figure 8.4: **Brazilian business sector's contribution to GERD as a share of GDP, 2012 (%)**

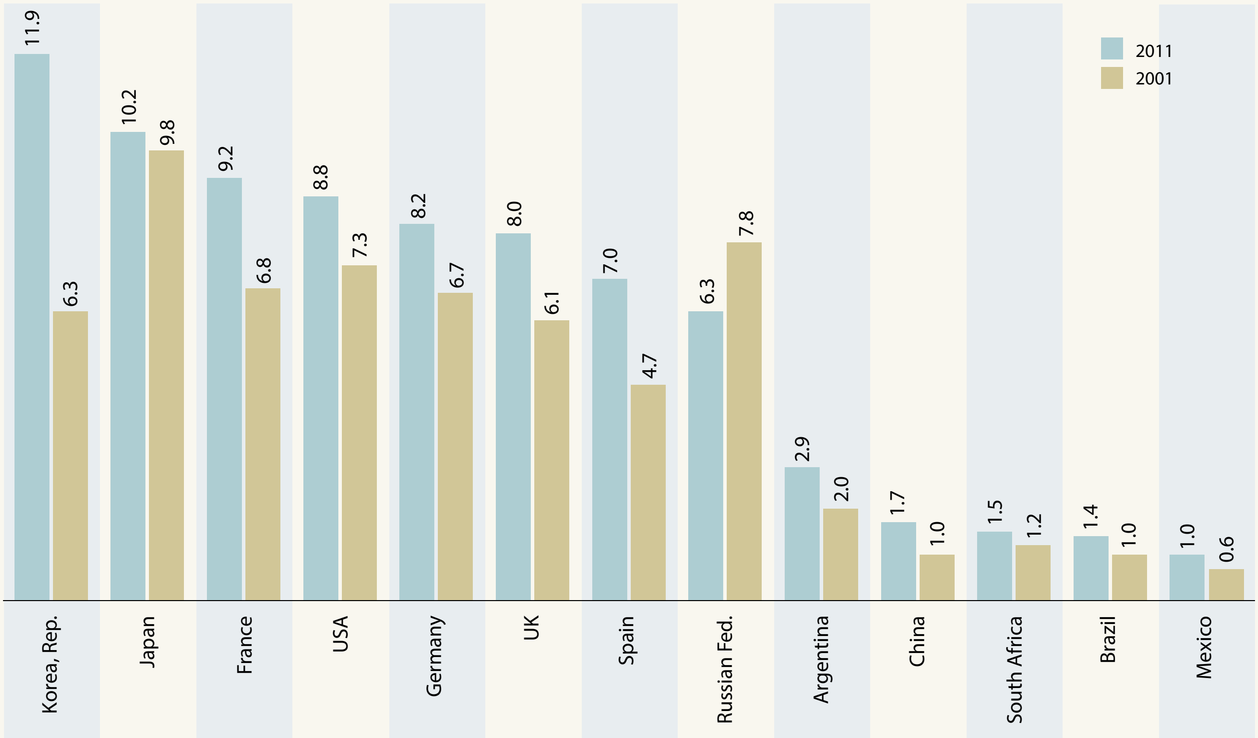
Other countries are given for comparison



Source: OECD's Main Science and Technology Indicators, January 2015; Brazilian Ministry of Science, Technology and Innovation

Figure 8.5: **Share of Brazilian FTE researchers per 1 000 labour force, 2001 and 2011 (%)**

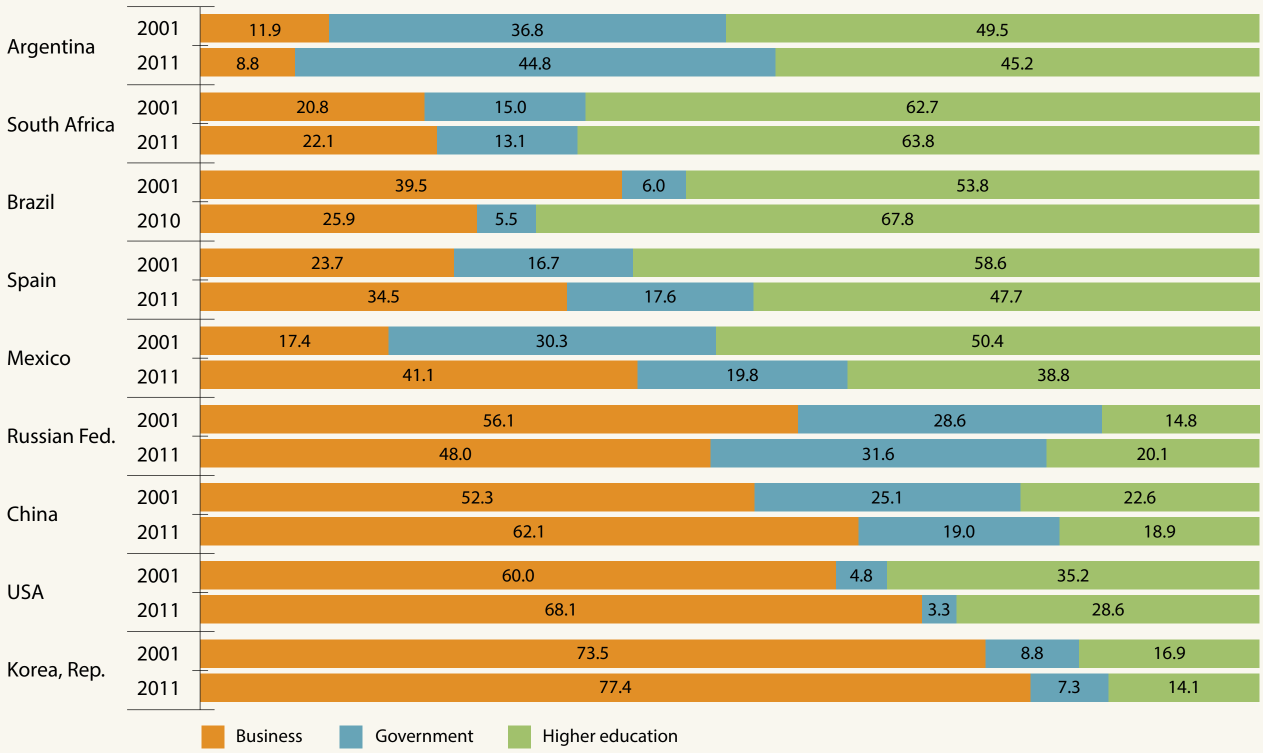
Other countries are given for comparison



Source: OECD's Main Science and Technology Indicators, January 2015

Figure 8.6: **FTE researchers in Brazil by sector, 2001 and 2011 (%)**

Other countries are given for comparison



Source: OECD's Main Science and Technology Indicators, January 2015

The main reasons for Brazil's low levels of private-sector R&D lie in the general population's low level of scientific and technical skills and the lack of incentives for businesses to develop new technology, new products and new processes. As we saw in the previous section, all available indicators show that Brazil's education system has not equipped the population to function properly in a technologically advanced society, nor to contribute effectively to technological progress.

As for Brazil's low level of innovation, this phenomenon is rooted in the deeply ingrained indifference of businesses and industry towards developing new technologies. There are fields where technological innovation sparks interest, of course: Embraer, the Brazilian aircraft manufacturer, Petrobrás, the state oil company and Vale, the large mining conglomerate, are all very competitive in their respective fields, with highly trained personnel and technologies and processes and products that are both innovative and competitive. These innovative companies share a common characteristic: their staple products are either commodities or used by the services industry, as in the case of commercial aeroplanes. Another area where Brazil has shown itself to be innovative and internationally competitive is agriculture, also a commodities sector. However, Brazil does not have a single company that is competing at the forefront of information and communications technologies (ICTs), in electronics or in biotechnology. Why is that so? In our view, the long-standing Brazilian industrial policy of protecting internal markets for locally produced goods (in various guises) has played a central role in this process. Only now are we coming to realize just how destructive this import substitution policy can be for the development of an innovative environment. Why would a local business invest heavily in R&D, if it is only competing with similar non-innovative companies operating within the same protectionist system? The consequence of this policy has been a gradual decline in Brazil's share of global trade in recent decades, especially when it comes to exports of industrial goods, a trend that has even accelerated in the past few years (Pedrosa and Queiroz, 2013).[6]

The situation is likely to deteriorate in the short term, as the most recent data indicate that 2014–2015 may turn out to be the worst years in decades for industry, especially for the transformation subsector of the manufacturing industry.

The current slowdown in the economy is already affecting the ability of the government's sectorial funds to collect revenue, since profits are down in many quarters. Created in the late 1990s, Brazil's sectorial funds have been one of the main sources of government funding for R&D. Each sectorial fund[7] receives money via taxes levied on specific industrial or service sectors, such as energy utility companies.

The 'Brazil cost' is holding companies back

Modern industrial development in Brazil is constrained by a lack of modern infrastructure, especially in logistics and electric power generation, along with cumbersome regulations relating to business registration, taxation or bankruptcy, all resulting in a high cost of doing business. This latter phenomenon has been described as the 'Brazil cost' (*Custo Brasil*).

The 'Brazil cost' is affecting the ability of Brazilian businesses to compete internationally and hindering innovation. Brazil has a relatively low level of exports. Their share of GDP even dropped from 14.6% to 10.8% between 2004 and 2013, despite the commodities boom. This trend cannot be explained solely by the unfavourable exchange rate.

Most Brazilian exports are basic commodities. These peaked at 50.8% of all exports in the first half of 2014, up from 29.3% in 2005. Soybean and other grains represented 18.3% of total exports, iron ore, meats and coffee making up another 32.5%. Just one-third of goods (34.5%) were manufactured, a sharp drop from 55.1% in 2005. Within manufactured exports, only 6.8% could be considered high technology, compared to 41.0% with a low-tech content (up from 36.8% in 2012).

The most recent figures paint a bleak picture. Industrial output declined by 2.8% between November and December 2014 and by 3.2% over the entire year. The decline was even more marked for capital (-9.6%) and durable goods (-9.2%) on an annual basis, indicating a drop in fixed capital investment.

Most government R&D expenditure goes to universities

The lion's share of government expenditure on R&D goes to universities, as in most countries (Figure 8.7). This level of spending increased slightly from 58% to 61% of total government funding of R&D between 2008 and 2012.

Among specific sectors, agriculture comes next, in a reflection of the sector's relevance for Brazil, the second-largest food-producing country in the world after the USA. Brazilian agricultural productivity has risen constantly since the 1970s, due to the greater use of innovative technology and processes. Industrial R&D comes third, followed by health and infrastructure, other sectors having shares of 1% or lower of government expenditure.

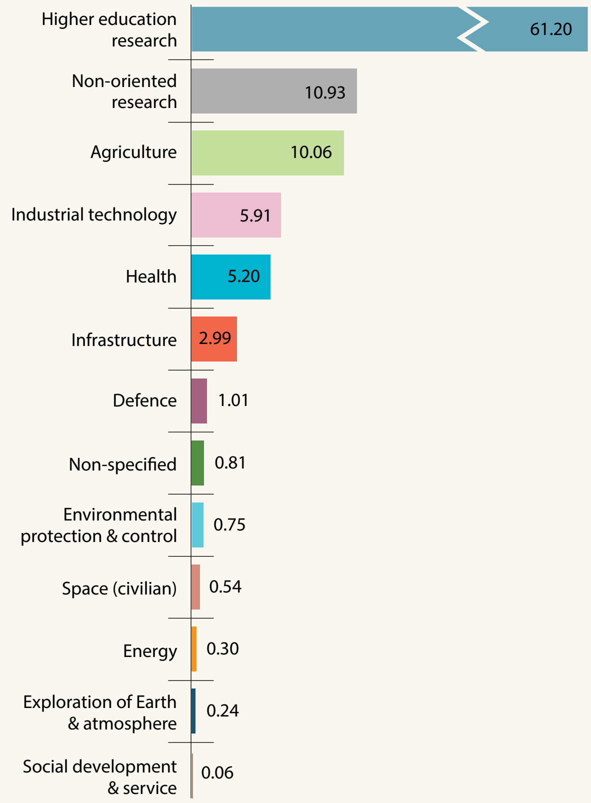
With some exceptions, the distribution of government spending on R&D in 2012 is similar[8] to that in 2000. After a sharp increase in industrial technology from 1.4% to 6.8%

6. Pedrosa and Queiroz (2013) present a detailed analysis of recent Brazilian industrial policies and their consequences in various areas, from the oil and wider energy sector to the auto-industry and other consumer goods.

7. For a detailed analysis of Brazilian sectorial funds, see the *UNESCO Science Report 2010*.

8. See t*he UNESCO Science Report 2010 for* a comparison with the years 2000 and 2008, p. 105.

Figure 8.7: **Government expenditure on R&D in Brazil by socio-economic objective, 2012 (%)**



Source: Ministry of Science, Technology and Innovation

between 2000 and 2008, its share of government expenditure declined to 5.9% in 2012. The share of space R&D (civilian) has been pursuing a downward spiral from a high of 2.3% in 2000. Defence research spending had been curtailed from 1.6% to 0.6% between 2000 and 2008 but has since rebounded to 1.0%. Research into energy has also declined from 2.1% (2000) to just 0.3% (2012). Overall, though, the allocation of government R&D spending seems to be relatively stable.

In May 2013, the Brazilian administrative body Redetec contracted the Argentine company INVAP to build a multipurpose nuclear reactor in Brazil for research and the production of radioisotopes employed in nuclear medicine, agriculture and environmental management. INVAP has already built a similar reactor for Australia. The multipurpose reactor is expected to be operational by 2018. It will be based at the Marine Technology Centre in São Paulo, with the Brazilian company Intertechne building some of the infrastructure.

Firms report a drop in innovative activity

In the latest innovation survey conducted by the Brazilian Institute of Geography and Statistics, all firms reported a drop in innovation activity since 2008 (IBGE, 2013). This survey covers all public and private firms in the extractive and transformative sectors, as well as firms in the services sector involving technology, such as telecommunications and internet providers, or electric power and gas utilities. For example, the proportion of companies undertaking innovative activities decreased from 38.1% to 35.6% between 2008 and 2011. The drop was most noticeable in telecommunications, both as regards the production of goods (-18.2%) and services (-16.9%). The larger companies seemed to have reduced their innovative activities by the biggest margin between 2008 and 2011. For example, among those with 500 or more employees, the share that were involved in developing new products declined from 54.9% to 43.0% over this period. A comparison of IBGE's innovation surveys over the periods 2004–2008 and 2009–2011 reveals that the 2008 crisis has had a negative impact on the innovative activities of most Brazilian firms. Since 2011, the economic situation in Brazil has further deteriorated, especially in the industrial sector. It can be expected that the next innovation survey will show even lower levels of innovative activity in Brazil.

Cutbacks in spending on renewable energy

Brazil's ambitions for biodiesel may have caught the headlines in the late 2000s when global energy and food prices spiked but energy-related industries have always had a high profile in Brazil. The state-controlled oil giant Petrobrás registers more patents than any other individual company in Brazil. Moreover, electricity-producing companies are directed by law to invest a given percentage of their revenue in R&D (Box 8.4).

The fact that energy is a key economic sector did not prevent the government from cutting back its spending on energy research from 2.1% to 1.1% of the total between 2000 and 2008 and again to 0.3% in 2012. Renewable energy sources have been the primary victim of these cuts, as public investment has increasingly turned towards deep-sea oil and gas exploration off Brazil's southeast coast. One area that has been directly affected by this is trend is the ethanol industry, which has had to close plants and cut back its own investment in R&D. Part of the ethanol industry's woes have resulted from Petrobrás' pricing policies. Under the influence of the government, its major stockholder, Petrobrás artificially depressed petrol prices between 2011 and 2014 to control inflation. This in turn depressed ethanol prices, making ethanol uneconomic to produce. This policy ended up eating into Petrobrás' own revenue, forcing it to cut back its investment in oil and gas exploration. As Petrobrás alone is responsible for about 10% of all fixed capital investment in Brazil, this trend, along with the corruption scandal currently shaking the company, will certainly have ramifications for Brazil's overall investment in R&D.

Brazil generates nearly three-quarters (73%) of its electricity from hydropower (Figure 8.8). This contribution was even as high as four-fifths in 2010 but the share of hydropower has been eroded by a combination of declining rainfall and ageing hydroelectric plants, many of which date back to the 1960s and 1970s.

Box 8.4: **Company investment in energy efficiency – a legal obligation in Brazil**

By law, Brazilian electricity companies must invest a share of their revenue in energy efficiency programmes and contribute to the National Science and Technology Development Fund (FNDCT).The law covers both public and private firms working in electricity generation, transmission and distribution. The FNDCT funds R&D conducted by universities, research institutes and industrial R&D centres.

The first such law was enacted in 2000 and the most recent one in in 2010.

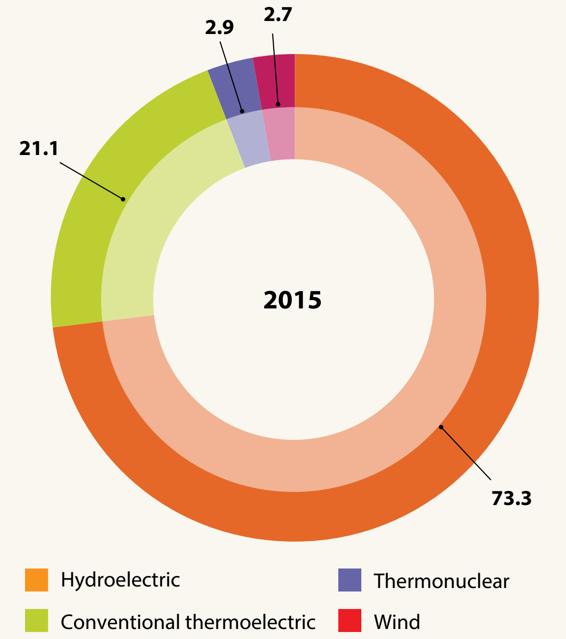
The law requires distribution companies to invest 0.20% of their net operating revenue (NOR) in R&D and 0.50% in energy efficiency programmes; a further 0.20% goes to FNDCT. For their part, generation and transmission companies must invest 0.40% of NOR in R&D and contribute 0.40% to FNDCT. The investment in energy efficiency programmes is considered business R&D expenditure, whereas the funds transferred to FNDCT are considered government funding. The law will remain in force until the end of 2015, when it is expected to be renewed or reviewed.

According to the National Agency of Electrical Energy, the energy efficiency programmes supported by this initiative helped to save 3.6 GWh between 2008 and 2014, a fairly modest amount. In 2014, R$ 342 million was spent on such projects, representing a drop of more than 50% before inflation from the R$ 712 million spent in 2011.

Source: authors
See also: www.aneel.gov.br

Intensive use of thermoelectric power plants operating on fossil fuels has compensated for much of the loss, since the share of new sources of renewable energy, such as solar and wind, in the energy mix remains small. Moreover, although Brazil has made great strides in the use of bioethanol in transportation, there has been little focus on research and innovation in energy generation, be it in terms of developing new sources of energy or improving energy efficiency. In light of the foregoing, there is little reason to expect public investment in energy R&D to rebound to the levels seen at the turn of the century that would rebuild Brazil's international competitiveness in this field.

Figure 8.8: **Electricity generation by type in Brazil, 2015**
Share of total electric power generation (%)



Source: National System Operator data: www.ons.org.br/home/

Technology transfer to private sector key to innovation

Despite the generally low level of innovation by Brazilian companies, there are exceptions like Embraer. Another example is Natura, a home-grown company dedicated to cosmetics (Box 8.5).

Technology transfer from public research institutions to the private sector is a major component of innovation in Brazil in fields ranging from medicine to ceramics and from agriculture to deep-sea oil drilling. Two key centres have been set up in recent years to foster the development of nanotechnology, the National Nanotechnology Laboratory for Agriculture (LNNA, est. 2008) and the Brazilian Nanotechnology National Laboratory (LNNano, est. 2011). This strategic investment, combined with federal and state funding of specific research projects in related fields, has led to considerable growth in the number of researchers working in materials science with the corollary of high-impact research and technology transfer. A report published by the Brazilian Materials Research Society (2014)[9] cites researcher Rubén Sinisterra from the Federal University of Minas Gerais, who has been developing drugs to alleviate hypertension. Sinisterra is confident that Brazilian universities now have the capacity to develop nanoscale materials for drug delivery but also observes that 'our domestic pharmaceutical companies don't have internal R&D capabilities, so we have to work with them to push new products and processes out to market'. According to Statnano, which crunches Thomson Reuters' data, the number of articles on nanoscience in Brazil rose from 5.5 to 9.2 per million inhabitants between 2009 and 2013 (see Figure 15.5). The average number of citations per article dropped, though, over the same period, from 11.7 to 2.6, according to the same source. In 2013, Brazilian output in nanoscience represented 1.6% of the world total, compared to 2.9% for scientific articles, in general.

9. See: http://iopp ublishing.org/newsDetails/brazil-shows-that-materials-matter

Box 8.5: **Innovation made in Brazil: the case of Natura**

Founded in 1986, Natura Cosméticos is Brazil's market leader for personal hygiene products, cosmetics and perfumes. Today a multinational corporation, it is present in many Latin American countries and in France, with net revenue of R$ 7 billion in 2013 (*circa* US$ 2.2 billion). Natura's stated mission is to create and commercialize products and services that promote well-being. It operates mainly through direct sales, with about 1.7 million mainly female consultants selling directly to their network of regular customers rather than through stores. Two-thirds of these consultants (1.2 million) are based in Brazil.

The company's philosophy is to turn socio-environmental issues into business opportunities through innovation and sustainability. In 2012, the Corporate Knights considered Natura the second-most sustainable company in the world (according to economic criteria) and the Forbes List ranked it the eighth-most innovative company in the world. As a result of its corporate behaviour, Natura became the largest enterprise in the world to obtain the B-Corp certification in 2014.

Natura employs a team of 260 people who are directly involved in innovation, over half of them with graduate degrees. It ploughs about 3% of its revenue back into R&D; in 2013, this represented an investment of R$ 180 million (*circa* US$ 56 million). As a result, two-thirds (63.4%) of revenue from sales in 2013 involved innovative products released in the previous two years. Overall growth has been very intense, the size of Natura having quadrupled in the past ten years.

Brazilian biodiversity is a key ingredient in Natura's innovation process, which uses plant extracts in new products. The incorporation of active biological principles derived from Brazilian flora requires interaction with Amazonian communities and partnerships with research institutes like the Brazilian Agricultural Research Company (Embrapa). One example is the Chronos line, which uses active principles from *Passiflora alata* (passion fruit), developed in partnership with the Federal University of Santa Catarina using federal funds (FINEP); the Chronos line has generated new patents and collaborative research.

Natura has also developed research centres in Cajamar (São Paulo), within the Ecoparque Natura in Benevides Pará. Its Manaus Innovation Centre in the capital city of the State of the Amazon establishes partnerships with the region's institutions and companies to turn locally developed knowledge and technology into new products and processes; this has incited other businesses to invest in the region.

Natura also participates in innovation hubs abroad like the Global Hub of Innovation in New York. It has also developed international partnerships with the Massachusetts Institute of Technology's Media Lab (USA), the Massachusetts General Hospital (USA) and Lyon University in France, among others.

Today, Natura interacts with over 300 organizations – companies, scientific institutions, funding agencies, specialists, NGOs and regulatory agencies – in implementing more than 350 projects related to innovation. In 2013, these partnerships accounted for more than 60% of all the projects undertaken by Natura. One highlight has been the inauguration of the Applied Research Centre in Wellbeing and Human Behaviour in 2015, in partnership with the São Paulo Research Foundation (FAPESP). The new centre includes research facilities based at the state's public universities.

Source: compiled by authors

Patents have grown at a slower pace than publications

Scientific publications by Brazil have more than doubled since 2005, primarily as a result of the jump in the number of Brazilian journals being tracked by the Thomson Reuters database between 2006 and 2008. Despite this artificial boost, the pace of growth has slowed since 2011 (Figure 8.9). Moreover, in terms of publications per capita, the country trails both the more dynamic emerging market economies and advanced economies, even if it is ahead of most of its neighbours (see Figure 7.8). In fact, when it comes to impact, Brazil has lost a lot of ground in the past decade. One possible cause may be the speed with which enrolment in higher education has expanded since the mid-1990s, especially as concerns students passing through the federal system of universities, some of which have resorted to hiring inexperienced faculty, including candidates without doctorates.

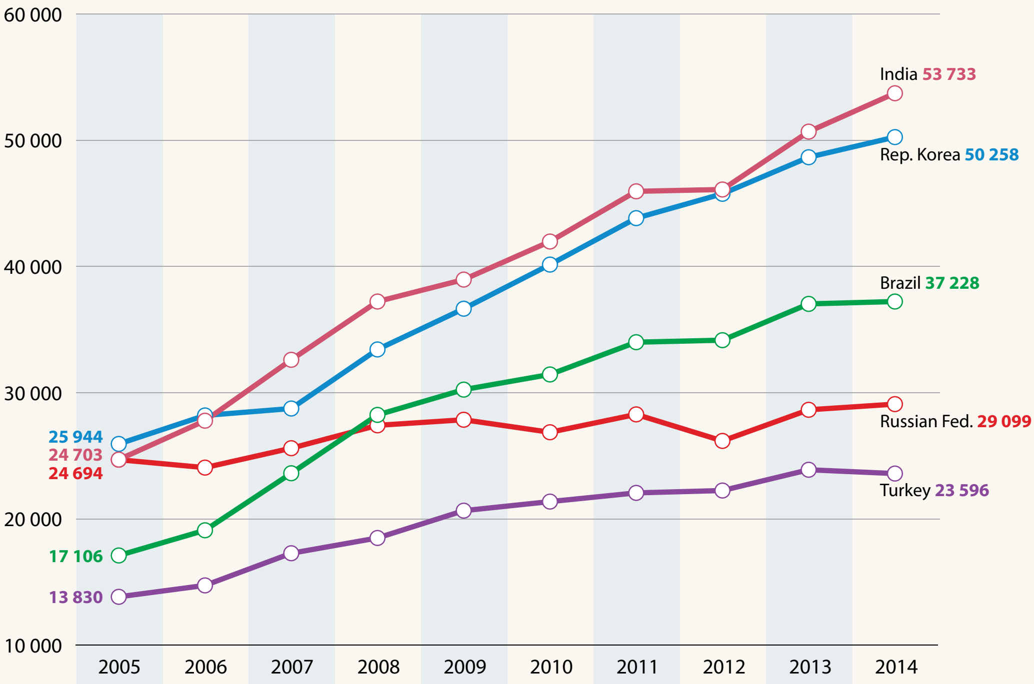
Patent applications to the Brazilian Patent Office (INPI) increased from 20 639 in 2000 to 33 395 in 2012, progressing by 62%. This rate pales in comparison with that of scientific publications over the same period (308%). Moreover, if one considers only patent applications by residents, the growth rate over this period was even lower (21%).

International comparisons using the number of patents granted by the US Patent and Trademarks Office (USPTO) provide an indirect measure of the extent to which an economy may be seeking international competitiveness on the basis of technology-driven innovation. Although Brazil has registered strong growth in this field, it trails its biggest competitors for the intensity of patenting relative to its size (Table 8.1). Compared to other emerging economies, Brazil also seems to be relatively less focused on international patenting than on publications (Figure 8.10).

Figure 8.9: **Scientific publication trends in Brazil, 2005–2014**

Growth in Brazilian publications has slowed slightly since 2008

Other countries are given for comparison



147

Publications per million inhabitants in 2008

184

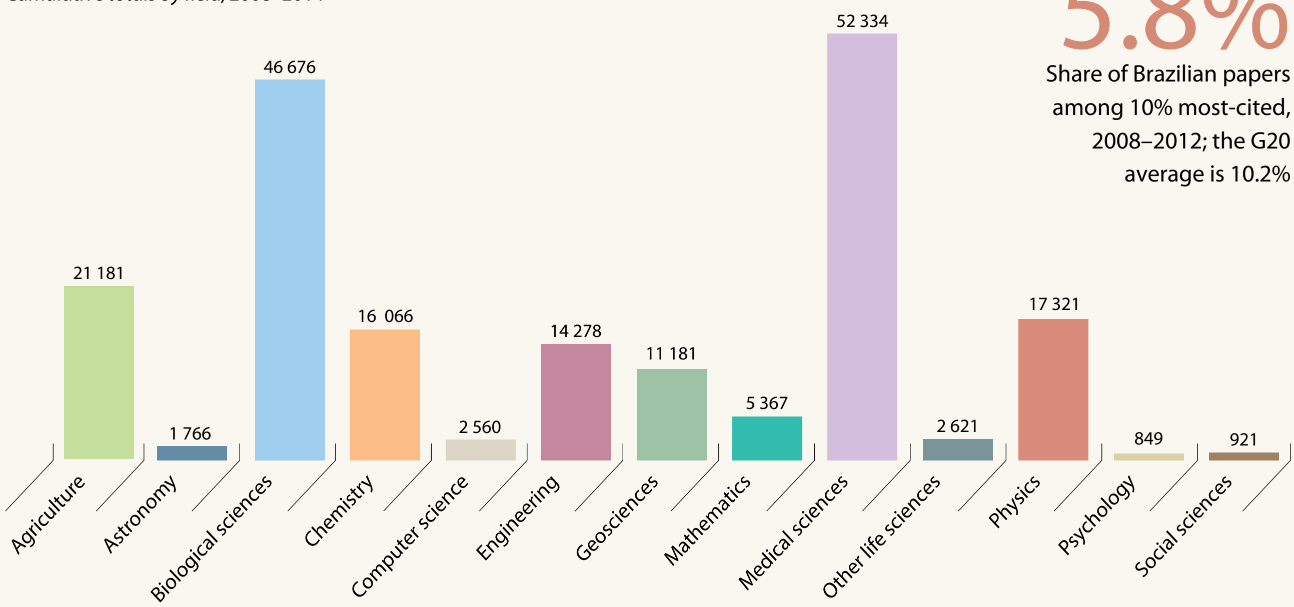
Publications per million inhabitants in 2014

0.74

Average citation rate for Brazilian publications, 2008–2012; the G20 average is 1.02

Life sciences dominate Brazilian publications

Cumulative totals by field, 2008–2014



5.8%

Share of Brazilian papers among 10% most-cited, 2008–2012; the G20 average is 10.2%

Note: Unclassified articles (7 190) are excluded from the totals.

The USA is Brazil's closest partner

Main foreign partners, 2008–2014

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Brazil	USA (24 964)	France (8 938)	UK (8 784)	Germany (8 054)	Spain (7 268)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

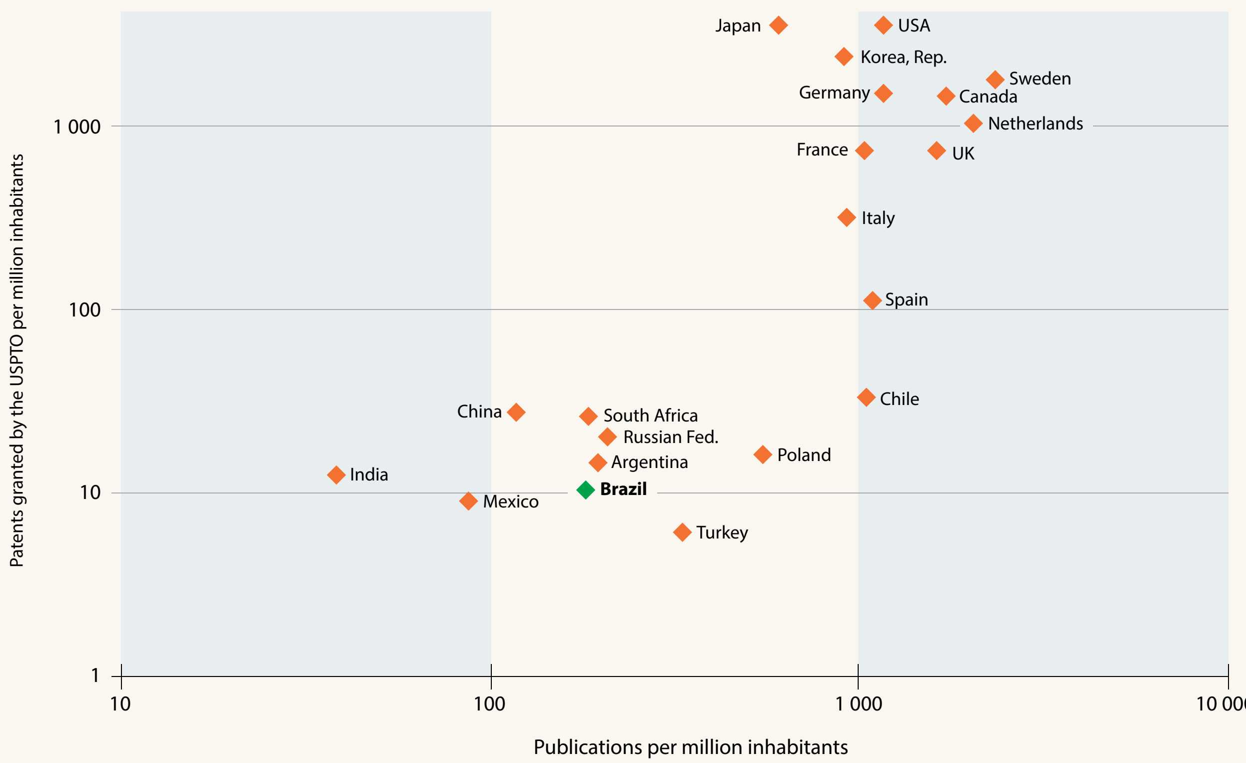
Chapter 8

Table 8.1: **Invention patents granted to Brazilians by USPTO, 2004–2008 and 2009–2013**

	No. of patents, 2004–2008	No. of patents, 2009–2013	Cumulative growth (%)	Per 10 million inhabitants, 2009–2013
Global average	**164 835**	**228 492**	**38.6**	**328**
Japan	34 048	45 810	34.5	3 592
USA	86 360	110 683	28.2	3 553
Korea, Rep.	3 802	12 095	218.1	2 433
Sweden	1 561	1 702	9.0	1 802
Germany	11 000	12 523	13.8	1 535
Canada	3 451	5 169	49.8	1 499
Netherlands	1 312	1 760	34.1	1 055
UK	3 701	4 556	23.1	725
France	3 829	4 718	23.2	722
Italy	1 696	1 930	13.8	319
Spain	283	511	80.4	111
Chile	13	34	160.0	33
China	261	3 610	1 285.3	27
South Africa	111	127	14.2	25
Russian Fed.	198	303	53.1	21
Poland	15	60	313.7	16
Argentina	54	55	3.4	14
India	253	1 425	464.2	12
Brazil	**108**	**189**	**74.6**	**10**
Mexico	84	106	25.1	9
Turkey	14	42	200.0	6

Source: USPTO

Figure 8.10: **Relative intensity of publications versus patenting in Brazil, 2009–2013**
Other countries are given for comparison. Logarithmic axes



Source: for patents: USPTO; for publications: Thomson Reuters; for population: World Bank's World Development Indicators

REGIONAL TRENDS

STI still dominated by the State of São Paulo

Brazil is a country of continental dimensions, with highly diverse levels of development across its 27 states. The southern and southeastern regions show a much higher level of industrialization and scientific development than the northern ones, some of which encroach on the Amazonian forest and river basin. The centre-west is Brazil's agricultural and cattle-raising powerhouse and has been developing rapidly recently.

The starkest example of this contrast is the southeastern State of São Paulo. Home to 22% (44 million) of the country's 202 million inhabitants, it generates about 32% of GDP and a similar share of the nation's industrial output. It also has a very strong state system of public research universities that is lacking in most other states and hosts the well-established São Paulo Research Foundation (Box 8.6). The State of São Paulo is responsible for 46% of GERD (public and private expenditure) and 66% of business R&D.

All indicators paint the same picture. Some 41% of Brazilian PhDs were granted by universities in the State of São Paulo in 2012 and 44% of all papers with Brazilian authors have at least one author from an institution based in São Paulo. São Paulo's scientific productivity (390 papers per million inhabitants over 2009–2013) is twice the national average (184), a differential which has been widening in recent years. The relative impact of publications by scientists from the State of São Paulo has also been systematically higher than for Brazil as a whole over the past decade (Figure 8.11).

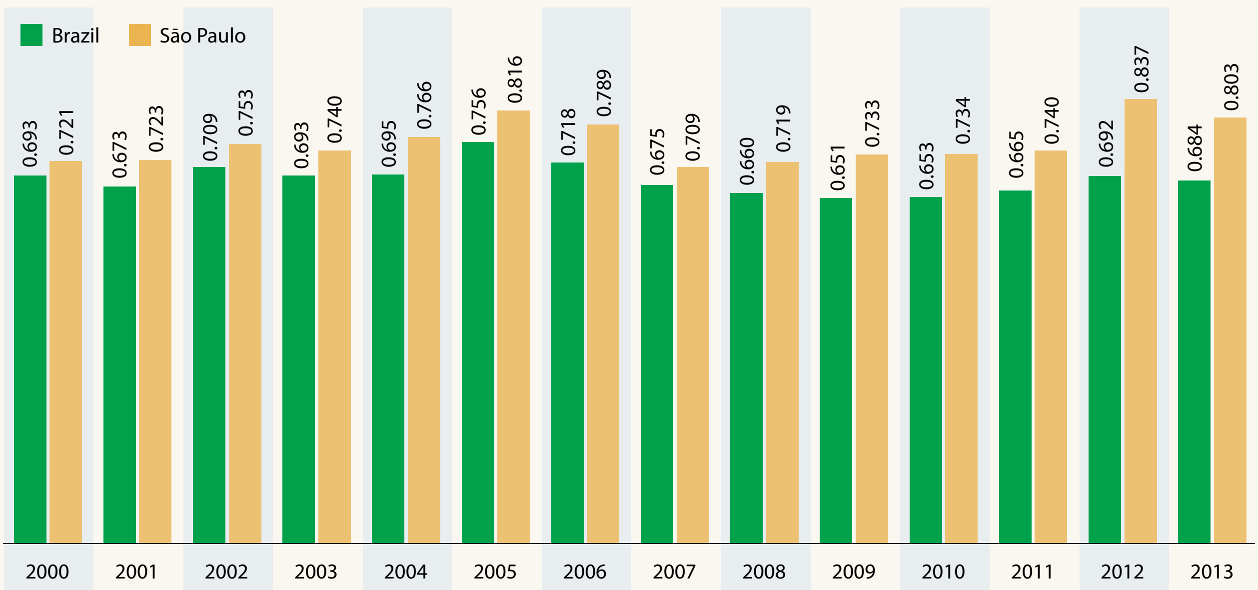
Two key factors explain São Paulo's success in scientific output: firstly, a well-funded system of state universities, including the University of São Paulo, University of Campinas (Unicamp) and the State University of São Paulo (Figure 8.12), all of which have been included in international university rankings;[10] secondly, the role played by the São Paulo Research Foundation (FAPESP, Box 8.6). Both the university system and FAPESP are allocated a fixed share of the state's sales tax revenue as their annual budgets and have full autonomy as to the use they make of this revenue.

Between 2006 and 2014, the share of Brazilian researchers hosted by southeastern institutions dropped steadily from 50% to 44%. Over the same period, the share of northeastern states rose from 16% to 20%. It is still too early to see the effect of these changes on scientific output, or in the number of PhD degrees being awarded but these indicators should logically also progress.

Despite these positive trends, regional inequalities persist in terms of R&D expenditure, the number of research institutions and scientific productivity. Extending the scope of research projects to other states and beyond Brazil would certainly help scientists from these regions catch up to their southern neighbours.

10. In the Times Higher Education 2015 ranking of universities in BRICS and other emerging economies, the University of São Paulo came 10th, Unicamp 27th and the Universidade Estadual Paulista (Unesp) 97th. Among the top 100, only one other Brazilian university features, the Federal University of Rio de Janeiro (UFRJ, 67th). In the 2015 QS Latin America ranking, the University of São Paulo comes first, Unicamp second, UFRJ fifth and Unesp eighth.

Figure 8.11: **Relative impact of scientific publications from São Paulo and Brazil, 2000–2013**

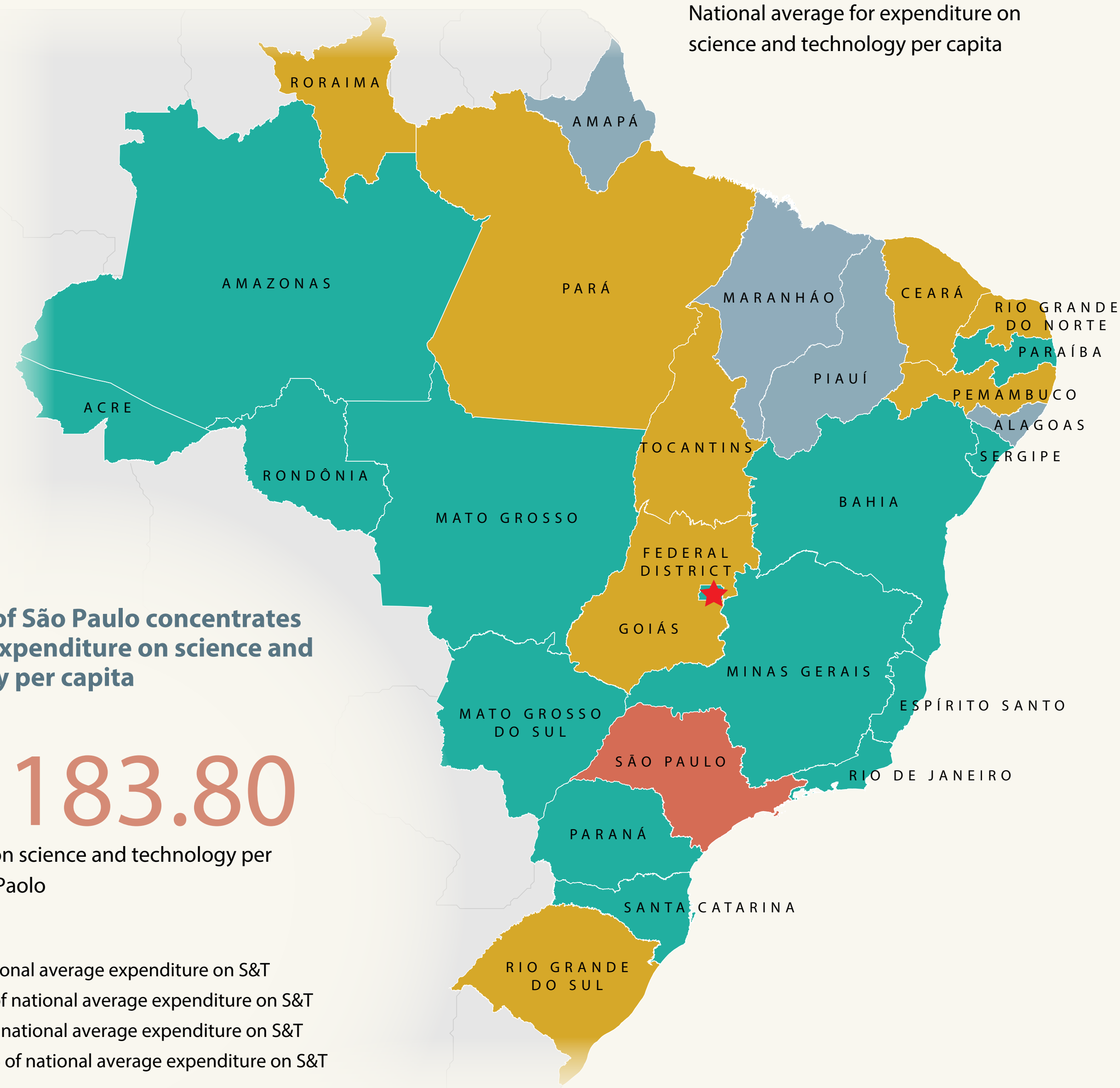


Source: InCites/Thomson Reuters, October 2014

Figure 8.12: **Relative shares of Brazilian states for investment in science and technology**

R$ 69.50

National average for expenditure on science and technology per capita



The State of São Paulo concentrates the most expenditure on science and technology per capita

R$ 183.80

Expenditure on science and technology per capita in São Paolo

- Above national average expenditure on S&T
- 50–100% of national average expenditure on S&T
- 25–50% of national average expenditure on S&T
- Below 25% of national average expenditure on S&T

Ten of Brazil's research universities are found in Rio de Janeiro and São Paulo

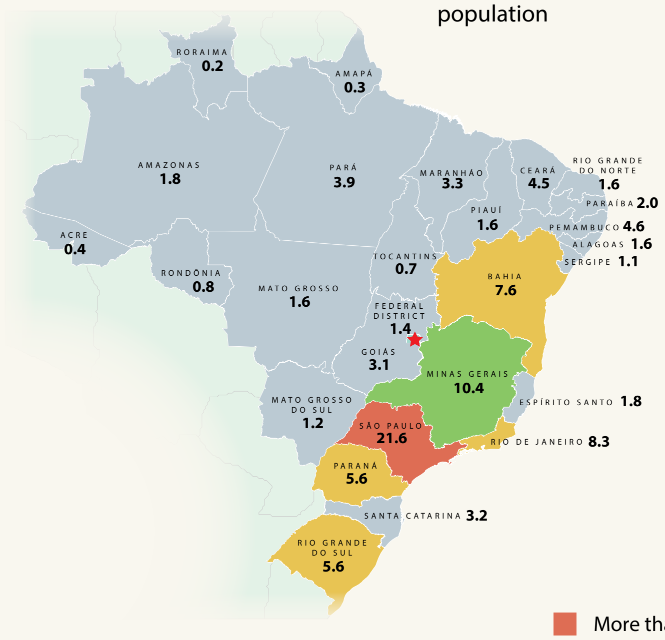
Research universities in Brazil

Region/ Federative unit	Research universities	Region/ Federative unit	Research universities
Ceará	Federal University of Ceará	**São Paulo**	University of São Paulo
Pernambuco	Federal University of Pernambuco		University of Campinas (Unicamp)
Minas Gerais	Federal University of Minas Gerais		State University of São Paulo
Rio de Janeiro	Federal University of Rio de Janeiro		Federal University of São Paulo
	Oswaldo Cruz Foundation		Federal University of São Carlos
	Pontifical Catholic University	**Rio Grande do Sul**	Federal University of Rio Grande do Sul
	University of Rio de Janeiro		Pontifical University of Rio Grande do Sul
	State University of Rio de Janeiro	**Santa Catarina**	Federal University of Santa Catarina
Paraná	Federal University of Paraná	**Distrito Federal**	University of Brasília

Six states account for 59% of the population

22%

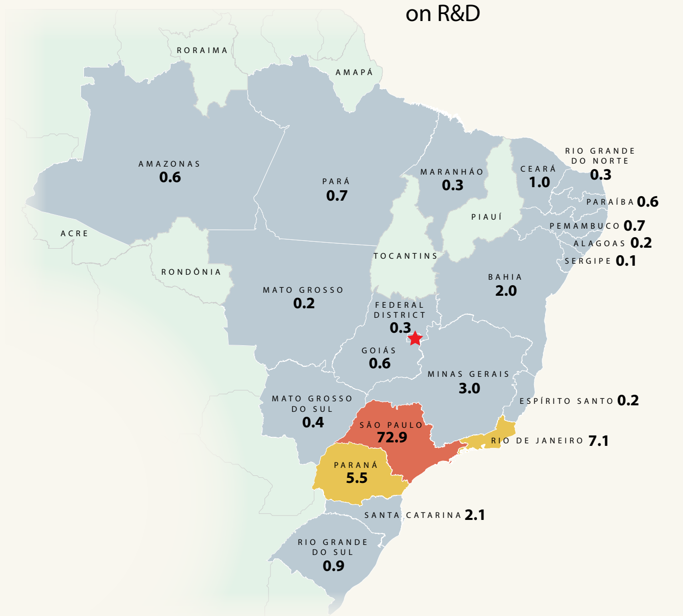
State of São Paulo's share of Brazilian population



The State of São Paulo concentrates three-quarters of public expenditure on R&D

73%

State of São Paulo's share of public expenditure on R&D

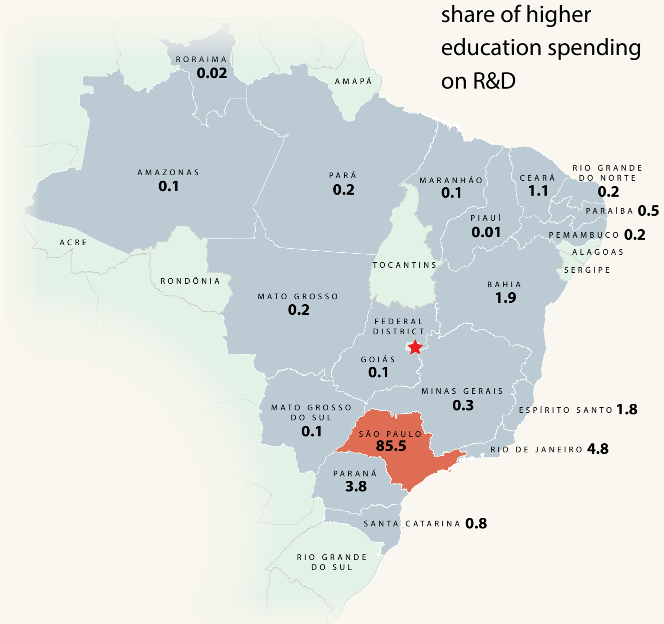


- More than 15% of total
- 10–14.9% of total
- 5–9.9% of total
- Less than 5% of total
- Data unavailable
- Number of research universities

São Paulo dominates higher education spending on R&D

86%

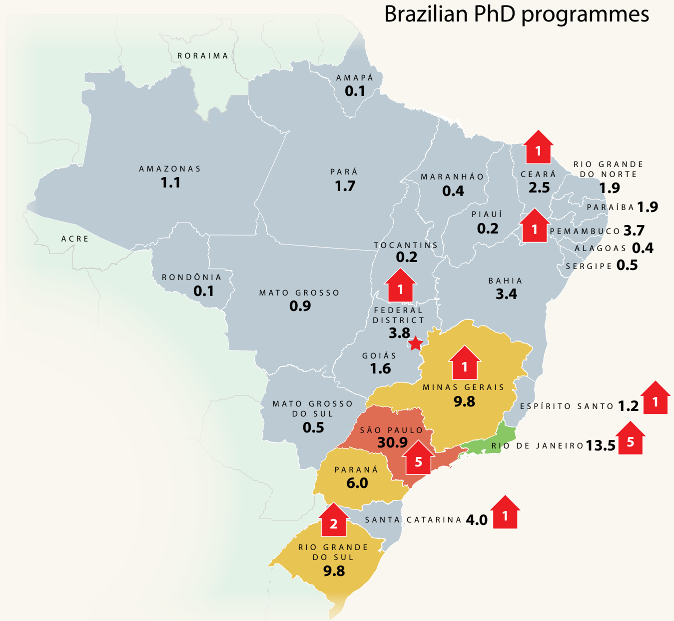
State of São Paulo's share of higher education spending on R&D



Five states concentrate more than half of Brazilian PhD programmes

31%

State of São Paulo's share of Brazilian PhD programmes



Source: Instituto Brasileiro de Geografia e Estatística (IBGE)

Box 8.6: The São Paulo Research Foundation: a sustainable funding model

The São Paulo Research Foundation (FAPESP) is the State of São Paulo's public research foundation. It receives sustainable funding in the form of an annual 1% share of state sales taxes, under a provision inscribed in the State Constitution. The Constitution also stipulates that only 5% of the Foundation's budget may be used for administrative purposes, thereby limiting misuse. The foundation thus enjoys stable funding and operational autonomy.

FAPESP operates through a peer-review system with the help of panels composed of active researchers and arranged by research theme. Besides funding research across the full spectrum of science, FAPESP supports four large research programmes covering biodiversity, bio-energy, global climate change and neurosciences.

In 2013, FAPESP's expenditure amounted to R$ 1.085 billion (*circa* US$ 330 million). The foundation maintains co-operation agreements with national and international research funding agencies, universities, research institutes and business enterprises. International partners include the Centre nationale de recherche scientifique in France, the Deutsche Forschungsgemeinschaft in Germany and the National Science Foundation in the USA.

FAPESP also offers a wide range of programmes to support foreign scientists wishing to work in São Paulo. These include postdoctoral fellowships, young investigator awards and visiting researcher grants.

Source: compiled by authors

CONCLUSION

Industry must embrace innovation to remain internationally competititve

In recent decades, Brazil has basked in the global recognition of its achievement in reducing poverty and inequality by means of active social policies. Since economic growth began to falter in 2011, however, progress towards social inclusion has also slowed. With much of the active population holding down a job these days (unemployment was down to 5.9% by 2013), the only way to kickstart economic growth once more will be to raise productivity. That will take two essential ingredients: STI and a well-educated labour force.

The volume of Brazilian publications has grown considerably in recent years. A number of individual researchers have also been recognized for the quality of their work, as in the case of Ártur Avila, who became the first-ever Latin American mathematician to receive the prestigious Fields Medal in 2014.

Nevertheless, there has been a general lack of progress in the overall impact of Brazilian science. Citations of Brazilian publications still fall well beneath the G20 average; to some extent, this may be due to the fact that many Brazilian articles are still published in Portuguese in Brazilian journals of limited circulation, thereby passing under the international radar. If so, this lack of visibility is a temporary price to pay for the surge in access to higher education in recent years. However, the fact remains that other emerging economies such as India, the Republic of Korea or Turkey have performed much better than Brazil in the past five years or so. Raising the quality and visibility of Brazilian science will require a concerted effort to expand and intensify international collaboration.

Education has become a central topic of national political debate. The new Minister of Education is promising to overhaul the secondary education system, which has been one of the main bottlenecks to improving the education level of the labour force, as the PISA results so eloquently illustrated. The new National Law of Education proposes some very ambitious goals to 2024, including those of broadening access to higher education further and raising the quality of basic education.

Another bottleneck is to be found in the low number of patents granted by USPTO to Brazilian applicants. This trend shows that Brazilian businesses are not yet internationally competitive when it comes to innovation. Private expenditure on R&D remains relatively low, in comparison with other emerging economies. More worryingly, there has been almost no progress in this area since the modest growth registered during the commodities boom between 2004 and 2010. Investment, in general, is declining, as is the share of industrial output in GDP and Brazil's participation in foreign trade, especially as regards exports of manufactured goods. These are all indicators of an innovative economy and they are all in the red.

The new Minister of Finance seems to be aware of the many bottlenecks and distortions that have undermined the economy in recent years, including misguided protectionism and favouritism in relation to some large economic groups.[11] He has proposed a series of measures to regain fiscal control as a means of preparing the terrain for a new growth cycle. Notwithstanding this, Brazilian industry is in such a dire state that the country's entire approach to industrial and trade policies needs to be overhauled. The national industrial sector must be exposed to international competition and encouraged to consider technological innovation as an essential part of its mission.

11. The investigation into the recent scandal involving the giant oil company, Petrobrás, has shed light on the large amount of subsidized funds received by some construction companies via the National Bank of Economic and Social Development (BNDES) for some international projects implemented with little oversight from Brazilian regulatory agencies.

KEY TARGETS FOR BRAZIL

- Brazilian 15-year-olds to attain a mathematics score of 473 by 2024 in the OECD's Programme for International Student Assessment (PISA);
- Raise the level of fixed capital investment from 19.5% in 2010 to 22.4% of GDP by 2014;
- Raise business expenditure on R&D from 0.57% in 2010 to 0.90% of GDP by 2014;
- Augment the share of the labour force having completed secondary education from 54% to 65%;
- Raise the share of knowledge-intensive businesses from 30.1% to 31.5% of the total by 2014;
- Increase the number of innovative SMEs from 37 000 to 58 000 by 2014;
- Diversify exports and increase the country's share in world trade from 1.36% to 1.60% by 2014; and
- Expand access to fixed broadband internet from 14 million to 40 million households by 2014.

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ACKNOWLEDGMENTS

The authors wish to thank Joana Santa-Cruz from the team in charge of STI indicators at the São Paulo Research Foundation (FAPESP) for her help in collecting and organizing the data used in the present chapter.

The European Union has adopted an energetic programme to 2020 to conjugate the crisis and foster smart, inclusive and sustainable growth, Europe 2020.

Hugo Hollanders and **Minna Kanerva**

In 2004, Professors André Geim and Kostya Novoselov from the University of Manchester in the UK isolated graphene, a material with potentially endless applications. Ultra-light, it is 200 times stronger than steel, yet extremely flexible. It can retain heat, yet is fire-resistant. It can also act as an impenetrable barrier, as not even helium can pass through it. This discovery earned Professors Geim and Novoselov the Nobel Prize in Physics in 2010.
Photo: © Bonninstudio/Shutterstock.com

9 · European Union

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Spain, Slovakia, Slovenia, Sweden, UK

Hugo Hollanders and Minna Kanerva

INTRODUCTION

A region in a protracted crisis

With the accession of Croatia in 2013, the European Union's membership swelled to 28 countries, representing a combined population of 507.2 million, or 7.1% of the global population (Table 9.1). The European Union (EU) is expected to expand further: Albania Montenegro, Serbia, the Former Yugoslav Republic of Macedonia and Turkey are all candidate countries that are in the process of integrating EU legislation into their national legal systems, whereas Bosnia and Herzegovina and Kosovo[1] have the status of potential candidates. Between 2004 and 2013, GDP increased by almost 47% in the 10 countries that had joined[2] the EU in 2004, compared to close to 20% for the 'older' EU15 countries.

1. Reference to Kosovo should be understood to be in the context of United Nations Security Council resolution 1244 (1999).

2. The EU was founded in 1957 by six countries: Belgium, France, Germany, Italy, Luxembourg and the Netherlands. Denmark, Ireland and the UK joined in 1973, Greece, Portugal and Spain in 1981 and Austria, Finland and Sweden in 1995. These 15 countries are known as the EU15. In 2004, ten more countries swelled the EU's ranks: Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia. They were followed by Bulgaria and Romania in 2007 and by Croatia in 2013.

Table 9.1: **Population, GDP and unemployment rates in the EU, 2013**

	Population 2013 (million)	5-year GDP growth rate (PPP €, %)	GDP per capita 2013 (PPP €)	Unemployment rate 2013 (%)	5-year change in unemployment rate (%)	Unemployment rate, persons below 25 years 2013 (%)	5-year change in Unemployment rate – persons below 25 years (%)
EU28	507.2	4.2	26 600	10.8	3.8	23.6	7.8
Austria	8.5	8.3	34 300	4.9	1.1	9.2	1.2
Belgium	11.2	10.4	31 400	8.4	1.4	23.7	5.7
Bulgaria	7.3	4.9	12 300	13.0	7.4	28.4	16.5
Croatia	4.3	-5.2	15 800	17.3	8.7	50.0	26.3
Cyprus	0.9	-1.5	24 300	15.9	12.2	38.9	29.9
Czech Rep.	10.5	3.4	21 600	7.0	2.6	18.9	9.0
Denmark	5.6	4.9	32 800	7.0	3.6	13.0	5.0
Estonia	1.3	7.9	19 200	8.6	3.1	18.7	6.7
Finland	5.4	-1.3	30 000	8.2	1.8	19.9	3.4
France	65.6	6.4	28 600	10.3	2.9	24.8	5.8
Germany	82.0	9.5	32 800	5.2	-2.2	7.8	-2.6
Greece	11.1	-21.0	19 300	27.5	19.7	58.3	36.4
Hungary	9.9	7.4	17 600	10.2	2.4	26.6	7.1
Ireland	4.6	3.9	34 700	13.1	6.7	26.8	13.5
Italy	59.7	-1.0	26 800	12.2	5.5	40.0	18.7
Latvia	2.0	2.4	17 100	11.9	4.2	23.2	9.6
Lithuania	3.0	9.8	19 200	11.8	6.0	21.9	8.6
Luxembourg	0.5	14.1	68 700	5.9	1.0	16.9	-0.4
Malta	0.4	16.3	23 600	6.4	0.4	13.0	1.3
Netherlands	16.8	-0.8	34 800	6.7	3.6	11.0	4.7
Poland	38.5	27.4	17 800	10.3	3.2	27.3	10.1
Portugal	10.5	-2.3	20 000	16.4	7.7	38.1	16.6
Romania	20.0	10.4	14 100	7.1	1.5	23.7	6.1
Slovakia	5.4	8.5	20 000	14.2	4.6	33.7	14.4
Slovenia	2.1	-3.9	21 800	10.1	5.7	21.6	11.2
Spain	46.7	-4.7	24 700	26.1	14.8	55.5	31.0
Sweden	9.6	7.9	34 000	8.0	1.8	23.6	3.4
UK	63.9	1.6	29 000	7.6	2.0	20.7	5.7

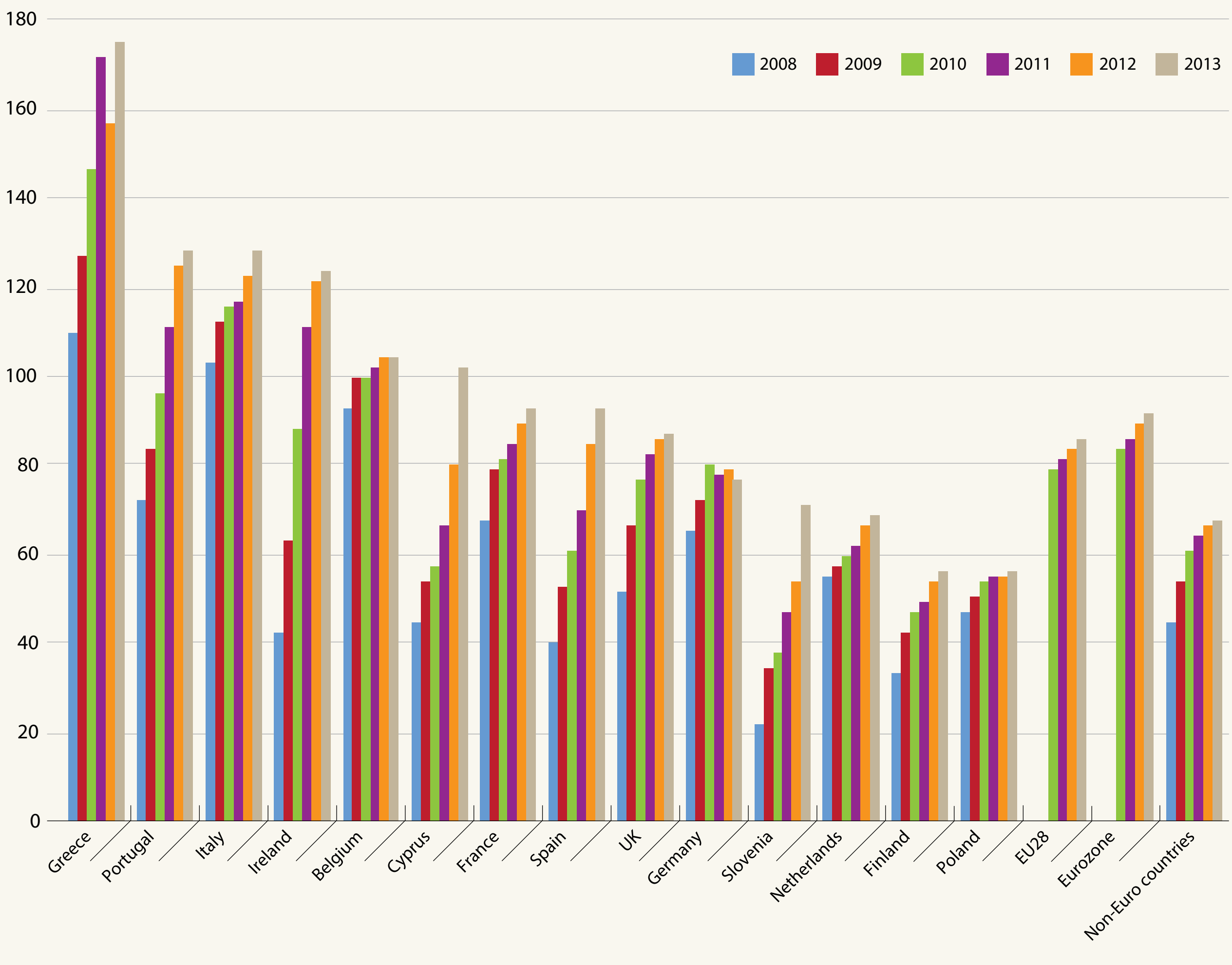
Source: Eurostat

The first signs of the economic stagnation that has plagued the EU since 2008 were already visible in the *UNESCO Science Report 2010*. Over the cumulative five-year period to 2013, real growth in the EU only amounted to 4.2%. Real GDP even declined over this period in Croatia, Cyprus, Finland, Italy, the Netherlands, Portugal, Slovenia and Spain, albeit to a modest extent, and much more severely in Greece. Belgium, Luxembourg, Malta, Poland and Romania, on the other hand, enjoyed real growth of 10% or more. In 2013, average GDP per capita amounted to € 26 600 for the EU28 as a whole but this figure masked wide differences: per capita GDP was lowest in the three newest member states, Bulgaria, Croatia and Romania, at less than € 16 000, close to € 35 000 in Austria, Ireland, the Netherlands and Sweden and as high as € 68 700 in Luxembourg.

The rising average unemployment rate in the EU is cause for concern but even more unsettling are the large differences among member states. In 2013, 11% of the European active population was unemployed, on average, an increase of nearly four percentage points over 2008. The youth unemployment rate was even higher, at almost 24% in 2013, having risen nearly eight percentage points since 2008. Worst hit were Greece and Spain, where more than one in four were job-seekers. In Austria, Germany and Luxembourg, on the other hand, the unemployment rate was lower than 6%. Germany also stands out for being the only country where the situation improved over the five-year period: from 7.4% in 2008 to 5.2% in 2013. A similar pattern can be observed for youth unemployment, with rates of 50% or more in Croatia, Greece and Spain. This compares with less than 10% in Austria and Germany. Germany and Luxembourg are the only two countries where the situation has improved since 2008.

In many member states, public debt soared between 2008 and 2013 (Figure 9.1). Hardest hit were Cyprus, Greece, Ireland and Portugal. Public debt progressed least in Bulgaria,

Figure 9.1: **Government debt to GDP ratio for selected EU countries, 2008–2013 (%)**



Source: Eurostat, April 2015; aggregate debt-to-GDP ratios for non-Eurozone countries based on authors' calculations

Hungary, Luxembourg, Poland and Sweden, all countries (with the notable exception of Luxembourg) which had not adopted the euro as their national currency. In most cases, the increase in public debt resulted from governments bailing out[3] banks. Many governments have implemented austerity programmes to reduce their budget deficits but these cuts have actually pushed up levels of public debt relative to GDP, delaying the return to growth. As a result, most member states have experienced one or more periods of recession since 2008, defined as two or more consecutive quarters where GDP declined in comparison to the previous period. Between 2008 and 2014, Greece, Croatia, Cyprus, Italy, Portugal and Spain were all in recession for more than 40 months. The only countries to have escaped recession altogether are Bulgaria, Poland and Slovakia (Figure 9.2).

3. Spain managed to leave the bailout mechanism in 2014.

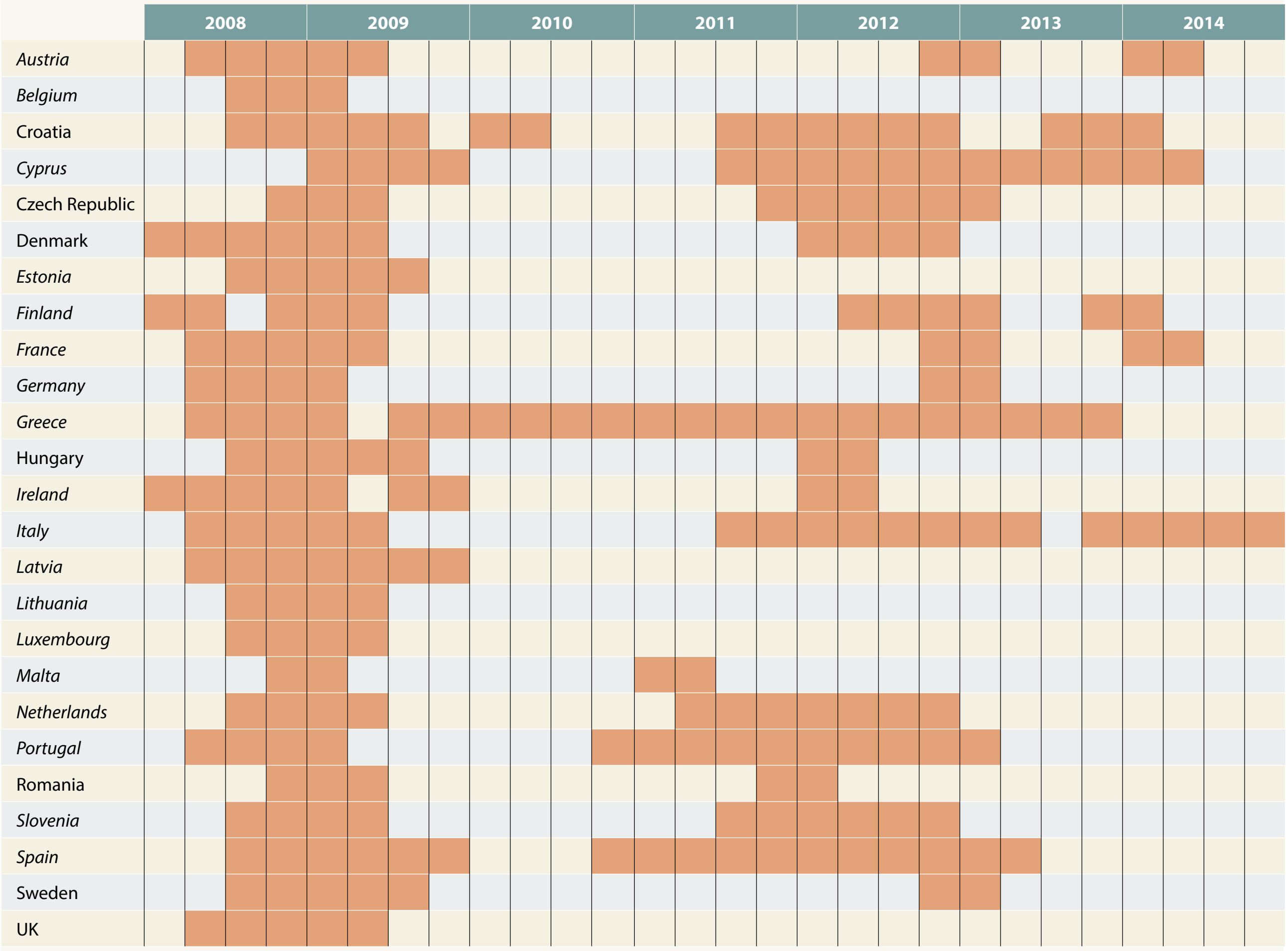
A serious debt crisis in the Eurozone

Nineteen member states[4] have adopted the euro as their common currency. In 2013, the countries of the Eurozone accounted for two-thirds of the EU28 population and for more than 73.5% of its GDP. Average GDP per capita was higher in the Eurozone than for the EU28 as a whole. Debt to GDP ratios in the Eurozone are, however, significantly higher than those of non-euro countries, even though these ratios have risen at about the same rate. The notable exceptions are Cyprus, Greece, Portugal, Ireland and Spain, where the debt to GDP ratio has soared.

Greece has been particularly hard hit by the economic crisis. Between 2008 and 2013, it was in recession for 66 out of

4. The euro replaced national currencies on 1 January 2002 in Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain. The euro was later adopted also by Slovenia (2007), Cyprus and Malta (2008), Slovakia (2009), Estonia (2011), Latvia (2014) and Lithuania (2015).

Figure 9.2: **Recession periods in the European Union, 2008–2014**



Note: For Croatia, data are only available up to the first quarter of 2014. Bulgaria, Poland and Slovakia do not figure here, as they did not experience any recession period. Slovakia is a member of the Eurozone. All other 18 members of the Eurozone are shown in italics.

Source: OECD and Eurostat

72 months. Whereas the economy of most member states had recovered to at least 95% of its size in 2008 by 2013, Greece managed less than 80%. Unemployment in Greece has increased from 7.8% in 2008 to 27.5% in 2013 and the debt to GDP ratio from 109 to 175. Financial markets' worries as to whether Greece will be able to repay its debt to the European Central Bank and the International Monetary Fund have had a negative impact on the exchange rate of the euro and on the interest rates of not only Greece but also other Eurozone countries such as Italy, Portugal and Spain. Despite a third bailout being negotiated in July 2015, there remains a real risk of a Greek exit (Grexit) from the Eurozone.

IN SEARCH OF A GROWTH STRATEGY THAT WORKS

Europe 2020: a strategy for smart growth

Under José Manuel Barroso, the European Commission's[5] president from November 2004 to October 2014, the EU adopted a ten-year strategy in June 2010 to help the EU emerge from the financial and economic crisis in a stronger position by embracing smart, sustainable and inclusive growth (European Commission, 2010). Dubbed *Europe 2020*, the strategy[6] observed that 'the crisis has wiped out years of economic and social progress and exposed structural weaknesses in Europe's economy' that have created a productivity gap. These structural weaknesses include low levels of investment in research and development (R&D), differences in business structures, market barriers and insufficient use of information and communication technologies (ICTs). The strategy deals with short-term challenges linked to the economic crisis and introduces structural reforms needed to modernize the European economy, at a time when the region is confronted with ageing societies. Five main targets are to be met by the EU as a whole by 2020 in the areas of employment, innovation, climate and energy, education and social inclusion namely:

- At least 75% of people between 20 and 64 years of age should be employed;
- On average, 3% of GDP should be invested in R&D;
- Greenhouse gas emissions should be reduced by at least 20% compared to emission levels in 1990[7], 20% of energy should come from renewables and there should be a 20% increase in energy efficiency (known as the 20:20:20 target);
- School dropout rates should be reduced to below 10% and at least 40% of people between 30 and 34 years of age should have completed tertiary education;
- The number of persons at risk of poverty or social exclusion should be reduced by at least 20 million.

The EU has launched seven flagship initiatives to support the *Europe 2020* objectives of fostering smart, sustainable and inclusive growth:

Smart growth

- *The Digital Agenda for Europe* sets out 'to exploit the potential of ICTs better by promoting a digital single market;'
- *The Innovation Union* sets out to create an innovation-friendly environment that makes it easier to transform great ideas into products and services that will generate growth and jobs; and
- *Youth on the Move* sets out to improve young people's education and employability, to reduce high youth unemployment by making education and training more relevant to young people's needs, by encouraging more young people to take advantage of EU grants to study or train in another country and by encouraging member states to simplify the transition from education to work.

Sustainable growth

- *A Resource-efficient Europe* provides a long-term framework supporting policy agendas for climate change, energy, transport, industry, raw materials, agriculture, fisheries, biodiversity and regional development to promote a shift towards a resource-efficient, low-carbon economy to achieve sustainable growth;
- *An Industrial Policy for Globalisation* aims to boost growth and jobs by maintaining and supporting a strong, diversified and competitive industrial base that offers well-paid jobs while becoming more resource-efficient.

Inclusive growth

- *An Agenda for New Skills and Jobs* aims to reach the employment target for 2020 of 75% of the working-age population by stepping up reforms that improve flexibility and security in the labour market by equipping people with the right skills for the jobs of today and tomorrow, improving the quality of jobs, ensuring better working conditions and by improving the conditions for job creation;
- *The European Platform against Poverty* is designed to help reach the target of lifting 20 million people out of poverty and social exclusion by 2020.

5. Headquartered in Brussels (Belgium), the European Commission is the EU's executive body. Its main roles are to propose legislation; enforce European law; set objectives and priorities for action; manage and implement EU policies and the budget; and to represent the EU beyond Europe. A new team of 28 commissioners is appointed every five years, one from each member state.

6. *Europe 2020* has inspired the Western Balkans' own strategy to 2020. See Chapter 10.

7. The target for 2020 would be 30%, if conditions at the global level were right. However, the EU recently adopted an even more ambitious target, a 40% reduction in its emissions by 2030, see: http://ec.europa.eu/clima/policies/2030/index_en.htm.

Juncker's ambitious investment plan

Shortly after succeeding the Barroso Commission in October 2014, the Juncker Commission – in reference to Jean-Claude Juncker, the Commission's new president – proposed a three-pronged strategy for inversing the decline in investment to GDP ratios since 2008 even among member states not fighting banking and debt crises. The *Juncker Plan for Investment in Europe* involves:

- setting up a European Fund for Strategic Investment to support enterprises with fewer than 3 000 employees;
- establishing a European investment project pipeline and European Investment Advisory Hub at EU level to provide investment projects with technical assistance; and
- structural reforms to improve the framework conditions affecting the business environment.

The European Fund for Strategic Investment was approved by the European Commission on 22 July 2015.[8] It has attracted mixed reactions. Some consider its ambition of using € 21 billion in public funds to leverage € 294 billion in private investment by 2018 to be unrealistic. The fact that almost the entire € 21 billion from the public purse is being diverted from existing innovation policy instruments delivering relatively high rates of return has sparked an outcry from leading representatives of the EU science establishment (Attané, 2015). The plan to allocate € 5 billion of the € 21 billion to SMEs has also been criticized, on the grounds that firms should be supported according to their potential for growth, rather than their size.

The € 21 billion includes € 5 billion to come from the European Investment Bank, € 3.3 billion from the Connecting Europe Facility and €2.7 billion from Horizon 2020, the EU's Eighth Framework Programme for Research and Technological Development (2014–2020).

The € 2.7 billion being drawn from Horizon 2020 has already led to cuts to several programmes. The biggest loser is the European Institute of Innovation and Technology (EIT), headquartered in Budapest (Hungary). It was set up in 2008 to foster innovation-driven growth by supporting qualifications (PhD programmes) and projects (through awards) that enhance collaboration between innovation drivers in the education, research and business sectors. EIT is expected to lose € 350 million, or 13% of its budget, between 2015 and 2020. Another casualty is the European Research Council, which was set up in 2007 to fund basic research, it is expected to lose € 221million. This represents a fraction of its € 13 billion budget over the Horizon 2020 period (2014–2020). Other cuts to the Horizon 2020 budget will affect sectorial research projects on ICTs (€ 307 million), nanotechnology and advanced materials (€ 170 million).

The plan excludes thematic or geographic 'pre-allocations', even though it designates the following as focus areas: infrastructure, notably broadband, energy networks and transport; education; R&D and energy efficiency and renewable energy. Perhaps a more important weakness lies in the absence of concrete targets and timelines for the third element[9] of the Juncker plan concerning reform of the framework conditions for research and innovation, such as researcher mobility or open access to scientific research.

TRENDS IN R&D

Chequered progress towards *Europe 2020* targets

The EU is making progress towards some of *Europe 2020*'s targets but not all (European Commission, 2014c). For instance, the total employment rate of 68.4% in 2012 was below that of 2008 (70.3%) and, extrapolating current trends, the employment rate is expected to reach 72% by 2020, still three percentage points below the target.

The rate of early school-leavers dropped from 15.7% to 12.7% and the share of 30–34 year olds who had completed tertiary education rose from 27.9% to 35.7% between 2005 and 2012. On the other hand, the number of people at risk of poverty and social exclusion increased between 2009 and 2012 from 114 million to 124 million.

Elusive R&D targets

In terms of research funding, the *Europe 2020* strategy hopes to succeed where the *Lisbon Strategy* (2003) has failed. The latter had called for the EU's average gross domestic expenditure on R&D (GERD) to rise to 3% of GDP by 2010. *Europe 2020* sets the delivery date for this target back to 2020. Between 2009 and 2013, the EU28 made relatively little progress towards this target, with average R&D intensity increasing only from 1.94% to 2.02%, a feat no doubt facilitated by repeated periods of recession. At this rate, it does not look as if the EU will make the new deadline (Table 9.2).

Some countries are already there, of course. At one end of the spectrum, Denmark, Finland and Sweden already spend 3% or more of GDP on R&D and should soon be joined by Germany. At the other end of the spectrum, many countries still spend less than 1% of GDP on R&D.

There are also large differences in the targets set for 2020, with Finland and Sweden aiming for an R&D intensity of 4%, whereas Cyprus, Greece and Malta are targeting less than 1%. Bulgaria, Latvia, Lithuania, Luxembourg, Poland, Portugal and Romania all aim to at least double their R&D intensity by 2020.

8. See: http://europa.eu/rapid/press-release_IP-15-5420_en.htm

9. The first two elements concerned reform of the banking union and the creation of a single market in energy.

Table 9.2: **GERD/GDP ratio in the EU28 in 2009 and 2013 and targets to 2020 (%)**

	GERD/GDP ratio, 2009	GERD/GDP ratio, 2013*	Target for 2020	Industry-financed share of GERD, 2013*
EU28	1.94	2.02	3.00	54.9
Austria	2.61	2.81	3.76	44.1
Belgium	1.97	2.28	3.00	60.2
Bulgaria	0.51	0.65	1.50	19.4
Croatia	0.84	0.81	1.40	42.8
Cyprus	0.45	0.48	0.50	10.9
Czech Rep.	1.30	1.91	–	37.6
Denmark	3.07	3.05	3.00	59.8
Estonia	1.40	1.74	3.00	41.3
Finland	3.75	3.32	4.00	60.8
France	2.21	2.23	3.00	55.4
Germany	2.73	2.94	3.00	66.1
Greece	0.63	0.78	0.67	32.1
Hungary	1.14	1.41	1.80	46.8
Ireland	1.39	1.58	2.00**	50.3
Italy	1.22	1.25	1.53	44.3
Latvia	0.45	0.60	1.50	21.8
Lithuania	0.83	0.95	1.90	27.4
Luxembourg	1.72	1.16	2.30–2.60	47.8
Malta	0.52	0.85	0.67	44.3
Netherlands	1.69	1.98	2.50	47.1
Poland	0.67	0.87	1.70	37.3
Portugal	1.58	1.36	3.00	46.0
Romania	0.46	0.39	2.00	31.0
Slovakia	0.47	0.83	1.20	40.2
Slovenia	1.82	2.59	3.00	63.8
Spain	1.35	1.24	2.00	45.6
Sweden	3.42	3.21	4.00	57.3
UK	1.75	1.63	–	46.5

** or latest available year*
*** The national target of 2.5% of GNP is estimated as being equal to 2.0% of GDP.*

Source: Eurostat, January 2015

Less high-tech R&D than Japan and the USA

The *Lisbon Strategy* fixed the target of having business contribute two-thirds of GERD (2% of GDP) by 2010. This target has not been reached either, although the business sector funds more than half of R&D (55%), on average (Figure 9.3). Business is currently the largest source of R&D funding in 20 member states, with shares of 60% or more of GERD in Belgium, Denmark, Finland, Germany and Slovenia. The general pattern in the EU is that the business sector spends more money on performing research than it does on financing it. This is the case in all but Lithuania and Romania. Interestingly, funding from abroad is the most important source for Lithuania, as also for Bulgaria and Latvia. As a group, the first 15 members of the EU lag behind many advanced economies when it comes to the intensity of business R&D (Figure 9.4). This largely reflects the economic structures of some of the larger member states such as Italy, Spain and the UK that are less focused than other economies on technology-intensive industries.

Company-level R&D intensity (as a share of net sales) tends to be strongly correlated with the productive sector. The EU R&D Scoreboard shows that EU businesses tend to be more heavily concentrated in R&D of medium-to-low and low intensity, in comparison to their principal competitors, the other two members of the Triad, the USA and Japan (Table 9.3 and Figure 9.5).

Moreover, although EU-based companies accounted for 30.1% of total R&D spending by the world's top 2 500 companies, there are only two EU-based companies in the top ten, both of them German and both in the automotive sector (Table 9.3). Indeed, the top three R&D performers in the EU are the German automotive companies Volkswagen, Daimler and BMW (Tables 9.3 and 9.4). The automotive sector represents one-quarter of R&D spending by EU companies covered in the EU R&D Scoreboard, three-quarters of which is accounted for by German automotive companies.

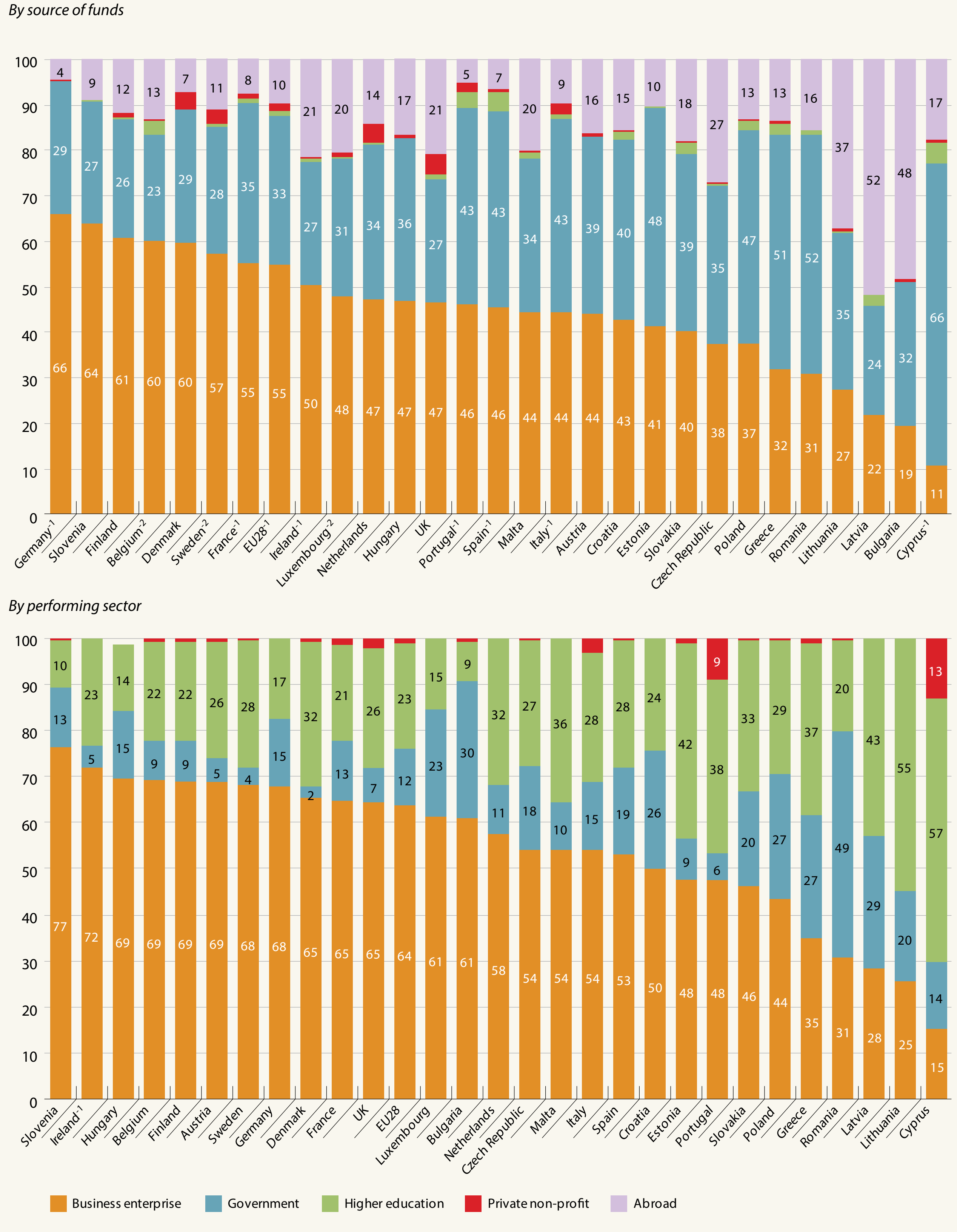
The EU is largely absent from the arena of internet-based companies active in new and emerging forms of innovation. According to Downes (2015), none of the 15 largest public internet companies today are European. Eleven are US-based and the remainder are Chinese. Indeed, the EU's attempts to replicate a Silicon Valley-type experience[10] have not lived up to expectations. The principal EU giants specializing in hardware within the digital economy (Siemens, Ericsson, Nokia) have even lost a lot of ground in the past decade in global R&D rankings. Nonetheless, the German-based software and IT services company SAP has recently joined the global top 50 R&D performers (Table 9.3).

Business R&D performance in the EU has also been weighed down by the disappointing growth of R&D in sectors such as pharmaceuticals and biotechnology (0.9 % R&D growth in 2013) or technology hardware and equipment (-5.4%), which are typically R&D-intensive. Whereas the EU is almost on a par with the USA in pharmaceuticals, it trails the USA in the area of biotechnology (Tables 9.5 and 9.6).

There are emerging concerns in Europe about the erosion of its science base through takeover bids from competitors. One illustration of this concern is the aborted takeover bid by the US pharmaceutical company Pfizer in 2014. Pfizer found itself obliged to reassure the UK government that its £ 63 billion bid to buy the Anglo-Swedish pharmaceutical company AstraZeneca would not affect research jobs in the UK. Although Pfizer promised that a combined company would

10. One example is the technology cluster in central and east London known as Tech City. See: www.techcityuk.com

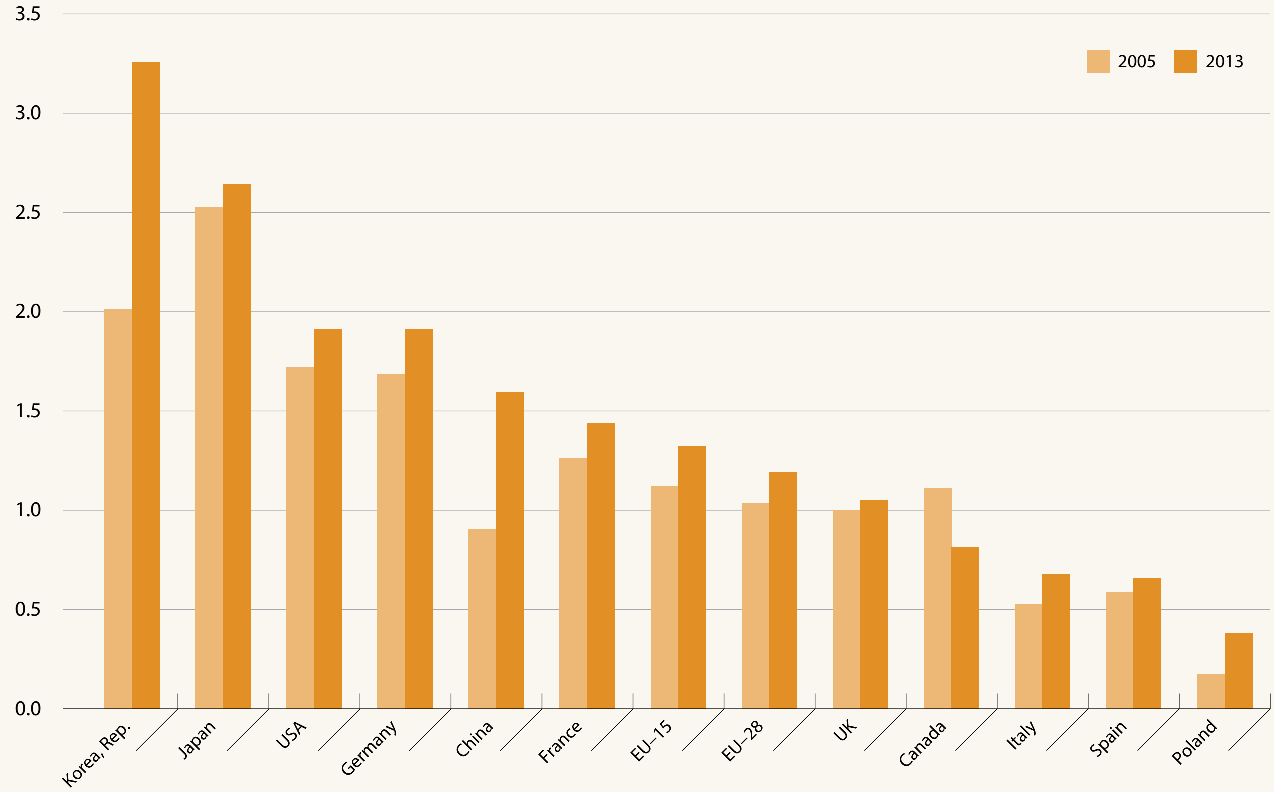
Figure 9.3: **GERD by source of funds and performing sector, 2013 or latest available year (%)**



-n = data refer to *n* years before reference year

Source: Eurostat, January 2015

Figure 9.4: **BERD as a share of GDP in the EU, 2005 and 2013 (%)**
Other economies are given for comparison



Source: OECD's Main Science and Technology Indicators, July 2015

employ one-fifth of its research staff in the UK and complete AstraZeneca's planned £ 300 million hub in Cambridge, Pfizer was forced to admit that research spending would be cut in the combined company. Ultimately, AstraZeneca's board rejected Pfizer's offer, concluding that it was motivated by a desire for cost savings and tax minimization in the USA rather than the optimization of drug delivery (Roland, 2015).

The sanctions imposed on the Russian Federation by the EU in 2014 may also have repercussions for EU companies installed in the Russian Federation. Large European multinationals such as Alstom, Ericsson, Nokia, Siemens and SAP have all set up R&D centres in technoparks like Sistema-Sarov, or are participating in the flagship Skolkovo research facility (see Box 13.1).

Only a handful of innovation leaders

The EU's innovation performance has been monitored since 2001 by the annual European Innovation Scoreboard, which was restyled and renamed the Innovation Union Scoreboard in 2010. The latest Innovation Union Scoreboard uses a measurement framework distinguishing between three main types of indicators (enablers, firm activities and output) and eight innovation dimensions, capturing in total 25 indicators (European Commission, 2015a). Overall innovation performance is measured by the Summary Innovation Index on a scale from 0 (the worst-performing country) to 1 (the best-performing country). On the basis of this index, EU regions can be divided into four different groups: *innovation leaders,* with an innovation performance well above the EU average, *innovation followers,* with an innovation performance close to the EU average, *moderate innovators* slightly below the EU average and *modest innovators* well below the EU average (Figure 9.6).

The innovation performance of most member states improved between 2007 and 2014, notable exceptions being Cyprus, Romania and Spain. Of note is that growth has been positive but very modest for Finland, Greece and Luxembourg. Over time, the innovative performance of countries is converging. However, the innovation performance did weaken for as many as 13 member states between 2013 and 2014, particularly for Cyprus, Estonia, Greece, Romania and Spain but also for the more innovative countries of Austria, Belgium, Germany, Luxembourg and Sweden. The declining share of enterprises active in innovation, coupled with the drop in public–private co-publications and lower venture capital investment, all signal a possible (delayed) repercussion of the economic crisis on businesses.

Table 9.3: **The global top 50 companies by R&D volume, 2014**

Rank in 2014	Company	Country	Field	R&D (€ millions)	Change in rank for R&D 2004-2007	R&D intensity*
1	Volkswagen	Germany	Automobiles & parts	11 743	+7	6.0
2	Samsung Electronics	Korea, Rep.	Electronics	10 155	+31	6.5
3	Microsoft	USA	Computer hardware & software	8 253	+10	13.1
4	Intel	USA	Semiconductors	7 694	+10	20.1
5	Novartis	Switzerland	Pharmaceuticals	7 174	+15	17.1
6	Roche	Switzerland	Pharmaceuticals	7 076	+12	18.6
7	Toyota Motors	Japan	Automobiles & parts	6 270	-2	3.5
8	Johnson & Johnson	USA	Medical equipment, pharmaceuticals, consumer goods	5 934	+ 4	11.5
9	Google	USA	Internet-related products & services	5 736	+ 173	13.2
10	Daimler	Germany	Automobiles & parts	5 379	-7	4.6
11	General Motors	USA	Automobiles & parts	5 221	-5	4.6
12	Merck USA	USA	Pharmaceuticals	5 165	+17	16.2
13	BMW	Germany	Automobiles & parts	4 792	+15	6.3
14	Sanofi-Aventis	France	Pharmaceuticals	4 757	+8	14.4
15	Pfizer	USA	Pharmaceuticals	4 750	-13	12.7
16	Robert Bosch	Germany	Engineering & electronics	4 653	+10	10.1
17	Ford Motors	USA	Automobiles & parts	4 641	-16	4.4
18	Cisco Systems	USA	Networking equipment	4 564	+13	13.4
19	Siemens	Germany	Electronics & electrical equipment	4 556	-15	6.0
20	Honda Motors	Japan	Automobiles & parts	4 367	- 4	5.4
21	Glaxosmithkline	UK	Pharmaceuticals & biotechnology	4 154	-10	13.1
22	IBM	USA	Computer hardware, middleware & software	4 089	-13	5.7
23	Eli Lilly	USA	Pharmaceuticals	4 011	+18	23.9
24	Oracle	USA	Computer hardware & software	3 735	+47	13.5
25	Qualcomm	USA	Semiconductors, telecommunications equipment	3 602	+112	20.0
26	Huawei	China	Telecommunications equipment & services	3 589	up > 200	25.6
27	Airbus	Netherlands**	Aeronautics	3 581	+8	6.0
28	Ericsson	Sweden	Telecommunications equipment	3 485	-11	13.6
29	Nokia	Finland	Technology hardware & equipment	3 456	- 9	14.7
30	Nissan Motors	Japan	Automobiles & parts	3 447	+4	4.8
31	General Electric	USA	Engineering, electronics & electric equipment	3 444	+6	3.3
32	Fiat	Italy	Automobiles & parts	3 362	+12	3.9
33	Panasonic	Japan	Electronics & electrical equipment	3 297	-26	6.2
34	Bayer	Germany	Pharmaceuticals & biotechnology	3 259	-2	8.1
35	Apple	USA	Computer hardware & software	3 245	+120	2.6
36	Sony	Japan	Electronics & electrical equipment	3 209	-21	21.3
37	AstraZeneca	UK	Pharmaceuticals & biotechnology	3 203	-12	17.2
38	Amgen	USA	Pharmaceuticals & biotechnology	2 961	+18	21.9
39	Boehringer Ingelheim	Germany	Pharmaceuticals & biotechnology	2 743	+23	19.5
40	Bristol–Myers Squibb	USA	Pharmaceuticals & biotechnology	2 705	+2	22.8
41	Denso	Japan	Automobile parts	2 539	+12	9.0
42	Hitachi	Japan	Technology hardware & equipment	2 420	-18	3.7
43	Alcatel–Lucent	France	Technology hardware & equipment	2 374	+4	16.4
44	EMC	USA	Computer software	2 355	+48	14.0
45	Takeda Pharmceuticals	Japan	Pharmaceuticals & biotechnology	2 352	+28	20.2
46	SAP	Germany	Software & computer services	2 282	+23	13.6
47	Hewlett–Packard	USA	Technology hardware & equipment	2 273	-24	2.8
48	Toshiba	Japan	Computer hardware	2 269	-18	5.1
49	LG Electronics	Korea, Rep.	Electronics	2 209	+61	5.5
50	Volvo	Sweden	Automobiles & parts	2 131	+27	6.9

* R&D intensity is defined as R&D expenditure divided by net sales.
** Although incorporated in the Netherlands, Airbus's principal manufacturing facilities are located in France, Germany, Spain and the UK.

Source: Hernández *et. al* (2014), Table 2.2

Table 9.4: **Top 40 EU companies for R&D, 2011–2013**

Company	Base	Activity	R&D intensity (3-year growth)	Sales (3-year growth)
Volkswagen	Germany	Automobiles & parts	23.3	15.8
Daimler	Germany	Automobiles & parts	3.5	6.5
BMW	Germany	Automobiles & parts	20.0	7.9
Sanofi-Aventis	France	Pharmaceuticals & biotechnology	2.7	2.7
Robert Bosch	Germany	Automobiles & parts	6.8	-0.8
Siemens	Germany	Electronic & electrical equipment	2.4	3.2
Glaxosmithkline	UK	Pharmaceuticals & biotechnology	-2.5	-2.3
Airbus	Netherlands	Aerospace & defence	5.1	9.0
Ericsson	Sweden	Technology hardware & equipment	0.1	3.8
Nokia	Finland	Technology hardware & equipment	-11.2	-18.0
Fiat	Italy	Automobiles & parts	20.2	34.3
Bayer	Germany	Pharmaceuticals & biotechnology	0.5	4.6
AstraZeneca	UK	Pharmaceuticals & biotechnology	0.9	-8.2
Boehringer Ingelheim	Germany	Pharmaceuticals & biotechnology	3.8	3.8
Alcatel-Lucent	France	Technology hardware & equipment	-3.6	-3.4
SAP	Germany	Software & computer services	9.7	10.5
Volvo	Sweden	Industrial engineering	5.2	1.0
Peugeot (PSA)	France	Automobiles & parts	-6.5	-1.2
Continental	Germany	Automobiles & oarts	8.0	8.6
BASF	Germany	Chemicals	7.1	5.0
Philips	The Netherlands	General industrials	2.5	3.1
Renault	France	Automobiles & parts	1.2	1.6
Finmeccanica	Italy	Aerospace & defence	-3.9	-5.0
Novo Nordisk	Denmark	Pharmaceuticals & biotechnology	8.6	11.2
Merck DE	Germany	Pharmaceuticals & biotechnology	2.5	6.1
Stmicroelectronics	Netherlands	Technology hardware & equipment	-6.4	-7.9
Banco Santander	Spain	Banking	-2.8	-1.7
Safran	France	Aerospace & defence	31.2	9.5
Royal Bank of Scotland	UK	Banking	6.9	-9.2
Telefonica	Spain	Fixed line telecommunications	5.1	-2.1
Unilever	The Netherlands	Food, cleaning and personal hygiene products	3.9	4.0
Alstom	France	Industrial engineering	0.8	-1.1
Telecomitalia	Italy	Fixed line telecommunications	11.9	-5.3
Royal Dutch Shell	UK	Oil & gas producers	9.0	7.0
Total	France	Oil & gas producers	9.9	6.9
Delphi	UK	Automobiles & parts	9.1	6.0
CNH Industrial	The Netherlands	Industrial engineering	12.7	6.5
Servier	France	Pharmaceuticals & biotechnology	9.0	5.9
Seagate Technology	Ireland	Technology hardware & equipment	11.9	7.3
L'Oréal	France	Personal goods (beauty products, etc)	8.8	5.6

Source: European Commission

Table 9.5: **EU's relative position in the global top 2 500 R&D companies, 2013**

	EU	USA	Japan	Other countries
Number of companies	633	804	387	676
R&D (€ billions)	162.3	193.6	85.6	96.8
Growth in 2010–2013 (%)	5.8	7.0	3.0	9.8
World share in 2013 (%)	30.1	36.0	15.9	18.0
R&D as a share of net sales (%)	2.7	5.0	3.2	2.2
Net sales (€ billions)	5 909.0	3 839.5	2 638.6	4 335.9

Source: Extracted from Hernández *et al.* (2014), Table 1.2

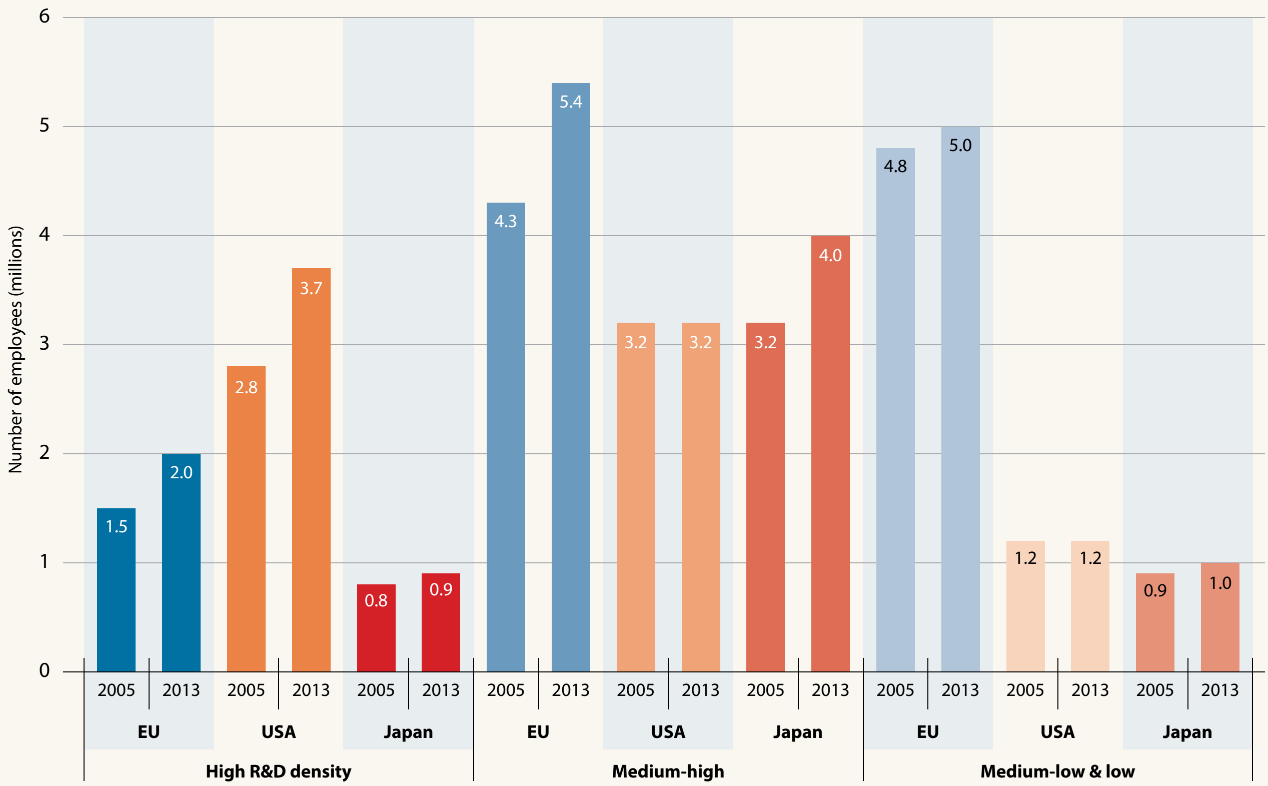
Table 9.6: **EU and US companies in selected R&D-intensive sectors, 2013**

Industry	Number of companies		R&D (€ millions)		R&D intensity (%)*	
	EU	USA	EU	USA	EU	USA
Health						
Pharmaceuticals	47	46	26781.9	29150.0	13.2	14.0
Biotechnology	20	98	1238.4	12287.3	16.0	27.2
Health care equipment & services	23	54	2708.2	7483.5	4.4	3.8
Software & services						
Software	33	86	4797.2	22413.9	14.8	15.0
Computer services	15	46	1311.1	6904.8	5.2	6.9
Internet	2	20	97.6	8811.5	6.3	14.3

* R&D intensity is defined as R&D expenditure divided by net sales.

Source: Extracted from Hernández *et al.* (2014), Table 4.5

Figure 9.5: **Employment by R&D intensity, 2005 and 2013 (%)**



Note: The data concern 476 EU companies, 525 US companies and 362 Japanese companies out of the world's top 2 500 companies according to the EU R&D Scoreboard.

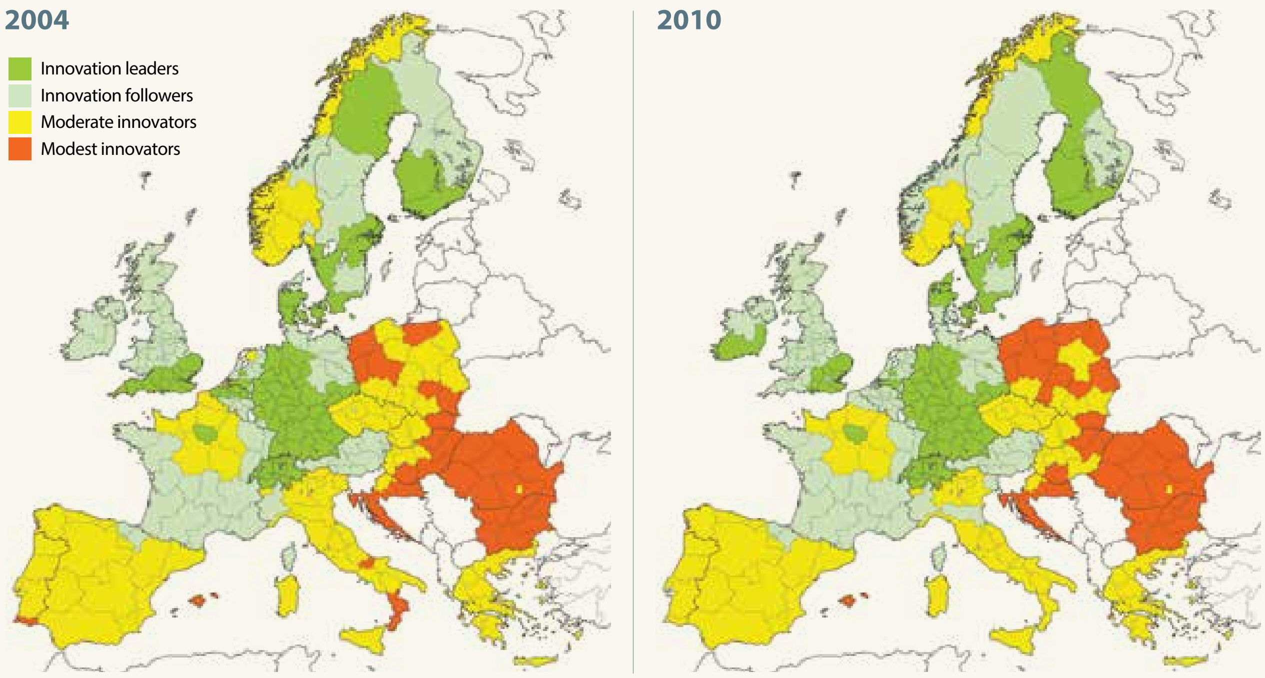
Source: Hernández *et. al* (2014), Figure S3

Making it easier for companies to innovate

Europe has been a major producer of new knowledge but it has performed less well in turning new ideas into commercially successful products and processes. Science and innovation face a more fragmented market than large economies comprised of only one nation state, such as the USA or Japan (Figure 9.6). The EU thus needs a common research policy to avoid duplicating research efforts in different member states.

EU research policy has had a strong focus on innovation since 2010, thanks to the introduction of the Innovation Union flagship project and the launch, in 2014, of Horizon 2020, the biggest EU research and innovation framework programme ever (European Commission, 2014b). The Innovation Union is one of the EU's seven flagship projects for reaching its *Europe 2020* targets (Table 9.7). This name covers 34 commitments and related deliverables designed to remove the obstacles to innovation –

Figure 9.6: **Innovation performance of EU regions, 2004 and 2010**



Source: European commission (2014c), Regional Innovation Union Scoreboard 2014; maps created using Region Map Generator

such as expensive patenting, market fragmentation, slow standard-setting and skills shortages – and revolutionize the way in which the public and private sectors work together, notably through innovation partnerships between European institutions, national and regional authorities and businesses. By 2015, considerable progress had been made for all but one commitment (Table 9.7).

Commitment 5 focuses on building world-class research and innovation infrastructure to attract global talent and foster the development of key enabling technologies. The European Strategy Forum on Research Infrastructures has identified 44 key new research facilities (or major upgrades to existing ones). The construction and operation of this infrastructure requires the pooling of resources by several member states, associated countries and also third countries. The target is for 60% of this research infrastructure to have been completed or launched by 2015.

Commitment 7 stresses the key role of SMEs in driving innovation as catalysts for knowledge spillovers. Tapping the full innovation potential of SMEs requires favourable framework conditions but also efficient support mechanisms. SME access to EU funding is hampered by the fragmentation of support instruments and administrative procedures ill-adapted to SMEs. With Horizon 2020, a new dedicated SME Instrument has been designed for highly innovative SMEs with the ambition of ensuring that a significant share of funding is reserved for SMEs.

Commitments 14 to 18 all serve to promote the single innovation market by making it easier for companies to innovate and to protect their intellectual property rights. European companies filing for patent protection currently need to do so in all 28 member states, piling on additional administrative requirements and translation costs. The 'unitary patent package' agreed upon by 25 EU member states (all but Croatia, Italy and Spain) between 2012 and 2013 includes regulations creating a unitary patent and establishing a translation regime applicable to the unitary patent, as well as the establishment of a single and specialized patent jurisdiction, the Unified Patent Court. The costs of a unitary patent related to procedural fees and translations are expected to fall considerably for all 25 member states, leading to savings of an estimated 85%. The Unified Patent Court is expected to start functioning in 2015 and should result in annual savings of between € 148 million and € 289 million (European Commission, 2014c).

To meet its ambitions for research, the EU will need to augment the number of researchers in the EU, a significant share of whom will have to come from third countries. For the EU to be able to compete with the USA in attracting research talent, for instance, EU legislation will need to be applied to the letter. Member states have already reformed their higher education sectors as part of the Bologna Process[11] and special scientific visas have been designed to help researchers obtain authorization to live and work in any member state more easily.

11. On the Bologna Process, see the *UNESCO Science Report 2010*, p. 150.

Table 9.7: **Progress by EU member states on Innovation Union commitments as of 2015**

	Commitment		Deliverables	Examples of implementation/remaining gaps
1	Put in place national strategies to train a critical mass of researchers	✓	■ Most countries have put strategies in place ■ The European Commission has put tools in place to favour this process	■ New innovative doctoral training opportunities available in some member states ■ Launch of EURAXESS, an information tool fostering mobility and collaboration among researchers across 40 pan-European countries, such as by publishing job offers online
2a	Test the feasibility of an independent university ranking	✓	■ Feasibility of the ranking tested	■ U-Multirank launched in 2014 to compare universities in new ways; ■ The first U-Multirank results were published in May 2014 for 500 institutions offering higher education and 1 272 disciplines; ■ The tool is available for students and researchers wishing to use it
2b	Create knowledge alliances between business and academia	✓	■ Knowledge alliances piloted and scaled up within the Erasmus+ programme for international university student exchanges ***Follow-up:*** ■ 150+ new knowledge alliances foreseen in the programming period 2014–2020	■ Universities and businesses took part in the first knowledge alliances and new ones were launched in 2014; ■ The results of the first knowledge alliance pilots are available
3	Propose an integrated framework for e-skills	✓	■ Grand coalition for digital jobs ■ E-competence framework 3.0 released ■ Roadmap for the promotion of ICT ■ professionalism and e-leadership 2014–2020 released	■ E-competence framework adopted as a standard by some member states
4	Propose a European Framework for Research Careers and supporting measures	✓	■ European Framework for Research Careers proposed in 2012, measures to be in place by 2014; ■ European Framework for Research Careers created; ■ Principles for innovative doctoral training defined, disseminated, verified and supported; ■ The Pan-European Pension fund established as a consortium, with funding foreseen in Horizon 2020	■ European Framework for Research Careers widely used for recruitment by universities, companies, etc.; ■ Joint programming initiatives ***Remaining gaps:*** Some member states still have to align their systems on the principles of the European Framework for Research Careers; ■ Pan-European Pension fund expected to be operational by late 2015
5	Construct priority European research infrastructure	✓	■ So far, 56% of the infrastructure has been implemented, the target is for 60% by 2015	■ 14 types of infrastructure are providing services to their user
6	Simplify EU research and innovation programmes and focus future ones on the Innovation Union	✓	■ Horizon 2020 launched in 2014 with a focus on the Innovation Union	■ First calls for research project proposals launched within Horizon 2020
7	Ensure stronger involvement of SMEs in future EU research and innovation programmes	✓	■ SMEs instrument integrated in Horizon 2020	■ SMEs instrument ready to be used in Horizon 2020
8	Strengthen the science base for policy-making through the Joint Research Centre and create European Forum for Forward Looking Activities	✓	■ Better connections with the Joint Research Centre developed; the latter has scientific institutes in Belgium (2), Germany, Italy, the Netherlands and Spain; ■ European Forum for Forward Looking Activities established	■ Work of the Joint Research Centre and the European Forum for Forward Looking Activities influencing Commission policy-making and strategic programming *continued overleaf...*

Table 9.7: *(continued)*

	Commitment		Deliverables	Examples of implementation/remaining gaps
9	Set out a strategic agenda for the European Institute of Innovation and Technology (EIT) set up in 2008	✓	■ Strategic Innovation Agenda implemented with a budget of € 2.7 billion within Horizon 2020; ■ Existing knowledge and innovation communities (KICs) in climate, ICT labs and InnoEnergy to be expanded; ■ New KICs launched in innovation for healthy living and active ageing and in the sustainable use of raw materials; ■ Three other KICs to be launched in 2016 (food4future and added-value manufacturing) and 2018 (urban mobility); ■ Activities of the EIT Foundation expanded	■ 35 master's degree courses created with the EIT label; ■ More than 1 000 students enrolled in EIT courses; ■ More than 100 start-ups created ; ■ More than 400 ideas incubated ; ■ 90 new products and services launched
10	Put in place EU-level financial instruments to attract private finance	✓	■ 'Access to Risk finance' available under Horizon 2020	
11	Ensure cross-border operation of venture capital funds	✓	■ The European Venture Capital Regulation entered into force in July 2013	■ At least two applications have been presented to member states
12	Strengthen cross-border matching of innovative firms with investors	✓	■ Expert group delivered recommendations to the Commission	■ These recommendations have been taken into account in the delivery of the financial instruments within Horizon 2020
13	Review State Aid Framework for R&D and innovation	✓	■ State Aid Framework for R&D and innovation reviewed	■ State Aid Modernisation rules ready for use as of July 2014
14	Deliver the EU Patent	✓	■ Unitary patent package agreed upon by 25 member states (excl. Italy, Spain and Croatia); ■ Machine translations available since 2013; ■ Implementing rules approved by the Select Committee in December 2014	***Remaining gaps:*** ■ 13 member states still to ratify the Unitary Patent Court agreement for it to enter into force (six ratifications so far: Austria, Belgium, Denmark, France, Malta and Sweden ■ Implementing rules for the Unitary Patent Court are being discussed within the Preparatory Committee, which is due to start functioning in 2015
15	Screen the regulatory framework in key areas	✓	■ Regulatory screening methodology developed and applied to regulations relating to eco-innovation and European Innovation Partnerships	■ Methodology applied to water directive and regulation on raw materials
16	Accelerate and modernize standard-setting	✓	■ Communication setting out a strategic vision for European standards adopted in 2011; ■ Regulation implemented since 2012	■ 37% faster standardization process
17a	Set aside national procurement budgets for innovation	✗	■ Commitment not taken up by the European Council	■ Some member states have introduced measures to use public procurement as an instrument for innovation policy, including Finland, Italy, Spain, Sweden and Denmark
17b	Set up an EU-level support mechanism and facilitate joint procurement	✓	■ Financial support for transnational co-operation being provided by the European Commission; ■ Revised Public Procurement directives facilitating the procurement of innovation adopted by Parliament and Council in 2014; ■ Guidance and awareness raising activities carried out by the Commission	■ Joint procurement under calls within the Seventh Framework Programme ***Remaining gaps:*** ■ Member states yet to transpose these directives into national law

Table 9.7: *(continued)*

	Commitment		Deliverables	Examples of implementation/remaining gaps
18	Present an eco-innovation action plan	✓	■ *Action Plan* adopted in 2011	■ *Strategic Implementation Plan* agreed in 2012 and currently under implementation;
19a	Establish a European Creative Industries Alliance	✓	■ European Creative Industries Alliance established in 2011	■ More than € 45 million mobilized on top of € 6.75 million in EU support for the European Creative Industries Alliance ■ More than 3 500 SMEs have benefited from the activities of the European Creative Industries Alliance and an additional 2 460 stakeholders participated in its activities
19b	Set up a European Design Leadership Board	✓	■ European Design Leadership Board established. It has delivered proposals on how to enhance the role of design in innovation	■ Staff working document on Implementing an Action Plan for Design-driven Innovation ■ European Design Innovation Platform established ■ European Design Innovation Initiative call
20	Promote open access; support smart research information services	✓	■ Communication diffused entitled *Towards Better Access to Scientific Information: boosting the Benefits of Public Investment in Research*, including recommendations for member states ■ Open access in Horizon 2020 ■ Search tools developed	■ ODIN project launched, an open access website providing lessons on web development
21	Facilitate collaborative research and knowledge transfer	✓	■ Clear and easy participation rules for Horizon 2020 ■ Analysis of impact on innovation of consortium agreements carried out ■ Analysis of knowledge transfer and open innovation	■ European Technology Transfer Offices established; ■ Guidance on the use of consortium agreements produced and integrated into the Horizon 2020 online grants manual
22	Develop a European knowledge market for patents and licensing	✓	■ Staff working document *Towards Enhanced Patent Valorisation for Growth and Jobs* published in 2012	■ Expert groups established on intellectual property valuation and on patent valorization; ■ Results of the expert group on patent valorization to be delivered
23	Safeguard against the use of IPRs for anti-competitive purposes	✓	■ Guidelines on horizontal agreements adopted in 2010	■ These rules now apply to national competition authorities, the European Commission, companies and national courts
24–25	Improve the use of structural funds for research and innovation	✓	■ Research and Innovation Strategies for Smart Specialisation introduced in the strategic planning of member states and country regions; ■ Smart specialization strategies introduced as an *ex ante* conditionality for access to finance from the European Regional Development Fund for research, technological development and innovation;	■ National and regional smart specialization strategies defined in most member states/regions within countries; ■ Smart Specialisation Platform launched in 2012
26	Launch a Social Innovation pilot and promote social innovation through the European Social Fund	✓	■ Social Innovation Europe platform launched in 2011; ■ Bigger role for social innovation incorporated in the European Social Fund	■ European Social Innovation Competition established; ■ Support given to networks of incubators for social innovation
27	Support a research programme on social innovation in the public sector and pilot a European Public Sector Innovation Scoreboard	✓	■ Social and public sector innovation included in Horizon 2020 topics; ■ European Public Sector Innovation Scoreboard piloted	■ European Prize for Innovation in the Public Sector launched; ■ Expert group on public sector innovation set up ■ First European Capital of Innovation Award (iCapital) awarded to Barcelona in 2014 *continued overleaf...*

Table 9.7: *(continued)*

	Commitment		Deliverables	Examples of implementation/remaining gaps
28	Consult social partners on interaction between the knowledge economy and market	✓	■ First consultations with EU social partners took place in 2013; ■ Further consultations are planned beyond 2014	■ European Workplace Innovation Network set up
29	Pilot and present proposals for European Innovation Partnerships	✓	■ European Innovation Partnerships launched, piloted and evaluated	■ More than 700 commitments for action ■ Reference sites for sharing lessons and replicating transferable results ■ Web-based marketplaces with well over 1 000 registered users for each ■ First results emerging: collections of good practices and toolkits for their replication, compilations of evidence on impact, etc.
30	Put in place integrated policies to attract global talent	✓	■ National measures being deployed to foster researcher mobility, including EURAXESS, an information tool for researchers wishing to pursue their career in Europe or stay connected to it; ■ Scientific visa; ■ Marie Skłodowska Curie Actions; ■ Destination Europe Events	■ EURAXESS and EURAXESS links; ■ New scientific visa to take effect in 2016, after transposition by member states
31	Propose priorities and approaches for scientific co-operation with third countries involving the EU and member states	✓	■ Communication adopted in 2012 on enhancing and focusing EU international co-operation in research and innovation	■ Strategic Forum for International Cooperation initiatives targeting China, Brazil, India and the USA; ■ On-going work of the Strategic Forum for International Cooperation to identify common priorities and implement joint actions. Roadmaps completed by end of 2014; ■ Ongoing dialogue with third countries and other regions of the world
32	Roll-out global research infrastructure	✓	■ New framework for co-operation agreed in 2013 at G8 level; ■ Report on list of existing infrastructure and priorities expected in 2015	
33	Self-assess national research and innovation systems and identify challenges and reforms	✓	■ Commission support made available to member states; ■ Four out of 28 member states have requested peer review: Belgium, Estonia, Denmark, Spain; ■ Progress monitored through European Semester, leading to country-specific recommendations	■ Peer review carried out for Belgium, Estonia, Denmark, Spain and Iceland; ■ Three countries have confirmed use of Self-Assessment Tool: Belgium, Estonia, Denmark; ■ New tool launched under Horizon 2020
34a	Develop an innovation headline indicator	✓	■ Communication adopted in 2013 on *Measuring Innovation Output in Europe: Towards a New Indicator*	■ Indicator used for country-specific recommendations in 2014
34b	Monitor progress using Innovation Union Scoreboard	✓	■ Innovation Union Scoreboard updated annually since 2010	■ Innovation Union Scoreboard published most recently in 2015

Source: adapted from European Commission (2014e)

MONITORING THE LATEST FRAMEWORK PROGRAMMES FOR RESEARCH

Horizon 2020: the EU's biggest research programme ever

The funding levels of the EU's successive framework programmes for research and development have grown consistently over time from € 4 billion for the first one from 1984 to 1988 to € 53 billion for the Seventh Framework Programme for Research and Technological Development (2007–2013) and nearly € 80 billion for Horizon 2020, the biggest EU research programme ever. Horizon 2020 was proposed by the European Commission in November 2011 and adopted by the European Parliament and European Council in December 2013.

Horizon 2020 focuses on implementing *Europe 2020*, in general, and the Innovation Union, in particular, by bringing together all existing EU research and innovation funding and providing support in a seamless way from idea to market, through streamlined funding instruments and a simpler programme architecture and rules for participation. The bulk of the € 80 billion will promote excellent science (32%) and address societal challenges (39%) [Table 9.8].

Green growth main societal challenge

Many of the societal challenges covered by Horizon 2020 relate to green growth areas, such as sustainable agriculture and forestry, climate action, green transportation or resource efficiency. Some of *Europe 2020's* most positive results so far concern reductions in greenhouse gas emissions. By 2012, the

Table 9.8: **Structure and budget of *Horizon 2020*, 2014–2020**

	Final breakdown (%)	Estimated final amount in € millions (in current prices)
Excellent science, of which	**31.7**	**24 441**
European Research Council	17.0	13 095
Future and Emerging Technologies	3.5	2 696
Marie-Skłodowska-Curie Actions	8.0	6 162
European research infrastructures (including Infrastructures)	3.2	2 488
Industrial leadership, of which	**22.1**	**17 016**
Leadership in enabling and industrial technologies	17.6	13 557
Access to risk finance	3.7	2 842
Innovation in SMEs	0.8	616
Societal challenges, of which	**38.5**	**29 679**
Health, demographic change and well-being	9.7	7 472
Food security, sustainable agriculture and forestry, marine maritime and inland water research and the bio-economy	5.0	3 851
Secure, clean and efficient energy	7.1	5 931
Smart, green and integrated transport	8.2	6 339
Climate action, environment, resource efficiency and raw materials	4.0	3 081
Europe in a changing world – Inclusive innovative and reflective societies	1.7	1 309
Secure societies – Protecting freedom and security of Europe and its citizens	2.2	1 695
Science with and for society	**0.6**	**462**
Spreading excellence and widening participation	**1.1**	**816**
European Institute of Innovation and Technology (EIT)	**3.5**	**2 711**
Non-nuclear direct actions of the Joint Research Centre	**2.5**	**1 903**
TOTAL EU REGULATION	**100.0**	**77 028**
Fusion indirect actions	45.4	728
Fission indirect actions	19.7	316
Nuclear direct actions of the Joint Research Centre	34.9	560
TOTAL Euratom regulation 2014–2018	**100.0**	**1 603**

Note: Owing to Euratom's different legal base, its budgets are fixed for five years. For the years 2014–2018, the budget is estimated to be € 1 603 million and for the years 2019–2020 an amount of € 770 million is foreseen.

Source: European Commission: http://ec.europa.eu/research/horizon2020/pdf/press/fact_sheet_on_horizon2020_budget.pdf

EU had already achieved an 18% reduction in greenhouse gas emissions over 1990 levels and is, thus, expected to meet its 2020 target of a 20% reduction.

Europe needs to embrace sustainable development to overcome a range of challenges that include overdependence on fossil fuels, environmental degradation, natural resource depletion and the impact of climate change. The EU is also convinced that environmentally sustainable (green) growth will increase its competitiveness.

Indeed, according to the latest *State of the Environment Synthesis Report* published by the European Environment Agency (2015), the environment industry had been one of the few European economic sectors to flourish in terms of revenue, trade and jobs, despite the 2008 financial crisis. The report emphasizes the role of research and innovation in furthering sustainability goals, including social innovation.

The EU has partly supported its ambitions with regard to energy sustainability and climate change, for example, by funding relevant research projects within its Seventh Framework Programme (2007–2013) and, furthermore, by emphasizing responsible research and innovation across its new framework programme for research, Horizon 2020. Europe is in a historically unique position to usher in a more sustainable society through research and innovation. In order to fulfil its potential, however, a shift in focus might be required to ensure that innovation is viewed more as a means to an end, rather than as an end in itself. (See, for example, van den Hove *et al.,* 2012.)

In the Seventh Framework Programme, the following five themes for co-operation projects focused particularly on sustainability and environmental protection: agriculture; energy; environment; health; and materials (Table 9.9). More than 75% of the topics under these themes can

Table 9.9: **Number of projects within Seventh Framework Programme related to sustainable development, 2007–2013**

	Agriculture	Environment	Energy	Health	Materials	All projects	Share of sustainability projects (%)
Austria	145	157	71	191	188	2 993	25.1
Belgium	331	214	140	295	355	4 552	29.3
Bulgaria	43	45	18	23	19	590	25.1
Croatia	25	23	14	21	9	351	26.2
Cyprus	15	21	15	10	11	436	16.5
Czech Republic	85	63	22	77	111	1 216	29.4
Denmark	197	130	97	200	186	2 275	35.6
Estonia	29	21	11	54	13	502	25.5
Finland	148	83	55	166	232	2 089	32.7
France	419	275	198	551	530	8 909	22.1
Germany	519	425	285	776	970	11 404	26.1
Greece	147	140	72	117	165	2 340	27.4
Hungary	87	57	23	96	75	1 350	25.0
Ireland	108	55	35	109	117	1 740	24.4
Italy	460	296	183	509	659	8 471	24.9
Latvia	24	11	13	17	14	267	29.6
Lithuania	24	19	12	24	27	358	29.6
Luxembourg	7	10	4	19	15	233	23.6
Malta	9	9	3	4	5	177	16.9
Netherlands	467	298	169	558	343	6 191	29.6
Poland	100	76	53	96	166	1 892	26.0
Portugal	123	94	69	68	125	1 923	24.9
Romania	41	69	17	48	81	898	28.5
Slovakia	26	19	15	18	41	411	29.0
Slovenia	55	55	23	48	81	771	34.0
Spain	360	291	211	388	677	8 462	22.8
Sweden	145	135	88	255	258	3 210	27.4
UK	508	379	191	699	666	12 591	19.4

Note: The total for the Seventh Framework Programme includes non- thematic cooperation projects.

Source: CORDIS (www.cordis.europa.eu), data downloaded on 4 March 2015 be considered as contributing positively to the EU's sustainable development targets. About one in four projects implemented under the Seventh Framework Programme concern these five themes. They are a priority for Denmark, Finland and Slovenia, in particular. For Cyprus, Malta and the UK, on the other hand, they represent fewer than one in five projects (Table 9.9).

The data for the Seventh Framework Programme can also be compared to those for patent applications in environment-related technologies, greenhouse gas emissions and the share of renewable energy in gross final energy consumption (Table 9.10). In 2011, Denmark, Finland, Germany and Sweden had the highest number of patent applications in environment-related technologies per billion PPP euro GDP; moreover, the absolute number of patent applications in this area also increased most in these four countries between 2005 and 2011. Denmark and Finland also figure prominently in 'high sustainability' research projects under the Seventh Framework Programme.

Greenhouse gas emissions down

By 2012, greenhouse gas emissions had declined for 20 EU countries in comparison to 1990 levels but, compared to 2005, they had actually increased in four member states: Estonia, Latvia, Malta and Poland. This said, many factors influence greenhouse gas emissions, including changes in energy

Table 9.10: **Key indicators for measuring progress towards *Europe 2020* objectives for societal challenges**

	Environment-related technologies: patent applications to the EPO per billion GDP in current PP€			Greenhouse gas emissions: 1990 = 100			Share of renewable energy in gross final energy consumption (%)		
	2005	2011	Change	2005	2012	Change (%)	2005	2012	Change (ratio)
EU28	0.31	0.46	0.15	93.2	82.1	-11.1	8.7	14.1	1.6
Austria	0.47	0.72	0.25	119.7	104.0	-15.7	24.0	32.1	1.3
Belgium	0.27	0.40	0.13	99.7	82.6	-17.1	2.3	6.8	3.0
Bulgaria	0.00	0.02	0.02	58.5	56.0	-2.5	9.5	16.3	1.7
Croatia	0.00	0.00	0.00	95.8	82.7	-13.1	12.8	16.8	1.3
Cyprus	0.00	0.02	0.02	158.1	147.7	-10.4	3.1	6.8	2.2
Czech Rep.	0.06	0.07	0.01	74.7	67.3	-7.4	6.0	11.2	1.9
Denmark	0.69	1.87	1.18	94.7	76.9	-17.8	15.6	26.0	1.7
Estonia	0.00	0.30	0.30	45.6	47.4	1.8	17.5	25.8	1.5
Finland	0.39	0.91	0.52	98.0	88.1	-9.9	28.9	34.3	1.2
France	0.33	0.43	0.10	101.5	89.5	-12.1	9.5	13.4	1.4
Germany	0.74	1.05	0.31	80.8	76.6	-4.2	6.7	12.4	1.9
Greece	0.01	0.05	0.04	128.2	105.7	-22.5	7.0	13.8	2.0
Hungary	0.11	0.12	0.01	80.7	63.7	-17.0	4.5	9.6	2.1
Ireland	0.09	0.16	0.07	128.2	107.0	-21.1	2.8	7.2	2.6
Italy	0.19	0.22	0.03	111.5	89.7	-21.8	5.9	13.5	2.3
Latvia	0.04	0.06	0.03	42.5	42.9	0.4	32.3	35.8	1.1
Lithuania	0.00	0.03	0.03	47.8	44.4	-3.3	17.0	21.7	1.3
Luxembourg	0.61	0.35	-0.26	108.3	97.5	-10.8	1.4	3.1	2.2
Malta	0.13	0.00	-0.13	147.8	156.9	9.2	0.3	2.7	9.0
Netherlands	0.33	0.50	0.17	101.8	93.3	-8.6	2.3	4.5	2.0
Poland	0.03	0.04	0.01	85.6	85.9	0.3	7.0	11.0	1.6
Portugal	0.04	0.08	0.04	144.5	114.9	-29.7	19.5	24.6	1.3
Romania	0.01	0.02	0.01	57.0	48.0	-9.1	17.6	22.9	1.3
Slovakia	0.04	0.03	-0.01	68.7	58.4	-10.3	5.5	10.4	1.9
Slovenia	0.03	0.10	0.08	110.2	102.6	-7.6	16.0	20.2	1.3
Spain	0.06	0.13	0.07	153.2	122.5	-30.8	8.4	14.3	1.7
Sweden	0.67	1.03	0.36	93.0	80.7	-12.3	40.5	51.0	1.3
UK	0.17	0.26	0.09	89.8	77.5	-12.3	1.4	4.2	3.0

Note: The term 'environment-related technologies' refers to patent applications in the following thematic areas: general environmental management; energy generation from renewable and non-fossil sources; combustion technologies with mitigation potential; technologies specific to climate change mitigation; technologies with a potential or indirect contribution to mitigating emissions; emissions abatement and fuel efficiency in transportation; and energy efficiency in buildings and lighting.

Source: for greenhouse gas emissions, the share of renewable energy in gross final energy consumption and GDP in current PP€: Eurostat; for the number of patent applications in environment-related technologies: OECD demand and fuel use, growth in particular economic sectors (or the collapse of others), economic downturns or recessions, changes in the means of transport and demand, technological developments like the deployment of renewable energy technologies and demographic changes (European Environment Agency, 2015). Some of these influences are the result of government policies, others intervene beyond the short-term influence of governments. As an example of the latter, the collapse of the Soviet Union had a knock-on effect on the economies of former Soviet bloc countries such as Estonia, Latvia and Poland and, thus, on their greenhouse gas emissions. Most former Soviet states have managed to sustain these lower emission levels. Similarly, the economic downturn since 2008 has impacted positively on European greenhouse gas emissions.

Lastly, the share of renewable energy in gross final energy consumption in 2012 was highest (30% or more) in Austria, Finland, Latvia and Sweden. However, many of these countries have a strong hydropower sector and the data do not show the contribution from newer technologies such as wind or solar power. Therefore, it is also interesting to look at the changes in these shares since 2005. For the EU as a whole, the share of renewable energy in gross final energy consumption has increased by a factor of 1.6. For Malta, starting from a very low share in 2005, this share has increased nine-fold, for Bulgaria and the UK it has tripled and, for another seven countries, it has at least doubled. Relatively minor improvements can be seen in Finland and Latvia but these countries are already among the best performers.

More for countries with modest research funding

The Seventh Framework Programme (2007–2013) identified four main objectives within programmes targeting co-operation, ideas, people and capacities:

- The Specific Programme for Co-operation provided project funding for collaborative, transnational research. This programme was broken down into several themes, including health, energy and transportation.
- The Specific Programme for Ideas provided project funding for individuals and their teams engaged in frontier research. This programme was implemented by the European Research Council (Box 9.1).

Box 9.1: The European Research Council: the first pan-European funding body for frontier research

The European Research Council (ERC) was created in 2007 under the Seventh Framework Programme. Through peer-reviewed competitions, the best researchers receive funding to perform their frontier research in Europe. The ERC is currently part of the first pillar (Excellent science) of Horizon 2020, with a budget of € 13.1 billion representing 17% of the overall budget for Horizon 2020.

Since 2007, more than 5 000 projects have been selected for funding from more than 50 000 applications. The ERC counts eight Nobel laureates and three Fields medalists among its grant holders. Over 40 000 scientific articles acknowledging ERC-funding appeared in peer-reviewed high-impact journals between 2008 and 2013 and one-third of all ERC grantees have published in articles listed among the top 1% most highly cited publications worldwide.

Within the ERC, there are three core funding schemes and one additional scheme:

- *ERC Starting Grants* provide funding for young post-docs with 2–7 years of experience. Funding is available for up to five years, with a maximum amount of € 1.5 million, and the research must take place in public or private research institutions.
- *ERC Consolidator Grants* focus on researchers with 7–12 years of experience who are about to move from being supervised to being an independent researcher. Funding is also for five years but with a maximum allocation of € 2 million.
- *ERC Advanced Grants* fund excellent researchers of any age or nationality to pursue groundbreaking high-risk projects. Funding is for five years and up to € 2.5 million.
- *Proof of Concept Grants* were launched in 2011 to promote the innovation potential of ideas resulting from ERC-funded research. Funding is for 18 months and up to € 150 000.

ERC grants can be seen as proxy for scientific excellence. Almost 600 research institutions from 29 countries – both EU member states and countries associated with the Seventh Framework Programme – have hosted at least one ERC grantee after the completed calls of 2007–2013. The great majority of the ERC grantees are hosted by institutions located in the EU (86 %). Most of the ERC grantees are nationals from the country of their host institution, with the notable exception of Switzerland and Austria (Figure 9.7). In absolute numbers, the UK hosts the largest group of foreign grantees (426), followed by Switzerland (237). Among EU members, the share of foreign grant-holders is very small in Greece (3 %), Hungary (8 %) and Italy (9 %). Some nationalities seem to prefer to work abroad rather than at home: around 55 % of the Greek, Austrian and Irish grantees are based in foreign countries. The absolute numbers are particularly high for Germany and Italy, with 253 and 178 nationals respectively hosted by institutions abroad (ERC, 2014).

- The Specific Programme for People funded the training, career development and mobility of researchers between sectors and countries worldwide. It was implemented through the Marie-Skłodowska-Curie Actions[12] and Specific Actions to Support European Research Area policies.

- The Specific Programme for Capacities funded research infrastructure for SMEs. It also hosted the following smaller programmes: Science in Society, Regions of Knowledge, Research Potential, International Co-operation and the Coherent Development of Research Policies.

By December 2014, almost half of all research projects within the Seventh Framework Programme had been completed. More than 43 000 scientific publications has been reported from 7 288 projects, almost half of which had appeared in high-impact journals. Germany and the UK had the largest number of applicants for project funding, about 17 000 over 2007–2013, whereas the much smaller Luxembourg and Malta each had less than 200 (Table 9.11).

When it comes to measuring the success rate, defined as the number of proposals retained, a different ranking emerges. Belgium, the Netherlands and France stand out here, with a success rate of at least 25%. If we take population size into account, it is the smaller countries that have been the most successful, with Cyprus and Belgium both having more than 500 retained proposals per million inhabitants.

In financial terms, the largest countries received the bulk of funding in absolute terms and France, Belgium and the Netherlands the greatest shares. However, if we compare Seventh Framework Programme funding with national levels of research funding, it transpires that framework funding is relatively higher for those countries with modest levels of national funding. This is the case for Cyprus, for instance, where framework funding amounted to almost 14% of GERD, as well as for Greece (just over 9%) and Bulgaria (more than 6%).

12. The Marie Skłodowska-Curie Actions provide researchers with grants at all stages of their career and encourage transnational, intersectorial and inter-disciplinary mobility. Between 2007 and 2014, more than 32 500 EU researchers received this type of funding.

A successful model

The ERC has been widely acknowledged as a highly successful model for competitive research funding. Its existence has had a strong impact at the national level. Since the ERC was created in 2007, 11 member states have set up national research councils, bringing the total to 23. Funding schemes inspired by the ERC structure have been launched by 12 member states: Denmark, France, Germany, Greece, Hungary, Italy, Ireland, Luxembourg, Poland, Romania, Spain and Sweden.

The ERC calls for proposals are very competitive: in 2013, the success rate was just 9% for Starting and Consolidator Grants and 12% for Advanced Grants. Consequently, 17 European countries* have developed national funding schemes to support their 'finalists' in the ERC competitions who were not awarded a grant (ERC, 2015).

* Belgium, Cyprus, Czech Republic, Finland, France, Greece, Hungary, Ireland, Italy, Luxembourg, Norway, Poland, Romania, Slovenia, Spain, Sweden and Switzerland

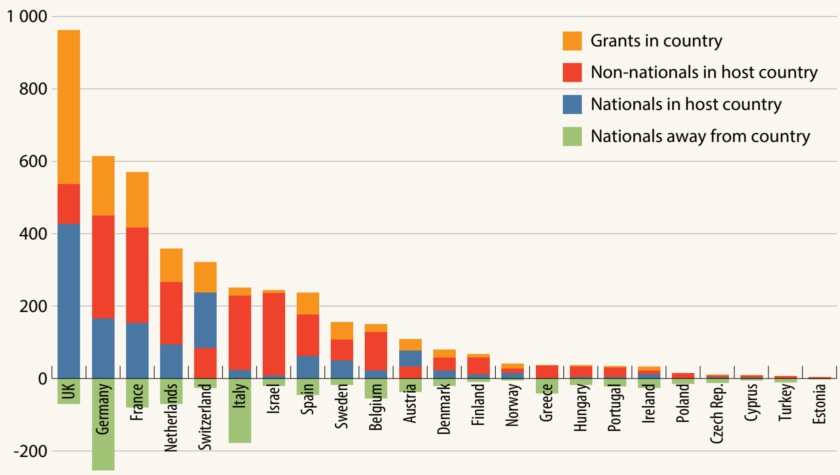
A scheme open to researchers everywhere

The ERC is open to top researchers from anywhere in the world. To raise awareness and forge closer ties with counterparts abroad, the ERC has toured all continents since 2007. The ERC also offers young researchers the opportunity to come to Europe to join the research teams of ERC grantees, an initiative supported by non-European funding agencies. Agreements have been signed with the National Science Foundation in the USA (2012), the Government of the Republic of Korea (2013), the National Scientific and Technical Research Council (CONICET) in Argentina (2015) and with the Japan Society for the Promotion of Science (2015).

Source: compiled by authors

Figure 9.7: **Grants by the European Research Council, 2013**

Top 23 grantees by country of host institution and origin of grantee



Source: ERC (2014)

Table 9.11: **EU member states' performance in calls for research proposals within Seventh Framework Programme, 2007–2013**

	Applicants in retained proposals					European Commission contribution to retained proposals				
	Total Number	Success rate (%)	Rank	Per million Inhabitants	Rank	Total (€ millions)	Success rate (%)	Rank	Share of R&D (%)	Rank
Austria	3 363	22.3	8	402.3	10	1114.9	20.9	6	2.0	21
Belgium	5 664	26.3	1	521.0	2	1806.3	23.8	2	3.4	9
Bulgaria	672	16.4	24	90.5	24	95.2	10.2	26	6.6	3
Croatia	388	16.9	23	90.3	25	74.2	11.1	24	3.0	14
Cyprus	443	15.0	27	542.3	1	78.9	9.7	27	13.8	1
Czech Rep.	1 377	20.3	13	132.1	22	249.3	14.8	15	1.5	25
Denmark	2 672	24.2	4	483.1	4	978.2	22.5	5	2.0	22
Estonia	495	20.6	12	371.6	12	90.2	16.3	10	4.7	5
Finland	2 620	21.3	11	489.6	3	898.1	15.9	11	1.9	23
France	11 975	25.1	3	185.2	19	4653.7	24.7	1	1.5	26
Germany	17 242	24.1	5	210.3	16	6967.4	23.3	4	1.4	27
Greece	3 535	16.4	24	317.2	13	924.0	13.2	19	9.3	2
Hungary	1 498	20.3	13	149.8	20	278.9	15.0	14	3.4	8
Ireland	1921	21.9	9	425.4	8	533.0	17.2	9	2.9	15
Italy	11 257	18.3	20	190.6	18	3457.1	15.1	13	2.5	18
Latvia	308	21.6	10	145.4	21	40.7	13.3	18	4.6	6
Lithuania	411	20.0	15	131.9	23	55.1	14.2	16	3.0	13
Luxembourg	192	18.5	18	380.8	11	39.8	13.7	17	1.0	28
Malta	183	18.9	17	442.9	7	18.6	11.0	25	5.9	4
Netherlands	7 823	25.5	2	472.1	5	3152.5	23.6	3	4.0	7
Poland	2 164	18.5	18	56.5	27	399.4	11.9	21	2.2	20
Portugal	2 188	18.1	21	207.5	17	470.9	13.1	20	2.7	16
Romania	1 005	14.6	28	49.3	28	148.7	9.0	28	3.3	10
Spain	10 591	19.0	16	229.2	15	2947.9	15.3	12	3.0	12
Slovenia	858	15.6	26	421.0	9	164.3	11.2	23	3.1	11
Slovakia	467	17.9	22	86.6	26	72.3	11.6	22	2.5	19
Sweden	4 370	23.6	6	468.1	6	1595.0	19.7	7	1.8	24
UK	16 716	22.6	7	267.4	14	5984.7	19.6	8	2.6	17

Source: European Commission (2015b)

Structural funds: narrowing the innovation gap between regions

At the regional level, the innovation divide mirrors that of countries. Most of the regional *innovation leaders and followers* are located in the countries defined as *innovation leaders and followers*. However, some regions fall into a higher performance group than the country as a whole. These regions tend to encircle the capital and to be endowed with a high level of services and universities. This is the case for the Île de France region, for instance, which includes Paris but also happens to be surrounded by an 'innovation desert.' Other examples are the capital cities of Lisbon (Portugal), Bratislava (Slovakia) and Bucharest (Romania).

Between 2004 and 2010, about half of the regions in the EU moved into a higher performance group, nearly two-thirds of which were located in less innovative countries. Countries have benefited economically from the development of a single internal market, with the less advanced member states receiving an additional boost from the European Commission's structural funds which transfer money from the more advanced regions of the EU to the less advanced ones.

Between 2007 and 2013, € 42.6 billion in structural funds was committed to narrowing the innovation gap between European regions in research and innovation, almost 16.3% of all available funds. The bulk of this amount went to regions with a per-capita income that was 75% below the EU average.

An analysis by the European Commission (2014a) of regions' performance in the Seventh Framework Programme and their use of structural funds for R&D shows that those regions receiving more than 20% above the average amount of framework programme funding also perform well in innovation, with the majority being regional *innovation leaders and followers*, including capitals such as the greater Berlin area (Germany), Brussels (Belgium), London (UK), Stockholm (Sweden) and Vienna (Austria). None of the regional *modest innovators* attract above-average shares of framework programme funding or structural funds, with the notable exception of the Portuguese Autonomous Region of Madeira. More than half of the regions that attract neither type of funding are regional *moderate* or *modest innovators*, suggesting that these regions do not consider innovation a priority area for investment.

A drop in government spending on defence R&D

At this point, we shall examine the national priorities for research in 2005 with those at the end of the Seventh Framework Programme in 2013. Government research spending can be broken down into 14 socio-economic objectives by using government budget appropriations or outlays for R&D (GBAORD). On average, the largest share of total government spending is earmarked for the general advancement of knowledge, a category that includes all university R&D financed by general purpose grants from Ministries of Education – so-called General University Funds – and funds from other sources, there being a lot of variation between countries in the way they classify research expenditure (Table 9.12). On average, 52% of GBAORD is spent on the general advancement of knowledge but shares range from just 23% in Latvia to more than 90% in Croatia and Malta.

A comparison with the data for GBAORD in 2005 presented in the *UNESCO Science Report 2010* shows that the EU as a whole is spending less on defence research, including that for military purposes[13] and basic, nuclear and space-related R&D financed by Ministries of Defence. This drop is apparent for all four major spenders on defence in 2005 (France, Spain, Sweden and the UK) and parallels the trend observed in the USA regarding defence R&D (see Chapter 5). The UK was the only EU country in 2013 to devote a two-digit share (16%) of the government budget to defence R&D and, even then, it was down from 31% in 2005.

Less industrial research may reflect declining role of manufacturing

The EU is also spending less on education and on industrial production and technology, with the notable exception of Luxembourg, which spends much more on research in this field than any other member state. Relative spending on R&D in industrial production and technology has declined in half of member states but particularly in Greece, Luxembourg, Portugal, Slovenia and Spain. This trend possibly reflects the decreasing share of manufacturing in the economy and the growing sophistication of R&D in the services sector, such as financial services.

Research spending up in energy, health and infrastructure

Spending levels are up, on the other hand, in the fields of energy, health, transportation, telecommunications and other infrastructure. Spending on health research has increased most in Latvia, Luxembourg and Poland, reflecting growing concern about health issues and whether the EU can maintain an affordable health care system for its ageing societies. The rise in spending on research in energy reflects growing concern among the public and policy-makers as to the sustainability of modern economies, a trend foreseen in the *UNESCO Science Report 2010*. Among the major economies, spending shares on R&D in energy have increased in France, Germany and the UK and remained stable in Italy. Relative spending on R&D in transportation, telecommunications and other infrastructure has increased in about half of member states, especially in France, Slovenia and the UK.

Space research a strategic investment

Space research is considered an increasingly crucial area of science within the EU. The governments of Belgium, France and Italy devote a relatively large share of their budget appropriations to the exploration and exploitation of (civil) space. Greece and Italy both spend about 5% on the exploration and exploitation of the Earth. Space research is expected to generate knowledge and new products, including new technologies for combating climate change and improving security, while contributing to the EU's economic and political independence (European Commission, 2011). Thanks to the European Space Agency, it is a field of research in which Europeans can pursue a common purpose. The European Space Agency chalked up a world first in November 2014, with the successful landing of the small robotic probe Philae on a comet, 11 years after the Rosetta spacecraft left Earth. Box 9.2 discusses another important product of European space research in the past decade, the Galileo navigation system.

The newer member states have progressed

There has been a marked improvement in the volume of R&D conducted by the ten countries which joined the EU in 2004. Their share of total R&D spending increased from less than 2% in 2004 to almost 3.8% by 2013 and their R&D intensity from 0.76 in 2004 to 1.19 in 2013. Although their R&D intensity remains well below that of the EU15 countries, the gap has been narrowing consistently since 2004 (Figure 9.8).

For Bulgaria, Croatia and Romania, on the other hand, which joined the EU in 2007 and 2013 respectively, the situation has deteriorated. All three contributed less to EU28 GERD in

13. According to the Stockholm International Peace Research Institute, the five top EU spenders on defence in 2014 were France, Greece and the UK (2.2% of GDP), Estonia (2.0%) and Poland (1.90%).

Table 9.12: **EU government budget appropriation for R&D by socio-economic objective, 2013 (%)**
Data for 2005 are given between brackets for comparison

	Exploration and exploitation of the Earth	Environment	Exploration and exploitation of space	Transport, tele-communication and other infrastructure	Energy	Industrial production and technology	Health	Agriculture	Education	Culture, recreation, religion and mass media
EU28	2.0 (1.7)	2.5 (2.7)	5.1 (4.9)	3.0 (1.7)	4.3 (2.7)	9.2 (11.0)	9.0 (7.4)	3.3 (3.5)	1.2 (3.1)	1.1
Austria	1.7 (2.1)	2.4 (1.9)	0.7 (0.9)	1.1 (2.2)	2.6 (0.8)	13.3 (12.8)	4.9 (4.4)	1.7 (2.5)	1.7 (3.4)	0.3
Belgium	0.6 (0.6)	2.2 (2.3)	8.9 (8.4)	1.7 (0.9)	1.9 (1.9)	33.5 (33.4)	2.0 (1.9)	1.3 (1.3)	0.3 (4.0)	2.1
Bulgaria	4.3	1.5	2.0	1.1	0.2	7.8	2.0	20.0	7.3	1.1
Croatia	0.2	0.4	0.2	0.9	0.1	0.6	0.7	0.4	0.1	0.6
Cyprus	0.2 (1.9)	1.0 (1.1)	0.0 (0.0)	0.7 (1.5)	0.0 (0.4)	0.0 (1.3)	3.3 (10.4)	11.6 (23.5)	4.9 (8.2)	0.9
Czech Rep.	1.8 (2.3)	2.0 (2.9)	1.9 (0.8)	4.3 (4.1)	3.2 (2.4)	14.6 (11.9)	6.4 (6.8)	3.8 (5.0)	1.2 (2.8)	1.7
Denmark	0.4 (0.6)	1.6 (1.7)	1.3 (2.0)	0.6 (0.9)	4.0 (1.7)	7.9 (6.3)	12.6 (7.2)	3.5 (5.6)	3.9 (6.3)	1.6
Estonia	1.0 (0.3)	5.5 (5.4)	2.8 (0.0)	6.1 (8.1)	1.4 (2.2)	10.4 (5.8)	9.0 (4.3)	9.5 (13.5)	3.5 (6.4)	4.6
Finland	1.3 (1.0)	1.3 (1.8)	1.6 (1.8)	1.7 (2.0)	8.4 (4.8)	20.6 (26.1)	5.3 (5.9)	4.8 (5.9)	0.1 (6.1)	0.2
France	1.1 (0.9)	1.9 (2.7)	9.7 (9.0)	6.1 (0.6)	6.7 (4.5)	1.6 (6.2)	7.6 (6.1)	2.0 (2.3)	6.6 (0.4)	6.6
Germany	1.7 (1.8)	2.8 (3.4)	4.6 (4.9)	1.5 (1.8)	5.2 (2.8)	12.6 (12.6)	5.0 (4.3)	2.8 (1.8)	1.1 (3.9)	1.2
Greece	4.7 (3.4)	2.0 (3.6)	1.4 (1.6)	4.1 (2.2)	2.4 (2.1)	2.1 (9.0)	8.0 (7.0)	3.3 (5.4)	0.5 (5.3)	19.0
Hungary	1.8 (2.9)	2.6 (9.7)	0.5 (2.3)	6.7 (2.1)	6.8 (10.4)	14.2 (19.6)	10.3 (13.1)	8.2 (16.4)	0.6 (9.1)	2.2
Ireland	0.4 (2.4)	1.2 (0.8)	2.4 (1.5)	0.5 (0.0)	0.5 (0.0)	22.3 (14.2)	5.7 (5.3)	13.4 (8.9)	2.9 (2.4)	0.0
Italy	5.5 (2.9)	2.7 (2.7)	8.7 (8.0)	1.2 (1.0)	3.8 (4.0)	11.7 (12.9)	9.6 (9.9)	3.4 (3.4)	3.9 (5.3)	0.9
Latvia	0.5 (0.6)	10.4 (0.6)	0.8 (1.1)	4.9 (2.3)	6.7 (1.7)	16.0 (5.1)	15.4 (4.0)	16.3 (7.3)	2.2 (1.7)	1.7
Lithuania	3.0 (2.6)	0.2 (6.8)	0.0 (0.0)	0.0 (1.8)	4.6 (3.4)	5.4 (6.0)	4.7 (12.4)	5.3 (17.5)	0.6 (20.1)	2.1
Luxembourg	0.5 (0.5)	3.2 (3.1)	0.4 (0.0)	1.0 (3.4)	1.6 (0.6)	13.2 (21.0)	18.3 (7.8)	0.5 (1.8)	11.6 (16.4)	0.4
Malta	0.2 (0.0)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.4 (0.0)	0.6 (0.0)	3.8 (5.6)	0.1 (6.9)	0.0
Netherlands	0.5 (0.3)	0.7 (1.2)	3.5 (2.5)	2.6 (3.6)	2.1 (2.2)	8.8 (11.5)	4.9 (3.8)	3.1 (6.1)	0.5 (2.1)	0.5
Poland	3.4 (1.8)	5.9 (2.4)	2.4 (0.0)	6.6 (1.2)	2.2 (0.9)	11.1 (5.9)	14.8 (1.9)	4.9 (1.3)	4.3 (0.9)	0.8
Portugal	1.9 (1.6)	3.4 (3.5)	0.7 (0.2)	4.0 (4.5)	2.2 (0.9)	6.9 (15.1)	11.5 (7.6)	3.6 (9.9)	2.9 (3.4)	3.0
Romania	3.7 (1.2)	7.4 (2.1)	1.8 (2.4)	3.7 (3.4)	3.7 (0.9)	12.9 (10.7)	2.8 (4.4)	4.9 (4.3)	4.7 (0.3)	0.4
Slovakia	1.7 (0.6)	2.7 (3.3)	0.6 (0.0)	1.6 (1.0)	1.0 (11.5)	7.4 (0.0)	7.9 (1.6)	4.2 (5.0)	2.9 (3.6)	3.1
Slovenia	1.2 (0.4)	3.1 (3.1)	0.5 (0.0)	3.3 (0.8)	2.9 (0.5)	15.2 (22.6)	7.3 (2.0)	4.0 (3.2)	1.2 (2.7)	1.8
Spain	1.7 (1.6)	3.9 (3.0)	5.0 (3.5)	3.5 (5.5)	2.3 (2.2)	6.8 (18.5)	15.5 (8.2)	6.6 (6.3)	1.0 (2.2)	0.6
Sweden	0.4 (0.7)	2.1 (2.2)	1.9 (1.2)	5.0 (3.8)	4.0 (2.3)	2.6 (5.4)	1.7 (1.0)	1.5 (2.2)	0.2 (5.0)	0.1
UK	3.1 (2.3)	2.8 (1.8)	3.3 (2.0)	3.4 (1.1)	2.5 (0.4)	3.4 (1.7)	21.1 (14.7)	4.0 (3.3)	0.4 (3.5)	1.8

Note: A direct comparison between the data for 2005 and 2013 is impossible for all objectives, as the classification was revised in 2007. Social structures and relationships has been split into Education, Culture, recreation, religion and mass media and Political and social systems, structures and processes and Other civil research has been distributed over all other socio-economic objectives except defence. Furthermore, for some countries, the categorization of expenditure under General advancement of knowledge differs considerably between 2005 and 2013.

2013 than in 2007 and their R&D intensity has shrunk over the same period from 0.57 to 0.51. The economic crisis since 2008 cannot be blamed for this weak performance, as the relative performance of the other ten new member states improved even during the crisis years.

All 13 new member states have increased their scientific output, including when population is taken into account. The share of EU28 publications produced by the ten countries which joined in 2004 increased from 8.0% in 2004 to 9.6% in 2014 (Figure 9.9) and the share of three latest newcomers from 1.9% in 2007 to 2.1% in 2014. The scientific productivity of the ten countries which joined the EU in 2004 increased from about 405 publications per million inhabitants in 2004 to about 705 in 2014; this represents an increase of 74%, double the 36.8% rise for the EU15 over the same period. In Bulgaria, Croatia and Romania, scientific productivity increased by 48% between 2007 and 2014.

The quality of the scientific publications produced by these 13 countries has also improved. For the ten which joined in 2004, their share of papers among the 10% most-cited rose from 6.3% in 2004 to 8.5% in 2012. This progression has, nevertheless, been slower than for the EU15. Bulgaria,

Political and social systems, structures and processes	General advancement of knowledge: share of R&D financed from General University Funds	General advancement of knowledge: R&D financed from sources other than GUF	Defence	Total R&D appropriations (€ millions)
2.8	34.6 (31.4)	17.3 (15.1)	4.6 (13.3)	92 094
1.2	56.1 (55.0)	12.3 (13.1)	0.0 (0.0)	2 589
3.2	17.1 (17.8)	25.1 (24.2)	0.2 (0.3)	2 523
1.7	9.1	40.5	1.4	102
0.7	64.1	31.0	0.0	269
0.0	40.1 (28.7)	37.3 (22.9)	0.0 (0.0)	60
1.4	22.9 (25.4)	33.4 (27.3)	1.5 (2.5)	1 028
2.6	47.8 (45.3)	11.8 (20.6)	0.3 (0.7)	2 612
2.0	0.0 (0.0)	43.8 (49.2)	0.5 (1.0)	154
4.7	28.4 (26.1)	19.5 (15.2)	1.9 (3.3)	2 018
5.1	25.3 (24.8)	19.8 (17.8)	6.3 (22.3)	14 981
1.8	40.0 (40.6)	17.1 (16.3)	3.7 (5.8)	25 371
2.6	41.3 (42.2)	8.1 (17.0)	0.4 (0.5)	859
1.4	9.3 (9.1)	35.4 (5.0)	0.2 (0.1)	663
1.0	17.8 (64.3)	31.9 (0.1)	0.0 (0.0)	733
5.7	39.4 (40.3)	2.6 (5.8)	0.8 (3.6)	8 444
0.9	0.0 (74.6)	22.9 (0.0)	1.2 (0.0)	32
1.4	50.9 (0.0)	21.6 (0.0)	0.1 (0.2)	126
13.4	11.2 (16.4)	24.7 (25.6)	0.0 (0.0)	310
0.1	94.4 (89.9)	0.0 (0.0)	0.0 (0.0)	22
2.3	52.4 (49.0)	16.9 (10.8)	1.2 (2.2)	4 794
0.7	1.6 (5.3)	36.2 (76.9)	5.2 (1.3)	1 438
2.4	40.2 (38.8)	17.2 (10.4)	0.2 (0.6)	1 579
2.4	0.0 (0.0)	50.0 (40.9)	1.4 (1.7)	297
1.7	48.2 (25.6)	15.6 (35.9)	1.4 (8.3)	289
2.2	0.3 (0.0)	56.4 (59.7)	0.7 (4.9)	175
1.0	29.4 (17.8)	21.3 (11.0)	1.4 (16.4)	5 682
2.4	49.9 (46.1)	22.0 (12.7)	4.0 (17.4)	3 640
1.5	23.6 (21.7)	13.3 (16.0)	15.9 (31.0)	11 305

Source: Eurostat, June 2015; for 2005 data between brackets: Eurostat data cited in *UNESCO Science Report 2010*

newcomers, their share of the 10% most-cited papers rising from 6.3% in 2007 to 8.5% in 2012.

Twinning institutions to narrow the research gap

Within Horizon 2020, the EU launched the Teaming action in 2013 to help narrow the research gap with the newest EU members and specific non-EU countries. Universities and other research institutions from these countries can apply for competitive funding from the Research Executive Agency to execute a project in partnership with internationally leading institutions from all over Europe.

By early 2015, the first 31 projects had been selected (out of 169 proposals) for funding of € 500 000. One of these projects is developing the Wroclaw Centre of Excellence in new materials, nanophotonics, additive laser-based technologies and new management organization systems. Within this project, the Wroclaw University of Technology and the Polish National Centre for Research and Development are collaborating with the German Fraunhofer Institute for Material and Beam Technology and the University of Würzburg in Germany to develop this centre of excellence.

Programmes of mutual benefit to the EU and its partners

The EU's framework programmes invite countries beyond the EU to participate, including developing countries. Some are associated with the framework programmes through a formal agreement. For Horizon 2020, this includes Iceland, Norway and Switzerland (see Chapter 11), Israel (see Chapter 16) and countries at various stages of negotiations regarding their future accession to the EU, as in the case of several Southeast European countries (see Chapter 10) and both Moldova and Turkey (see Chapter 12). As part of its Association Agreement concluded with the EU in 2014, Ukraine has also formally become a Horizon 2020 partner (see Chapter 12). There is some doubt as to Switzerland's continued participation in Horizon 2020 after 2016, in light of the anti-immigration vote in a popular referendum in 2014 which flies in the face of one of the EU's key principles, the free movement of people (see Chapter 11).

A wider list of countries, including numerous developing ones, are in principle automatically eligible to submit research proposals through Horizon 2020 programmes. Association with the EU's framework programmes can represent a significant contribution to the partner country's research volume and help it develop linkages with international networks of excellence. In turn, the EU has derived substantial benefit from the scientific talent of countries from the former Soviet bloc and elsewhere (e.g. Israel) through its framework programmes.

Russian research centres and universities are participating in Horizon 2020 within international consortia (see Chapter 13). Moreover, in 2014, at the height of tensions over Ukraine, the Agreement on Co-operation in Science and Technology was renewed for another five years by the European Commission and the Russian government. A roadmap for establishing the EU–Russia Common Space for Research and Education is also currently being implemented, involving, *inter alia*, the stepping up of collaboration in space research and technologies.

China has enjoyed extensive co-operation with the EU ever since the signing of the EU–China Science and Technology Agreement in 1999. Relations have deepened, in particular,

Box 9.2: Galileo: a future rival for GPS

The European Galileo navigation system is potentially a serious rival for the US Global Positioning System (GPS). Equipped with the best atomic clocks ever used for navigation, the European system will have the precision of one second for every three million years. Its more inclined orbit will give it greater coverage than GPS, particularly over northern Europe.

Another difference between GPS and Galileo is that Galileo has always been a civil project, whereas GPS was designed by the US Department of Defense and only later adapted to civil use, in recognition of the potential for commercial spin-offs and the prospect of competitive systems being developed.

Once operational, Galileo will not only facilitate road, maritime and air traffic flows but should also help to develop services like e-ecommerce and mobile phone applications. It can also be used by scientists for atmospheric studies and environmental management. In 2014, an article published in *Science* reported that a GPS system had detected an elevation of land in Western USA caused by the prolonged drought in this region; satellite navigation systems could thus be used around the world to detect changes in the amount of water stored in the subsoil. Galileo should be able to offer these services once the first ten satellites out of 22 have been placed in orbit, alternately by the Russian Soyouz and European Ariane 5 launchers.

On 22 August 2014, satellites five and six were launched by Soyouz from French Guyana. However, they ended up in an elliptical orbit 17 000 km above the Earth rather than in their intended circular orbit 23 000 km above the Earth. An investigation into the mishap found that the fuel had frozen in the upper section of Soyouz.

The project has been plagued with problems since its inception in 1999. Initially, European countries were divided as to the project's usefulness, some considering Galileo superfluous, given the existence of GPS, others stressing the advantages of an independent navigation system for Europe.

The conclusion of an agreement with the USA in 2004 guaranteed the compatibility of the dual systems but the costs of Galileo then began to skyrocket: from € 3.3 billion initially to € 5.5 billion by 2014. This inflation put paid to the initial public–private partnership, two-thirds funded by the private sector; the partnership was abandoned in 2007 when the project was entrusted to the European Space Agency.

From this point on, the project took off. However, the German company entrusted with building the 22 satellites, OHB, proved incapable of delivering them on time. This forced the European Space Agency to appeal for help to OHB's competitors, Airbus and the French company Thales. Ultimately, the launch of satellites five and six was delayed a year, until August 2014. If all goes according to plan, all the remaining satellites will have been deployed by 2017.

In the meantime, other countries have launched their own programmes. These include the Russian navigation system Glonasa, the Chinese Beidou, the Japanese QZSS system and India's INRSS project.

Source: adapted from Gallois (2014)

since the creation of the EU–China Comprehensive Strategic Partnership in 2003. During the Seventh Framework Programme, China was the EU's third-largest partner country (after the USA and the Russian Federation) for the number of participating organizations (383) and collaborative research projects (274), particularly those focusing on health, environment, transportation, ICTs and the bio-economy (European Commission, 2014b).

Co-operation with China is significant for qualitative reasons, as many projects focus on frontier technologies, such as clean and efficient carbon capture. In addition to facilitating a convergence of views between researchers of different backgrounds, this co-operation has had some positive spillovers to other regions in in complex cross-disciplinary areas, one example being the project for Advancing Universal Health Coverage in Asia over 2009–2013).[14] The EU and China are also co-operating within Euratom[15] via its fission programme and construction of the International Thermonuclear Experimental Reactor in France to further research into nuclear fusion.[16] Between 2007 and 2013, nearly 4 000 Chinese researchers received funding through the Marie Curie Actions (European Commission, 2014b).

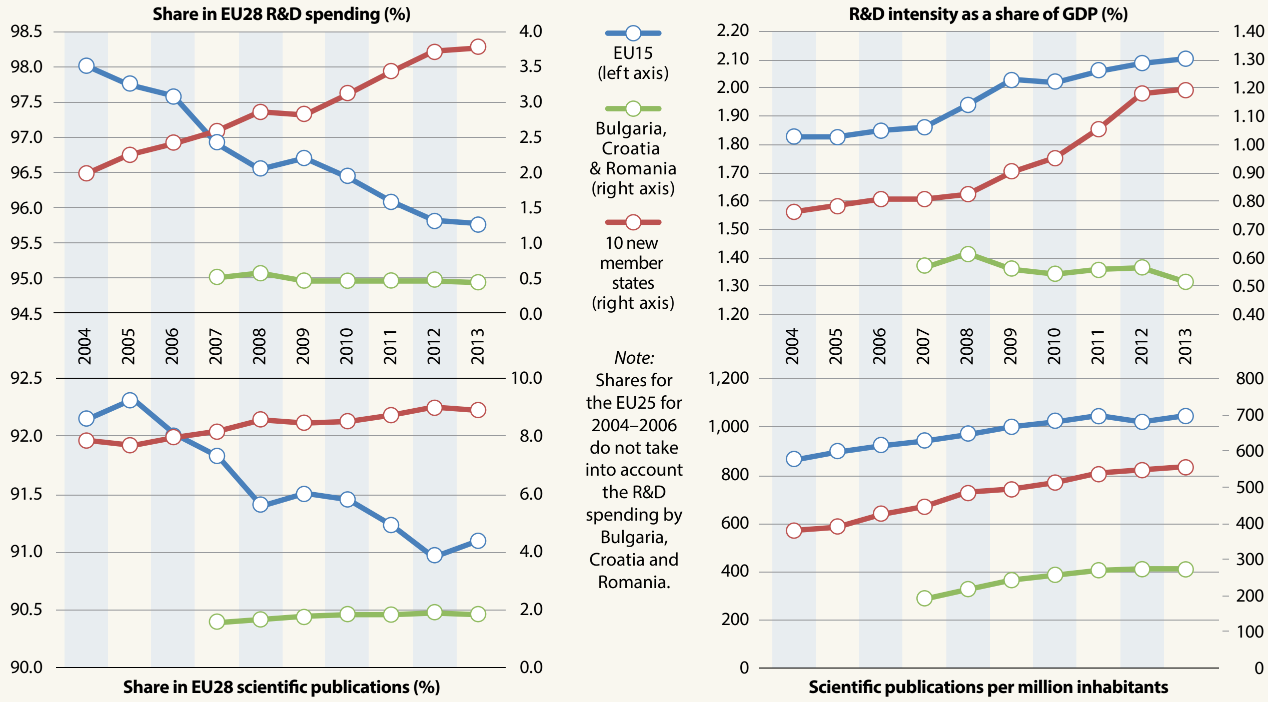
The EU intends for China to remain an important partner of Horizon 2020, even though China is no longer eligible for funding from the European Commission, meaning that EU

14. See: http://ec.europa.eu/research/infocentre/all_headlines_en.cfm

15. The European Atomic Energy Community (Euratom) was founded in 1957 with the purpose of creating a common market for nuclear power in Europe to ensure a regular and equitable supply of nuclear fuel to EU users.

16. For details, see the *UNESCO Science Report* 2010, p. 158.

Figure 9.8: **Uptake of STI activities by new EU member states, 2004–2013**



Source: for top two graphs: Eurostat, January 2015; for bottom two graphs: computed by Science–Metrix using Thomson Reuters' Web of Science

and Chinese participants will be expected to secure funding themselves for their joint project proposals. The initial work programme (2014–2015) under Horizon 2020 will most likely focus on food, agriculture and biotechnology; water; energy; ICTs; nanotechnology; space; and polar research.[17] China's co-operation with the Euratom Work Programme on topics related to fusion and fission is also expected to continue.

Initially framed within the *Cotonou Agreement* (2000) covering sub-Saharan, Caribbean and Pacific countries but excluding South Africa, the EU's co-operation with Africa is increasingly being organized in partnership with Africa's own frameworks for co-operation, in particular the African Union, as well as within the Joint Africa–EU Strategy adopted by African and European Heads of State at the Lisbon Summit in 2007.[18]

The ERAfrica initiative (2010–2014) funded by the Seventh Framework Programme has enabled European and African countries to launch joint calls for proposals in three thematic fields: Renewable Energy; Interfacing Challenges; and New Ideas; this has resulted in 17 collaborative research projects being backed by € 8.3 million. Meanwhile, the Network for the Coordination and Advancement of sub-Saharan Africa–EU Science and Technology Cooperation Plus (CAAST-Net Plus, 2013–2016) focuses on food security, climate change and health, with the participation of 26 research organizations across both continents.[19]

South Africa is the only African country to participate in the EU's Erawatch programme. One out of four of South Africa's almost 1 000 applications to the Seventh Framework Programme for research project funding was successful, representing a total of more than € 735 million, according to the 2012 Erawatch report on South Africa.

African countries are expected to participate in Horizon 2020 through similar arrangements to those for the Seventh Framework Programme. By mid-2015, institutions from 16 African countries had reportedly obtained € 5 million from Horizon 2020 in the form of 37 individual grants, the majority of which are related to climate change and health research. However, African involvement in Horizon 2020 so far is below expectations (and lower than for the Seventh Framework Programme); according to the EU, this primarily reflects the need to set up national contact points in more African countries and to increase their capacity through supportive EU projects.[20] Between 2008 and 2014, several EU countries figured among the closest collaborators of African scientists (see Figures 18.6, 19.8 and 20.6).

17. See: https://ec.europa.eu/programmes/horizon2020/horizon-2020-whats-it-china

18. http://ec.europa.eu/research/iscp/index.cfm?lg=en&pg=africa#policydialogue

19. http://www.caast-net-plus.org

20. See Ralphs, G. (2015) African participation drops in Horizon 2020. *Research*, 18 May: www.researchresearch.com

Figure 9.9: **Scientific publication trends in the European Union, 2005–2014**

Growth is generally stronger in the newer EU member states but Austria, Denmark and Portugal have also made great strides

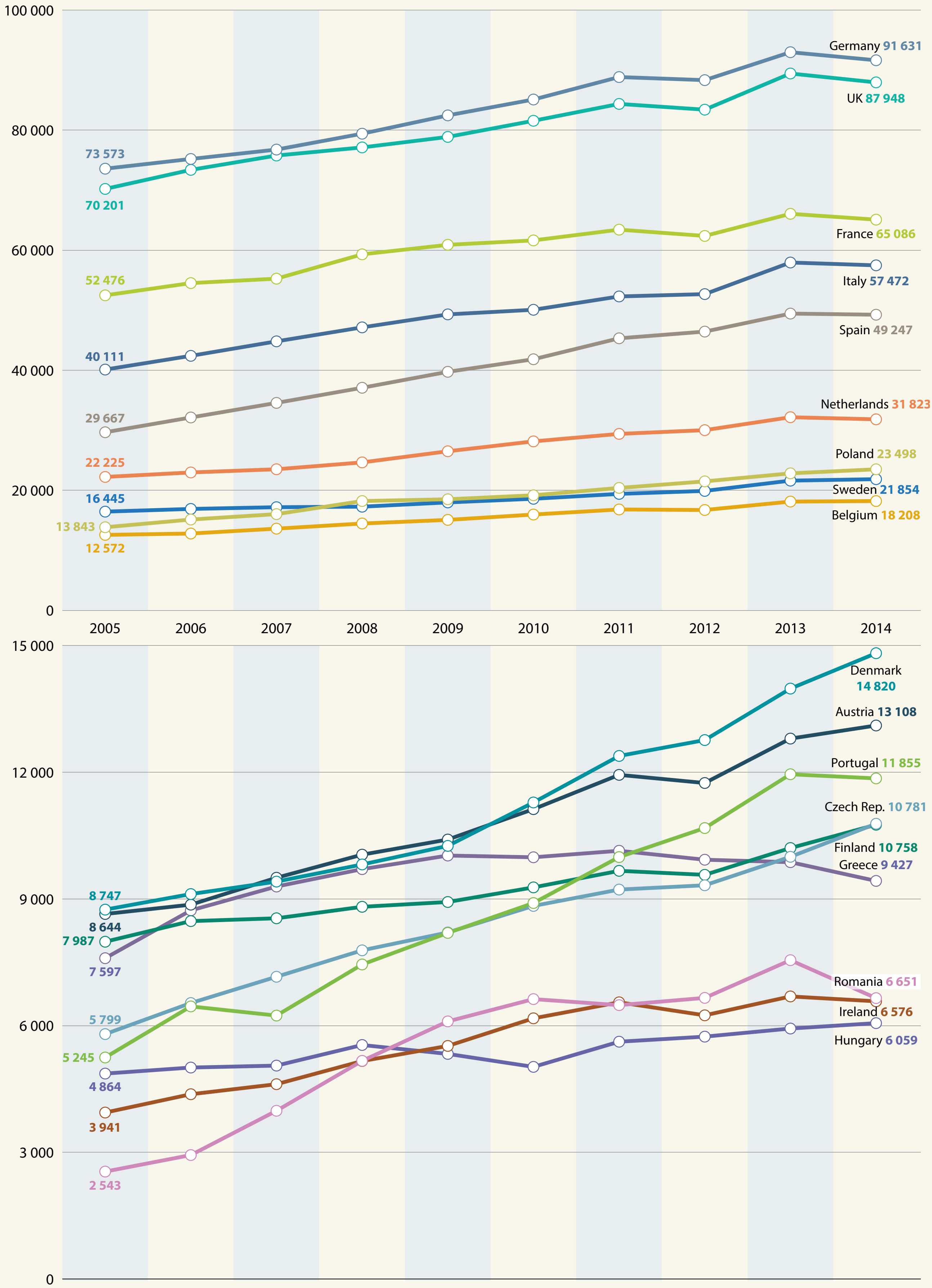
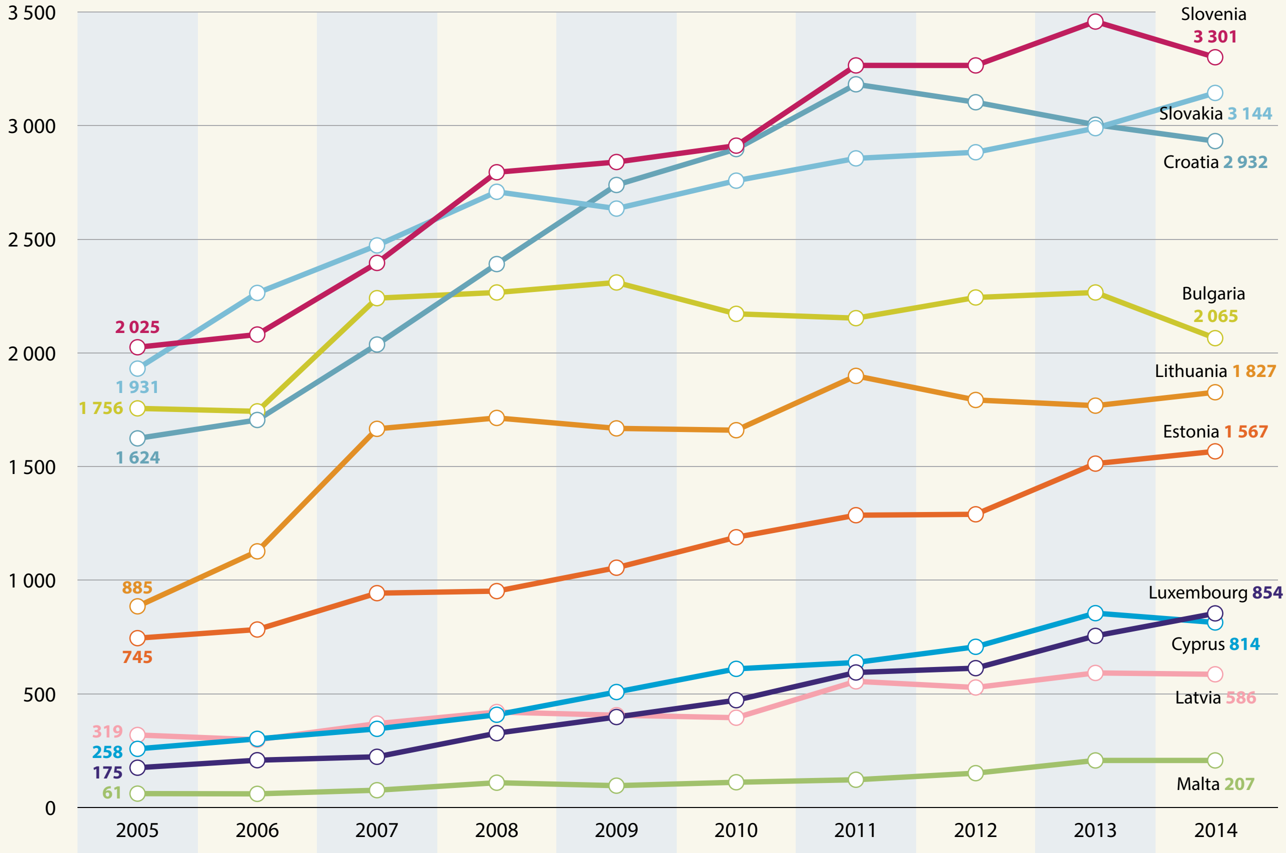
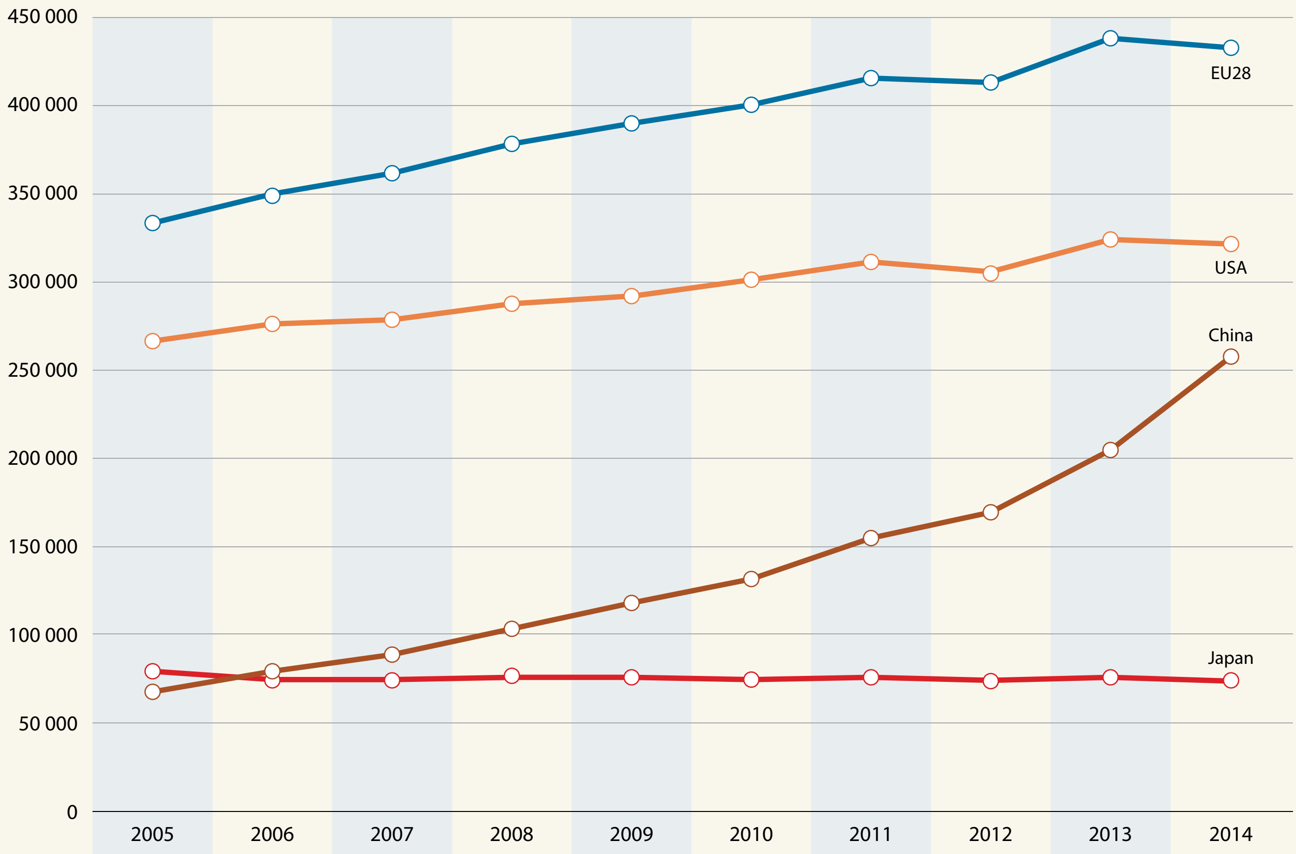


Figure 9.9 *(continued)*



With a 34% share of world publications in 2014, the EU is still the largest bloc for absolute authorship

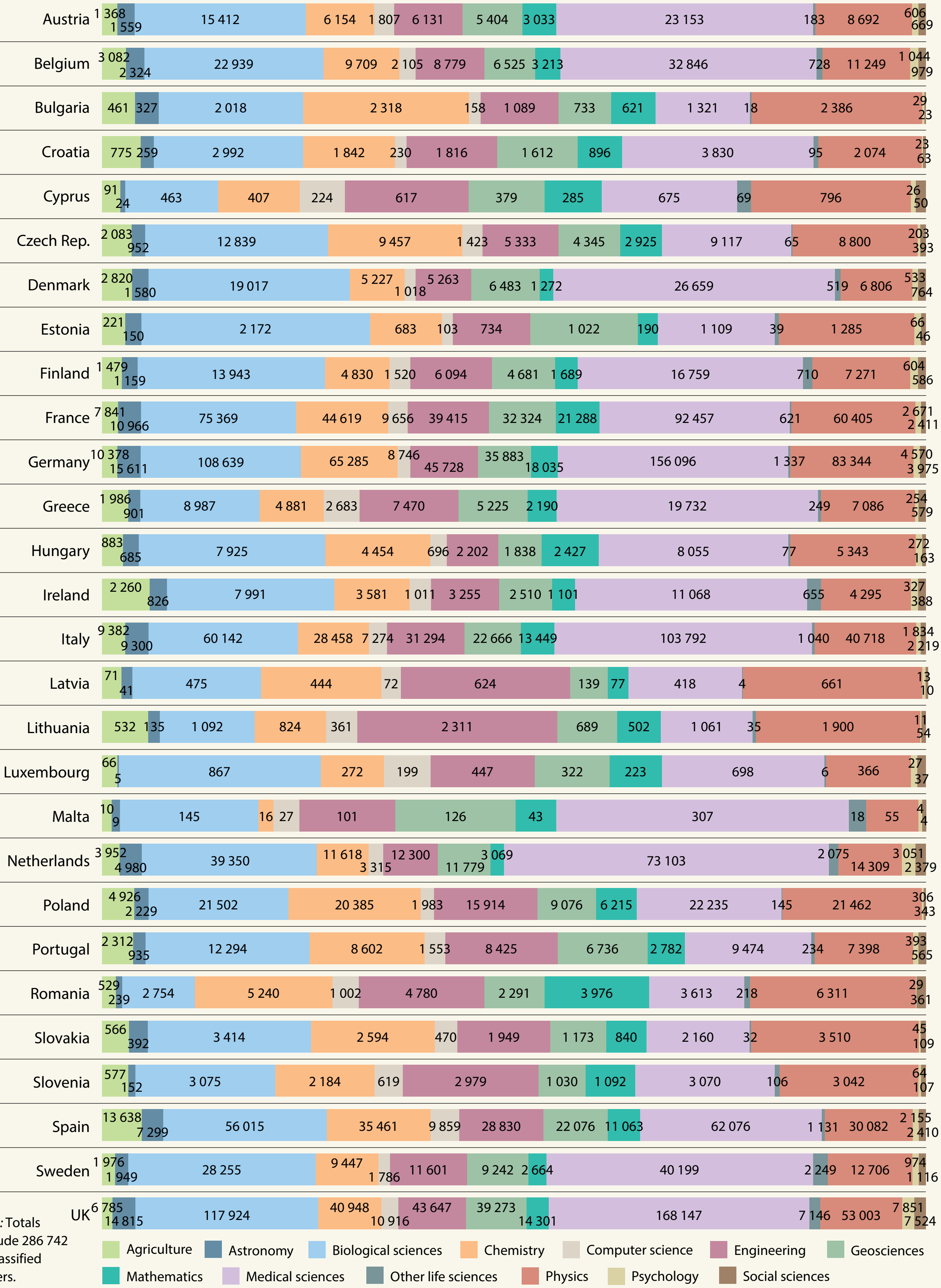


Chapter 9

Figure 9.10: **Publication profiles in the European Union, 2008–2014**

Life sciences dominate but the wide research base includes chemistry, physics, engineering and geosciences. French authors contribute to a fifth of the EU's scientific output in mathematics British authors contribute to a third of the EU's scientific output in psychology and social sciences

Cumulative totals by field, 2008–2014

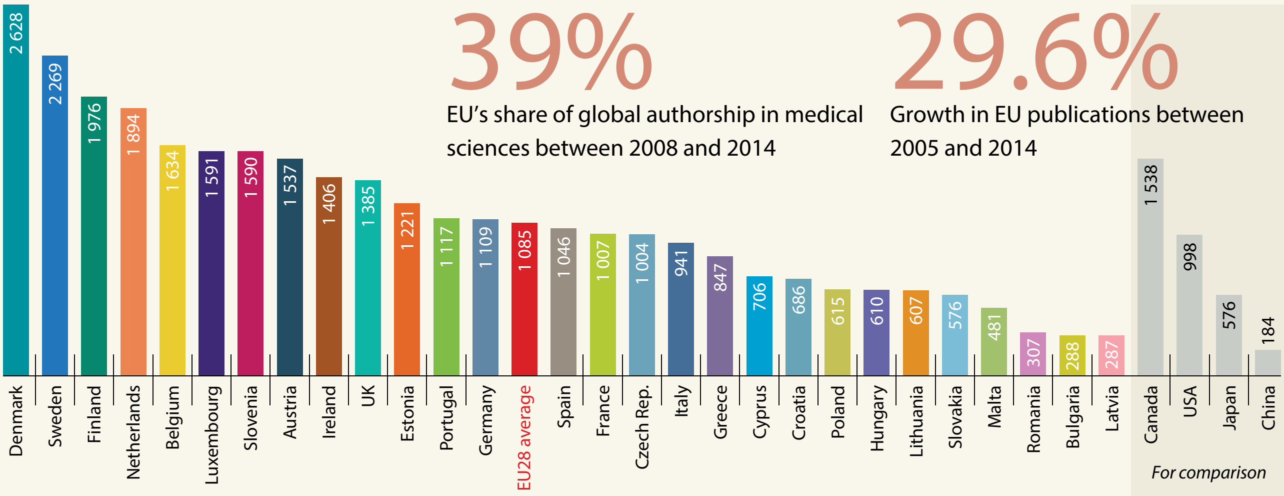


Note: Totals exclude 286 742 unclassified papers.

Figure 9.11: **Publication performance in the European Union, 2008–2014**

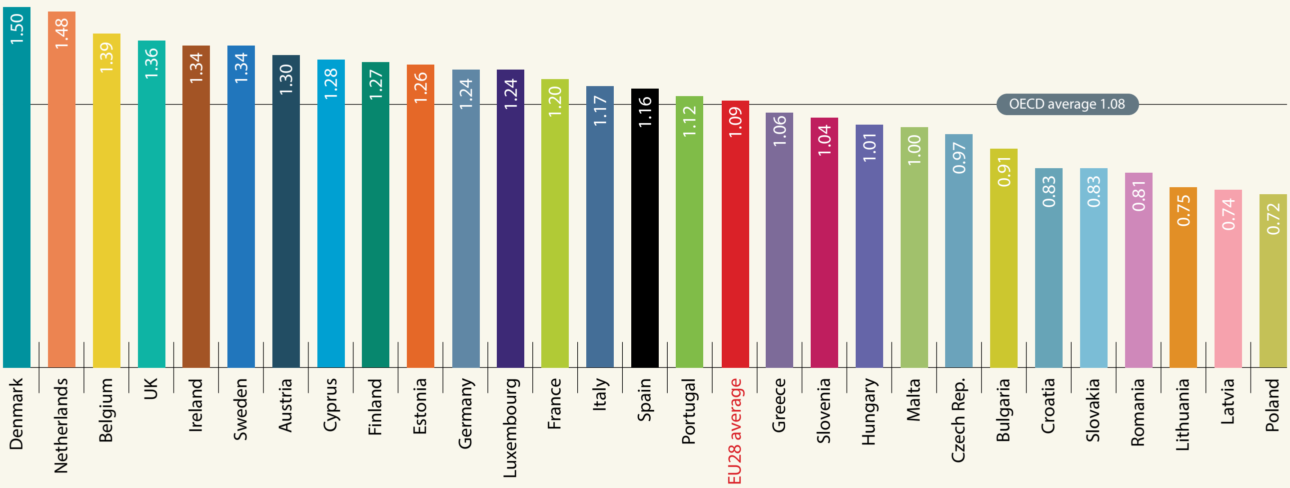
The Nordic EU members have the highest publication intensities

Publications per million inhabitants in 2014



Among the large EU members, the UK has the highest average citation rate, followed by Germany

Average citation rate for publications, 2008–2012



The Netherlands tops the EU for quality, Cyprus and Estonia lead among the newcomers

Share of papers among 10% most-cited, 2008–2012

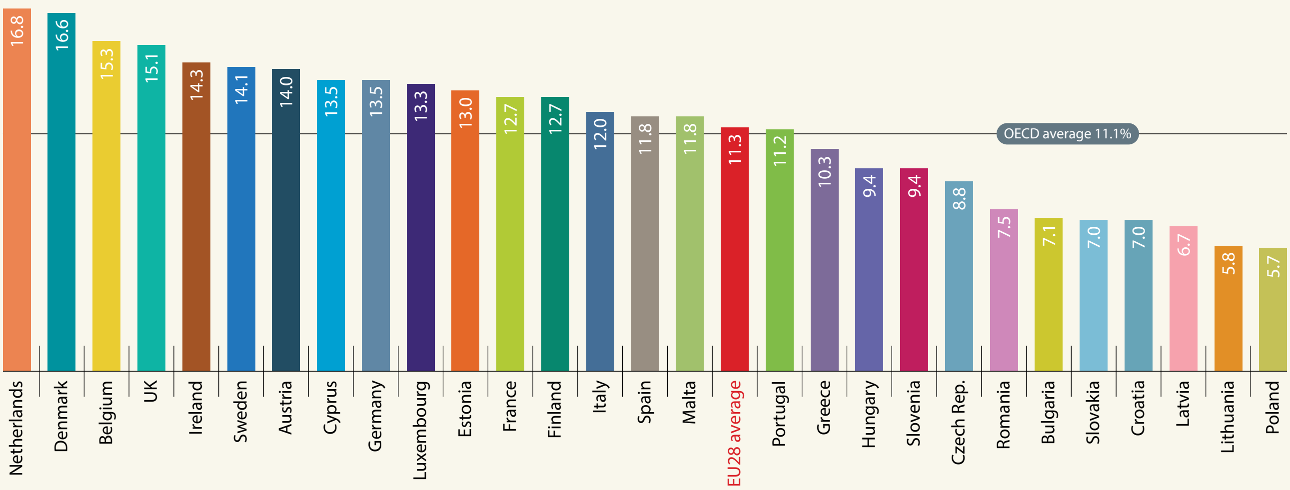
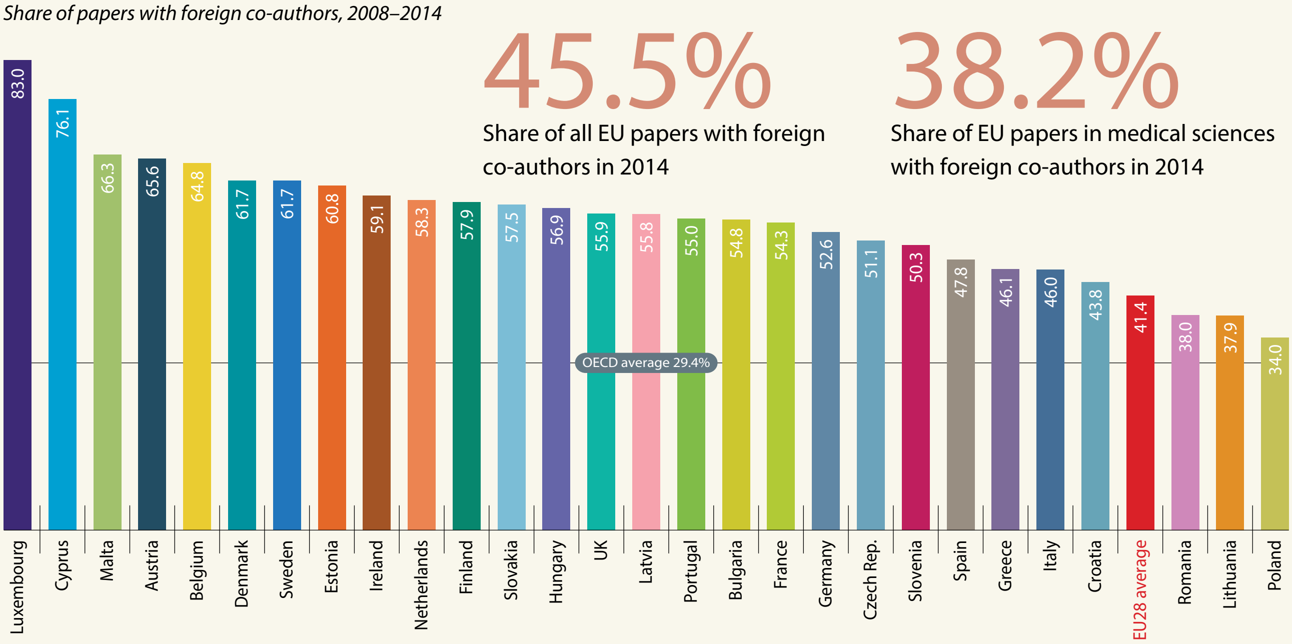


Figure 9.11 *(continued)*

All EU members are well above the OECD average for the intensity of international co-operation

Share of papers with foreign co-authors, 2008–2014



The USA is the top partner for 14 EU members, including all six most-populous ones

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Austria	Germany (21 483)	USA (13 783)	UK (8 978)	Italy (7 678)	France (7 425)
Belgium	USA (18 047)	France (17 743)	UK (15 109)	Germany (14 718)	Netherlands (14 307)
Bulgaria	Germany (2 632)	USA (1 614)	Italy (1 566)	France (1 505)	UK (1 396)
Croatia	Germany (2 383)	USA (2 349)	Italy (1 900)	UK (1 771)	France (1 573)
Cyprus	Greece (1 426)	USA (1 170)	UK (1 065)	Germany (829)	Italy (776)
Czech Rep.	Germany (8 265)	USA (7 908)	France (5 884)	UK (5775)	Italy (4 456)
Denmark	USA (15 933)	UK (12 176)	Germany (11 359)	Sweden (8 906)	France (6 978)
Estonia	Finland (1 488)	UK (1 390)	Germany (1 368)	USA (1 336)	Sweden (1 065)
Finland	USA (10 756)	UK (8 507)	Germany (8 167)	Sweden (7 244)	France (5 109)
France	USA (62 636)	Germany (42 178)	UK (40 595)	Italy (32 099)	Spain (25 977)
Germany	USA (94 322)	UK (54 779)	France (42 178)	Switzerland (34 164)	Italy (33 279)
Greece	USA (10 374)	UK (8 905)	Germany (7 438)	Italy (6 184)	France (5 861)
Hungary	USA (6 367)	Germany (6 099)	UK (4 312)	France (3 740)	Italy (3 588)
Ireland	UK (9 735)	USA (7 426)	Germany (4 580)	France (3 541)	Italy (2 751)
Italy	USA (53 913)	UK (34 639)	Germany (33 279)	France (32 099)	Spain (24 571)
Latvia	Germany (500)	USA (301)	Lithuania (298)	Russian Fed. (292)	UK (289)
Lithuania	Germany (1 214)	USA (1 065)	UK (982)	France (950)	Poland (927)
Luxembourg	France (969)	Germany (870)	Belgium (495)	UK (488)	USA (470)
Malta	UK (318)	Italy (197)	France (126)	Germany (120)	USA (109)
Netherlands	USA (36 295)	Germany (29 922)	UK (29 606)	France (17 549)	Italy (15 190)
Poland	USA (13 207)	Germany (12 591)	UK (8 872)	France (8 795)	Italy (6 944)
Portugal	Spain (10 019)	USA (8 107)	UK (7 524)	France (6054)	Germany (5 798)
Romania	France (4 424)	Germany (3 876)	USA (3 533)	Italy (3 268)	UK (2530)
Slovakia	Czech Rep. (3 732)	Germany (2 719)	USA (2 249)	UK (1750)	France (1744)
Slovenia	USA (2 479)	Germany (2 315)	Italy (2 195)	UK (1889)	France (1666)
Spain	USA (39 380)	UK (28 979)	Germany (26 056)	France (25 977)	Italy (24571)
Sweden	USA (24 023)	UK (17 928)	Germany (16 731)	France (10 561)	Italy (9371)
UK	USA (100 537)	Germany (54 779)	France (40 595)	Italy (34 639)	Netherlands (29 606)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

Given the sheer size of the EU, the following country profiles are necessarily brief and limited to those countries with a population of more than 10 million. Moreover, the European Commission regularly publishes detailed country profiles of EU member states via its Erawatch series. For a profile of Croatia and Slovenia, see Chapter 10.

BELGIUM

A steep rise in R&D intensity

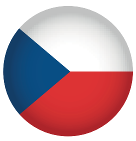
Belgium has a high-quality research system. There is a general consensus on the need to foster innovation-based competitiveness. R&D expenditure in both the public and private sectors has climbed steeply since 2005, placing Belgium among the EU leaders for R&D intensity (2.3% of GDP in 2013).

In Belgium, it is the regions and communities which are mostly responsible for research and innovation, the federal government's role being circumscribed to providing tax incentives and funding specific areas like space research.

Belgium experienced a period of political instability between 2007 and 2011, with the Dutch-speaking Flemish community advocating a devolution of power to the regions, whereas the French-speaking Walloon community preferred to maintain the status quo. The election of a new federal government in December 2011 put an end to the political stalemate, with the agreed partition of the Brussels – Halle – Vilvoorde region and the adoption of policies to tackle the country's economic downturn.

In the Dutch-speaking region of Flanders, science and innovation policy focuses on six thematic areas addressing societal challenges. In the French-speaking Walloon region, the focus is on a cluster approach, with the launch of transsectorial innovation platforms and new tools targeting SMEs. The French-speaking Brussels region, which also hosts the European Commission, has adopted a smart specialization approach.

CZECH REPUBLIC

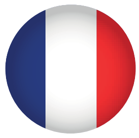


Reforms to develop innovation

The Czech Republic has a strong presence of R&D-performing foreign affiliates. However, there is insufficient co-operation and knowledge transfer between science and the business world. This has led to a weak domestic private base for R&D and explains the Czech Republic's average commitment to R&D by EU standards (1.9% of GDP in 2013).

Since 2007, the government has made an effort to reform the national innovation system, through the *National Policy for Research, Development and Innovation* covering 2009–2015 and the *National Innovation Strategy* (2011). These documents focus on infrastructure development, support for innovative firms and fostering partnerships between the public and private sectors. The EU's structural funds have also supported this reform of public research. The governance of the Czech innovation system remains very complex but it is expected that the new government Council for Research, Development and Innovation will help improve co-ordination.

FRANCE



Towards the Industry of the Future

France has a large science base but the level of business R&D is lower than in similar countries. The government estimates[21] that 'dis-industrialization' over the past decade has cost France 750 000 jobs and 6% of the GDP earned from industry.

France has substantially reformed its research and innovation system in recent years. Under President Sarkozy (2007–2012), the existing system of tax credits for co mpany research was recalculated on the basis of the volume of research spending rather than the size of the increase in spending over the previous two years. As a result, companies became entitled to a rebate of about 30% on their research expenditure for the first € 100 million and 5% thereafter. Between 2008 and 2011, the number of enterprises benefiting from this tax rebate doubled to 19 700. By 2015, the cost of this tax rebate was ten times higher (*circa* € 6 billion) than in 2003. A report published in 2013 by the Cour des comptes, France's watchdog for public finances, questioned the efficacy of an increasingly costly measure, while acknowledging that it had helped to preserve innovation and research jobs during the crisis of 2008–2009. It has also been suggested that larger companies ended up benefiting more from the tax credits than SMEs. In September 2014, President Hollande affirmed his intention of preserving the tax rebate, which is thought to project a positive image of France abroad (Alet, 2015).

A 'New Deal for Innovation'

Since the election of President Hollande in May 2012, the government has oriented its industrial policy towards supporting economic development and job creation, in a context of stubbornly high unemployment (10.3% in 2013), particularly among the young (24.8% in 2013). A total of 34 sectorial industrial plans have been introduced with a strong focus on innovation, as well as a *New Deal for Innovation* designed to 'promote innovation for all,' which

21. See (in French): www.gouvernement.fr/action/la-nouvelle-france-industrielle comprises a package of 40 measures to foster innovative public procurement, entrepreneurship and venture capital availability.

In April 2015, the government announced its Industry of the Future project. This project launches the second phase of the government's New Industrial France initiative, which aims to modernize industrial infrastructure and embrace the digital economy to tear down the barriers between services and industry. The Industry of the Future project focuses on nine priority markets: New Resources; Sustainable Cities; Ecological Mobility; Transportation of Tomorrow; Medicine of the Future; The Data Economy; Intelligent Objects; Digital Confidence; and Intelligent Food.

A first call for project proposals in future-oriented fields (3D printing, augmented reality, connected objects, etc.) is due to be launched in September 2015. Companies which modernize will be entitled to tax cuts and advantageous loans. The Industry of the Future project has been designed in partnership with Germany's Industry 4.0 project (Box 9.3). Germany will thus be a key partner, with both countries planning to develop joint projects.

GERMANY

Digitalizing industry: a priority

Germany is the EU's most populous member state and biggest economy. Manufacturing is one of the economy's strengths, particularly in medium-to-high-tech sectors such as automotive, machinery and chemicals, but its dominance of high-tech manufacturing, such as in pharmaceuticals and optical industries, has eroded over time. The Federal Ministry for Education and Research has developed a *High-tech Strategy* to improve co-operation between science and industry, in order to maintain Germany's international competitiveness. Launched in 2006, the strategy was updated in 2010, with a focus on public–private partnerships in forward-looking projects, including some oriented towards tackling the following societal challenges: health, nutrition, climate and energy security, communication and mobility. One key focus of the *High-tech Strategy* since 2011 has been the digitalization of industry (Box 9.3).

In 2005, the *Pact for Research and Innovation* was introduced. Within this pact, the federal government and the regions

Box 9.3: Germany's strategy for the fourth industrial revolution

The German government has taken a distinctly forward-looking approach to what Germans call Industry 4.0 or, in other words, the fourth industrial revolution; this entails bringing the internet of things and the internet of services to industry, estimated by Accenture to add € 700 billion to the German economy by 2030.

Germany's high-tech strategy since 2011 has had a strong focus on Industry 4.0. The German government has a dual plan. If Germany can manage to become a leading supplier of smart manufacturing technologies, such as cyber-physical systems, this should give a huge boost to German machinery and plant manufacturing, as well as to the automation engineering and software sectors. The hope is that a successful Industry 4.0 strategy will help Germany's manufacturing industry retain its dominant position in global markets.

Based on a literature review, Hermann *et al.* (2015) define six design principles of Industry 4.0, namely, interoperability (between cyber-physical systems and humans), virtualization (through which cyber-physical systems monitor production), decentralization (with cyber-physical systems making independent decisions), real-time capability (to analyse production data), service orientation (internally but also by offering individualized products) and modularity (adapting to changing requirements).

In addition to modernizing industry, customizing production and generating smart products, Industry 4.0 will address issues such as resource and energy efficiency and demographic change, while promoting a better work–life balance, according to Kagermann *et al.* (2013). Some trade unions, however, fear an increase in job insecurity, such as via cloud workers, and job losses.

A new Industry 4.0 platform called Made in Germany was launched in April 2015. It is operated by the federal government (economic affairs and research ministries), firms, business associations, research institutes (in particular, the Fraunhofer institutes) and trade unions.

Although some Industry 4.0 technologies are already becoming a reality, with some smart factories like that of Siemens already in existence, a lot of research remains to be done.

According to the 2013 recommendations from the Industry 4.0 working group, the main research focus areas in the German strategy are (Kagermann *et al.*, 2013):

- Standardization and reference architecture;
- Managing complex systems;
- A comprehensive broadband infrastructure for industry;

(*Länder*) agreed to increase their joint funding of the major public research institutes regularly, such as the Fraunhofer Society or the Max Planck Society. In 2009, it was agreed to increase the annual growth rate of institutional funding from 3% to 5% for the period 2011–2015, in order to give the research output of Germany's public research institutes a further boost. In addition, the Central Innovation Programme for SMEs introduced in 2008 funds more than 5 000 projects annually.

FAIR: a major facility for basic research in physics

Germany is to host one of the world's largest centres for basic research in physics, the Facility for Antiproton and Ion Research (FAIR). The particle accelerator is being built in the city of Darmstadt and should be completed by 2018. Some 3 000 scientists from more than 50 countries are collaborating on the project design, in order to reduce costs and broaden the pool of expertise. In addition to Germany, the project involves seven EU partners (Finland, France, Poland, Romania, Sweden, Slovenia and the UK), plus India and the Russian Federation. The lion's share of the budget is being provided by Germany and the State of Hesse and the remainder by international partners.

Key targets for the coalition government

The coalition agreement signed by the Conservatives and Social Democrats three months after the federal election in September 2013 establishes the following targets, *inter alia*:

- raising GERD to 3% of GDP by the end of the legislature (2.9% in 2013);
- raising the share of renewable energy to 55–60% of the energy mix by 2035;
- reducing national greenhouse gas emissions by at least 40% by 2020 over 1990 levels;
- concluding Germany's nuclear phase-out by 2022 (decided in 2012 after the Fukushima nuclear disaster);
- introducing a nationwide minimum wage of € 8.50 (US$ 11.55) per hour in 2015, with industry being able to negotiate exceptions until 2017; and
- introducing a 30% quota for women on company boards of directors.

- Safety and security;
- Work organization and design;
- Training and ongoing professional development;
- Regulatory framework; and
- Resource efficiency.

Since 2012, the German Ministry of Education and Research has provided funding of more than € 120 million for Industry 4.0 projects so far. Furthermore, the Ministry for Economic Affairs and Energy is currently providing funds of nearly € 100 million through two programmes, Autonomics for Industry 4.0 and Smart Service World.

The Industry 4.0 strategy has a strong focus on SMEs. Although much of Germany's industry is buzzing from the Industry 4.0 talk, many German SMEs are not prepared for the structural changes that it implies, either because they lack the necessary specialist staff or because they are reluctant to initiate major technological change.

The German government hopes to overcome some barriers through pilot applications and best practice examples, by expanding the high speed broadband infrastructure further and by providing training. Other major challenges relate to data security and the creation of a digital single market at the European level.

Germany's competitors have also been investing in research on the digitalization of industry in recent years, such as through the Advanced Manufacturing Partnership in the USA (see Chapter 5), the Chinese Internet of Things Centre or the Indian Cyber-physical Systems Innovation Hub. According to Kagermann *et al.* (2013), this research may not be as strategically focused as in Germany.

The EU has also funded research on the topic through its Seventh Framework Programme, such as within the public–private partnership dubbed Factories of the Future, and is continuing to do so within Horizon 2020.

Moreover, France's Industry of the Future project has been designed in partnership with Germany's Industry 4.0 project with a view to developing joint projects.

See also: plattform-i40.de: www.euractive.com/sections/innovation-enterprise; www.euractive.com/sections/industrial-policy-europe

GREECE

Aligning research with societal challenges

Greece has a low R&D intensity (0.78% in 2013) by EU standards, despite a modest increase in recent years that may be tied to its economic woes, since Greece lost about one-quarter of its GDP in six years of recession. The structural problems of the Greek economy, which have led to a series of financial and debt crises over the past five years, have further weakened the Greek innovation system and science base. Greece performs poorly in technological innovation and has few high-tech exports. There is little exploitation of research results by the business sector, no integrated legal framework for those which perform research and a weak articulation of research policy with other policies.

Since 2010, the economic adjustment programme for Greece has focused on structural reforms to make the Greek economy more resilient to future shocks. These reforms are meant to foster growth by strengthening competitiveness and stimulating exports, for instance.

Since 2013, the General Secretariat for Research and Technology has embarked upon an ambitious reform of the Greek innovation system. Measures announced include the completion of *the National Strategy for Research, Technological Development and Innovation 2014–2020.* The emphasis is on developing research infrastructure and making research centres more efficient by aligning their mandate with societal challenges facing Greece. Greece is expected to benefit from a considerable amount of EU cohesion funding for research and innovation over the 2014–2020 period.

ITALY

A focus on partnerships and knowledge transfer

Italy devotes a smaller share of GDP to R&D than many of its larger neighbours (1.3% of GDP in 2013). This makes it difficult for Italy to move towards a more efficient research system and reduce its specialization in low-tech sectors.

In 2013, the Ministry of Education, the University and Research launched a strategic document, the *Horizon 2020 Italia*, to boost the Italian innovation system, by aligning national research programmes with European ones and by reforming the governance of the research system, such as through new competitive procedures, evaluation mechanisms and impact assessment of public funding. A year later, the government introduced the National Research Programme 2014–2020, which proposes strengthening the Italian research system by fostering public–private partnerships, knowledge transfer and better working conditions for researchers.

Business innovation is being supported by the design of new legal frameworks for innovative start-ups and by simplifying access to finance for SMEs. Innovative start-ups are:

- exempt from the costs of setting up their business;
- entitled to 12 months more than other firms to recover their losses;
- allowed to raise capital using crowdfunding;
- given easier access to government funding (Central Guarantee Fund for Small and Medium-Sized Enterprises);
- entitled to benefit from special labour law provisions which do not require them to justify entering into a fixed-term agreement; and
- the beneficiaries of several tax incentives, such as the possibility for personal income taxpayers who invest in innovative start-ups to obtain a tax credit equal to 10% of the amount invested up to a maximum of € 500 000.[22]

NETHERLANDS

Improving public–private co-ordination

The Netherlands is a strong performer in both science and innovation. In terms of both quantity and quality, scientific output is among the highest in the EU, when population is taken into account. Although R&D expenditure remains low (2.0% of GDP in 2013) in comparison with the other more advanced member states, it is increasing (1.7% of GDP in 2009).

The Netherlands' innovation policy aims to provide a favourable environment for all firms and targeted support for nine so-called top sectors; the top sectors approach was introduced in 2011 and helps businesses, the government and research institutes co-ordinate their activities (OECD, 2014). The nine top sectors are: agriculture and food; horticulture and propagation materials; high-tech systems and materials; energy; logistics; creative industry; life sciences; chemicals; and water. These nine sectors account for more than 80% of business R&D; over the 2013–2016 period, they are expected to generate more than € 1 billion (OECD, 2014).

22. See Latham and Watkins (2012) *Boosting Innovative Start-ups in Italy: the New Framework*. Client Alert no. 1442.

POLAND

A shift towards competitive research funding

For Poland, the benefit of accession to the EU was most visible in 2004–2008 when the risk of doing business dropped, Poland's attractiveness for investment and financial credibility improved and barriers to capital flows were eliminated. Poland took advantage of these years to modernize its economy, in part by investing in better quality education (Polish Ministry of Economic Affairs, 2014, p.60).

During the wider economic crisis of 2009–2013, the flow of investment to Poland and private consumption slowed but this only mildly affected Poland's economy, for several reasons. For one thing, Poland had used EU structural funds to develop its infrastructure. In addition, the Polish economy was less open than that of most other countries, so was less exposed to international turbulence. In addition, unlike in most other countries, foreign investment had been geared much more towards modernizing the industrial sector than towards the services sector. Poland also had low levels of private and public debt at the start of the crisis. Last but not least, Poland benefits from a flexible exchange rate (Polish Ministry of Economic Affairs, 2014, p.61–62).

R&D expenditure has been rising consistently since 2007. This said, Poland's R&D intensity remains well below the EU average, at 0.9% of GDP in 2013, and less than half of GERD is performed by the business sector. The need to make Polish companies more innovative and strengthen science–industry co-operation has been a long-standing challenge for Poland. Among the policy responses proposed in recent years, a series of major reforms to the science and higher education systems in 2010–2011 have shifted the focus towards competitive bidding for funding and a greater number of public–private partnerships. By 2020, half of the country's science budget should be distributed through competitive funding.

More recently, the 2013 *Strategy for Innovation and Effectiveness of the Economy 2020* aims to stimulate private-sector research and innovation. In parallel, the Enterprise Development Programme foresees, among other things, the introduction of tax incentives for innovative firms; the Smart Growth Operational Programme adopted in 2014 will be implementing the Enterprise Development Programme with a budget of € 8.6 million for R&D that focuses on the development of in-house innovation and funding business R&D.

The role of public procurement in supporting innovation has been stressed by a project implemented since 2013 by the National Centre for Research and Development. The project has selected 30 'brokers of innovation' who will deal with the commercialization of research and the creation of spin-off companies.

PORTUGAL

Technology transfer for smart specialization

Over the past decade, Portugal has largely enjoyed a political consensus and continuity in its policy for research and innovation. The focus has been on expanding the national innovation system, increasing public and private investment in research and training more researchers.

The economic recession had an impact on this drive but not overwhelmingly so. Despite this drive, however, Portugal remains below the EU average when it comes to public–private partnerships, knowledge transfer and employment in knowledge-intensive industries. One of the main challenges concerns the weak in-house technological organizational and marketing capabilities of SMEs.

In 2013, the government adopted a new *Strategy for Smart Specialization* and undertook an analysis of the strengths and weaknesses of the national innovation system. This led to a revision of the regulations governing the financing of research institutions and a re-orientation of indirect R&D funding towards international co-operation. The latter reform will ensure that the Portuguese innovation agency remains autonomous. It has already given rise to an evaluation of the national clustering strategy (providing support to 19 identified clusters), the creation of new advisory bodies and the launch of a Programme for Applied Research and Technology Transfer to Companies.

ROMANIA

Raising business R&D to 1% of GDP by 2020

Romania's innovation system is primarily based in the public sector: only 30% of the country's R&D is performed by the business sector. Romania's scientific output is among the lowest in the EU but it has improved significantly over the past five years. The *National Strategy for Research and Innovation 2007–2013* has encourged Romanian scientists to publish in international journals, increased the share of competitive funding, promoted public–private co-operation by providing grants for projects involving industrial partners and promoted business innovation by introducing innovation vouchers and tax incentives.

The new *National Strategy for Research and Innovation 2014–2020* is expected to introduce a shift from support for research and its corresponding infrastructure to support for innovation. It should include additional measures to orient research oriented towards practical goals, by developing a partnership for innovation. This partnership is expected to boost business R&D spending to 1% of GDP by 2020.

SPAIN

Making investment go further

Investment in R&D has suffered in Spain from the impact of the economic crisis. Fiscal constraints caused a cut in public R&D expenditure from 2011 onwards and business R&D expenditure began declining as early as 2008.

To minimize the impact of this financial drought, the government has taken a number of steps to improve the effectiveness of investment in R&D. The Law for Science, Technology and Innovation adopted in 2011 simplifies the allocation of competitive funding for research and innovation. The rationale behind this scheme is that legal reform will encourage foreign researchers to move to Spain and stimulate the mobility of researchers between the public and private sectors. The *Spanish Strategy for Science, Technology and Innovation* and the *State Plan for Scientific and Technical Research and Innovation*, adopted in 2013, follow a similar rationale.

New policies are being designed to facilitate technology transfer from the public to the private sector to promote business R&D. In 2013, several programmes were launched to provide risk and equity funding for innovative firms, one example being the European Angels Fund (*Fondo Isabel La Católica*) providing equity funding to business angels.

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

Innovation a priority investment

The UK is known for having a strong science base, a rich supply of high-level skilled professionals and for being a pole of attraction for globally mobile talents. The business world is adept at creating intangible assets and the country counts a large services sector, including financial services.

Policies focus on strengthening the UK's ability to innovate and commercialize new technologies. In 2013, research and innovation joined the list of priority areas for investment detailed in the *National Infrastructure Plan*.

Regional development agencies were dissolved in 2012, after the government decided that all programmes and funding for research and innovation should be co-ordinated henceforth at the national level. It is the ministerial Department for Business, Innovation and Skills which manages science and innovation policies at the national level, sponsoring the seven UK research councils, the Higher Education Funding Council (HEFCE) and the Technology Strategy Board.

Research funding can either be competitive and project-based for researchers from universities and public research institutes, through the country's research councils, or it can be disbursed through the HEFCE for England and its counterparts in Northern Ireland, Scotland and Wales. HEFCE provides annual grants for research, knowledge transfer and infrastructure development. These annual grants are conditional on the institution's research being of a minimum quality. HEFCE does not stipulate how the grant for research should be used by each institution.

The Technology Strategy Board is responsible for funding business innovation and technological development and for a range of programmes targeting innovation, such as the use of tax credits to fund business R&D. SMEs are entitled to a deduction of 125% in corporate tax for qualifying expenditure and large companies to a 30% deduction. In 2013, a Patent Box scheme was launched which offers a reduced rate of tax to profits from patents.

A pole of attraction for students

The UK has generally been an attractive destination for students and researchers. As of 2013, it not only hosted the largest number of ERC grantees of any EU country but also the largest number of non-nationals conducting ERC-funded research (Figure 9.7). Exports of education services were worth an estimated £ 17 billion in 2013, representing a key source of funding for the UK's university system. This system has come under pressure in recent years. In an effort to reduce the public deficit, the coalition government tripled student fees in 2012 to about £ 9 000 per year. To sweeten the pill, it introduced student loans but there is some concern that part

Box 9.4: The Ogden Trust: philanthropy fostering physics in the UK

The Ogden Trust was set up in 1999 by Sir Peter Ogden with £ 22.5 million of his personal wealth. The Trust originally provided high-achievers from state schools with scholarships and bursaries to attend leading private schools. In 2003, it broadened its scope to students wishing to study physics or an associated degree at a leading British university up to the completion of their master's degree.

The Trust also runs a programme which allows alumni to secure paid internships at UK universities for the purpose of conducting research in physics or to gain work experience in physics-related companies.

To address the shortage of school physics teachers with qualifications in physics, the Trust has launched the Scientists in Schools programme to provide funding for postgraduate, PhD and postdoctoral students to gain experience teaching physics before entering teacher training.

Source: Adam Smith, master's student in physics and Ogden Trust scholar of these loans may never be repaid. The steep rise in tuition fees may also deter students from pursuing their education to graduate level and discourage international students (British physics students from a modest background can apply for a scholarship from the Ogden Trust, see Box 9.4). In July 2015, the Chancellor of the Exchequer (Minister of Finance) placed the university system under renewed pressure by proposing cuts to government subsidies for tuition fees paid by UK and other EU nationals.

Despite the attractiveness of the UK and its reputation for quality – it produces 15.1% of the world's most highly cited articles for a share of just 4.1% of the global research pool –, its persistently low R&D intensity has been of concern to the country's scientific establishment (Royal Society *et al.,* 2015).

The country's openness to international flows of knowledge may also be at risk. The general election in May 2015 returned the Conservative government to power with a solid majority. In the run-up to the election, the prime minister had promised voters that the Conservatives would hold a referendum on whether or not the UK should remain a member of the EU by the end of 2017. This referendum will thus be held within the next two years and perhaps as soon as 2016. A British exit (Brexit) from the EU would have far-reaching repercussions for both British and European science (Box 9.5).

Box 9.5: **What impact would a Brexit have on European research and innovation?**

The cornerstones of the EU's single market are what are known as the four freedoms: the free movement of people, goods, services and capital. It is the free movement of people which has cristallized discontent in the UK. The government would like to restrict this freedom and is planning to consult the population on a possible exit from the EU by the end of 2017, if it does not obtain satisfaction from its European partners concerning its demand for a revision of relevant treaties.

The UK is one of the largest net contributors to the EU budget, so its departure from the EU would have far-reaching repercussions for both the UK and the EU. The negotiations over the various options for a post-withdrawal relationship would be complex. There exist several 'model relationships' for European countries situated outside the EU. The 'Norwegian model' or the 'Swiss model' are the options currently seen as being the most applicable to the UK. Were the UK's future relationship with the EU to be modelled on Norway, which is a member of the European Economic Area, the UK would continue to make a significant financial contribution to the EU – potentially even close to the level of its current net contribution of about € 4.5 billion. In this case, the UK would be subject to much of the body of EU law and policy, yet its future influence on the EU would be limited.

If, on the other hand, the UK opted for the Swiss model, it would not remain a member of the European Economic Area. The UK would have to pay less attention to EU legislation and make a smaller financial contribution but it would have to negotiate separate agreements in many different areas, including trade in goods and services, or the movement of people between the UK and the EU (see Chapter 11).

The impact of a Brexit on science and innovation in both the UK and in the EU would depend heavily on the post-withdrawal relationship between the UK and the EU. It is likely that the UK would wish to remain an associated member of the European Research Area, like Norway and Switzerland, in order to continue participating in the EU framework programmes. These are considered increasingly important in the UK for funding research, training PhDs and exchanging ideas and people. However, the co-operation agreement for each framework programme would have to be negotiated separately, especially if the UK were not a member of the European Economic Area. This could be a difficult negotiation, as Switzerland has discovered since the tightening of its own immigration laws in 2014, following a popular referendum, prompted the EU to grant Switzerland only limited rights to participation in Horizon 2020 (see Chapter 11).

The EU's structural funds would also be out of reach for the UK, were it to leave the EU. A withdrawal from the EU might also incite international firms to scale down their plans to invest in R&D in the UK. The country would no longer be a gateway to EU markets, nor would its probably stricter immigration laws be particularly supportive of such investment. Lastly, a Brexit would be likely to make the international movement of university researchers between the UK and the rest of Europe, or the world, more complicated and less appealing, owing to the greater anti-immigration sentiment in the country.

In its public discourse, the research community in the UK seems to be clearly against a Brexit. Within days of the May 2015 parliamentary elections, a campaign website entitled Scientists for the EU had been set up. A letter signed by prominent scientists was also published by the *Times* on 22 May 2015 and articles appeared in The *Guardian* newspaper on 12 May and in *Nature News* on 8 May 2015. According to an article published in the *Economist* on 29 April, whatever the British public decides, the referendum itself is likely to create 'political and economic turmoil' in Britain.

Were the Brexit to become a reality, whatever the post-withdrawal relationship, the UK would lose its driving seat for research and innovation within the EU, which would be a loss for both sides.

Source: Böttcher and Schmithausen (2014); The Economist (2015)

CONCLUSION

Innovation performance down for half of EU

The EU, in general, and the 19 members of the Eurozone, in particular, have been hard hit by the economic crisis. Unemployment rates have spiralled upwards, with one out of four EU citizens below the age of 25 years being without a job in 2013. This economic hardship has created political instability, with some countries questioning their place in the EU and the UK even contemplating a Brexit.

The Eurozone countries have had to bail out several banks over the past five years. Today, they face additional problems, as the growing public debt burden of some members sows doubts as to their financial credibility. Eurozone countries, the European Central Bank and the International Monetary Fund have all had to lend substantial amounts of money to Ireland, Italy, Portugal, Spain and, above all, Greece. Whereas the other countries have managed to restore their economy by implementing structural reforms, the Greek economy is still convalescent. Despite Greece having adopted a new austerity package in July 2015, there is still a risk that it may have to leave the Eurozone as a result of what increasingly appears to be an unbearable public debt burden.

The EU has adopted an energetic programme to 2020 to conjugate the crisis and foster smart, inclusive and sustainable growth, *Europe 2020*. One of the key strategies is the Innovation Union, a compilation of more than 30 commitments for improving the capacity of countries to innovate. The EU's eighth framework programme for research and technological development, Horizon 2020, is endowed with by far the greatest budget ever, € 80 billion. With almost one-third of this amount to be spent on promoting research excellence, Horizon 2020 should raise the EU's scientific output considerably.

Scientific excellence is being fostered by the European Research Council, which is responsible for 17% of the overall budget of Horizon 2020 in the form of grants to researchers at different stages of their career. The European Research Council has had a profound impact on scientific output and on national research funding, with many member states having created similar institutions and funding schemes.

Despite the framework programmes, EU funding makes up only a modest share of total funding for R&D. The lion's share comes from national governments and businesses. The EU has formulated an ambitious goal of spending 3% of GDP on R&D by 2020 but progress has been slow in many countries.

Although the gap between the least and most innovative countries has narrowed, the innovation performance of almost half of member states has worsened. This worrying trend is a consequence of the drop in the share of innovative companies, public–private scientific collaboration and the availability of risk capital. This calls for further support of innovation at both the EU and national levels by making access to finance easier for SMEs, facilitating the inflow of researchers from beyond the EU, by promoting collaboration within but also between the private and public sectors and by harmonizing national support programmes and even replacing them with EU support programmes to increase the scale of EU research and avoid overlap between national activities.

There is support for business innovation in the new Horizon 2020 programme but, even more importantly, member states are taking the initiative in this area. Several countries are re-emphasizing the importance of technology-intensive manufacturing, including France and Germany, and acknowledging the special role that SMEs play in this area by making funds more accessible to smaller companies. Knowledge and technology transfer are being reinforced through the promotion of public–private partnerships.

Only time will tell whether this intensified support for research and innovation has had a positive, marked impact on innovation in Europe. That analysis will have to wait for the next *UNESCO Science Report* in five years' time.

KEY TARGETS FOR THE EUROPEAN UNION

- At least 75% of people between 20 and 64 years of age should be employed by 2020;
- On average, 3% of GDP should be invested in research and development (R&D) by 2020;
- By 2020, greenhouse gas emissions should be limited by at least 20% compared to emission levels in 1990, 20% of energy should come from renewables and there should be a 20% increase in energy efficiency (known as the 20:20:20 target);
- School dropout rates should be reduced to below 10% and at least 40% of people between 30 and 34 years of age should have completed tertiary education by 2020;
- The number of persons at risk of poverty or social exclusion should be reduced by at least 20 million by 2020.

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Southeast European countries are advised to invest more and better in research and innovation, prioritizing investment and a 'smart specialization' of the region.

Djuro Kutlaca

The distinctive blue trams in Zagreb, Croatia, are equipped with an energy recovery system. When the driver brakes, the power generated is fed back into the electrical network.

Photo: © Zvonimir Atletic / Shutterstock.com

10 · Southeast Europe

Albania, Bosnia and Herzegovina, Croatia, Former Yugoslav Republic of Macedonia, Montenegro, Serbia, Slovenia

Djuro Kutlaca

INTRODUCTION

A heteroclitic region with a common goal

Southeast Europe[1] was home to 25.6 million inhabitants in 2013. The region is characterized by strong economic disparities, with GDP per capita being three times higher in the richest country (Slovenia) than in the poorest (Albania) [Table 10.1].

Countries are also at different stages of European integration. Slovenia has been a member of the European Union (EU) since 2004 and Croatia since 2013. Three countries have candidate status: the Former Yugoslav Republic of Macedonia since 2005, Montenegro since 2010 and Serbia since 2012. Albania was proposed for candidate status in June 2014. As for Bosnia and Herzegovina, it was identified as a potential candidate for EU membership as long ago as June 2003, during the Thessaloniki European Council Summit, but uncertainty hangs over the procedure for its membership. For all five non-member countries, European integration represents the only viable project for ensuring social and political coherence. Their integration would benefit Slovenia and Croatia too, as prosperous neighbours would offer the best guarantee of political stability and economic growth.

1. Excluding Greece; Greece is mentioned at times in the present chapter for comparative purposes but, having been a member of the European Union since 1981, it is covered in Chapter 9.

Following the disintegration of Yugoslavia in the 1990s, all Southeast European countries were confronted with the challenge of post-socialism. Unfortunately, this economic transition came at a cost; it fragmented and deteriorated countries' science systems, resulting in brain drain and obsolete infrastructure for research and development (R&D), as described in the *UNESCO Science Report 2005*. Like Croatia and Slovenia, all five non-EU countries have since completed their transition to open market economies. They remain burdened, however, with high unemployment rates, unacceptable levels of corruption and underdeveloped financial systems.

Economies shaken by the global recession

Croatia, Greece and Slovenia have been more badly affected by the global financial crisis than their neighbours (Table 10.1), having experienced negative average growth rates between 2009 and 2013. Across the region, recovery has been fragile and partial, with unemployment rates rising steeply in Croatia, Greece, Serbia and Slovenia and remaining high in the other countries. Like the Eurozone, the Western Balkans are experiencing what the International Monetary Fund (IMF) terms 'low-flation', a combination of durably poor economic growth and low inflation rates which raise the spectre of deflation. With a deficit of 12.7% and 14.7% respectively in 2013, according to Eurostat, Greece and Slovenia are among the seven countries which failed to respect the 3% deficit ceiling imposed by the Eurozone's[2] Stability Pact.

2. The Eurozone comprises the 19 EU countries which have adopted the single currency of the euro.

Table 10.1: **Key socio-economic indicators for Southeast Europe, 2008 and 2013**

	Inflation, consumer prices (annual %)		Annual average GDP growth rate		GDP per capita, current $PPP		Unemployed (% of labour force)		Employment in industry (% total employment)		Gross fixed capital formation * (% of GDP)		Exports of goods and services % of GDP)		FDI net inflows (% of GDP)	
	2008	2013	2002–2008 (%)	2009–2013 (%)	2008	2013	2008	2013	2008	2012	2008	2012	2008	2012	2008	2012
Albania	3.4	1.9	5.5	2.5	8 874	10 489	13.0	16.0	13.5	20.8^{-2}	32.4	24.7	29.5	31.3	9.6	10.0
Bosnia and Herzegovina	7.4	-0.1	5.6	-0.2	8 492	9 632	23.9	28.4	–	30.3	24.4	22.1	41.1	31.2	5.4	2.0
Croatia	6.1	2.2	4.4	-2.5	20 213	20 904	8.4	17.7	30.6	27.4	27.6	18.4	42.1	43.4	8.7	2.4
Greece	4.2	-0.9	3.6	-5.2	29 738	25 651	7.7	27.3	22.3	16.7	22.6	13.2	24.1	27.3	1.7	0.7
FYR Macedonia	8.3	2.8	4.1	1.5	10 487	11 802	33.8	29.0	31.3	29.9	23.9	21.2	50.9	53.2	6.2	2.9
Montenegro	8.8	2.1	5.6	0.2	13 882	14 318	16.8	19.8	19.6	18.1	27.7	16.9	38.8	42.4	21.6	14.1
Serbia	12.4	7.7	4.9	0.0	11 531	12 374	13.6	22.2	26.2	26.5	20.4	26.3^{-1}	31.1	38.2^{-1}	6.3	0.9
Slovenia	5.7	1.8	4.5	-1.9	29 047	28 298	4.4	10.2	34.2	30.8	27.5	19.2^{-1}	67.1	71.3^{-1}	3.3	-0.5

-n = data refer to n years before reference year.

Source: World Bank's World Development Indicators, January 2015

The effects of the crisis can be observed in the Western Balkans through the changing structure of exports in 2009–2010. Some studies show that intraregional Western Balkan trade is relatively concentrated, with the top six products representing 40% of total imports: four commodity products (mineral fuels, iron, steel and aluminium) and two other industrial product types: beverages and electrical machinery and equipment. The main export market for all Western Balkan economies is the EU. This high level of dependence is exacerbated by EU trade preferences and the prospect of EU membership for Western Balkan countries (Bjelić *et al.*, 2013).

Easing into EU integration via regional trade

All seven countries have been party to the Central European Free Trade Agreement (CEFTA) at one time. CEFTA was launched in 1992 to help countries prepare for EU integration and counted Poland, Hungary, the Czech Republic and Slovakia among its initial members. Slovenia joined in 1996 and Croatia in 2003 but their membership automatically ended once they became EU members (see Chapter 9).

On 19 December 2006, the five remaining countries of Southeast Europe joined CEFTA, as well as the United Nations Interim Administration Mission in Kosovo[3] on behalf of Kosovo. Despite its professed objective of helping countries integrate the EU, a certain number of trade barriers remain today. In construction, there are limitations on cross-border supplies and on the acceptance of foreign licenses. In land transport, trade is limited by heavy regulations, market protectionism and the presence of state-owned monopolies. Most restricted of all is the legal sector, where the only services open to non-nationals are advisory services. By contrast, information technology (IT) services are only lightly regulated, with trade in this sector depending largely on other factors, such as demand for such services and the level of intellectual property protection. Of note is that the barriers and regulations differ from one country to another. This means that CEFTA countries with restricted trade in services can learn from their neighbours with more open systems how to liberalize these services.

Since 2009, Parties to CEFTA have been systematically identifying barriers to trade and proposing solutions, including via the development of a database to help pinpoint the correlation between barriers to market access and trade volume.

3. This designation is without prejudice to positions on status and is in line with United Nations Security Council Resolution 1244 and the International Criminal Court Opinion on the Kosovo Declaration of Independence made in February 2008.

TRENDS IN STI GOVERNANCE

Slovenia could serve as a model for its neighbours

All seven countries of Southeast Europe share a common desire to adopt the EU's science-oriented innovation model. They can be grouped into four categories, according to the pace of transition: Albania and Bosnia and Herzegovina show the slowest and most uncertain dynamics, despite ongoing support from UNESCO for Albania and the EU for Bosnia and Herzegovina. The Former Yugoslav Republic (FYR) of Macedonia and Montenegro fall into the second category: they are still searching for an appropriate innovation system. The third group consists of Croatia and Serbia, which both have fairly developed infrastructure and institutions. Croatia is having to speed up its restructuration process since incorporating the EU, as it now needs to apply EU regulations and practices in terms of smart specialization (see below), regional governance, foresight exercises for priority-setting and innovation policy as a governance model, among other things.

Slovenia is in a category of its own; it is not only the most advanced country in an economic sense but also in terms of the dynamism of its innovation system: Slovenia devoted 2.7% of GDP to R&D in 2013, one of the highest ratios in the EU. Of course, the growth and innovation capacity of a country depends not only on the supply of R&D but also on the country's ability to absorb and diffuse technology, combined with demand for its generation and utilization (Radosevic, 2004). Aggregating these four dimensions gives the national innovation capacity (NIC) index. According to Kutlaca and Radosevic (2011):

> *Slovenia emerges as the clear regional leader. It is the only Southeast European economy which ranks around the EU average for the majority of NIC indicators. Slovenia is followed by Hungary, Croatia, Bulgaria and Greece. These countries are above the Southeast European average. The national innovation capacities of Serbia, Romania, the FYR of Macedonia and Turkey are least developed. If data were available for Bosnia and Herzegovina and for Albania, we suspect that these economies would belong to the lower segment of Southeast European countries.*

Slovenia could serve as a model for other Southeast European countries where universities still favour teaching over research and the structure of R&D systems remains oriented more towards scientific authorship than co-operation with industry and the development of new technologies.

The big challenge for Southeast European countries will be to integrate their R&D system into the economy. The *Western Balkans Regional Research and Development Strategy* *for Innovation* should serve as a framework for collective reforms, in order to promote the Western Balkans' most urgent priority of nurturing innovation, economic growth and prosperity (Box 10.1). The strategy stresses the distance still to travel. '*The Western Balkans' economic and political transition in the 1990s had serious, often negative consequences for the region's research and innovation sectors. With economic reforms dominating the policy agenda, science, technology and innovation policies became a secondary priority, research capacity deteriorated and links with the productive sector disappeared*' (RCC, 2013).

Towards smart specialization

The goal of the *South East Europe (SEE) 2020 Strategy: Jobs and Prosperity in a European Perspective*[4] is to improve living conditions and bring competitiveness and development back into focus. Inspired by its namesake, the EU's *Europe 2020 Strategy*, the SEE strategy has been designed to favour regional co-operation, accelerate harmonization with the EU's regulatory framework and support the accession process.

The *SEE 2020 Strategy's* main targets are to more than double regional trade turnover from € 94 billion to € 210 billion, raise the region's GDP per capita from 36% to 44% of the EU average, reduce the region's trade deficit from 15.7% (on average between 2008 and 2010) to 12.3% of GDP and open up the region to 1 million new jobs, including 300 000 jobs for the highly qualified.

The *SEE 2020 Strategy* was adopted in Sarajevo on 21 February 2013, at the Ministerial Conference of the South East Europe Investment Committee. It had been under preparation by the Regional Cooperation Council since 2011, in collaboration with national administrations, within a project funded by the EU.

4. See: www.rcc.int/pages/62/south-east-europe-2020-strategy

Box 10.1: The Western Balkans' first innovation strategy

The first *Western Balkans Regional Research and Development Strategy for Innovation* was endorsed in Zagreb, Croatia, on 25 October 2013 by the ministers of science from Albania, Bosnia and Herzegovina, Croatia, Kosovo, FYR Macedonia, Montenegro and Serbia.

The proposed *Action Plan for Regional Co-operation* complements, strengthens and builds upon national strategies, policies and programmes, while recognizing the different levels of development of research systems and their contribution to development. The action plan proposes five regional initiatives:

- The Western Balkans Research and Innovation Strategy Exercise (WISE) Facility provides regional technical assistance to support the implementation of reforms in Western Balkan countries, including via training. The WISE facility serves as a platform for policy exchange, public policy dialogue, capacity-building and policy advocacy;
- A research excellence fund to promote collaboration between local scientists and the scientific diaspora, along with further integration of young scientists in the European Research Area;
- A programme to encourage the development of 'networks of excellence' in areas consistent with the 'smart specialization' of the region and the rationalization of resource use, focusing research on areas with greater economic impact;
- A technology transfer programme for public research organizations, to facilitate their collaboration with industry, including joint and contract research, technical assistance, training, technology licensing and the creation of spin-offs from public research organizations; and
- An early-stage start-up programme to provide pre-seed funding (proof of concept and prototype development) and business incubation and mentoring programmes to help bridge the 'valley of death' stage in bringing an idea to the marketplace and help develop a pipeline for venture capital investors.

The strategy was developed between December 2011 and October 2013 within an EU project, in collaboration with UNESCO and the World Bank. The project was co-ordinated jointly by the Regional Cooperation Council, European Commission and government officials from the aforementioned countries, who formed the Project Steering Committee.

The process was launched by the Joint Statement of Sarajevo, signed on 24 April 2009 by the ministers of science from the Western Balkans, the EU Commissioner for Science and Research and the Czech Republic Presidency of the European Council, under the auspices of the Secretary-General of the Regional Cooperation Council.

The European Commission and Regional Cooperation Council oversaw the implementation of the project, which was financed through one of the EU's Multi-beneficiary Instruments for Pre-accession Assistance (IPA).

Source: World Bank and RCC (2013)

Box 10.2: Southeast Europe defines its energy future

Southeast Europe's first *Energy Strategy* was adopted by the Ministerial Council in October 2012 and covers the period to 2020. The aim is to provide sustainable, secure and affordable energy services. The countries of the region adopted this *Energy Strategy* in order to implement energy market reforms and promote regional integration, as signatories to the Energy Community Treaty, which entered into force in July 2006.

As the European Commission put it in a report to the European Parliament and Council (2011), *'The very existence of the Energy Community, only ten years after the end of the Balkan conflict, is a success in itself, as it stands as the first common institutional project undertaken by the non-European Union countries of South East Europe."*

The Energy Community Secretariat has its seat in Vienna, Austria. The Parties to the treaty establishing the Energy Community are the European Union plus eight Contracting Parties, namely: Albania, Bosnia and Herzegovina, Kosovo, FYR Macedonia, Moldova, Montenegro, Serbia and Ukraine. With the decision, in December 2009, to authorize the accession of Moldova and Ukraine to the Energy Community, the geographical concept of the Western Balkans, with which the process was initially linked, lost its raison d'être. Today, the mission of the Energy Community has thus evolved into importing the EU energy policy into non-EU countries.

Southeast Europe's *Energy Strategy* to 2020 proposed a choice of three possible scenarii for future action: current trends, minimal investment costs and a low emissions/sustainability scenario which presumed that the region would progress on a sustainable development path.

The SEE 2020 Strategy: Jobs and Prosperity in a European Perspective sets the region on the EU's sustainable growth path by making sustainable growth one of the five pillars of the region's new development model (see below). It states that '*sustainable growth requires sustainable and accessible transport and energy infrastructure, a competitive economic base and a resource efficient economy… The need to reduce our carbon footprint, while at the same time meeting the increasing level of energy consumption, requires new technological solutions, modernization of the energy sector and more and better dialogue with our neighbours. New market mechanisms need to be introduced that will be appropriate to accommodate new energy sources'.*

One of the *SEE 2020 Strategy*'s key targets is to develop and implement measures to increase efficient use of energy by achieving a minimum 9% energy-saving target by 2018, in line with its commitments to the Energy Community, through the adoption of the Energy Services Directive in 2009. A second target is to achieve a 20% share of renewable energy in gross energy consumption by 2020.

These energy targets complement those for the transport, environment and competitiveness dimensions of the sustainable growth pillar. For instance, rail and river transportation is to be developed; the volume of annual forestation is to be increased, partly in order to provide a larger carbon sink; and countries are to be encouraged to create an enabling environment for private sector participation in financing water infrastructure.

Source: www.energy-community.org

The strategy is built around five interrelated 'pillars of the new development model':

- *Integrated growth*: through regional trade and investment linkages and policies;
- *Smart growth*: through education and competencies, R&D and innovation, digital society, cultural and creative sectors;
- *Sustainable growth*: energy (Box 10.2), transport, environment, competitiveness;
- *Inclusive growth*: employment, health;
- *Governance for growth*: effective public services, anti-corruption, justice.

The reasoning behind the smart growth pillar is that innovation and a knowledge economy are the main drivers of growth and job creation in the 21st century. To support the building block of R&D and innovation, Southeast European countries are advised to invest more and better in research and innovation, prioritizing investment and a 'smart specialization' of the region. This implies advancing institutional and policy reforms and investing strategically in four areas:

- Improving research excellence and productivity by investing in human capital for research; upgrading and better using available infrastructure; improving the incentive regime for research performance; and advancing the Bologna Process[5] and further integration into the European Research Area;
- Facilitating science–industry collaboration and technology transfer by further aligning the regulation of intellectual property management in public research organizations;

5. See the *UNESCO Science Report 2010*, p. 150

developing technology transfer organizations (such as technology transfer offices), financial support for science–industry collaboration and for the development of proof of concept and building a closer, structural relationship with the business community;

- Promoting business innovation and innovative start-ups by improving the business environment, providing mentoring systems from prototype and pre-seed to growth and expansion and guaranteeing a proper supply of technology, science parks and incubation services that can host and nurture young firms;
- Strengthening the governance of national research and innovation policies, continuing capacity-building in key institutions, reforming career development to better reward research excellence, science–industry collaboration and technology transfer; reforming research institutes to improve performance; and increasing the transparency, accountability and impact evaluation of research and innovation policies.

The actions proposed within the smart growth pillar are those defined by the *Western Balkans Regional R&D Strategy for Innovation*.

A need for better statistics

With the exception of Croatia and Slovenia, there is a lack of statistical data on R&D systems in Southeast Europe and questions as to the quality of available data. The collection of data on R&D in the business enterprise sector is particularly problematic.

In October 2013, the UNESCO Institute for Statistics and UNESCO's Regional Office for Science and Culture in Europe, which is based in Venice, put the final touches to their strategy for helping the statistical systems of the Western Balkans adopt EU standards in monitoring national trends in research and innovation by 2018.

The strategy proposes launching a regional project which could be funded and implemented within the *Western Balkans Regional R&D Strategy for Innovation*. The project would provide opportunities for training and staff exchanges, while fostering networking among statistical offices. It would also provide national data to help assess the extent to which the *Western Balkans Regional R&D Strategy for Innovation* succeeds in boosting R&D activity by 2020.

UNESCO proposes establishing a Regional Co-ordination Mechanism in the area of STI statistics which could be hosted either by UNESCO's office in Venice or its antenna in Sarajevo and managed in close co-operation with the UNESCO Institute for Statistics and Eurostat.

Adhering to Horizon 2020 to accelerate EU integration

In July 2014, the remaining five non-EU countries in Southeast Europe announced their decision to join the EU's Horizon 2020 programme, which succeeds the EU's Seventh Framework Programme for Research and Technological Development (2007–2013), in which they also participated. The relevant association agreements, which apply retroactively from 1 January 2014, allow entities from these five countries to compete for R&D funding under the Horizon 2020 programme.

Meanwhile, all seven Southeast European countries are developing bilateral scientific co-operation with their European neighbours and participating in a number of multilateral frameworks, including the European Cooperation in Science and Technology (COST) programme, which fosters co-operative networking by funding researchers' participation in conferences, short-term scientific exchanges and the like. Another example is Eureka, a pan-European intergovernmental organization which fosters market-driven industrial R&D through a bottom-up approach that allows industry to decide which projects it wishes to develop. Southeast European countries also participate in the North Atlantic Treaty Organization's Science for Peace and Security programme and are members of various United Nations bodies, including the International Atomic Energy Agency.

TRENDS IN R&D

Still a long way to go towards competitive business

Most Southeast European countries are faced with stagnating or falling investment in R&D. The exception is Slovenia, which almost doubled its R&D effort to 2.65% of GDP between 2007 and 2013, despite being hit by recession (Figure 10.1).

Differences in gross domestic expenditure on research and development (GERD) become clearer when population size is taken into account (Figure 10.2). For example, in 2013, Slovenian investment per capita in R&D was 4.4 times that of Croatia and 24 times that of Bosnia and Herzegovina.

In all but Slovenia, the government remains the main source of funding (Figure 10.3). Increasingly, the academic sector is funding and performing R&D, while the business sector continues to play a modest role. This confirms that countries are still in the process of restructuring their R&D systems to make them more innovative and competitive (Table 10.2). Even in Slovenia, the combination of negative growth and an indebted public banking sector has shaken investor confidence (Table 10.1 and page 291).

Figure 10.1: **GERD/GDP ratio in Southeast Europe, 2003–2013 (%)**

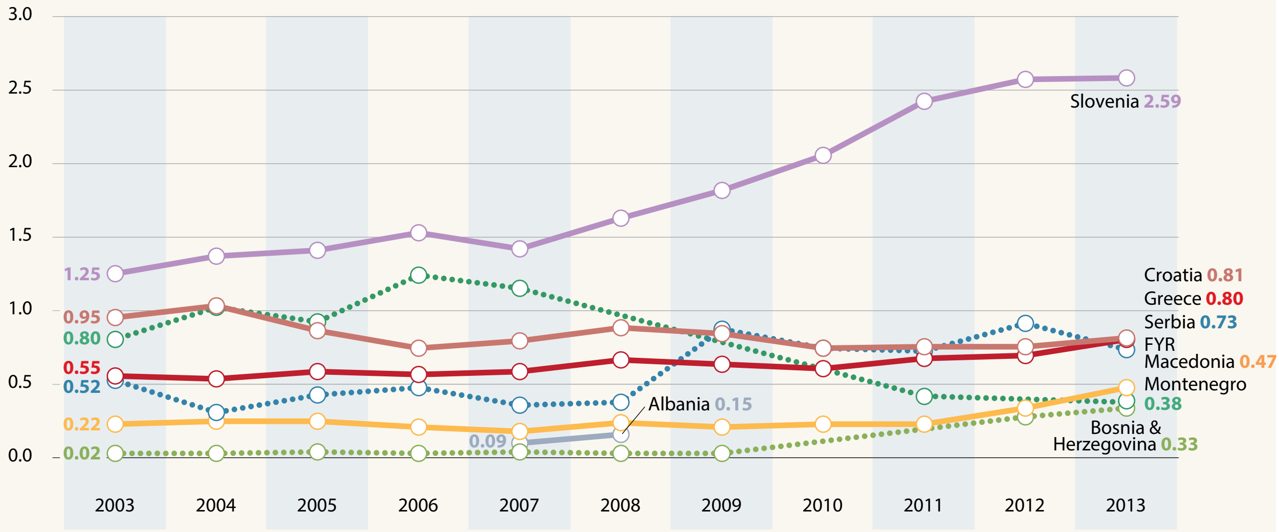
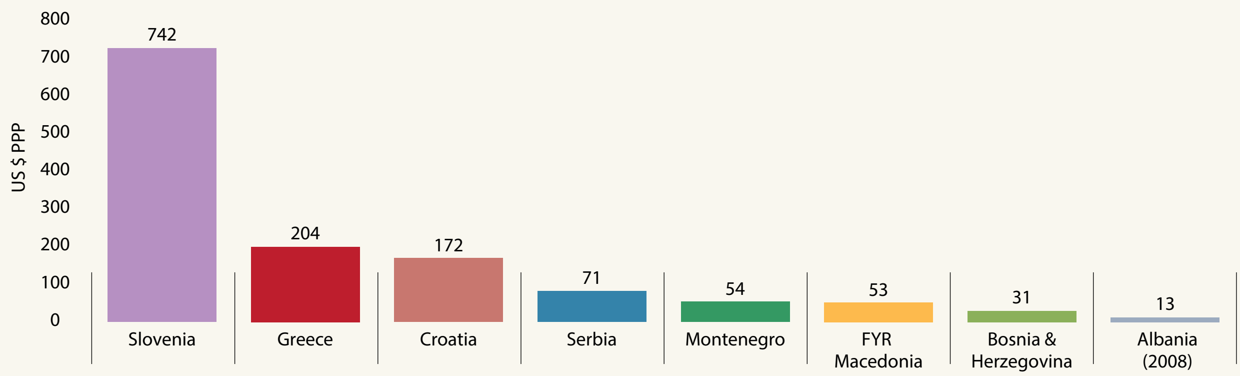
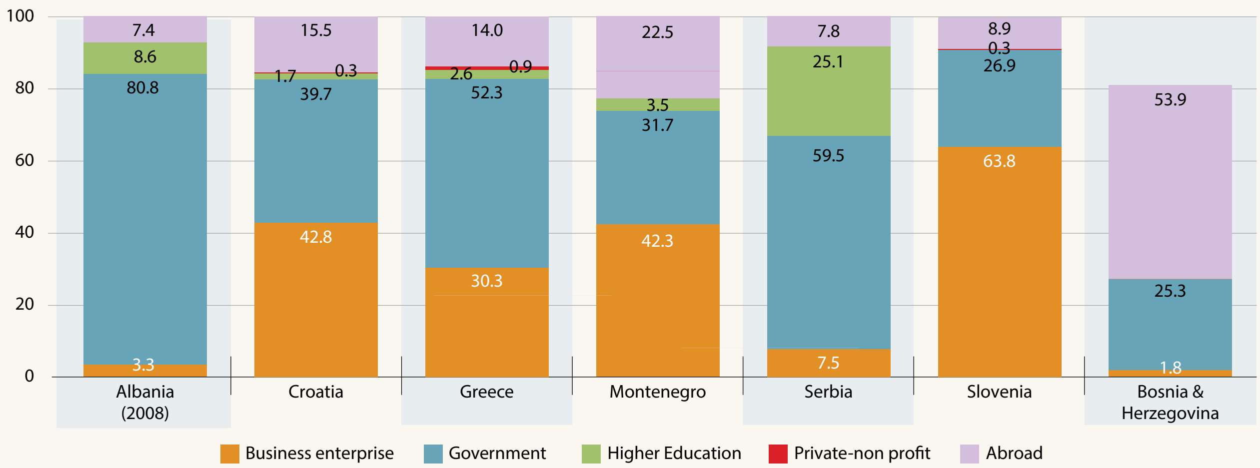


Figure 10.2: **GERD per capita in Southeast Europe, 2013 (%)**



Source: UNESCO Institute for Statistics, August, 2015

Figure 10.3: **GERD in Southeast Europe by source of funds, 2013 (%)**



Note: The total for Bosnia & Herzegovina does not add up to 100%, as a further 19% has not been attributed. There are no recent data for FYR Macedonia.
Source: UNESCO Institute for Statistics, August 2015

A region still struggling with brain drain

During the transition to a market economy, Southeast European countries suffered severe brain drain. Sluggish economic growth in recent years has not staunched the flow, even in Slovenia. All countries in the region rank poorly for their capacity to retain and attract talent, according to the Global Competitiveness Report (WEF, 2014). Only three countries rank in the top 100 out of 148 countries for their ability to retain talent: Albania, Greece and Montenegro. Of these, Greece slips to 127th place for its capacity to attract talent, a consequence of the debt crisis the country has been experiencing[6] since 2008 (Table 10.3). The Government of Albania made a concerted effort to attract talent through its Brain Gain Programme in 2008–2009 by opening up 550 vacancies in higher education to international recruitment and committing state funds to this programme for the first time (Republic of Albania, 2009).

6. Government debt represented 121% of GDP in 2008. In return for an emergency bail-out package from the European Central Bank which swelled Greece's total debt burden to 164% of GDP in 2012, the government has been obliged to make drastic cuts in public expenditure.

More graduates means a bigger research base

The strong growth in the number of tertiary graduates over the period 2005–2012 has logically translated into a greater number of researchers (Figures 10.4 and 10.5). The majority of employment opportunities tend to be in academia. In Bosnia and Herzegovina and Slovenia, the surge in researchers has been spectacular but this rise is above all a consequence of better statistical coverage (Table 10.4). For Slovenia, the rise can be explained by a massive injection of R&D funding in recent years. In all but Croatia and Slovenia, demand for business sector R&D is low. In Albania and Bosnia and Herzegovina, it is almost non-existent (Figure 10.3).

Table 10.2: **Global competitiveness in Southeast Europe, 2012–2014**

	Ranking out of 144 countries			Stage* of development
	2012	2013	2014	2014
FYR Macedonia	80	73	63	Efficiency-driven
Montenegro	72	67	67	Efficiency-driven
Slovenia	56	62	70	Innovation-driven
Croatia	81	75	77	Transition from efficiency-driven to innovation-driven
Greece	–	91	81	Innovation-driven
Bosnia & Herzegovina	88	87	–	Efficiency-driven
Albania	89	95	97	Efficiency-driven
Serbia	95	101	94	Efficiency-driven

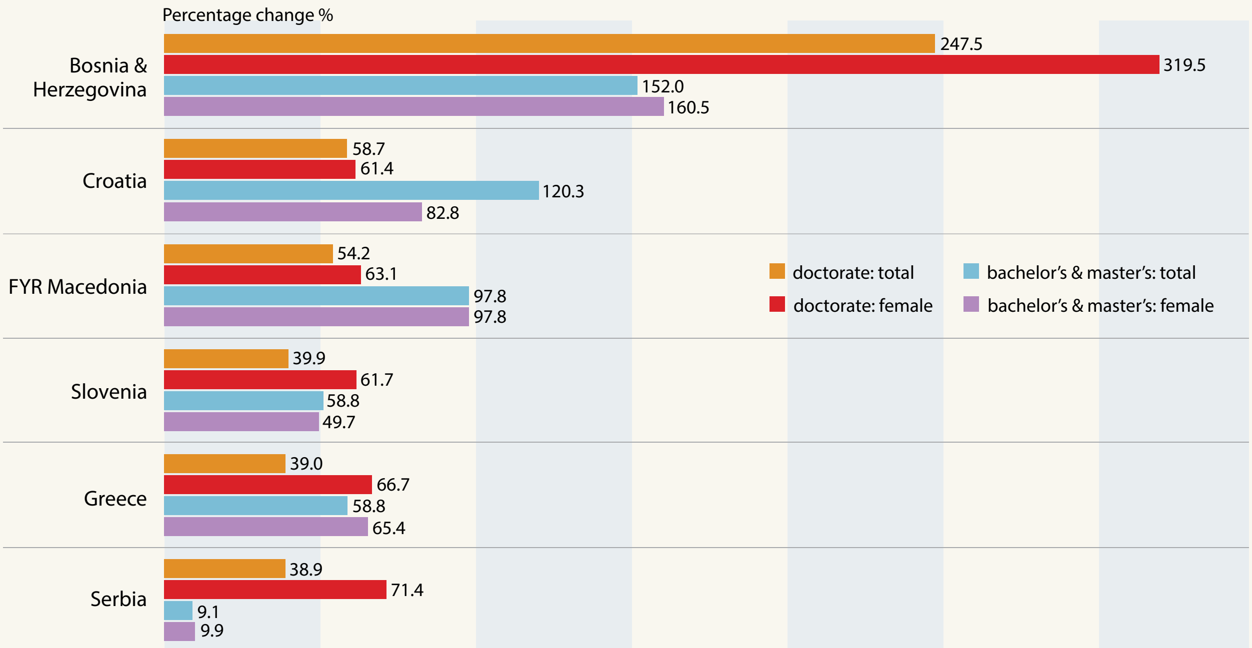
*See the glossary on page 738 *Source:* WEF (2012, 2013, 2014) *Global Competitiveness Reports*. World Economic Forum

Table 10.3: **Capacity of Southeast Europe to retain and attract talent, 2014**

Country's capacity to retain talent			Country's capacity to attract talent		
Country	Value	Rank (148 countries)	Country	Value	Rank (148 countries)
Albania	3.1	93	**Albania**	2.9	96
Bosnia & Herzegovina	1.9	143	**Bosnia & Herzegovina**	1.9	140
Croatia	2.1	137	**Croatia**	1.8	141
Greece	3.0	96	**Greece**	2.3	127
FYR Macedonia	2.5	127	**FYR Macedonia**	2.2	134
Montenegro	3.3	81	**Montenegro**	2.9	97
Serbia	1.8	141	**Serbia**	1.6	143
Slovenia	2.9	109	**Slovenia**	2.5	120

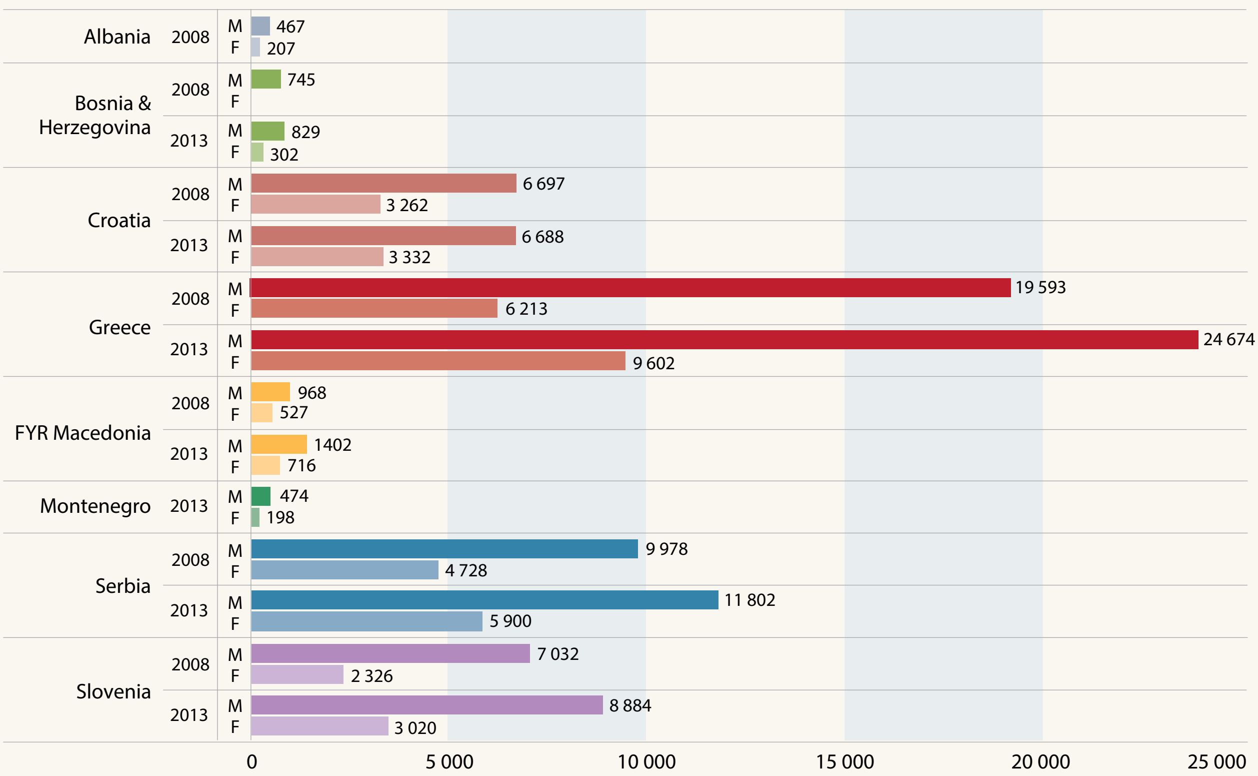
Source: WEF (2014) *Global Competitiveness Report 2014–2015;* for Bosnia and Herzegovina: WEF (2013) *Global Competitiveness Report 2013–2014*

Figure 10.4: **Growth in number of tertiary graduates in Southeast Europe, 2005–2012**
Selected countries



Note: For Bosnia & Herzegovina and Serbia, the period covered is 2007–2012 and for Greece, 2007–2011.
Source: UNESCO Institute for Statistics, April 2015

Figure 10.5: **Number of researchers in Southeast Europe, 2008 and 2013**



Source: UNESCO Institute for Statistics, April 2015

The share of women researches in Southeast Europe is much higher than the EU average. Within the region, all but Greece and Slovenia have maintained or attained gender parity since 2005, or are on the verge of attaining it, as in the case of Albania (Table 10.4).

A region where engineering dominates research

The majority of researchers tend to be engineers in Croatia, Greece, Serbia and Slovenia. In FYR Macedonia, most researchers work in engineering, followed by medical sciences. Researchers in Montenegro tend to be employed in medical sciences and those in Albania in agriculture. It is interesting to note that about one in three engineers are women. Slovenia stands out as being the only case where women represent just one in five engineers. In medical sciences and the humanities, there even tend to be more women researchers than men (Table 10.5). This also happens to be the case for agriculture in Montenegro, Serbia and Slovenia, for natural sciences in Montenegro, Serbia and FYR Macedonia and for social sciences in Slovenia.

Researchers tend to gravitate towards the government or higher education sectors in all but Slovenia, where industry is the biggest employer (Figure 10.6). Given the current problems with collecting data on industrial R&D, this picture may change somewhat once the statistics improve.

Table 10.4: **Researchers in Southeast Europe (HC) per million inhabitants by gender, 2005 and 2012**

	Total population ('000s) 2012	Per million inhabitants 2005	Per million inhabitants 2012	Total 2005	Total, 2012	Women, 2005	Women, 2012	Women (%), 2005	Women (%), 2012
Albania	3 162	–	545^{-4}	–	$1\,721^{-4}$	–	763^{-4}	–	44.3^{-4}
Bosnia & Herzegovina	3 834	293	325^{+1}	1 135	$1\,245^{+1}$	–	484^{+1}	–	38.9^{+1}
Croatia	4 307	2 362	2 647	10 367	11 402	4 619	5 440	44.6	47.7
Greece	11 125	3 025	$4\,069^{-1}$	33 396	$45\,239^{-1}$	12 147	$16\,609^{-1}$	36.4	36.7
FYR Macedonia	2 106	1 167	$1\,361^{+1}$	2 440	$2\,867^{+1}$	1 197	$1\,409^{+1}$	49.1	49.1^{+1}
Montenegro	621	1 028	$2\,419^{-1}$	633	$1\,546^{-1}$	252	771^{-1}	39.8	49.9^{-1}
Serbia	9 553	1 160	1 387	11 551	13 249	5 050	6 577	43.7	49.6
Slovenia	2 068	3 821	5 969	7 664	12 362	2 659	4 426	34.8	35.8

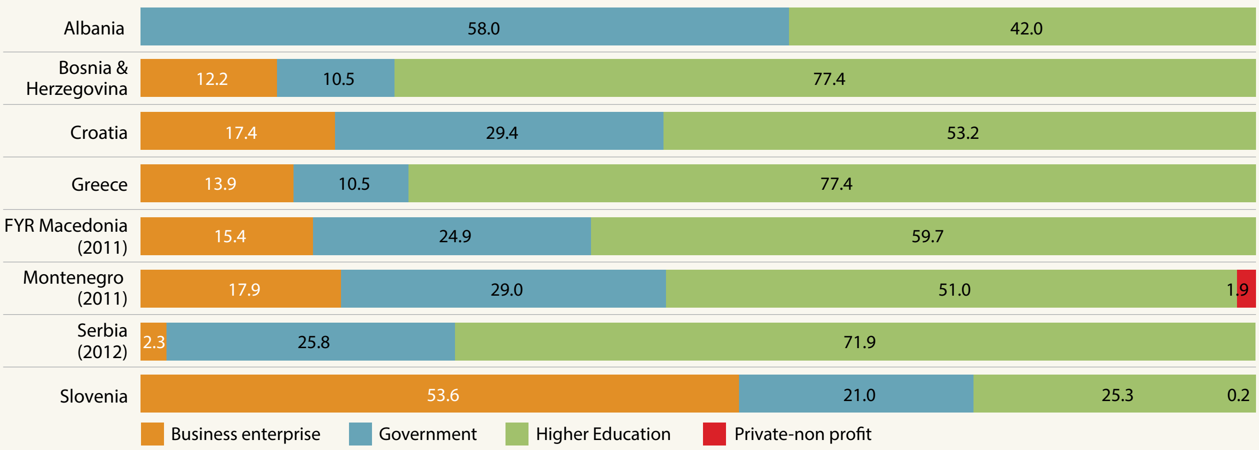
+n/-n = data refer to *n* years before or after reference year
Source: UNESCO Institute for Statistics, April 2015

Table 10.5: **Researchers in Southeast Europe (HC) by field and gender, 2012**

	Natural sciences	Women (%)	Engineering and technology	Women (%)	Medical and health sciences	Women (%)	Agriculture	Women (%)	Social sciences	Women (%)	Humanities	Women (%)
Albania, 2008	149	43.0	238	30.3	156	60.3	330	37.9	236	37.7	612	52.1
Bosnia & Herzegovina, 2013	206	43.7	504	29.6	31	58.1	178	42.7	245	54.7	68	19.1
Croatia	1 772	49.7	3 505	34.9	2 387	56.1	803	45.8	1 789	55.6	1 146	55.4
Greece, 2011	6 775	30.7	15 602	29.5	9 602	43.0	2 362	33.1	5 482	38.0	5 416	54.1
FYR Macedonia, 2011	–	–	567	46.4	438	65.1	103	49.5	322	50.0	413	64.2
Montenegro, 2011	104	56.7	335	37.0	441	58.5	66	54.5	291	46.0	309	51.8
Serbia	2 726	55.2	3 173	35.9	1 242	50.4	1 772	60.0	2 520	47.9	1 816	57.2
Slovenia	3 068	37.5	4 870	19.5	1 709	54.2	720	52.8	1 184	49.8	811	52.5

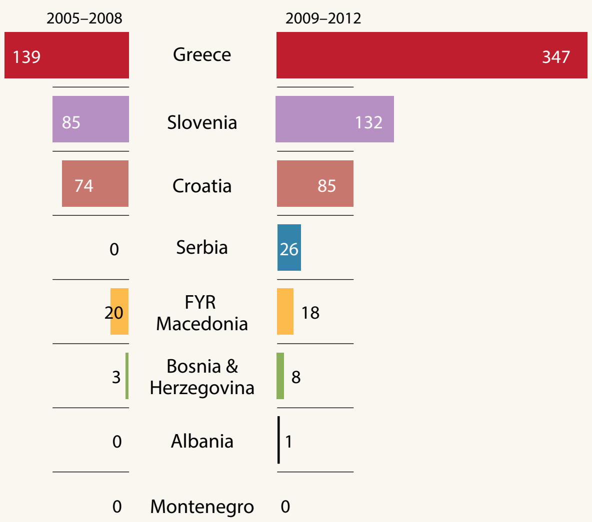
Source: UNESCO Institute for Statistics, April 2015

Figure 10.6: **Researchers (FTE) in Southeast Europe by sector of employment, 2013 (%)**



Source: UNESCO Institute for Statistics, April 2015

Figure 10.7: **USPTO patents granted to Southeast European countries, 2005–2008 and 2009–2012**



In terms of research output, there has been a marked improvement in Croatia and Slovenia in the number of patents and in Slovenia for royalty payments since the *UNESCO Science Report 2010*. Other countries have witnessed more modest progress (Figure 10.7 and Table 10.6).

Most countries have a good publishing record, a sign of their solid integration in the international scientific community. Again, Slovenia dominates with 33 times more publications per million inhabitants than Albania and more than twice as many as Croatia. Of note is that output has climbed steeply in all countries since 2005 (Figure 10.8). Serbia almost tripled its output between 2005 and 2014, moving up from third to first place in terms of sheer volume. There is a good balance in most countries between scientific fields, with engineering and the physical sciences rivalling life sciences.

Table 10.6: **Patents, publications and royalty payments in Southeast Europe, 2002–2010**

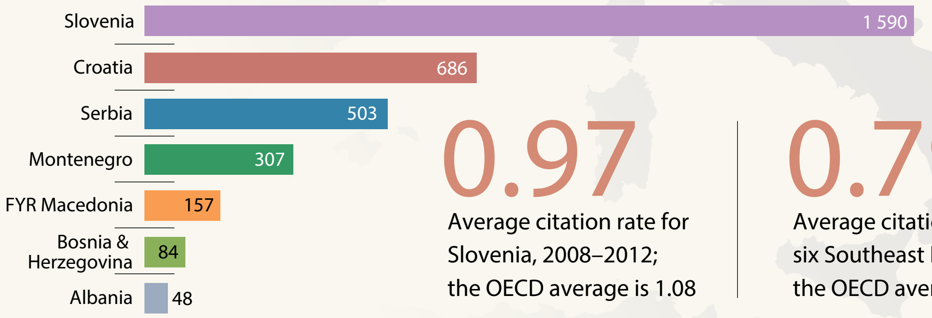
	Royalty payments and receipts (US$ per capita)		University–industry research collaboration 1 (low) – 7 (high)		Patents granted by USPTO per million inhabitants
	2006	2009	2007	2010	2002–2013
Albania	2.39	6.39	1.70	2.20	0.3
Bosnia & Herzegovina	–	4.87	2.40	3.00	3.9
Croatia	50.02	55.25	3.60	3.40	45.9
Greece	–	–	–	–	52.4
FYR Macedonia	6.64	12.91	2.90	3.50	25.6
Serbia	–	28.27	3.10	3.50	2.8
Slovenia	85.62	159.19	3.80	4.20	135.1

Note: Data are unavailable for Greece and Montenegro.
Source: UNESCO Science Report 2010 and World Bank Knowledge for Development database, accessed October 2014

Figure 10.8: **Scientific publication trends in Southeast Europe, 2005–2014**

Slovenia has by far the greatest publication density

Publications per million inhabitants in 2014



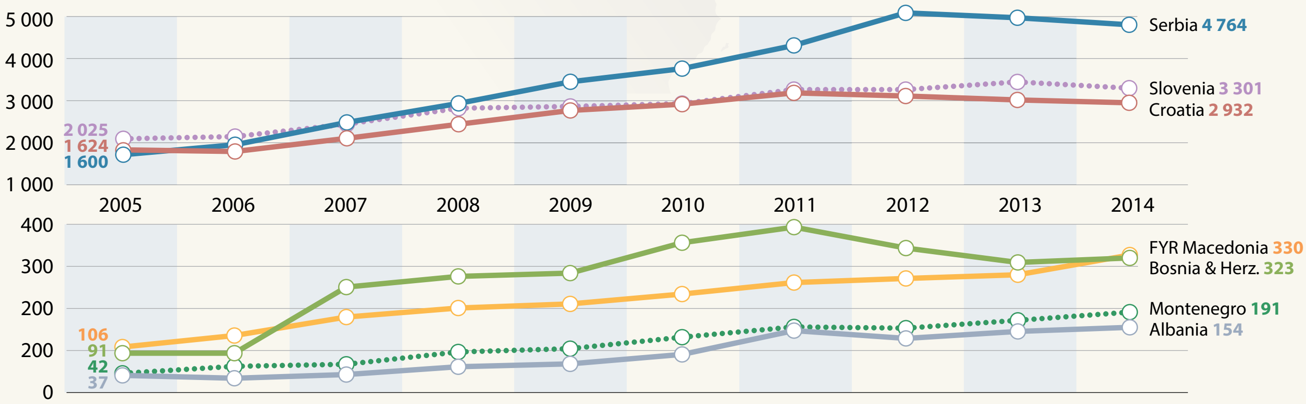
0.97

Average citation rate for Slovenia, 2008–2012; the OECD average is 1.08

0.79

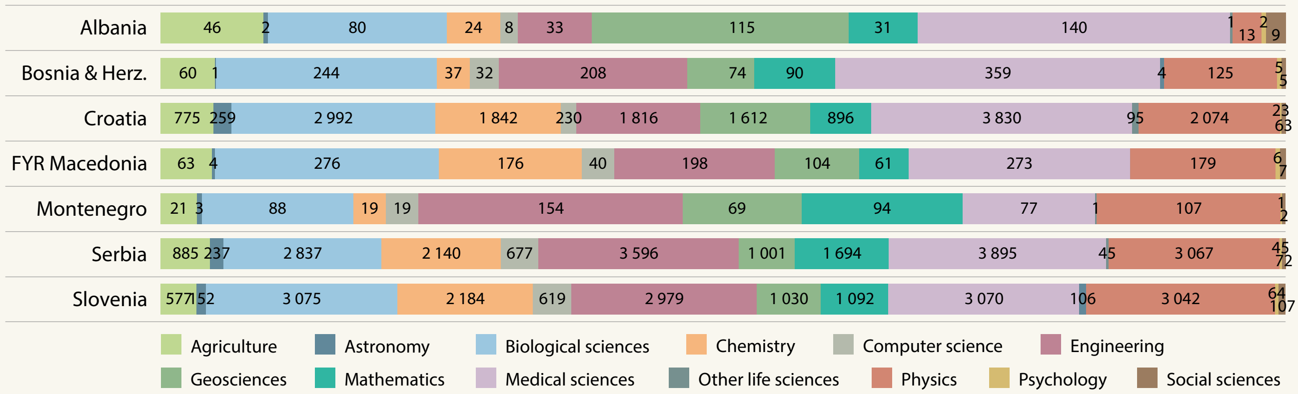
Average citation rate for the other six Southeast European countries; the OECD average is 1.08

Output has grown rapidly in all countries since 2005



Most articles concern life sciences, physics and engineering

Totals by field, 2008–2014



Note: Totals exclude unclassified articles.

The main collaborators are in Europe and the USA

Main foreign partners,2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Albania	Italy (144)	Germany (68)	Greece (61)	France (52)	Serbia (46)
Bosnia & Herz.	Serbia (555)	Croatia (383)	Slovenia (182)	Germany (165)	USA (141)
Croatia	Germany (2 383)	US A (2 349)	Italy (1 900)	UK (1 771)	France (1 573)
FYR Macedonia	Serbia (243)	Germany (215)	USA (204)	Bulgaria (178)	Italy (151)
Montenegro	Serbia (411)	Italy (92)	Germany (91)	France (86)	Russia (81)
Serbia	Germany (2 240)	USA (2 149)	Italy (1 892)	UK (1 825)	France (1 518)
Slovenia	USA (2479)	Germany (2 315)	Italy (2 195)	UK (1 889)	France (1 666)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

ALBANIA

Business R&D is almost non-existent

Before the global financial crisis, Albania was one of the fastest-growing economies in Europe, enjoying annual real growth rates of 6% on average. After 2008, this rate halved and macro-economic imbalances emerged, including rising public debt (60% of GDP in 2012). Poverty levels, which had halved to about 12.4% of the population between 2002 and 2008, climbed back to 14.3%. Unemployment rose from 13.0% in 2008 to 16.0% in 2013 – and even 26.9% for youth. Economic growth dipped to 1.3% in 2013, reflecting the deteriorating situation in the Eurozone and difficulties in the energy sector. The World Bank forecasts that Albania's economy will grow by 2.1% in 2014 and 3.3% in 2015.

According to the latest Erawatch report on Albania (2013), which cites the Ministry of Finance, foreign direct investment (FDI) flows into the country tripled between 2006 and 2012, from about € 250 million to € 900 million. Despite this, FDI was estimated at 7.7% of GDP in 2011, about 1.2% lower than in 2010. The presence of multinational companies in the Albanian economy is boosting revenue considerably. Foreign investors are obviously attracted by the lower production costs and potentially higher profit margins than in a more developed economy. However, the rapid growth of FDI inflows to the country is also attributable to the improved business environment and the opportunities created by the privatization of state enterprises. FDI tends to be concentrated in low technology areas of manufacturing and services.

Albania devoted 0.15% of GDP to GERD in 2008, just 3.3% of which came from the business enterprise sector. The *National Strategy for Science, Technology and Innovation 2009–2015* states that GERD was close to € 15 million in 2009, which corresponds to less than 0.2% of GDP. The strategy foresees total cumulative funding for research over 2009–2015 of € 151.95 million, nearly half of which will go to the academic sector (€ 69.45 million). The only programme funding research *per se* is that managed by the Ministry of Education and Science (€ 30 million). Some € 3.3 million will be used to equip laboratories through the World Bank Research Infrastructure project and a similar amount will finance the running costs of the Agency for Research, Technology and Innovation (€ 3.25 million).

The *National Strategy for Science, Technology and Innovation 2009–2015* is Albania's main strategy for research and innovation. It was adopted in July 2009 after being developed by the Ministry of the Economy, Trade and Energy, in response to a UNESCO assessment of Albania's strengths and weaknesses and, in particular, its lagging position in Europe and the Balkan region. New programmes and funds focus on improving research infrastructure, expanding graduate and postgraduate programmes and creating sustainable linkages between academia and the private sector. This strategy introduces competitive-based funding criteria (for projects and grants) into the main policy instruments. The strategy also outlines specific targets for R&D, such as raising GERD to 0.6% of GDP by 2015, introducing innovation into 100 companies and carrying foreign co-operation funding to 40% of GERD. Some 12% of GERD came from abroad in 2007 and 7% in 2008.

Endowed with a budget of € 10.31 million, the *Business Innovation and Technology Strategy 2011–2016* is linked to the *National Strategy for Science, Technology and Innovation 2009–2015*. It introduces support measures for reaching the targets described in the preceding paragraph. Some € 4.8 million has been set aside for an Innovation Fund which awards grants to small and medium-sized enterprises (SMEs) for product development and process improvement through technology adoption, among other types of support. This strategy is to be mainly funded by foreign donors, with 76.5% expected to come from the EU and other donors (€ 7 893 million). SMEs will receive assistance in adopting new information and communication technologies (ICTs), which the strategy considers as being a major driver of modernization and innovation.

The *Business Innovation and Technology Strategy* was launched in 2010 by the Ministry of the Economy, Trade and Energy. It complements the ministry's Strategic Programme for Innovation and Technological Development of SMEs *for 2011–2016,* which was approved in February 2011. The programme is supported by a EuropeAid project, as it is recognized that Albanian firms have a weak technological capacity to upgrade by absorbing existing advanced technologies.

The *Business Innovation and Technology Strategy* and its *Action Plan* are being implemented by the Business Relay and Innovation Centre, which is hosted by the Albanian Investment Development Agency[7] and has been operational since June 2011. The four main thrusts of this strategy for 2011–2016 are the: Innovation Fund; Business Innovation Services; Business Incubator Programme; and Albanian Cluster Programme.

A need for a more targeted approach to business innovation

It is a pity that Albania is not taking a more targeted approach to business innovation and technological development, which is only implied in the *National Strategy for Science, Technology and Innovation 2009–2015*. Albania's innovation system also faces a number of structural challenges: a lack of reliable and comparable statistics on R&D and innovation;

7. See: http://aida.gov.al/?page_id=364 limited co-operation between the public and private sectors; delays and inefficiencies in implementing strategies and programmes; and persistent weaknesses in human resources development. The 2013 Erawatch report on Albania observes that weaknesses in human resources development are exacerbated by the slow growth in brain circulation and the training of new researchers and PhD-holders in S&T fields.

In June 2013, Albania adopted its second *National Strategy for Development and Integration 2013–2020,* the purpose of which is to move Albania closer to EU integration. This strategy defines new priority sectors for research which are deemed important for meeting societal challenges and for stimulating growth and productivity to absorb high unemployment.

These sectors are:

- ICTs;
- agriculture (veterinary, zoo-technical), food and biotechnology;
- social sciences and Albanology;
- biodiversity and environment;
- water and energy;
- health; and
- materials science.

BOSNIA AND HERZEGOVINA

Low R&D spending even before the recession

Bosnia and Herzegovina is composed of three individual entities: the Federation of Bosnia and Herzegovina, the Republic of Srpska and Brčko District. The state-level Ministry of Civil Affairs co-ordinates science policy and international co-operation through its Department of Science and Culture. The co-ordination of SME policies at state level is done by the Ministry of Foreign Trade and Economic Relations but the country's complex constitutional structure means that responsibility for policy implementation and funding is devolved to each individual entity.

When R&D data were first collected in 2003, they did not cover the entire country. The first national figures appear in the latest survey by the UNESCO Institute for Statistics; they show that GERD progressed from 0.27% to 0.33% of GDP between 2012 and 2013, or from PPP$ 97.0 million to PPP$ 120.5 million. These data come against a backdrop of negative economic growth in 2012 and a rise in unemployment from 24% to 29% of the adult population between 2008 and 2013 (Table 10.1).

The latest available data for the Federation of Bosnia and Herzegovina show that civil engineering, mechanical engineering and electrical engineering received a slightly higher priority in its cantons of Sarajevo, Tuzla and Zenica–Doboj than in the country's other entities in 2010 (Jahić, 2011).

As for the data published by the Bureau of Statistics of the Republic of Srpsk, these indicate a budget of € 13.4 million for R&D in 2011, corresponding to 0.3% of the entity's GDP. This breaks down into the following priority economic sectors:

- exploration and exploitation of the Earth (25%);
- general advancement of knowledge (23%);
- environment (10%);
- agriculture (9%);
- industrial production and technology (9%);
- culture, recreation, religion and mass media (5%).

A multiplicity of strategies and conflicting targets

Since 2009, Bosnia and Herzegovina has adopted no fewer than three strategies for STI: a national strategy and two state-level strategies. These propose conflicting targets.

Adopted in 2009, the *Strategy for the Development of Science in Bosnia and Herzegovina 2010–2015* fixes the ambitious target of increasing GERD to 1% of GDP by 2015. This growth is predicated on forecast economic growth of 5% per year by 2015. The government estimates that such growth would be sufficient to pay the salaries of 3 000 researchers and 4 500 other research personnel in Bosnia and Herzegovina (Council of Ministers, 2009). This strategy also envisages that the business enterprise sector will contribute one-third of GERD by 2015. This sector performed about 59% of GERD in 2013 but financed only about 2% – although the destination of 19% of GERD was unspecified in the government's reply to the UNESCO Institute for Statistics' survey.

After the disintegration of Yugoslavia in the 1990s, the young republic had a high ratio of business to government funding of R&D of 2:1 or even 3:1. The strategy adopted by the Federation of Bosnia and Herzegovina in 2011 envisages returning to this ratio. It also fixes a target of raising GERD to 1% of GDP by 2013 and to 2% by 2017.

As for the Republic of Srpska, its strategy for STI (2012) envisages raising GERD from 0.25% GDP in 2010 to a minimum of 0.5% of GDP by 2016 and to 1% by 2020, in line with its *Europe 2020* strategic goals (Republic of Srpska, 2012). This strategy optimistically envisages that business spending on R&D will represent 60% of the entity's GERD by 2016 (0.3% of GDP).

According to Jahić (2011), the most important structural challenges facing Bosnia and Herzegovina are to:

- harmonize the long-term goals of STI strategies at national and entity levels and to balance public and private sector R&D;
- foster domestic demand for R&D;
- increase collaboration with the business sector;
- facilitate knowledge and technology transfer;
- transform the role of predominantly teaching-oriented universities into the main performers of research.

A desire to increase R&D spending

The priorities for developing the national innovation system in the next five years have been identified as being to:

- stimulate scientific excellence and enable the transfer of knowledge and results of scientific discoveries to industry and business (Council of Ministers, 2009);
- strengthen co-operation with the EU to fund scientific research, together with funds allocated Ministry of Civil Affairs' budget for co-financing of international projects (Council of Ministers, 2009);
- enhance the commercialization of research results and the competitiveness of products and processes by adopting policies and funding that support industrial R&D (Republic of Srpska, 2012);
- enhance the role of intermediaries to facilitate industrial research and raise the share of business spending on R&D (Government of RS, 2012);
- adhere to the 2006 *UNESCO Guidelines for a Science and Research Policy in Bosnia and Herzegovina* (Papon and Pejovnik, 2006) and gradually increase GERD to 2% of GDP by 2020 (Federation of Bosnia and Herzegovina, 2011).

CROATIA

EU funds should be a boon for Croatian R&D

Croatia is a relative newcomer to the EU, having obtained membership on 1 July 2013. Before the global financial crisis, the Croatian economy was growing by 4–5% annually. In 2009, it fell into recession (-7%) but has since recovered somewhat. The economy is expected to grow by 0.5% in 2014 and Croatia's prospects for 2015 are viewed with optimism, as exports and investment are projected to pick up in the Eurozone. The privatization of large state-owned enterprises and the availability of EU funds, which represent about 2% of GDP in net terms, should also help Croatia's growth prospects in the medium term.

Unemployment remains one of the highest in Europe, however, at 17.7% in late 2013 and even over 40% for youth. Public debt is estimated to have risen above 64% of GDP in 2013 and external debt will likely be close to 103% of GDP, according to the World Bank.

There is one economic sector which has weathered the storm of the past few years. Croatia's natural beauty draws in millions of tourists each year, earning revenue which represents about 15% of GDP. Croatia remains one of Europe's ecological treasures, with 47% of its land and 39% of its marine area designated as specially protected areas.

Despite the recession, GERD ratio dipped only slightly between 2009 and 2013, from 0.84% to 0.81% of GDP. An analysis of longer term trends reveals that Croatia's GERD has dropped since 2004, when it represented 1.05% of GDP.

Just over one-third of GERD came from the business enterprise sector in 2013 (42.8%) and as much as 15.5% from abroad. This means that Croatia has some way to go before it achieves the target ensconced in the national *Science and Technology Policy 2006–2010* of devoting 1% of the public purse to R&D. Nor is the situation likely to improve in the near future, as the government has decided to trim the budget for the Ministry of Science, Education and Sports from 9.69% of the state budget in 2012 to 8.75% in 2015, according to the 2012 Erawatch report on Croatia. In fact, two-thirds of government budget outlays for R&D are used to pay the salaries of researchers in public institutions and universities. The remaining resources fund research project grants, equipment and so on. Only about 5.7% of the budget outlay is allocated to competitive research grants and a further 1.4% to technological projects.

The Ministry of Science, Education and Sports is the main funding body but four other mechanisms also contribute research funding (EU, 2013):

- the Croatian Science Foundation, which was established in 2001 to foster scientific excellence;
- the Business Innovation Agency of Croatia (BICRO), which supports technology transfer from academia to industry and the setting-up of start-ups and spin-off companies. BICRO supports the implementation of various EU programmes in Croatia, including the Instrument for Pre-Accession Assistance and the programme for the Development of Knowledge-based Enterprises (RAZUM). In May 2010, BICRO launched the Croatian segment of the EU's Proof of Concept programme, which ensures pre-commercial funding for technical and commercial testing of innovative concepts. The Croatian Institute of Technology was merged with BICRO in February 2012 to ensure that EU structural instruments in the areas

of research, development and innovation are invested effectively.

- the Unity through Knowledge Fund, which supports co-operation between local researchers and the diaspora, as well as between the public and private sectors via a Research in Industry and Academia grant scheme set up in 2007;
- the Science and Innovation Investment Fund, which was set up in 2009 to foster technology transfer and academic entrepreneurship via the commercialization of universities' research results.

Croatia also has two non-funding agencies: the Agency for Science and Higher Education, which is responsible for setting up a national network for quality assurance; and the Croatian Agency for Mobility and the EU Programme, which organizes programmes in lifelong learning and mobility in the EU.

The Ministry of Entrepreneurship and Crafts and the Ministry of the Economy complement the Ministry of Science, Education and Sports when it comes to funding innovation-based entrepreneurship and business infrastructure.

A shift from project to programme financing

The most important change in Croatia's national innovation system in recent years has been a shift from project to programme financing. The Law on Science and Higher Education provides the legal basis. Adopted by parliament in July 2013, it makes provision for a new model of 'programme contracts' between the Ministry of Science, Education and Sports and research-performing organizations. The main objective is to put an end to the current practice of funding a large number of small scientific projects with a high acceptance rate of more than 80% of proposed projects. In addition, the law transfers responsibility for allocating competitive research grants from the ministry to the Croatian Science Foundation, which has been charged with devising a new scheme for competitive projects and programmes based on the model of EU collaborative research (EU, 2013).

The Second Science and Technology Project was launched in 2012 with an estimated budget of € 24 million for 2012–2015. This project sets out to improve the efficiency of public R&D institutions, bring BICRO and the Unity for Knowledge programme in line with EU regulations and prepare submissions to the EU's structural funds and cohesion funds.

No explicit policy for regional development

No explicit regional research policy currently exists in Croatia, mainly due to insufficient resources which prevent counties and municipalities from taking a more active part in developing institutional capacity. Croatia is nearing completion of its *National Research and Innovation Strategy on Smart Specialization*, which is designed to support innovation and business competitiveness. Such a strategy is a prerequisite for securing support for infrastructure development from the European Regional Development Fund, one of the EU's structural funds. The Ministry of Regional Development and European Funds is expected to play a greater role once the first European Regional Development Funds become available.

According to the Innovation Union Scoreboard (EU, 2014)[8], Croatia is a *moderate innovator* which performs below the EU average. This group of countries includes Poland, Slovakia and Spain. The priority areas defined by the *Science and Technology Policy 2006–2010* were all related to innovation: biotechnologies, new synthetic materials and nanotechnologies. However, business expenditure on R&D has stagnated at 0.36% of GDP in 2008 and 0.35% in 2013, even though this sector performed 50.1% of R&D in 2013.

Croatia has a very generous system of tax breaks for R&D compared to countries of the Organisation for Economic Cooperation and Development (OECD), corresponding to a subsidy of about 35 cents for every dollar spent on R&D. In 2012, Croatia's ranking in the Innovation Union Scoreboard receded slightly, however, after businesses suffered a drop in sales of innovative products they had recently put on the market.

An environment that is not conducive to innovation

Croatia tends to be more productive in scientific publishing than in patenting, with a ratio of about 100 articles to every registered patent. The higher education sector applied for 13 patents in 2010, which was around 23% of all patent applications for Croatia that year.

Today, Croatia faces five main structural challenges:

- its R&D policy is obsolete and lacks vision, not to mention a coherent and integrated policy framework; the *National Research and Innovation Strategy on Smart Specialization* due to be adopted in 2015 should go some way towards tackling this challenge;
- the business environment is not conducive to innovation;
- with the exception of a few big spenders, private companies show little interest in R&D;
- reform of the research and higher education system has been sluggish so far; and
- the regional research and innovation system remains weak.

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8. See also the glossary on page 738

Box 10.3: A first incubator in Croatia for bioscience start-ups

The Incubation Centre for Bioscience and Technology Commercialisation (BIOCentar) is the first centre of its kind in Croatia and the wider region. It is due to open its doors in 2015 on the campus of the University of Zagreb. The centre will cover about 4 500 m^2 for a cost of about HRK 140 million (*circa* US$ 23 million).

Once operational, the incubator will support the creation and development of spin-off companies from research done by public institutions and universities. The centre will provide small and medium-sized enterprises in the field of bioscience and biotechnology with the infrastructure and services they need to develop their business.

BIOCentar is Croatia's first major infrastructural project and a greenfield investment financed though the EU's Instrument for Pre-Accession Assistance.

The University of Zagreb is one of three universities which serve as technology transfer offices in Croatia, the others being the University of Spit and the University of Rijeka. The technology transfer office at the University of Rijeka has recently grown into a fully fledged Science and Technology Park.

Source: EU (2013)

The *National Strategy for the Development of Croatian Innovation Development 2014–2020* has been prepared by local experts in co-operation with the OECD. It defines the five strategic pillars for the future development of Croatia's innovation system and some 40 guidelines for their implementation:

- enhancement of business innovation potential and the creation of a regulatory environment supportive of innovation;
- greater knowledge flows and interaction between industry and academia;
- a strong S&T base and more efficient technology transfer among research institutions; see also Box 10.3;
- the development of human resources for innovation;
- better governance of the national innovation system.

In December 2012, the Ministry of Science, Education and Sports adopted a *Science and Society Action Plan*. It proposes equalizing the gender ratio for researchers in management structures in particular, with a minimum of one woman to every three men on national councils, key committees, scientific and political bodies, etc. (EU, 2013).

FORMER YUGOSLAV REPUBLIC OF MACEDONIA

A need for better governance of innovation

The Former Yugoslav Republic of Macedonia has not weathered the economic crisis too badly. Initial sluggish growth is now being driven by construction and exports, with projected growth of 3% in 2014 and 2015. Public debt also remains moderate, at 36% of GDP in 2013.

The country was granted EU candidate status in 2005 and has been in a 'high level accession dialogue' with the European Commission since March 2012. It is one of the poorest countries in Europe, with annual GDP per capita of € 3 640, just 14% of the EU27 average. Unemployment peaked at 31.4% in 2011 and was still extremely high in the first quarter of 2014, at 28.4% according to the State Statistical Office.

GERD is modest but the country's R&D effort has grown in recent years, from 0.22% of GDP in 2011 to 0.47% in 2013, according to the UNESCO Institute for Statistics. The public sector funds about two-thirds of R&D, according to Erawatch, which has also observed that private R&D funding dropped from € 3.32 million to € 2.77 million between 2009 and 2010, representing a contraction of 18.0% of GERD; in 2010, funds from abroad covered 16.7% of total R&D spending.

According to the EU's Innovation Union Scoreboard of 2014, the Former Yugoslav Republic of Macedonia is a *modest innovator*, well below the EU average. This places it on a par with the likes of Bulgaria, Latvia and Romania. The country's innovation performance did improve, however, between 2006 and 2013.

The structural challenges facing the Macedonian research system are as follows:

- inefficient governance of the innovation system;
- a lack of quality human resources for R&D;
- weak science–industry linkages;
- a low capacity for innovation among firms; and
- a non-existent national roadmap for building quality research infrastructure.

A strategy to boost research and innovation

The government has opted for a strategy of boosting R&D through tax incentives and subsidies. The tax incentives were introduced in 2008 by Scientific Subsidies and followed, in 2012, by Creative Subsidies. There is no evidence of the level of funds involved, however, or the impact of these measures on R&D.

In 2012, the government adopted the country's *Innovation Strategy for 2012–2020*, which had been prepared by the Ministry of the Economy. The same year, the Ministry of Education and Science prepared and adopted the *National Strategy for Scientific R&D Activities 2020* and the National Programme for Scientific R&D Activities 2012–2016. Both strategies clearly define national research priorities and propose an action plan for their implementation. Whereas the former takes a horizontal approach to fostering business innovation, including by proposing a more amenable regulatory environment, the national strategy and programme are more 'citizen-centric'.

Plans to raise R&D spending and develop a low carbon society

The primary goal of both the *National Strategy for Scientific R&D Activities 2020* and the National Programme for Scientific R&D Activities is to create a knowledge society by raising GERD to 1.0% of GDP by 2016 and 1.8% of GDP by 2020, with a 50% participation from the private sector. The *National Strategy* defines general thematic priorities which are mainly influenced by Europe's 2020 agenda. These same thematic priorities are defined more precisely by the National Programme for Scientific R&D Activities:

- The development of an open society and competitive economy via support for socio-economic development, economic policies, structural reforms, education, research, the information society and the overall development of the national innovation system;
- The development of a low carbon society through energy efficiency, renewable energy sources, sustainable transport and the use of clean technologies;
- Sustainable development, including sustainable management of natural resources, quality of air, water and land;
- Security and crisis management; and
- Socio-economic and cultural development.

MONTENEGRO

Greater spending on R&D but little impact on business

The global economic crisis exposed some pre-existing fissures in the foundations of Montenegro's economy which made it more vulnerable than anticipated to recession, with a contraction of 5.7% of GDP in 2009. Economic growth averaged 2.9% in 2010 and 2011 before slowing significantly in 2012, due to a sluggish use of credit, adverse weather conditions which reduced energy production, the bankruptcy of a major steel mill company (Nikšić) and a decline in production at a loss-making aluminium plant (KAP). In 2013, the economy returned to growth and inflation fell from 3.6% the previous year to 2.1%. Growth is expected to rise to around 3.2% from 2014–2016, supported by FDI in tourism and energy, as well as public investment.

In 2013, GERD represented 0.38% of GDP, a significant increase over previous years despite a highly restrictive budgetary policy. One of the main reasons for this increase is the implementation of a € 5 million call in 2012 for scientific and research projects covering the period 2012–2014. The call was announced by the Ministry of Science, in co-operation with the Ministries of Agriculture and Rural Development, Health, Information Society and Telecommunications, Sustainable Development and Tourism, Education and Sport, and Culture. Some 104 projects were selected out of 198 proposals.

The business sector funds four-tenths of R&D

As of 2013, the business enterprise sector funded 42% of GERD in Montenegro and three sectors concentrated the majority of R&D companies: agriculture, energy and transportation. These three sectors accounted for 22% of GERD in 2011. More than a third of GERD comes from the public purse (35.2% in 2013) and a further 23% from abroad, mainly from the EU and other international bodies.

In May 2012, Montenegro became a member of the World Trade Organization as a consequence of the government's commitment to opening the country to regional and international trade. In October 2011, the European Commission recommended opening accession negotiations with Montenegro, which were officially initiated on 29 June 2012.

A number of policy documents[9] have identified the main challenges facing the Montenegrin innovation system:

9. Including government documents such as *Montenegro in the 21st Century: In the Era of Competitiveness* (2010). *National Development Plan* (2013) and the *Strategy for Employment and Human Resource Development 2012–2015*, as well as external reviews by the OECD and World Bank and the Erawatch Country Report for Montenegro (2011).

- a small number of researchers;
- inadequate research infrastructure;
- a low level of scientific output;
- little mobility among researchers;
- insufficient commercialization of research and collaboration with the business sector; and
- a low level of company R&D expenditure and little application of research results in the economy.

A project devoted to strengthening higher education and research

In late 2012, the government adopted a new version of its *Strategy for Scientific Research Activity for 2012–2016*. The strategy defines three strategic goals:

- Develop the scientific research community;
- Strengthen multilateral, regional and bilateral co-operation;
- Foster co-operation between the scientific research community and the business sector.

The Higher Education and Research for Innovation and Competitiveness (HERIC) project should help to attain these goals. The aim of this project is to strengthen the quality and relevance of higher education and research in Montenegro. The project is being implemented from May 2012 to March 2017 with € 12 million in funding from a World Bank loan. There are four components: reform of higher education finance and the introduction of quality assurance norms; human capital development through the internationalization of training and research; establishment of a competitive research environment and, lastly; a component on project management, monitoring and evaluation.

One of the first initiatives taken by the Ministry of Science and the Ministry of Education to kick-start the HERIC project has been the establishment of the first pilot centre of excellence in late 2012. The Ministry of Science is also setting up the country's first science and technology park by 2015. The plan is for this park to comprise three units in Nikšić, Bar and Pljevlja, with the core centre in Podgorica co-ordinating the network.

SERBIA

A better performance in innovation

Serbia is slowly recovering from the global financial crisis. After a 3.5% contraction of GDP in 2009, the economy has managed to maintain positive growth since 2011. For the first time in years, GDP grew by 2.5% in 2013 but should shrink to just 1% in 2014, reflecting the impact of fiscal tightening, a lower inflow of investment and the ongoing fragile situation in the domestic financial sector. More robust growth rates of around 2–3% are forecast over the medium term.

Persistently high unemployment rates (22.2% in 2013 overall and about 50% for 15–24 year olds) and stagnant household incomes are ongoing political and economic headaches for the government. In June 2013, it revised the budget by raising the 2013 government deficit target from 3.6% to 5.2% of GDP. At the same time, the government adopted a programme of public sector reform, including an action plan for completing restructuring by the end of 2014, including the privatization of 502 state companies. Exports were the only driver of growth in 2012, boosted by 13.5% thanks to the opening of an assembly line in the second half of 2012 by Italian car-maker Fiat.

In 2013, Serbia's R&D effort amounted to 0.73% of GDP. The business enterprise sector contributed just 8% of the total, leaving the funding burden to be borne essentially by the government (60%) and higher education (25%) sectors. Foreign sources contributed 8% of GERD and private non-profit organizations virtually none of it. Non-profit organizations are the only category which benefits from a tax incentive for R&D in Serbia; they are exempted from paying tax on R&D services they provide to clients under non-profit contracts.

According to the Innovation Union Scoreboard (EU, 2014), Serbia is a *moderate innovator*, like Croatia. Serbia's innovation performance has improved, however, since 2010, according to this scoreboard, thanks to greater collaboration among SMEs and the efforts of various categories of innovator. Serbia performs very well in terms of youth education at the upper secondary level and employment opportunities in knowledge-intensive sectors. It also rates well for non-R&D innovation expenditure. It is relatively weak, on the other hand, in community design, community trademarks (despite strong growth) and business R&D expenditure. There has been strong growth in public R&D expenditure but this is countered by a decline in exports of knowledge-intensive services and in the number of non-EU PhD students in Serbia.

The key structural challenges facing Serbia's national innovation system today are:

- an absence of co-ordinated governance and funding;
- a linear understanding on the part of government of the innovation process, resulting in a highly fragmented innovation system; this is the main obstacle to networking the R&D sector with the rest of economy and society at large;
- persistent brain drain of highly educated individuals;

- an innovation system which is insufficiently attractive to private investment; the government needs to restructure the public R&D system and integrate the private sector into the national innovation system;
- lack of a culture of technological entrepreneurship in universities and the government sector;
- the absence of an evaluation culture; and
- a system which favours the supply side of R&D over the demand side.

The 1% GERD/GDP ratio goal within reach

In February 2010, Serbia adopted its *Strategy for the Scientific and Technological Development of the Republic of Serbia 2010–2015*. The overriding goal of this policy is to devote 1% of GDP to GERD by 2015, not counting investment in infrastructure, a goal which is currently within reach but requires additional effort. The strategy is guided by two basic principles: focus and partnership. Focus is to be achieved by defining a list of national research priorities; partnership is to be achieved through the strengthening of ties with institutions, companies and other ministries to allow Serbia to validate its ideas in the global market and enable scientists to participate in infrastructural and other projects in Serbia.

The strategy defines seven national R&D priorities, namely: biomedicine and human health; new materials and nanoscience; environmental protection and climate change mitigation; agriculture and food; energy and energy efficiency; ICTs; and better decision-making processes, as well as the affirmation of the national identity.

The *Strategy for the Scientific and Technological Development of the Republic of Serbia* launched the Serbian R&D Infrastructure Investment Initiative in January 2011 with a budget of € 420 million, half of which comes from an EU loan. Its priorities are to: upgrade existing capacities (*circa* € 70 million); adapt existing buildings and laboratories; purchase new capital equipment for research; develop centres of excellence and academic research centres (*circa* € 60 million); develop supercomputing via the Blue Danube initiative, as well as other ICT infrastructure (€ 30–80 million); create a campus for the technical science faculties of the University of Belgrade; build science and technology parks in Belgrade, Novi Sad, Niš and Kragujevac (*circa* € 30 million); and implement basic infrastructure projects, such as the construction of apartment buildings for researchers in Belgrade, Novi Sad, Niš and Kragujevac (*circa* € 80 million).

In 2012, basic sciences accounted for 35% of all research done in Serbia, applied sciences for 42% and experimental development for the remaining 23%, according to the UNESCO Institute for Statistics. The *Strategy* sets out to raise the ratio of applied sciences. This goal is supported by a new Programme for Co-funding of Integrated and Interdisciplinary Research for the Research Cycle, which emphasizes the commercialization of research results.

Another priority of the *Strategy* has been the creation of a national innovation fund to increase the monetary value of grants awarded to selected innovation projects. The fund is endowed with an initial treasury of € 8.4 million through the Innovation Serbia Project, which is financed by the EU pre-accession funds allocated to Serbia in 2011 and implemented through the World Bank.

A second programme finances the modernization of research facilities: the Programme for Providing and Maintaining Scientific Research Equipment and Scientific Research Facilities for the Research Cycle 2011–2014.

SLOVENIA

Despite recession, Slovenia's R&D effort has soared

With excellent infrastructure, a well-educated labour force and a strategic location between the Balkans and Western Europe, Slovenia has one of the highest levels of GDP per capita in Southeast Europe. On 1 January 2007, it became the first of the EU entrants of 2004 to adopt the euro. Slovenia has experienced one of the most stable political transitions to a market economy in Central and Southeast Europe. In March 2004, it became the first transition country to graduate from borrower status to donor partner status at the World Bank. In 2007, Slovenia was invited to begin the process for joining the OECD, which admitted it as a member in 2012.

However, long-delayed privatizations, particularly within Slovenia's largely state-owned and increasingly indebted banking sector, have fuelled investor concerns since 2012 that the country might need financial assistance from the EU and IMF. These woes have also affected Slovenia's competitiveness (Table 10.2). In 2013, the European Commission granted Slovenia permission to begin recapitalizing ailing lenders and transferring their non-performing assets into a 'bad bank' established to restore bank balance sheets. The strong demand among yield-seeking bond investors' for Slovenian debt helped the government to keep financing itself independently on international markets in 2013. The government has embarked on a programme of state asset sales to bolster investor confidence in the economy, which was poised to contract (by 1%) for the third year in a row in 2014.

Slovenia has managed the feat of raising GERD from 1.63% to 2.59% of GDP between 2008 and 2013, one of the highest ratios in the EU. Obviously, the fragile state of the economy has facilitated this rise by keeping the GDP denominator low. However, the dynamism of R&D in the business enterprise sector has also been a contributing factor; the number of researchers employed by businesses rose by nearly 50% over this period: from 3 058 to 4 664 (in FTE). By 2013, the business enterprise sector was contributing two-thirds (64%) of GERD and foreign sources just under 9%. As a share of GDP, it has almost tripled, from 0.09% of GDP in 2008 to 0.23% in 2013, thanks largely to the influx of EU structural funds; these have gone largely towards funding centres of excellence and competency centres, which are considered part of the business enterprise sector. The structural funds have also made it possible to raise the number of academic researchers from 1 795 to 2 201 (in FTE) over the same period.

Slovenia's *Development Strategy* for 2014–2020 defines R&D and innovation as being one of three driving forces for the country's development, the others being the creation and growth of SMEs and, thirdly, employment, education and training for all ages. Half of the funds allocated within the *Development Strategy* to 2020 will be used to foster:

- a competitive economy with a highly educated labour force, internationalized economy and strong investment in R&D;
- knowledge and employment;
- a green living environment through the sustainable management of water resources, renewable energy, forests and biodiversity;
- an inclusive society which provides intergenerational support and high-quality health care.

Slovenia has also adopted a *Smart Specialization Strategy* for 2014–2020 outlining how the country plans to use research and innovation to foster the transition to a new model of economic growth. The strategy includes an implementation plan for restructuring the Slovenian economy and society on the basis of R&D and innovation with the support of the EU funds. The strategy represents Slovenia's contribution to the 'smart pillar' of the *Western Balkans Regional R&D Strategy for Innovation* (Box 10.2).

Slovenia performs above the EU average for innovation

Slovenia is considered an *innovation follower* by the Innovation Union Scoreboard (EU, 2014), which means that it performs above the EU average. Other countries in this category include Austria, Belgium, Estonia, France, the Netherlands and the UK. This reflects the findings of an evaluation undertaken by the EU of measures implemented by Slovenia between 2007 and 2013 to promote innovation, which revealed that strong linkages had formed between the academic sphere and the economy. This confirms that Slovenia has shifted from a linear model to a second-generation R&D system based on an interactive organizational model.

Slovenia's National Research and Development Programme 2006–2010 had focused on increasing the quality of Slovenian science through competitive grants and an emphasis on linking promotion to the number of articles an academic published. This approach resulted in a significant increase in the number of published articles. The priority research fields for 2006–2010 were: ICTs; advanced (new and emerging) synthetic metallic and non-metallic materials and nanotechnologies; complex systems and innovative technologies; technologies for a sustainable economy; and health and life sciences.

Current public funding disbursed via the Slovenian Research Agency focuses on scientific excellence *per se* and allows for a significant degree of bottom-up initiative in the selection of specific priorities. The proportions of funding for the various scientific fields have remained unchanged over the years; for example, in 2011, 30% went to engineering and technology, 27% to natural sciences; 11.8% to the humanities and between 9.6% and 9.8% to each of biotechnology, social sciences and medical sciences. Multidisciplinary projects and programmes received 1.5% of all funds disbursed.

Slovenia commissioned an OECD *Review of Innovation Policy in Slovenia* (2012) to inform the preparation of its own research and innovation strategy to 2020. The review recommended that Slovenia address, *inter alia,* the following issues:

- Maintain sustainable public finances, this being one of the most important prerequisites for dynamic public and private investment in innovation;
- Pursue efforts to reduce the administrative burden on businesses, including start-ups;
- Consider streamlining the current large array of technology funding programmes, as a smaller number of large programmes will be more effective;
- Develop and improve demand-side measures, such as innovation-oriented public procurement;
- Continue to foster the use of non-grant financial instruments such as equity, mezzanine capital, credit guarantees or loans;
- Start a full-scale university reform, making autonomy – firmly tied to accountability and performance – the key precept underlying reforms;
- Alleviate or remove labour legislation and policies that impede mobility between universities and among universities, research institutions and industry;

- Increase the number of researchers in industry, including by pursuing programmes which fund the transfer of young researchers to firms;
- Reduce explicit and implicit barriers to working in Slovenia for highly qualified people from all over the world; and
- Use EU structural funds, in particular, to pool resources in its centres of excellence so that these can form the core of Slovenia's future research excellence.

The *Research and Innovation Strategy of Slovenia 2011–2020* defines the current policy priorities as being to achieve:

- a better integration of research and innovation;
- a contribution from publicly funded science and scientists to economic and social restructuring;
- closer co-operation between public research organizations and the business sector; and
- greater scientific excellence, partly by improving the competitiveness of stakeholders and partly by providing the necessary human and financial resources.

The government has raised the R&D tax subsidy considerably, which represented 100% in 2012. The ceiling for tax credits for investment in R&D by private enterprises has been raised to € 150 million to the end of 2013. In addition, the Slovenian Enterprise Fund offers credit guarantees.

Since 2012, the government has launched a programme for the Formation of a Creative Nucleus (€ 4 million) and the Research Voucher Scheme (€ 8 million), both co-financed by EU structural funds. The first measure makes public and private research institutions and universities in less developed parts of Slovenia eligible for 100% government funding for the development of human resources, research equipment, infrastructure and the like, in order to foster the decentralization of research and higher education. The second measure introduces research vouchers to help enterprises commission research at R&D institutes and/or universities (both private and public) for a period of three years. With each research voucher being worth € 30 000–100 000, enterprises should be able to co-finance the industrial research needed to develop new products, processes or services.

CONCLUSION

Research systems need to be more responsive to social and market demands

It is unlikely that any of the last five countries in Southeast Europe will become EU members before at least 2020, as the EU's current priority is to consolidate the cohesion of its 28 existing members. It is generally admitted in Europe, however, that the EU membership of these five countries is ultimately inevitable, in order to ensure political and economic stability across the region.

All five countries should use this time to make their research systems more responsive to social and market demands. They can learn a lot from Croatia and Slovenia, which are now formally part of the European Research Area. Since becoming an EU member in 2004, Slovenia has turned its national innovation system into a driving socio-economic force. Slovenia now devotes a greater share of GDP to GERD than the likes of France, the Netherlands or the UK, thanks largely to the rise of the business enterprise sector, which today funds two-thirds of Slovenian R&D and employs the majority of researchers. Slovenia's economy remains fragile, however, and it has chronic problems in attracting and retaining talent.

Having only been an EU member since 2013, Croatia is still searching for the most effective configuration for its own innovation system; it is currently striving to follow the best practices of the EU and incorporate its body of law and institutional and empirical legacy into the national innovation system.

Like Croatia, Serbia is what the EU calls a *moderate innovator*. These two countries are poles apart, however, when it comes to the weight of business R&D funding; this accounts for 43% of GERD in Croatia but only 8% in Serbia (in 2013). The Serbian government's biggest challenge will be to overcome a linear understanding of the innovation process which has resulted in a highly fragmented innovation system; this fragmentation is the biggest obstacle to networking the R&D sector with the rest of the economy and society at large.

Albania, Bosnia and Herzegovina, the Former Yugoslav Republic of Macedonia and Montenegro are all faced with structural adjustments and political and economic challenges which tend to have relegated the reform of their respective innovation systems to a lower priority. All are suffering from sluggish economic growth, the ageing of researchers, severe brain drain, a lack of private sector R&D and a system which encourages academics to focus on teaching rather than research or entrepreneurship.

Countries will be able to draw on the *Western Balkans Regional Research and Development Strategy for Innovation* and the *SEE 2020 Strategy* as a framework for implementing the policy and institutional reforms that should allow them to promote the 'smart specialization' that will set them on the path to sustainable development and long-term prosperity.

KEY TARGETS FOR SOUTHEAST EUROPE

- Raise GDP per capita in the region to 44% of the EU average by 2020;
- Double turnover from regional trade from € 94 billion to € 210 billion;
- Open up the region to 300 000 new highly qualified jobs by 2020;
- Achieve minimum 9% energy savings in the region by 2018;
- Raise the share of renewable energy in gross energy consumption to 20% by 2020;
- Raise the GERD/GDP ratio to 0.6% in Albania and to 1% in Bosnia and Herzegovina and Serbia by 2015;
- Raise the GERD/GDP ratio to 1% in the FYR Macedonia by 2016 and to 1.8% by 2020 with a 50% private-sector participation.

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A few adjustments and the future looks bright for the countries of the European Free Trade Association.

Hans Peter Hertig

Bertrand Piccard waves after the first entirely solar-powered jet, *Solar Impulse*, lands at Nanjing Lukou International Airport on 22 April 2015, on its landmark 20-day journey around the globe. A Swiss psychiatrist and balloonist, Bertrand Piccard is the person who initiated the *Solar Impulse* project.

Photo: © ChinaFotoPress/Getty Images

11 · European Free Trade Association

Iceland, Liechtenstein, Norway, Switzerland

Hans Peter Hertig

INTRODUCTION

A relatively quick recovery

The four countries which make up the European Free Trade Association (EFTA) are among the wealthiest in the world. Liechtenstein has a strong banking sector and successful companies in machinery and the construction business. Switzerland does very well in the services sector – particularly in banking, insurance and tourism – but also specializes in high-tech fields such as microtechnology, biotechnology and pharmaceuticals. Norway has built up its wealth by exploiting North Sea oil since the 1970s and Iceland's economy is dominated by the fishing industry, which accounts for 40% of exports. In order to reduce their dependency on these traditional sources of income, the two Nordic states have developed capacities in a wide range of knowledge-based sectors, such as software design, biotechnology and environment-related technologies.

This solid base and the resultant high per-capita income didn't prevent the four EFTA countries from being buffeted by the global financial crisis in 2008–2009; however, they suffered to varying degrees, like most countries in the western hemisphere (Figure 11.1). Iceland was particularly shaken, with three of its largest banks collapsing in late 2008; the country's inflation and unemployment rates more than doubled to almost 13% (2008) and 7.6% (2010) respectively, while central government debt almost tripled from 41% (2007) to 113% (2012) of GDP as the country struggled to conjugate the crisis. These same indicators barely budged in Liechtenstein, Norway and Switzerland, which continued to count unemployment levels of just 2–4% on average. Iceland has since put the crisis behind it but recovery has been slower than for its neighbours.

Growth in all four countries has nevertheless stalled recently (Figure 11.1) and there are some question marks regarding the short-term outlook. The strong, overrated Swiss franc[1] may have a negative impact on key sectors of the Swiss economy, such as the export industry and tourism, suggesting that predictions for GDP growth in 2015 will probably need to be lowered. The same may be necessary for Norway as a result of the slump in oil prices since 2014.

Not surprisingly, Europe[2] is EFTA's main trading partner. In 2014, it absorbed 84% of Norway's merchandise exports and 79% of Iceland's but only 57% of Switzerland's own exports, according to the United Nations COMTRADE[3] database. When it comes to imports of European goods, however, Switzerland takes the lead (73% in 2014), ahead of Norway (67%) and Iceland (64%). EFTA began diversifying its trading partners in the 1990s and has since signed free trade agreements[4] with countries on every continent. Similarly global is the EFTA countries' engagement in the field of science and technology (S&T), albeit with a clear focus on Europe and the activities of the European Commission.

Part of Europe but different

EFTA is an intergovernmental organization devoted to promoting free trade and economic integration in Europe. Its headquarters are based in Geneva (Switzerland) but another office in Brussels (Belgium) liaises with the European Commission. Twelve years after EFTA was founded in 1960, it counted nine member states: Austria, Denmark, Finland, Iceland, Norway, Portugal, Sweden, Switzerland and the UK. All but three had joined the European Union (EU) by 1995: Iceland, Norway and Switzerland. Liechtenstein's adhesion since 1991 brings EFTA's current membership to four.

A turning point in EFTA's development came with the signing of an agreement with the EU on the creation of a single European market. The Agreement on the European Economic Area (EEA) was signed by Iceland, Liechtenstein and Norway and entered into force in 1994. It provides the legal framework for the implementation of the four cornerstones of the single market: the free movement of people, goods, services and capital. The agreement established common rules for competition and state aid and promoted co-operation in key policy areas, including research and development (R&D). It is through this agreement that three of the four EFTA members participate in the EU's main R&D activities as associated states on the same footing as the EU member states.

Switzerland, on the other hand, was unable to sign the EEA treaty, even though it had participated actively in drawing it up, owing to a negative vote in a Swiss referendum in November 1992. A bilateral agreement with the EU nevertheless allows Switzerland to take advantage of the main EU instruments in place, including the seven-year framework programmes for research and innovation, the

1. In January 2015, the Swiss franc soared by almost 30% against the euro, after the Swiss National Bank removed the cap it had imposed in 2011 to prevent such a scenario. Since then, the effect has softened to a 15–20% rise.

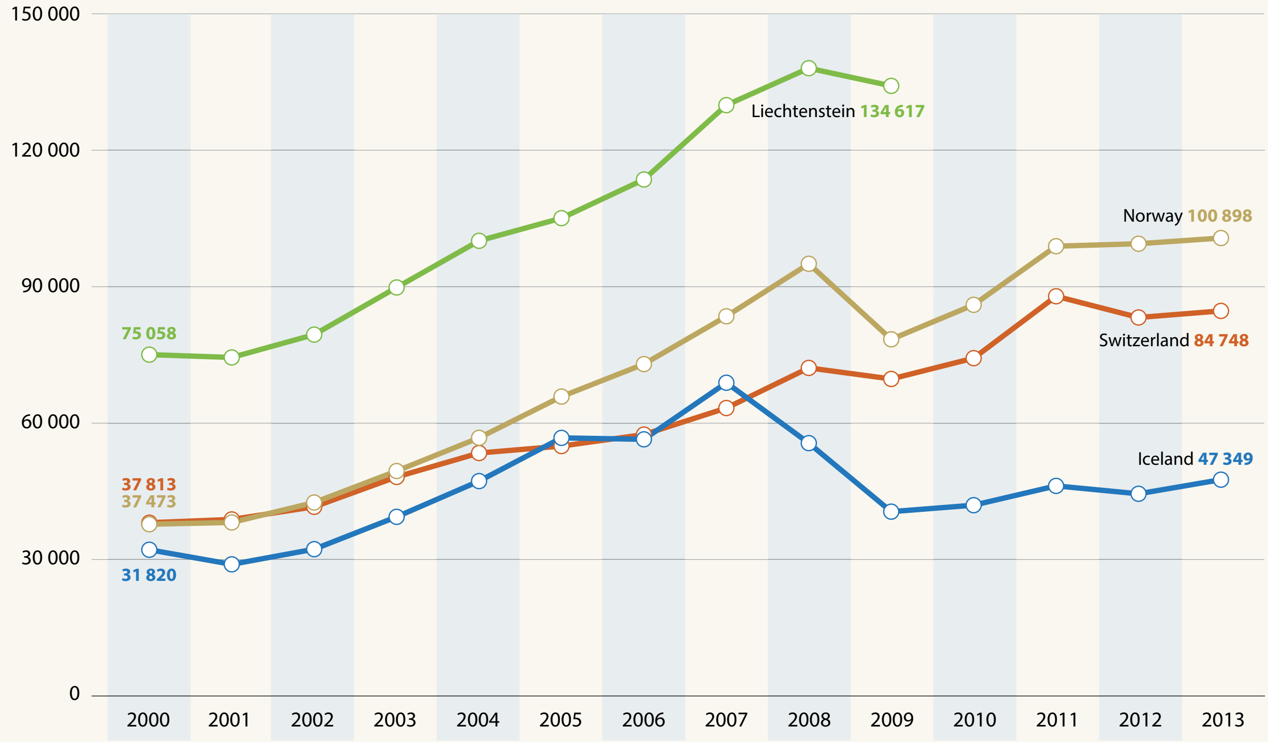
2. Here, Europe encompasses the EU, Southeast Europe and Eastern Europe but not the Russian Federation.

3. Liechtenstein's trade is covered in Swiss statistics.

4. See: www.efta.int/free-trade/fta-map

Figure 11.1: **Trends in GDP per capita in EFTA countries, 2000–2013**

In PPP$ at current prices



Source: World Bank's World Development Indicators, April 2015

Future and Emerging Technologies programme, the grants of the European Research Council and the Erasmus programme for student exchange, but Switzerland's political ties to the EU are more tenuous than those of the three other EFTA members. Moreover, as we shall see, Switzerland's relations with the EU have been jeopardized recently by yet another referendum.

The four EFTA members do not have a unified legal and political status vis-à-vis the EU and the EFTA group itself is anything but homogeneous. It consists of:

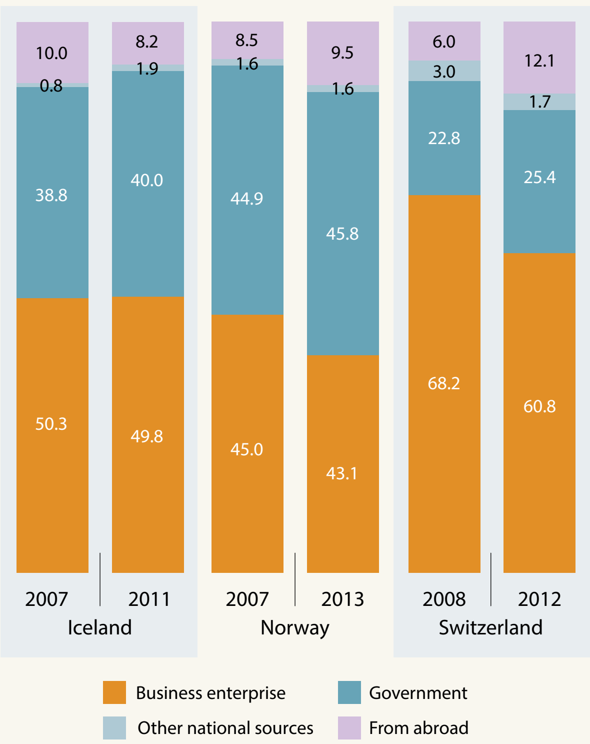
- two geographically remote countries with lengthy sea coasts (Iceland and Norway) and abundant natural resources, versus two inland nations (Liechtenstein and Switzerland) at the heart of Europe which are entirely dependent on the production of high-quality goods and services;
- two small countries (Norway and Switzerland) with a population of 5.1 million and 8.2 million respectively, versus a very small country (Iceland, 333 000 inhabitants) and a mini-state (Liechtenstein, 37 000 inhabitants);
- one country severely hurt by the 2008 financial crisis (Iceland) and another three which were able to digest it relatively painlessly; and
- two countries involved in multinational regional activities in Europe's north – Iceland and Norway are active partners in the Nordic co-operation scheme – and another two, Liechtenstein and Switzerland, which share a common language, maintain close neighbourly co-operation in a multitude of areas and have formed a customs and monetary union since 1924.

The list could be a lot longer but these examples suffice to make the point: the very heterogeneity of the EFTA countries make them interesting case studies for the *UNESCO Science Report*, in which they feature for the first time. There are no R&D activities *per se* within EFTA as, in this area, the EEA treaty has split the small group of four into a group of three plus one. All four are nevertheless involved in most of the European Commission's activities, as well as some other pan-European initiatives such as European Co-operation in Science and Technology (COST) and Eureka, a co-operative scheme providing companies, universities and research institutes with incentives for cross-border market-driven research. They also take part in the Bologna Process, the collective effort of European countries to harmonize and co-ordinate higher education. Norway and Switzerland are also members of the European Organization for Nuclear Research (CERN), which is hosted by the latter on the Franco-Swiss border and attracts thousands of physicists from around the world.

In the following pages, we shall be analysing the ways in which these countries perform individually and as a group in the European context. We shall also analyse the reasons which make Switzerland, in particular, such a high-achiever when it comes to innovation: it topped both the EU's Innovation Scoreboard and the Global Innovation Index in 2014 and belongs to the top three countries for innovation among members of the Organisation for Economic Co-operation and Development (OECD).

Table 11.1 provides key indicators for Iceland, Norway and Switzerland; it doesn't cover Liechtenstein, which is simply too small to have meaningful statistics for this comparative table. Some data are given in the country profile of Liechtenstein (see p. 303). Switzerland belongs to the top three countries in Europe, according to all indicators for science input, science output, innovation and competitiveness in the region, Iceland and Norway rank in the first tier or in the midfield. Norway has considerably increased its gross domestic expenditure on research and development (GERD) but its GERD/GDP ratio remains well below the EFTA and EU28 averages (Table 11.1; see also Figure 11.2). Another weak point is Norway's seeming unattractiveness for foreign students: just 4% of those enrolled in advanced research programmes on Norwegian campuses are international students, against 17% in Iceland and 51% in Switzerland, according to the OECD's *Education at a Glance* (2014); nor can Norway be satisfied with its score in

Figure 11.2: **GERD in EFTA countries by source of funds, 2007 and 2013 or closest years (%)**



Source: OECD (2015) *Main Science and Technology Indicators*

the EU Innovation Union Scoreboard 2014: it is ranked 17th in a field of 35, placing it in the modest group of *moderate innovators*[5] which fall below the EU average (see glossary, p. 738).

All three countries, with some reservations for Norway, have a highly mobile future generation of scientists (Table 11.1) and are strong publishers – Iceland increased its output by 102% between 2005 and 2014 – with a large share of international co–authors (Table 11.1 and Figure 11.3). The country with the highest publication growth rate has also done especially well impact-wise: Iceland ranks fourth for the share of scientific publications among the top most cited (Table 11.1). The clouds on Iceland's horizon are to be found elsewhere; it did not manage to improve its innovation performance between 2008 and 2013. Although it remains in the category of *innovation followers* and above the EU average, Iceland has been overtaken by no fewer than six EU countries and it has lost 11 places in the World Economic Forum's competitiveness index. We shall discuss possible measures Iceland could adopt in order to get back on track later in the chapter.

Before profiling the four nations individually, we shall take a brief look at the common activities Iceland, Norway and Liechtenstein undertake related to R&D within the framework of the EEA agreement.

Common research within the EEA

The EEA agreement affords Iceland, Liechtenstein and Norway the status of fully associated partners in EU research programmes. Iceland and Norway take full advantage of this opportunity; they were among the most successful countries per capita for the obtention of competitive research grants from the Seventh Framework Programme (FP7) over 2007–2013. For its part, Iceland had the best success rate of all European Research Area countries in the FP7–Cooperation programme, which set out to strengthen co-operation in R&D between universities, industry, research centres and public authorities across the EU and the rest of the world. Iceland showed special strengths in environment, social sciences, humanities and health; Norway was one of the leaders in environmental research, as well as in energy and space (DASTI, 2014).

Participation in EU activities is not free, of course. Besides paying a lump sum to each framework programme, the three EEA countries contribute to reducing socio-economic disparities in Europe by promoting social cohesion, via a special programme administered autonomously by the EEA Secretariat: the EEA/Norway grants programme. Although

5. In the opinion of Statistics Norway, the verdict in the European Commission's report is too severe, for it underestimates Norway's innovation potential (see Research Council of Norway, 2013, p. 25).

Table 11.1: **International comparisons for EFTA countries in science, 2014 or closest year**

		Iceland	Norway	Switzerland
Human resources	Human resources in S&T* as a share of the active population, 2013 (%)	53	57	57
	Corresponding ERA** ranking (41 countries)	7	2	2
	Public expenditure on higher education as a share of GDP, 2011 (%)	1.6^{-1}	2.0^{-1}	1.4
GERD	GERD/GDP ratio (2007)	2.9^{-1}	1.6	2.7^{+1}
	GERD/GDP ratio (2013)	1.9	1.7	3.0^{-1}
	Corresponding EU ranking (28 countries)	8	16	3
	Public expenditure on R&D in higher education as a share of GDP (2012)	0.66^{-1}	0.53^{+1}	0.83
Researcher mobility	Share of postdocs having spent more than 3 months abroad in past 10 years (%)	49	43	53
	Corresponding EU ranking (28 countries)	3	10	1
	International students as a percentage of enrolment in advanced research programmes (2012)	17	4	51
	Corresponding OECD ranking (33 countries)	15	25	2
Publication intensity	International scientific co-publications per million inhabitants (2014)	2 594	1 978	3 102
Publication impact	Share of scientific publications in top 10% most cited, 2008–2012	18	13	18
Research excellence	Number of universities in top 200, according to Shanghai Academic Ranking of World Universities, 2014	0	1	7
	Number of universities in top 200, according to QS World University Rankings 2014	0	2	7
	Number of ERC grants per million population 2007–2013	3	8	42
	Corresponding ERA ranking	18	12	1
Patent activity	Number of triadic patent families per million population (2011)	11	23	138
	Corresponding OECD ranking (31 countries)	15	12	2
	RANK IN INTERNATIONAL INDICES			
Innovation potential	Rank in EU's Innovation Union Scoreboard , 2008 (35 countries)	6	16	1
	Rank in EU's Innovation Union Scoreboard 2014 (35 countries)	12	17	1
Competitiveness	Rank in WEF World Competitiveness Index, 2008 (144 countries)	20	15	2
	Rank in WEF World Competitiveness Index, 2013 (144 countries)	30	11	1
	Rank in IMD World Competitiveness Scoreboard, 2008 (57 countries)	not ranked	11	4
	Rank in IMD World Competitiveness Scoreboard, 2013 (60 countries)	25	10	2

-n/+n = data are for *n* years before or after reference year
* individuals who have obtained a tertiary-level qualification in an S&T field and/or are employed in an occupation where such a qualification is required
** ERA comprises the 28 EU members, the four EFTA states, Israel and the EU candidates in the year of the study.

Note: Comparative data are unavailable for Liechtenstein; its patents are covered in Swiss statistics.

Source: Eurostat, 2013; European Commission (2014a) *Researchers' Report; WEF (2014) Global Competitiveness Report 2014–2015;* European Commission (2014b) *ERA Progress Report;* European Commission (2014c) *Innovation Union Scoreboard;* OECD (2015) *Main Science and Technology Indicators;* OECD (2014) *Education at a Glance;* IMD (2014) *World Competitiveness Yearbook;* EU (2013) *Country and Regional Scientific Production Profiles;* IMF (2014) *World Economic Outlook;* UNESCO Institute for Statistics, May 2015; Iceland Statistics this is not really an R&D programme, education, science and technology play a crucial role in the areas covered by the programme, from environmental protection, renewable energy and the development of green industries to human development, better working conditions and the protection of cultural heritage. Between 2008 and 2014, the three EEA donors invested € 1.8 billion in 150 programmes that had been defined jointly with 16 beneficiary countries in central and southern Europe. In relation to climate change, for instance, one of the programme's priority themes, a joint project enabled Portugal to draw on the Icelandic experience to tap its geothermal potential in the Azores. Portugal has also co-operated with the Norwegian Institute for Marine Research to keep its seas healthy. Through another project, Innovation Norway and the Norwegian Water Resource and Energy Administration have helped Bulgaria to improve its energy efficiency and innovate in green industries.

The EEA grants/Norway grants programme will continue in the years to come, albeit with small changes to the programme structure, a likely increase in spending levels and a merger of the two types of grant into a single funding scheme. As in the past, Iceland and Norway will be participating as fully associated members in the new framework programme covering the period from 2014 to 2020, Horizon 2020 (see Chapter 9). Liechtenstein, on the other hand, has decided to refrain from an association with Horizon 2020, in light of the small number of scientists from this country and its resultant low participation level in the two former programmes.

COUNTRY PROFILES

ICELAND

A fragmented university system

Iceland was severely hit by the global financial crisis of 2008. After its three main banks failed, the economy slipped into a deep recession for the next two years (-5.1% in 2009). This hindered ongoing efforts to diversify the economy beyond traditional industries such as fisheries and the production of aluminium, geothermal energy and hydropower into high-knowledge industries and services.

Although most of the figures in Table 11.1 look good, they would have looked even better a few years ago. The country invested 2.9% of GDP in R&D in 2006, making it one of the biggest spenders per capita in Europe, surpassed only by Finland and Sweden. By 2011, this ratio was down to 2.5% and, by 2013, had hit 1.9%, its lowest level since the late 1990s, according to Iceland Statistics.

Iceland has an excellent publication record, both quantitatively and qualitatively (Table 11.1 and Figure 11.3). It has one internationally known university, the University of Iceland, which ranks between 275th and 300th in the *Times Higher Education Supplement*. The country's strong publication record is no doubt largely due the country's highly mobile younger generation of scientists. Most spend at least part of their career abroad; half of all doctorates are awarded in the USA. Moreover, 77% of articles have a foreign co-author. Even if it is true that this high percentage is typical of small countries, it places Iceland in the group of the most internationalized science systems in the world.

Like Norway, Iceland has a solid science base that does not translate into a high innovation potential and competitiveness (see p. 304). Why is this so? Norway can blame this paradox on its economic structure, which encourages specific strengths in areas requiring low research intensity. Restructuring an economy to favour high-tech industries takes time and, if there is steady high income falling in the government's lap from low-tech industries in the meantime, there can be little incentive to put the necessary measures in place.

Unlike Norway, Iceland was well on the way to a more diversified and more knowledge-based economy in the years before the 2008 crisis. When the crisis struck, it had widespread repercussions. Research expenditure at universities and public research institutes slid from 1.3% of GDP in 2009 to 1.1% in 2011. Efforts to complement the foreign training of Icelandic scientists and strengthen their active role in international networks by developing a solid home base with a strong Icelandic research university were stopped in their tracks. This put Iceland in a double bind: it fuelled the brain drain problem while lowering the country's chances of attracting multinational companies in research-intensive domains.

The European Commission produces a series of Erawatch reports for the EU and EEA countries. Iceland's Erawatch report (2013) identified a number of key structural and financial challenges faced by Iceland's STI system. Besides the shortcomings mentioned above, the report cited weaknesses in governance and planning, a low level of competitive funding with an insufficient number of grants that were also too small, inadequate quality control and a fragmented system, with too many players (universities and public laboratories) for a country the size of Iceland. The country has seven universities, three of which are private; the University of Iceland had about 14 000 students in 2010, compared to fewer than 1 500 at most of the other institutions.

At least some of these weaknesses are addressed in the first policy paper published by the government-elect in 2013. Its *Science and Technology Policy and Action Plan 2014–2016* advocates:

Figure 11.3: **Scientific publication trends in EFTA countries, 2005–2014**

Growth has slowed in Iceland since 2010 and remained steady in Norway and Switzerland

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Iceland	427	458	490	575	623	753	716	810	866	864
Liechtenstein	33	36	37	46	41	50	41	55	48	52
Norway	6 090	6 700	7 057	7 543	8 110	8 499	9 327	9 451	9 947	10 070
Switzerland	16 397	17 809	18 341	19 131	20 336	21 361	22 894	23 205	25 051	25 308

2 594

Publications per million inhabitants in Iceland in 2014

1 978

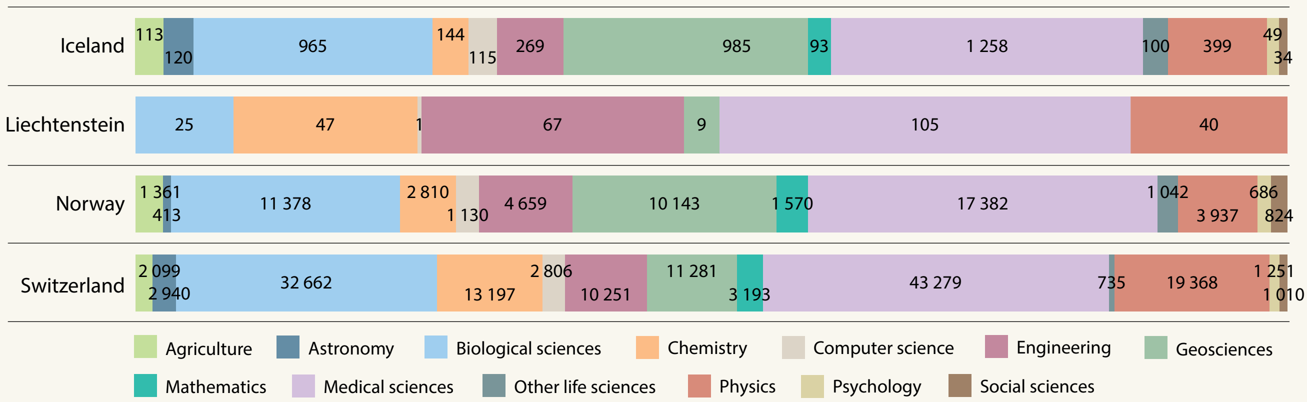
Norwegian publications per million inhabitants in 2014

3 102

Swiss publications per million inhabitants in 2014

Countries specialize in medical sciences, Switzerland stands out in physics

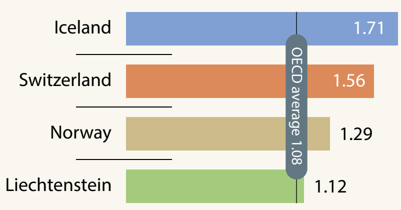
Cumulative totals by field, 2008–2014



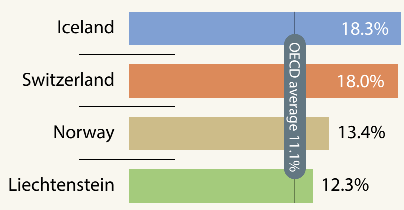
Note: The totals by field do not include unclassified publications, which are quite numerous for Switzerland (13 214), Norway (5 612) and Iceland (563). See the methodological note on p. 792.

All countries surpass the OECD average by far for key indicators

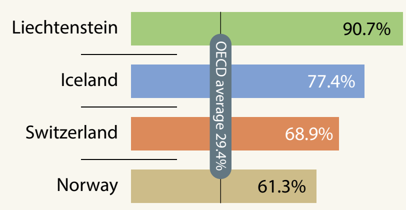
Average citation rate for publications 2008–2012



Share of papers among 10% most-cited 2008–2012



Share of papers with foreign co-authors, 2008–2014



The main partners are in Europe or the USA

Main foreign partners between 2008 and 2014 (number of papers)

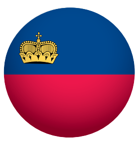
	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Iceland	USA (1 514)	UK (1 095)	Sweden (1 078)	Denmark (750)	Germany (703)
Liechtenstein	Austria (121)	Germany (107)	Switzerland (100)	USA (68)	France (19)
Norway	USA (10 774)	UK (8 854)	Sweden (7 540)	Germany (7 034)	France (5 418)
Switzerland	Germany (34 164)	USA (33 638)	UK (20 732)	France (19 832)	Italy (15 618)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

- a higher contribution to tertiary education in order to reach the level of other Nordic countries;
- restoration of the pre-2008 target of raising the GERD/GDP ratio to 3% by 2016;
- measures to increase Iceland's participation in international research programmes;
- the definition of long-term funding projects and the research infrastructure they call for;
- strengthening competitive funding at the cost of fixed contributions;
- a better use of the tax system to encourage the private sector to invest in R&D and innovation; and, lastly,
- a better system for evaluating the quality of domestic research and innovation.

Unfortunately, these recommendations hardly touch on the problem of fragmentation pinpointed by the Erawatch country report in 2013. Iceland counts one university for every 50 000 inhabitants! Of course, prioritizing some institutions over others is a politically difficult manoeuvre; it impinges on STI but also has regional, social and cultural dimensions. Notwithstanding this, channelling available resources to a single strong university likely to impress the international scientific community and attract students and faculty from abroad is an absolute must. This institution would then be able to take the lead in Iceland's most promising research fields – health, information and communication technologies (ICTs), environment and energy – and perhaps develop others. The brilliant young Icelanders living abroad would be more willing to return home with their new ideas. Maybe it will take this young generation to heed the message from an independent expert group that recently reviewed Iceland's STI system commissioned by the European Commission. If Iceland wishes to put an end to institutional fragmentation, they said, to improve co-ordination of the main players, foster co-operation and develop an efficient evaluation and quality assessment system, the way forward can be summed up in two words: pull together.

LIECHTENSTEIN



Innovation drives Liechtenstein's economy

Liechtenstein is a special case in many respects. It is one of Europe's few remaining principalities, a constitutional democracy combining a parliament with a hereditary monarchy. One-third of inhabitants are foreigners, mainly Swiss, German and Austrian. Its tiny size – 37 000 inhabitants in 2013 – excludes it from most comparative S&T statistics and rankings. Its public expenditure on R&D amounts to less than the budget of a small university and its publication output represents a couple of hundred citable documents per year. The EEA agreement links it closely to Iceland and Norway but its geographical location on Switzerland's eastern border, national language (German) and the long tradition of close collaboration in many policy fields with the Swiss make joint ventures with Switzerland a much more evident and pragmatic solution. Science and technology are no exception. Liechtenstein is fully associated with the Swiss National Science Foundation, giving its researchers the right to participate in the foundation's activities. Moreover, Liechtenstein enjoys the same privilege with the Austrian Science Fund, the Austrian equivalent of the Swiss National Science Foundation.

Liechtenstein boasts an impressive GERD/GDP ratio of 8 %, according to the national education authority, but this is of limited meaning in international comparisons on account of the extremely small number of actors and nominal figures. Nevertheless, this ratio reflects the high level of R&D undertaken by some of Liechtenstein's internationally competitive companies in machinery, construction and medical technology, such as Hilti, Oerlikon-Balzers or Ivoclar Vivadent AG; the latter develops products for dentists, employs 130 people in Liechtenstein and about 3 200 people worldwide in 24 countries.

Liechtenstein's public funding of R&D – roughly 0.2% of GDP – goes mainly to the country's sole public university, the University of Liechtenstein. Founded in its present form in 2005 and formally accredited in 2011, the university concentrates on areas of special relevance for the national economy: finance, management and entrepreneurship, and, to a lesser degree, architecture and planning. The school has got off to a good start; it is attracting a growing number of students from beyond its German-speaking neighbours, not least because of a highly attractive faculty/student ratio. A large proportion of the country's youth nevertheless studies abroad, mainly in Switzerland, Austria and Germany (Office of Statistics, 2014).

Whether Liechtenstein will continue to flourish and earn the international reputation and status it covets remains to be seen. Liechtenstein's development will, in any case, determine the future of its public R&D sector. If the University of Liechtenstein lives up to expectations in terms of growth and quality, this may incite parliament to rethink its recent decision to drop out of the EU's Horizon 2020 programme. Innovation is the key element behind Liechtenstein's strong economy and supportive R&D measures by the public sector could well prove a useful complement to private R&D investment for preserving the country's advantages in the long run.

NORWAY

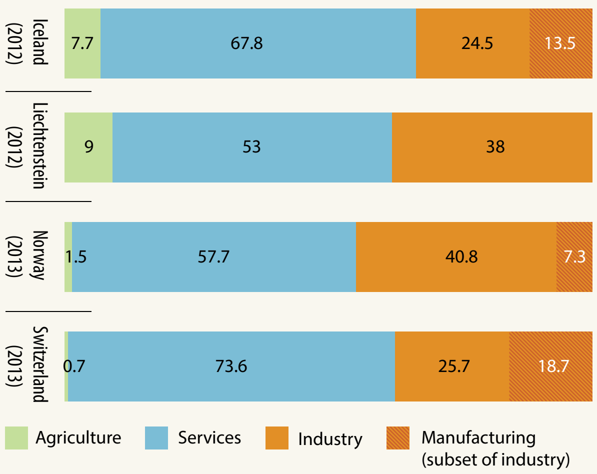
Knowledge not translating into innovation

Norway has one of the highest income levels in the world (PPP$ 64 406 per capita in current prices in 2013). Despite this, the country's strong science base contributes less to national wealth than its traditional economic assets: crude oil extraction from the North Sea (41% of GDP in 2013); high productivity in manufacturing; and an efficient services sector (Figure 11.4).

As shown in Table 11.1, the first links in the added value chain are promising. The share of the adult population with tertiary qualifications and/or engaged in the STI sector is one of the highest in Europe. Norway did have a traditional weakness in the relatively low number of PhD students and graduates but the government has managed to remove this bottleneck; since 2000, the number of PhD students has doubled to match those of other northern European countries. Together with public R&D expenditure above the OECD median and a large pool of researchers in the business enterprise sector, this makes for solid input to the S&T system (Figure 11.5).

It is at this point that the clouds appear: output is not what the level of input would suggest. Norway ranks third in Europe for the number of scientific publications per capita but the share of Norwegian-authored articles in top-ranked journals is only just above the ERA average (Table 11.1). Similarly, Norway's performance in the first seven calls by the ERC for research proposals is good but not excellent and the same is true for the international prestige of its universities:

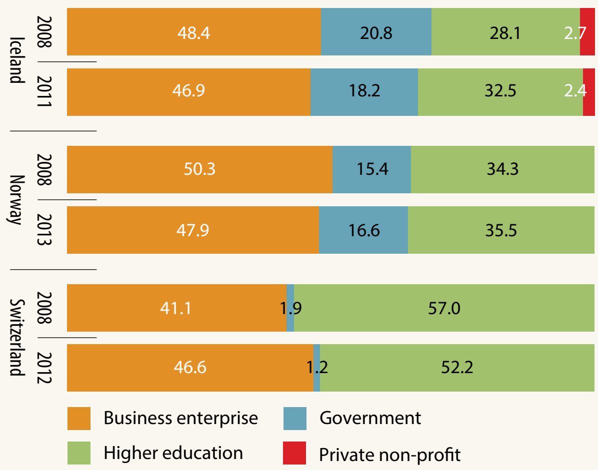
Figure 11.4: **GDP in EFTA countries by economic sector, 2013 or closest year (%)**



Note: For Liechtenstein, manufacturing is included in other industry; 'agriculture' includes households and corresponds mainly to the rental activities of real estate agencies.

Source: World Bank's World Development Indicators, April 2015; for Liechtenstein: Office of Statistics (2014)

Figure 11.5: **Researchers (FTE) in EFTA countries by sector of employment, 2008 and 2013 or closest years (%)**



Note: The category of 'other researchers' includes private non-profit and not elsewhere classified, reported only in Iceland. For Switzerland, federal and central government researchers only are classified as 'government'.

Source: UNESCO Institute for Statistics, April, 2015

Norway's leading institution, the University of Oslo, ranks 63rd in the Shanghai Academic Ranking of World Universities, a sign of world-class research. However, if we look at rankings that consider criteria other than research quality, an obvious problem emerges. Two Norwegian universities figure among the top 200 in the QS World University Rankings: the University of Oslo (101st) and the University of Bergen (155th) [Table 11.1]. Both do well citation-wise but disappoint when it comes to the internationalization count. This reflects a Norwegian pattern. Also disappointing is the small proportion of international students enrolled in advanced research programmes (Table 11.1);[6] Switzerland, Iceland and other small European countries such as Austria, Belgium or Denmark do much better for this indicator. Clearly, Norwegian universities face a vicious circle: the main asset for attracting high-performing international students and faculty members is a university's reputation, the number one reputation-maker in globalized higher education is the rankings and a key criterion for good positions in the league tables is having adequate percentages of international students and faculty members. Whether one likes it or not, rankings are the signposts on the avenues of international talent circulation.[7]

How can Norway break this circle and better brand itself as an attractive destination for study[8] and research? Norway

6. The OECD figures for Norway may have a tendency to underestimate the percentage because of the specificities of Norwegian statistics and/or because a large share of foreign students have either obtained resident status or are EU citizens.

7. For a discussion of the relationship between universities, rankings, regional context and globalized higher education, see UNESCO (2013) and Hertig (in press).

8. Canada is asking itself the same question. See Chapter 4.

faces two severe handicaps for the internationalization of its science system, of course: location and language. To overcome these handicaps, it could remove legal and logistical barriers to cross-border mobility, undertake campus upgrades, reform study programmes so that they better suit the needs of a foreign clientele and extend PhD and postdoctoral programmes abroad, including special measures to reintegrate students afterwards – but this may not be enough. Another measure is probably necessary to make a visible difference: the establishment of additional research flagship programmes that shine on the international scene like that for arctic science (Box 11.1).

One such flagship programme has recently caught the attention of the scientific community beyond the immediate circle of neuroscientists, after the director of the Kavli Institute for Systems Neuroscience was awarded the Nobel Prize in Physiology or Medicine in 2014 for discovering that the human brain has its own positioning system. Edvard Moser shares the prize with fellow Norwegian, May-Britt Moser, Director of the Centre for Neural Computation in Trondheim, and John O'Keefe from University College London. The Kavli Institute for Systems Neuroscience is hosted by the Norwegian University of Science and Technology in Trondheim and is part of Norway's centres of excellence scheme. The first 13 of these centres of excellence were established in 2003. Twenty-one additional centres were established in two separate rounds in 2007 (8) and 2013 (13). These centres receive stable public funding over a period of ten years to the tune of € 1 million per centre per year. This sum is rather low; similar centres in Switzerland and the USA receive two to three times more. Allocating a higher sum to a couple of institutions that Norway is bent on profiling internationally may warrant further reflection. Investing more in such centres would also lead to more balanced support for the different types of research. Basic research is not Norway's top priority; few other European countries have a portfolio more oriented towards applied science and experimental development (Figure 11.6).

Measures like the above would help Norway to fix some of the weak spots in its generally very good public science system. However, as mentioned above, Norway's main weakness is its performance in the later stages of the added value chain. Scientific knowledge is not being efficiently transformed into innovative products. Norway's most negative STI indicator in the OECD's 2014 country report concerns the number of patents filed by universities and public laboratories; the lowest per capita figure within the OECD. It does not suffice to blame academia for this predicament. The problem goes deeper; patents are the result of an active relationship between the producers of basic knowledge and the private companies using, transforming and applying it. If the business side is not

Box 11.1: **Arctic research in Svalbard**

Svalbard (Spitsbergen) is a Norwegian archipelago situated midway between continental Norway and the North Pole. Its natural environment and unique research facilities at a high latitude make it an ideal location for arctic and environmental research.

The Norwegian government actively supports and promotes Svalbard as a central platform for international research collaboration. Institutions from around the world have established their own research stations there, most of them in Ny-Ålesund. The first two polar institutes were established by Poland in 1957 and Norway in 1968. Norway has since set up four other research stations: in 1988 (shared with Sweden), 1992, 1997 and 2005. The most recent addition was the Centre for Polar Ecology in 2014, which is part of the University of South Bohemia in the Czech Republic. Other research stations have been set up by China (2003), France (1999), Germany (1990 and 2001), India (2008), Italy (1997), Japan (1991), the Republic of Korea (2002), the Netherlands (1995) and the UK (1992).

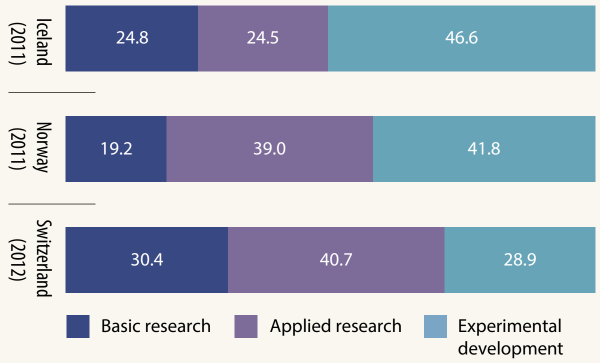
Longyearbyen, the world's most northerly city, hosts research bodies and infrastructure such as the:

- European Incoherent Scatter Scientific Association (est. 1975), which conducts research on the lower, middle and upper atmosphere and ionosphere using the incoherent scatter radar technique;
- Kjell Henriksen Auroral Observatory (est. 1978); and the
- University Centre in Svalbard (est. 1993), a joint initiative of several Norwegian universities. It undertakes arctic and environmental research, such as studying the impact of climate change on glaciers; it also offers high-quality courses at under-graduate and postgraduate levels in arctic biology, arctic geology, arctic geophysics and arctic technology.

Svalbard has been linked with the rest of the digital world since 2004 through a fibre optic cable. Norway is committed to developing Svalbard further as a 'science spot' and to improving the access of the international research community to its infrastructure and scientific data.

Source: Norwegian Ministry of Education and Research and Ministry of Foreign Affairs

Figure 11.6: **GERD in EFTA countries by type of research, 2012 or nearest year (%)**



Note: For Iceland, the data do not add up to 100%, as 4% of research is unclassified. For Norway, data are based on current costs only, not total expenditure, and thus exclude both current and capital expenditure.

Source: UNESCO Institute for Statistics, April, 2015

well developed, publicly funded science will also falter. This is what is happening in Norway. Despite having a productive, prosperous economy, Norway only has a small proportion of high-tech companies that conduct in-house R&D and creaking bridges to publicly funded research.

Moreover, it has only a handful of home-grown multinational companies implanted in top research hubs around the globe. Few other OECD countries have lower private R&D expenditure per capita than Norway, despite its generous tax incentives for R&D since 2002. Less than half of Norwegian companies have reported being engaged in innovation activity in the past couple of years, compared to almost 80% in Germany; Norwegian companies also score poorly for the percentage of turnover from innovative products. Some hurdles are external to the national innovation system, the most important among these being high tax rates and restrictive labour regulations, according to the 2014 WEF *Global Competitiveness Report*.

Not easy to intensify R&D in a low-growth period

One of the goals proclaimed by Norway's incoming government in 2013 in its strategy for future co-operation with the EU was to 'make Norway one of the most innovative countries in Europe' (Government of Norway, 2014). The 2014 budget consequently allocates more funds to instruments that support business R&D. Although the amount and growth rate may be too timid to make a real difference, it is certainly a step in the right direction. Norway needs to do more, though, to smooth its path to innovation paradise. It needs to strengthen basic science and the main actors in charge of it, research universities, through the measures proposed above. It also needs to strengthen existing programmes and invent powerful new ones to forge alliances between enterprises and research groups in academia.

All this will come at a cost, of course. Quite uncharacteristically for Norway, finding sufficient public funds may present the most important challenge of all in the years to come. With the plunge in the Brent crude oil price to just half its value between July 2014 and January 2015, it looks like the long period of unbroken high annual GDP growth has become a thing of the past. Consequently, optimistic long-term goals like that fixed by the previous government in a white paper of doubling the country's GERD/GDP ratio to 3% by 2015 no longer seem very realistic. Like many other European countries, Norway will have no choice but to diversify into more innovative economic sectors by intensifying R&D. In the current times of low economic growth, the task will be anything but easy (Charrel, 2015).

SWITZERLAND

Can Switzerland keep its place in the sun?

For the sixth year running, Switzerland led the list of 144 countries analysed in the 2014 WEF *Global Competitiveness Report*. It performs particularly well in higher education, training and innovation. It is also an unrivalled hotspot for innovation, according to the European Commission's 2014 Innovation Union Scoreboard, ahead of all the EU countries, its fellow EFTA members and key world players such as Japan, the Republic of Korea and USA. What is the secret behind this striking performance and what are the chances that Switzerland will be able to keep its place in the sun?

For one thing, Switzerland has a remarkably strong science base. Seven of its 12 universities figure among the top 200 in the Shanghai ranking, a league table mainly focusing on research output. Switzerland is among the top three countries in most global rankings for the impact of its scientific publications and is by far the most successful country per capita in the calls for project proposals issued by the European Research Council, a grant-funding scheme that has become the most prestigious instrument for the support of basic science in Europe (see Box 9.1).

Obviously, in a small country, world-class performance and internationalism are closely linked. More than half of all PhD-holders at the 12 Swiss universities and close to half of the R&D personnel in the private sector are non-Swiss. Two-thirds of faculty members of the two Federal Institutes of Technology (ETH), the Eidgenössische Technische Hochschule (ETHZ) in the German-speaking city of Zürich and the École polytechnique fédérale de Lausanne (EPFL) in the French-speaking part of Switzerland, are non-Swiss.

Complementing the excellent performance of its publicly funded universities and a couple of the institutes attached to the ETH domain is a research-intensive private sector, led by globally active world leaders in engineering (ABB), the food industry (Nestlé), agriculture and biotechnology (Syngenta) and pharmaceuticals (Novartis, Roche), the pharmaceutical industry accounting for one-third of all Swiss in-house R&D spending. These companies share a striking characteristic with Swiss academia: the ability to attract leading researchers from all over the world to engage in Swiss research efforts at home and in their laboratories around the world.

Scientific strength is one thing, turning it into innovative, competitive products is another, as Norway knows only too well. The following characteristics of the Swiss system are key factors in its success:

- First and foremost is the combination of world-class universities working in high-tech fields in tandem with research-intensive multinationals, sophisticated companies that themselves operate at the high end of the value chain within a small geographical area.
- Secondly, Swiss universities and companies have essential research strengths for the development of competitive products for the global market; more than 50% of publications are in biological and medical sciences, other top fields being engineering, physics and chemistry (Figure 11.3).
- Thirdly, more than half of the labour force is qualified to do demanding jobs in science and engineering (Table 11.1); Switzerland leads all other European countries for this indicator. This results less from having a high percentage of people with university degrees – Switzerland doesn't particularly shine in this regard – than from having a labour force that has obtained the requisite qualifications through other means: on the one hand, there is the excellent vocational curriculum provided through apprenticeships and universities specialized in applied research and vocational training (Fachhhochschulen/Hautes écoles spécialisées); on the other, the hiring of top professionals from abroad.
- Fourthly, there is a clear working division between the public and private sectors. Almost two-thirds of Switzerland's R&D is funded by industry (Figure 11.2). This not only guarantees efficient technology transfer – the shortest route from scientific breakthroughs to competitive products are in-house channels – but also allows the public sector to concentrate on non-oriented basic research.
- Fifthly, there has been no break in the high levels of investment in R&D, which has been managed in a stable political system with stable policy priorities. Like most countries in the western hemisphere, Switzerland was hit by the 2008 financial crisis but not only was its GDP rapidly back on track, the impact on R&D spending was also minimal. Even in the private sector, investment in R&D only shrank marginally, from 1.9% to 1.8% of GDP. The universities were particularly spoiled, as, in just four years, their budgets grew by one-third.
- Last but not least, Switzerland has a swath of local advantages for business, in general, and high-tech companies, in particular: excellent research infrastructure and good connectivity (87% of the population had access to internet[9] in 2013), low taxes, a lightly regulated job market, few barriers to founding companies, high salaries and an excellent quality of life. What an asset, too, to be situated at the heart of Europe, unlike Iceland and Norway.

Switzerland could become a lone(ly) wolf in Europe

Switzerland has built its recipe for success in STI on developing a sturdy international network. It is ironic that the fallout from the referendum of 2014 may jeopardize this proud achievement.

The adoption of a popular initiative restricting immigration to Switzerland in February 2014 offends one of the guiding principles of the EU, the free movement of persons (Box 11.2). Shortly after the vote, the Swiss government informed the EU and Croatia that it was unable to sign a protocol to its agreement with the European Commission that would have automatically extended this agreement to the new EU member state. Giving Croatian citizens unrestricted access to the Swiss job market would have been incompatible with the 'yes' vote of the Swiss on the 'stop mass immigration' initiative (Box 11.2).

The EU reacted without delay. The European Commission excluded Switzerland from research programmes potentially worth hundreds of millions of euros for its universities and suspended negotiations on Switzerland's participation as a full member in the world's largest and best-funded research and innovation programme, the € 77 billion Horizon 2020. The European Commission also suspended Switzerland from the Erasmus student exchange programme. According to the ATS news agency, some 2 600 Swiss students took advantage of Erasmus in 2011 and Switzerland played host that same year to about 2 900 foreign students within the same EU-funded programme.

Thanks to intense diplomatic activity behind the scenes and fruitful bilateral discussions, the situation was looking less dramatic by mid-2015. In the end, Switzerland will be able to participate in Excellent Science, the central pillar of Horizon 2020. This means that its universities will be entitled to benefit from grants offered by the European Research Council and by the Future and Emerging Technologies programme, among other instruments. This is welcome news for the École

9. The ratio is even higher in Liechtenstein (94%), Norway (95%) and Iceland (97%).

polytechnique fédérale de Lausanne (EPFL), which is leading one of the two flagship projects[10] of the Future and Emerging Technologies Programme, the Human Brain Project, which seeks to deepen our understanding of how the brain functions.

So far, so good, you might say, but the Sword of Damocles is hanging over the Swiss government. The current agreement is limited in time and will expire in December 2016. If Switzerland doesn't come up with an immigration policy in accord with the principle of the free movement of persons by then, it will lose its status as a fully associated member of Horizon 2020 and retain the status of a third party in Erasmus+. Should that happen, even though it won't affect Swiss engagement in Europe (such as CERN) beyond EU projects, Switzerland will still become a very lonely wolf in Europe's S&T landscape.

10. The other flagship project is developing the new materials of the future, such as graphene.

Disappointing economic growth could affect R&D targets

Remaining part of the European Research Area is crucial but it is not the only challenge Switzerland faces, if it wishes to stay in the lead. The country will also need to maintain the current heady levels of R&D spending. In the financial plan for 2013–2016, education, research and innovation all enjoy exceptionally high annual growth rates in the range of 4%. However, that was before the Swiss franc gained so much value against the euro in January 2015, undermining exports and tourism. Targets that looked like a piece of cake in early 2015 have become a gamble: as in Norway, albeit for different reasons, economic growth is in trouble; since growth is a prerequisite for higher public spending, R&D, like many other policy areas, may suffer.

Overdependent on a handful of multinationals

Another bottleneck is the recruitment of highly qualified R&D personnel. In just three years, Switzerland dropped from 14th to 24th position in the WEF *Global Competitiveness Report*

Box 11.2: A vote on immigration ricochets on Swiss science

Assessing public attitudes to science and technology from informal opinion polls is one thing, making decisions on scientific topics through legally binding referenda is quite another.

Popular referenda are part of the political routine in Switzerland's direct democracy. The Swiss vote on literally everything, from new opening hours for retail stores and bonus ceilings for top managers to multinational treaties. Now and then, they also vote on science and technology.

If one eliminates the many votes in which attitudes to specific technologies were not necessarily the main argument for a 'yes' or a 'no' vote, such as on issues related to nuclear energy, there have been four referenda at the federal level in the past 20 years on legal provisions that would severely restrict research; each of these referenda has asked citizens to vote on a highly complex issue, questioning vivisection, stem cells, genetic modification of agricultural products and reproductive technologies. Is there a voting pattern? Yes, clearly so. In each of these four referenda, the great majority voted against measures that would have restricted or hindered scientific research.

Considering the very positive attitude of the Swiss towards science and technology, why then, in 1992, did they vote against the Agreement on the European Economic Area, which would have automatically given them access to the European Research Area? Even more critically, why did they vote in favour of an initiative in February 2014 limiting the number of immigrants to Switzerland that severely endangers the country's co-operation with the EU in science and technology? One in four Swiss residents was born abroad and about 80 000 immigrants move to Switzerland each year, most of whom are EU citizens.

There were two main reasons for the rejection. The first is evident: in both cases, science and technology were just one part of the package and, as shown in post-voting polls, the fact that voting against one of the four principles of the EU – the free movement of persons – would also weaken Swiss science was either not understood by voters or judged less important than other considerations.

This, of course, leads directly to the second reason. The Swiss political elite, who favoured the European Economic Area agreement and were opposed to strict immigration controls, missed an opportunity to put science and technology on the campaign agenda. Would it have changed the outcome? Yes, probably, since the outcome of both referenda was extremely tight. The initiative 'against massive immigration' in February 2014 was adopted by 1 463 854 votes to 1 444 552. Had the heads of Swiss universities and other important actors of the Swiss science scene thought to pen a couple of enlightening articles in major newspapers in the weeks prior to the referendum highlighting the potential cost of a 'yes' vote in terms of the loss of access to EU research and student exchanges (Erasmus), this would most likely have turned the outcome around.

Source: compiled by author

2014 for its capacity to find and hire the talent it needs to preserve its advantages with respect to innovation. There are also the more structural dangers, such as the economy's distinct dependence on the performance of a handful of R&D-intensive multinational companies. What if they falter? The latest OECD and EU reports show that the proportion of Swiss firms investing in innovation has fallen and that Swiss small and medium-sized enterprises are exploiting their innovation potential less effectively than in the past.

In view of this, the Swiss government may have to become more interventionist (Box 11.3). It has already taken a step in this direction. In 2013, the government transferred responsibility for R&D from the Department for Internal Affairs to the Department for Economic Affairs. Of course, the transfer is not without risk but, as long as the new political environment acknowledges the key role of basic research in the added value chain and supports science to the same extent as the former ministry, the greater proximity to publicly funded applied research may prove beneficial. There are a number of initiatives in the pipeline which go in this direction. One is the creation of two regional innovation parks around the two Federal Institutes of Technology, ETHZ in Zürich and EPFL in the Lake Geneva area, a region known as western Switzerland's Health Valley.[11] A second initiative in the pipeline is the funding of a set of technology competence centres as a 'technology' complement to the highly successful National Centres of Competence in Research run by the Swiss National Science Foundation since 2001. A third initiative foresees the establishment of a network of energy research centres piloted by the Commission for Technology and Innovation that will be reorganized and better funded, to help them perform this and other technology-driven tasks. Also in preparation is a package of measures designed to improve the career prospects of the up and coming generation of scientists which include better working conditions for PhD students, positive discrimination to increase the share of women in senior academic positions and, in a mid-term perspective, the introduction of a nation-wide tenure track system (Government of Switzerland, 2014).

11. on account of the presence of numerous biotech and medical-cum technical companies, the excellent clinical research conducted by several hospitals and world-class life science at top universities

Box 11.3: **Swissnex: a Swiss formula for science diplomacy**

Among the factors that may explain Switzerland's success in STI, one element resurfaces regularly: Switzerland's global presence. The country manages to attract top people from abroad and to be present where it counts. Swiss institutions of higher learning are extremely well connected (Table 11.1); the same is true for Swiss companies in research-intensive fields. They act globally and have established companies and research laboratories close to other centres of world-class science, such as the Boston area or parts of California in the USA. Around 39% of their patented discoveries are joint ventures with research groups from abroad, the highest percentage in the world.

Moreover, when it comes to helping the Swiss 'seduce' foreign territories, even the anything-but-interventionist Swiss government likes to mingle: Switzerland may have the busiest and most entrepreneurial science diplomacy in the world. In addition to the classic network of science attachés maintained by most industrialized countries in their key embassies around the world, it has begun establishing specialized hubs in specific hotspots for science and technology, the so-called 'Swissnex.' Swissnex are joint ventures between two ministries; although they are formally annexed to Swiss consulates and embassies and thus part and parcel of the diplomatic complex, strategically and in terms of content, they fall under the State Secretariat for Education, Research and Innovation.

A first Swissnex opened midway between Harvard University and the Massachusetts Institute of Technology in the USA in 2000. Five others have since been established in San Francisco (USA), Singapore, Shanghai (China), Bangalore (India) and Rio de Janeiro (Brazil).

Swissnex is a unique construct: a small enterprise located in the grounds of a diplomatic mission that is financed jointly by the Swiss government and private sponsors and shares a common mission at all locations: to diversify Switzerland's image from that of the land of chocolate, watches and beautiful alpine scenery to that of a leading nation in STI.

A parallel goal is to facilitate co-operation between the public and private R&D constituency at home and in the host country by adapting the portfolio to the local context. Obviously, building bridges between Switzerland and the USA calls for a different approach to that adopted in China. Whereas the USA has an open science system and is home to a host of branches of high-tech Swiss companies, the Swiss science scene is still little-known in China and the country has a much more political way of doing things. The Swissnex approach fits the bill and it is one of the many assets helping Switzerland to stay on top.

Source: compiled by the author, including from Schlegel (2014)

Taken together, all these measures may enable Switzerland to defend its position at the top but, importantly, none of them suggests ways in which Switzerland could play an active role in Europe. There is some hope that this oversight may be remedied in the near future. At least, another referendum proposing to restrict immigration even further was strongly defeated in November 2014 – and this time Swiss science made its voice heard prior to the vote.[12]

CONCLUSION

A few adjustments and the future looks bright

There is no doubt about it: the four small and micro-states that make up EFTA are well positioned economically, with GDP per capita well above the EU average and strikingly low unemployment rates. Even if added value chains are anything but linear, the excellent quality of higher education and R&D output are certainly key factors in their success.

Switzerland either tops international rankings, or figures in the top three, for R&D performance, innovation potential and competitiveness. Its main challenge in the years to come will be to defend its primacy, maintain high investment in basic research in order to preserve the exceptional quality of its universities and inject fresh public funds reserved for national and regional initiatives into more applied, technology-oriented fields of research. Switzerland will also need to resolve its political problems with the EU before the end of 2016 in order to ensure full participation in Horizon 2020, the world's most comprehensive and best-funded multinational R&D programme.

For Norway, the challenge will be to reduce its strong economic dependence on the not particularly R&D-intensive petroleum industry by diversifying the economy with the help of innovative high-tech companies and linking them to the public R&D sector. Neither public nor private investment in R&D does justice to a country with such a high level of income; both will need a push.

Iceland's prime challenge will be to heal the remaining open wounds from the 2008 financial crisis and to recover lost ground; less than a decade ago, it was an astonishingly strong player in the research field, considering its size and remote geographical location, with world-class figures for its GERD/GDP ratio, scientific publications per capita and publication impact.

Last but not least, tiny Liechtenstein faces no obvious challenges in the field of R&D, apart from ensuring a solid financial base for its higher education flagship, the University of Liechtenstein, established in its present form a decade ago. The government will also need to maintain a political framework that allows the country's prosperous industries to continue investing in R&D at the traditionally heady levels.

The future looks bright, for if there is one common feature which characterizes the four EFTA countries and explains their strength within Europe and beyond, it is their political stability.

KEY TARGETS FOR EFTA COUNTRIES

- Raise Iceland's GERD/GDP ratio to 3% by 2016;
- Iceland to introduce tax incentives to foster investment in innovative enterprises;
- Norway to invest US$ 250 million between 2013 and 2023 in funding research conducted by its 13 new centres of excellence;
- Switzerland to set up two innovation parks in the vicinity of ETHZ and EPFL, sponsored by the host cantons, the private sector and institutions of higher education;
- Switzerland has until the end of 2016 to resolve the current political problem with the EU regarding the free movement of persons, if it is to preserve its status of associated partner in Horizon 2020.

12. See for instance the editorial by EPFL President Patrick Aebischer, in EPFL's campus newspaper, *Flash*, in the days before the referendum.

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All seven countries would benefit from a stronger culture of evaluation in the area of STI policies.

Deniz Eröcal and **Igor Yegorov**

Istanbul Technical University's experimental solar-powered car Ariba VI negotiating heavy traffic on a bridge over the Bosphorus on its first long-distance test drive on 20 August 2013.

Photo: © Istanbul Technical University Solar Car Team

12 · Countries in the Black Sea basin

Armenia, Azerbaijan, Belarus, Georgia, Moldova, Turkey, Ukraine

Deniz Eröcal and Igor Yegorov

INTRODUCTION

Turkey is making progress, others have lost ground

For want of a better term, the seven countries covered in the present chapter shall be referred to collectively as the 'Black Sea countries.' They do not constitute a world region in the traditional sense[1] but they do present some structural similarities. For one thing, they share geographical proximity, with all but Armenia and Azerbaijan being situated in the Black Sea basin. In addition, all seven are middle-income economies seeking to move into a higher income bracket. Their differences are equally instructive. If we take trade in manufactured goods, for instance, we can discern three groups: countries with traditionally close economic integration with the Russian Federation (Armenia, Belarus, Moldova and Ukraine), some of which are now diversifying their trading partners (Moldova and Ukraine); countries which are increasingly integrated in global markets (Georgia and Turkey) and countries with a weak focus on trade in manufactured goods (Azerbaijan) [Table 12.1]. All seven, however, have made efforts over the past two decades to strengthen their mutual economic and institutional ties. The best illustration of this is the Organization of the Black Sea Economic Cooperation (Box 12.1).

Six of the seven Black Sea countries were part of the former Union of Soviet Socialist Republics (USSR) up until the early 1990s. The seventh, Turkey, was less industrialized and had been beset by recurrent economic crises up until this period.

A great deal has changed since. Turkey is gradually catching up to the advanced economies, whereas some of the other Black Sea countries are losing ground. Notwithstanding this, these seven countries are arguably more comparable with one another today in economic and technological terms than at any other time in modern history. Certainly, all harbour an undeniable potential for accelerated development.

In the five years to 2013, the economies of Azerbaijan, Belarus, Georgia, Moldova and Turkey grew faster than those of high-income countries – themselves beset by recession following the US subprime crisis – but below the average for middle-income economies. All but Azerbaijan and Belarus fell into recession in 2009 before returning to modest positive growth the following year. Ukraine's economy shrank most in 2009, by 15%; it is the only Black Sea country where GDP per capita remains below 2008 levels. The current economic crisis in Ukraine is associated with the ongoing conflict, which saw GDP drop by more than 6% in 2014. Macro-economic indicators for most other countries have remained under control, with the notable exception of inflation in Belarus, which climbed to more than 50% in 2011 and 2012 before falling back to 18%, and unemployment, which has been cruising on a 16–18% plateau in Armenia and Georgia and at around 10% in Turkey and Ukraine, according to the International Labour Organization. Over this five-year period, only Turkey showed progress in terms of human development, as defined by the UNDP's index. Growth in Azerbaijan was largely driven by high oil prices.

1. Bulgaria and Romania also lie on the Black Sea but they are covered in Chapter 9.

Table 12.1: **Socio-economic trends in the Black Sea countries**

	Population trends		Internet access	Trends in GDP			Employment		Manufactured exports		
	Population ('000s) 2014	Cumulative growth 2008–2013	Per 100 population 2013	Per capita (current PPP$) 2008	Per capita (current PPP$) 2013	Average growth per annum 2008–2013	As a share of adult population 2013 (%)	Share employed in industry, average 2010–2012 (%)	As a share of total merchandise exports, 2012 (%)	As a share of GDP 2012 (%)	Change over 10 years in share of GDP, 2012 (%)
Armenia	2 984	0.0	46.3	7 099	7 774	1.7	63	17	22.1	3.2	-8.4
Azerbaijan	9 515	6.0	58.7	13 813	17 139	5.5	66	14	2.4	1.1	-0.9
Belarus	9 308	-2.1	54.2	13 937	17 615	4.4	56	26	46.7	33.8	-1.0
Georgia	4 323	-1.6	43.1	5 686	7 165	3.5	65	6	53.4	8.0	4.3
Moldova	3 461	-4.1	48.8	3 727	4 669	4.0	40	19	37.2	11.0	-1.0
Turkey	75 837	6.5	46.3	15 178	18 975	3.3	49	26	77.7	15.0	2.0
Ukraine	44 941	-2.6	41.8	8 439	8 788	-0.2	59	26	60.6	23.5	-5.0

Source: UNESCO Institute for Statistics; for employment and manufactured exports: World Bank's World Development Indicators, accessed November 2014

Many post-Soviet states suffer from diminished territorial integrity, which hinders their ability to focus on long-term development issues. They bear the stigma of what have been termed 'frozen conflicts,' the legacy of short-lived wars which have led to part of their territory escaping their control: the mountainous Karabakh (Arcakh) region, disputed by Armenia and Azerbaijan since 1991, the breakaway Transnistria region in Moldova (since 1992), the breakaway regions of Abkhazia and South Ossetia in Georgia (both since 1990–1992) and, most recently, Crimea and the Donbass regions in Ukraine. Since 2014, the European Union (EU), USA and a number of other countries have imposed sanctions on the Russian Federation, which they accuse of fostering separatism in Ukraine. Tensions with the Russian Federation had emerged in 2013 after Georgia, Moldova and Ukraine announced their intention of signing association agreements with the EU to foster closer political ties and economic integration.

In addition to economic and geopolitical problems, most Black Sea countries also face demographic challenges. The population is declining in all but Azerbaijan and Turkey. Since the mid-2000s, Turkey has been able to reverse the decline in its employment-to-population ratio by implementing a series of pro-market economic reforms. High emigration rates have prevented Moldova from stemming its own haemorrhage. Most other countries in this group have managed to maintain relatively high employment rates, unlike many advanced economies.

TRENDS IN REGIONAL STI GOVERNANCE

Black Sea scientists co-operate with East and West

For the Black Sea countries, the EU collectively represents the most important node for international co-operation in science and technology (S&T). A glance at cross-border co-operation in scientific authorship (see p. 322) suggests that all seven countries do indeed have links with the principal scientific powers of the Organisation of Economic Co-operation for Development (OECD) but that most of the former Soviet states have also maintained their historic scientific ties with the Russian Federation. The data also reveal that there is now close collaboration between Azerbaijan and Turkey. The USA is a key partner for all seven countries, thanks partly to the active academic diaspora from Armenia and Georgia living in the USA. Turkey's own academic diaspora is tipped to grow in coming years, owing to the large presence of Turkish PhD students in the USA.

The EU's Framework Programme for Research and Technological Development, including its current Horizon 2020 Programme (2014–2020), is an important instrument for co-operation. Having signed an association agreement with the EU as long ago as 1964, Turkey has been an Associated Country of the European Research Area and the EU's six-year Framework Programmes for some time now. It is also a member of a

Box 12.1: The Organization of the Black Sea Economic Cooperation

The Organization of the Black Sea Economic Cooperation (BSEC) comprises 12 members: Albania, Armenia, Azerbaijan, Bulgaria, Georgia, Greece, Moldova, Romania, the Russian Federation, Serbia, Turkey and Ukraine. Belarus is not a member.

The BSEC was founded in 1992, shortly after the disintegration of the USSR, in order to develop prosperity and security within a region centred on the Black Sea Basin and straddling the European Union. It officially became an intergovernmental organization through an agreement signed in 1998.

One of BSEC's strategic goals is to deepen ties with the European Commission in Brussels. To some extent, the institutions of BSEC mirror those of the EU. The Council of Ministers of Foreign Affairs is BSEC's central decision-making organ. It meets every six months. There is also a Parliamentary Assembly modelled on that of the Council of Europe and a Permanent International Secretariat, based in Istanbul, which is headed by a Secretary-General.

The BSEC Business Council is made up of experts and representatives of Chambers of Commerce of the member states; it promotes co-operation between the public and private sectors. Another structure is the Black Sea Trade and Development Bank, which administers the funding allocated to regional co-operation projects. In this task, the bank receives support from the European Investment Bank and the European Bank for Reconstruction and Development. There is also an International Centre for Black Sea Studies.

The BSEC has adopted two *Action Plans on Cooperation in Science and Technology*. The first covered the period 2005–2009 and the second 2010 –2014. With no dedicated budget, the second action plan was funded on a project basis. Two key projects were the EU-funded Scientific and Technological International Cooperation Network for Eastern European and Central Asian countries (IncoNet EECA) and the Networking on Science and Technology in the Black Sea Region project (BS–ERA–Net), which had got under way in 2008 and 2009 respectively. Another thrust of the action plan targeted the development of physical and virtual multinational infrastructure by pooling the resources of BSEC member states, the networking of research institutes and universities in BSEC countries and their connection to the European gigabit network and other EU e-networks like e-Science.

Source: www.internationaldemocracywatch.org; www.bsec-organization.org research body supported by the Framework Programme, known as European Cooperation in Science and Technology (COST). Like Ukraine, Turkey also participates in Eureka, an intergovernmental organization providing pan-European funding and co-ordination for market-driven industrial R&D. The recent geopolitical developments in the Black Sea region or, for that matter, in the Middle East, do not necessarily imply that there will be major shifts in the orientation of Turkey's co-operation in S&T. However, anecdotal evidence suggests that Turkey's ambitions for advanced defence-related R&D are growing.

The EU's association agreements signed with Georgia, Moldova and Ukraine in mid-2014 envisage enhancing these countries' participation in Horizon 2020. Whereas it is too early to detect the impact on S&T of the past two years' geopolitical tensions in the region, it is probable that they will accelerate Ukraine's co-operation[2] with the EU. In March 2015, Ukraine signed an agreement with the EU for associate membership of the Horizon 2020 Programme (2014–2020) with significantly more advantageous conditions on the table than previously, notably the possibility for Ukraine to participate in scientific co-operation at a fraction of the original cost. This should pave the way to more active involvement by Ukrainian scientists in Horizon 2020 but may also increase the emigration of Ukrainian scientists to the EU in the short term. A similar but milder effect can be expected from Moldova's own association agreement with the EU. Moldova has been officially associated with the Framework Programme since 2012 (Sonnenburg *et al.*, 2012).

Those Black Sea countries which do not have association agreements with the EU are also eligible for Framework Programme funding; moreover, projects such as ERA's Networking on Science and Technology in the Black Sea (BS–ERA–Net) have sought to enhance their involvement in the Framework Programme. In co-operation with the BSEC, the EU's Networking on Science and Technology in the Black Sea Region project (2009–2012) has been instrumental in funding a number of cross-border co-operative projects, notably in clean and environmentally sound technologies (Box 12.1). The absence of a formal co-operation framework may, however, be constraining Belarus' ability to participate in the Framework Programme, despite the country's relatively high level of international collaboration in R&D.

Other multilateral projects are presently striving to expand their reach. One example is the Science and Technology Centre in Ukraine, funded by Canada, the EU, Sweden and the USA. This intergovernmental organization has the status of a diplomatic mission. It was established in 1993 to promote nuclear non-proliferation but its scope has since been extended to fostering co-operation in a wide range of technological fields with Azerbaijan, Georgia, Moldova and Uzbekistan[3].

The impetus to create a Eurasian Economic Union – the other major consequence of the recent geopolitical tensions – has also gained strength, with the signing of the Union's founding treaty in May 2014 by Belarus, Kazakhstan and the Russian Federation, followed by Armenia's accession to it in October 2014 (see Chapter 14). As co-operation in S&T within the latter group of countries is already considerable and well-codified in legal texts, the Eurasian Economic Union is expected to have a limited additional impact on co-operation among public laboratories or academia but it may encourage R&D links among businesses.

TRENDS IN HUMAN RESOURCES AND R&D

High tertiary enrolment rates

Education is one of the region's strengths. Belarus and Ukraine both compare well with developed countries for the gross tertiary enrolment rate: more than nine-tenths of 19–25 year-olds in Belarus and eight-tenths in Ukraine. As for Turkey, which started from low levels, it has recently made great strides (Table 12.2). Of note is that Moldova and Ukraine invest heavily in higher education: 1.5% and 2.2% of GDP respectively (Figure 12.1). Two countries are experiencing difficulty, however, in converging with advanced economies, or even in maintaining their current levels of tertiary attainment: Azerbaijan and Georgia.

Gender equality a reality in most Black Sea countries

In Georgia, Moldova and Ukraine, the majority of PhD graduates are women. The figures are almost as high in Belarus and Turkey, which have achieved gender parity in this respect. In Armenia and Azerbaijan, women make up one-third of the total. In natural sciences, they make up half of PhD graduates in Belarus, Georgia, Turkey and Ukraine.

Ukraine is regressing[4] from its historically high density of researchers, in a context of a declining or stagnating population, whereas Belarus has managed to preserve its advantage. The most striking trend concerns Turkey, where the researcher density has gone from being the lowest in the region in 2001 to the highest (Figure 12.2). Women tend to represent between one-third and two-thirds of researchers,

2. Ukraine and the EU signed an agreement in 2010 which determined key thematic areas for co-operation: environmental and climate research, including observation of the Earth's surface; biomedical research; agriculture, forestry and fisheries; industrial technologies; materials science and metrology; non-nuclear power engineering; transport; information society technologies; social research; S&T policy studies and training and the exchange of specialists.

3. See: www.stcu.int

4. Only Moldova, Turkey and Ukraine claim to publish data on researchers in full-time equivalents (FTE), in line with international best practice. However, the prevalence of multiple part-time jobs among R&D personnel makes head count data a more precise measure for Ukraine.

Table 12.2: **Tertiary education in the Black Sea countries**

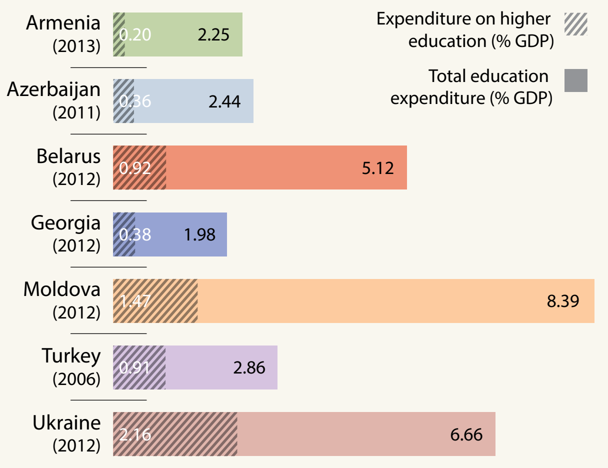
	Labour force with tertiary education		Gross enrolment ratio for tertiary education		PhD or equivalent graduates 2012 or closest year							
	Highest score 2009–2012 (%)	Change over five years (%)	Highest score 2009–2013 (% of age cohort)	Change over five years (%)	Total	Women (%)	Natural sciences	Women (%)	Engineering	Women (%)	Health and welfare	Women (%)
Armenia	25	2.5	51	-3.0	377	28	92	23	81	11	10	30
Azerbaijan	16	-6.0	20	1.4	406^{-1}	31^{-1}	100^{-1}	27^{-1}	45^{-1}	13^{-1}	23^{-1}	39^{-1}
Belarus	24	–	93	19.3	1 192	55	210	50	224	37	180	52
Georgia	31	-0.3	33	7.8	406	54	63	56	65	40	33	64
Moldova	25	5.0	41	3.0	488	60	45	56	37	46	57	944
Turkey	18	4.4	69	29.5	$4\,506^{-1}$	47^{-1}	$1\,022^{-1}$	50^{-1}	628^{-1}	34^{-1}	515^{-1}	72^{-1}
Ukraine	36	5.0	80	1.0	8 923	57	1 273	51	1 579	35	460	59

-*n* = refers to *n* years before reference year

Note: The total PhD data cover natural sciences, engineering, health and welfare, agriculture, education, services, social sciences and humanities. Natural sciences cover life sciences, physical sciences, mathematics and computing.

Source: UNESCO Institute for Statistics; for the labour force with tertiary education: World Bank's World Development Indicators, except for Ukraine: State Statistics Service

Figure 12.1: **Government expenditure on education, as a percentage of GDP (%) in Black Sea countries, 2012 or closest year**



Source: UNESCO Institute for Statistics

although they are less present in Turkey than in the post-Soviet states (Figure 12.2). Belarus appears to be the only Black Sea country that is maintaining its historically high density of researchers but, like its neighbours, it suffers from underinvestment in R&D.

Investment in R&D remains low

Gross domestic expenditure on R&D (GERD) has never recovered in the post-Soviet states to the heady levels of 1989, when it represented 3% of GDP in Ukraine and well over 1% in most other countries covered by the present chapter, with the notable exception of Azerbaijan (0.7%)[5]. By the early 2010s, it had dropped to a quarter of its 1989 level in Ukraine and to just one-tenth in Armenia. Turkey, meanwhile, went in the opposite direction, with its GERD/GDP ratio hitting a high of nearly 0.95% in 2013; it has been able to use its economic growth in recent years to increase its commitment to R&D (Figures 12.3 and 12.4). Georgia has not done any comprehensive R&D survey since 2006, so no conclusions can be drawn as to its evolution.

One of the most striking trends since 2005 has been the growth in business R&D in Belarus, which now represents two-thirds of the national effort. Industrial R&D still plays a major role in Ukraine but its share has actually declined in recent years. Turkey differs from the other countries in that similar shares of R&D are now performed by both universities and the business enterprise sector (Figure 12.5).

Not yet in same league as advanced economies for innovation

The outcome of innovation is notoriously difficult to measure. Among the seven Black Sea countries, only Turkey participates in the Eurostat Community Innovation Survey (CIS), where its performance is comparable to that of middle-ranking[6] EU members, although Ukraine does conduct surveys itself every 2–3 years which are based on the CIS methodology.

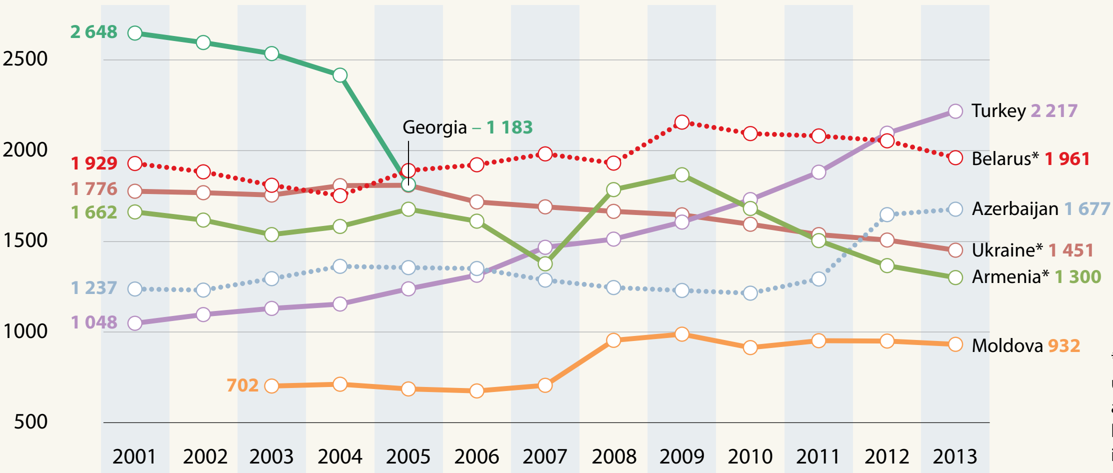
5. According to the *Statistical Yearbook: National Economy of the Ukrainian Soviet Socialist Republic, 1990,* published in Kiev in 1991

6. See : http://ec.europa.eu/eurostat

Figure 12.2: **Trends in researchers from the Black Sea countries, 2001–2013**

Turkey's researcher density has doubled in a decade

Researchers per million inhabitants, by head count



* based on underestimated data, as many researchers have secondary jobs in R&D

Researchers in Black Sea countries by field of employment and gender, 2013

By head counts

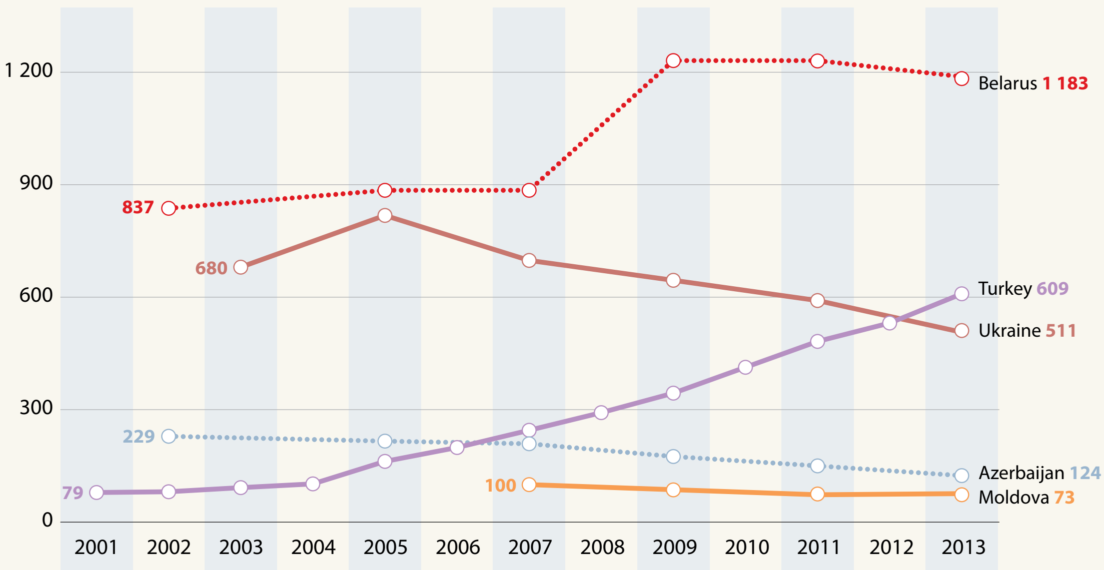
	Total		Natural sciences		Engineering		Medical sciences		Agricultural sciences		Social sciences		Humanities	
	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)
Armenia*	3 870	48.1	2 194	46.4	546	33.5	384	61.7	45	66.7	217	47.0	484	60.5
Azerbaijan	15 784	53.3	5 174	53.9	2 540	46.5	1 754	58.3	1 049	38.5	2 108	48.9	3 159	63.1
Belarus	18 353	41.1	3 411	50.6	11 195	31.5	876	64.6	1 057	60.1	1 380	59.1	434	60.8
Moldova	3 250	48.0	1 168	45.7	448	29.0	457	52.5	401	45.4	411	68.4	365	52.6
Turkey	166 097	36.2	14 823	35.9	47 878	24.8	31 092	46.3	6 888	31.6	24 421	41.1	12 350	41.9
Ukraine	65 641	45.8	16 512	44.5	27 571	37.2	4 200	65.0	5 289	55.0	4 644	61.4	2 078	67.8

Note: Data for Turkey are for 2011.

*Partial data

Researchers employed by business enterprises

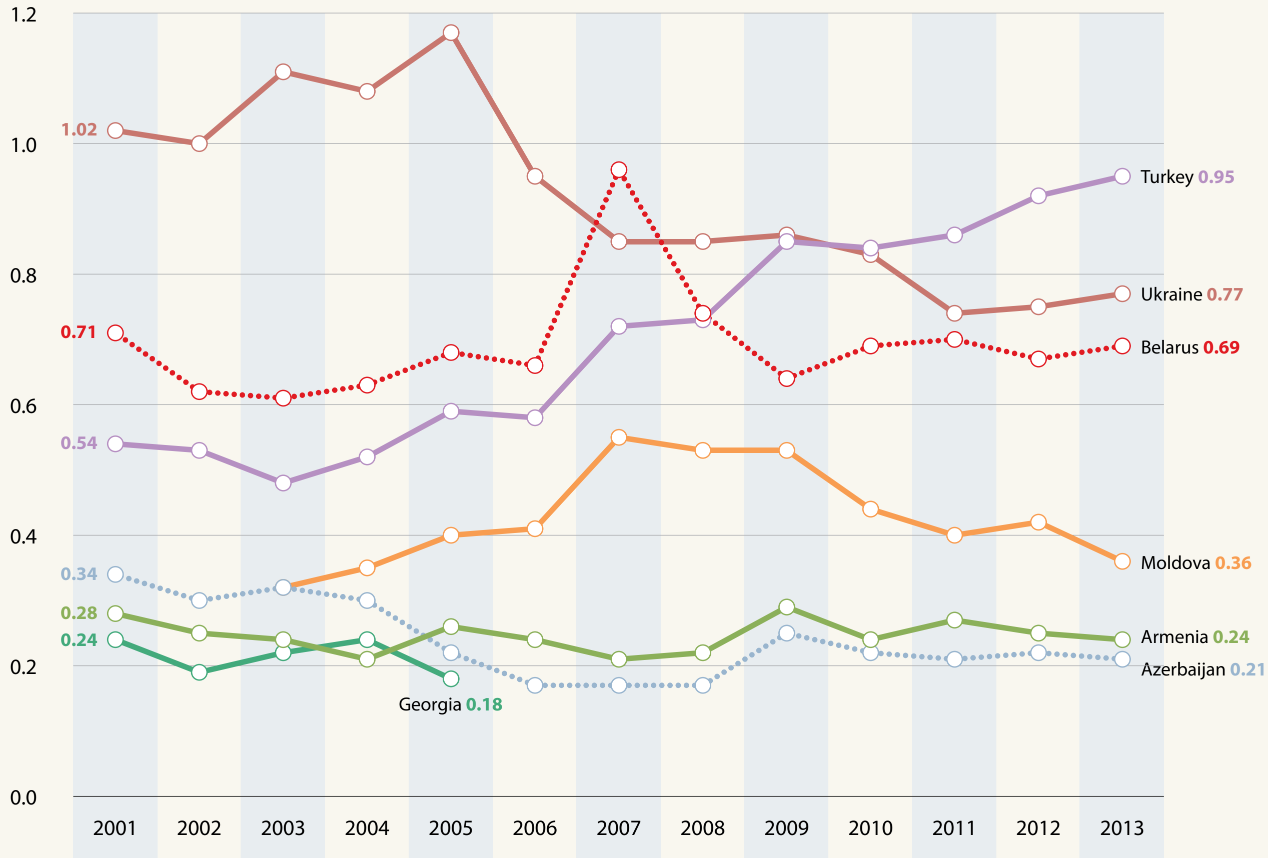
Researchers per million inhabitants by head count



Note: This figure is more useful for discerning the evolution over time than strict cross-country comparisons, as the latter do not all apply international statistical methodologies. Data are unavailable for Armenia and Georgia.

Source: UNESCO Institute for Statistics, March 2015

Figure 12.3: **GERD/GDP ratio for the Black Sea countries, 2001–2013**



Source: UNESCO Institute for Statistics, March 2015

High-tech exports[7] provide a more approximate measure; they place Belarus and Ukraine, and to a lesser extent Turkey, at levels similar to those of some major middle-income countries but their performance is by no means comparable to that of countries pursuing global competitiveness through technology-intensive production, such as Israel or the Republic of Korea (Table 12.3). This said, the fact that some countries are expanding production and trade in medium-tech products can also attest to STI activity, as we shall see in some of the country profiles that follow.

Patents provide an even more roundabout indicator of innovation. Moreover, most Black Sea countries do not have patent indicators using the 'nowcasting' method, which provides reasonably accurate and timely estimates for OECD countries. With this caveat in mind, we can observe the following (Table 12.4):

- Per unit of GDP, the number of patents filed by residents at the national patent offices of Black Sea countries was among the highest in the world in 2012, according to the Global Innovation Index (2014).
- Patent Cooperation Treaty applications, indicating an extra effort to protect intellectual property internationally, have been growing moderately in Armenia, Moldova and Ukraine and very strongly in Turkey. Applications to the two largest developed country offices (European Patent Office and the US Patent and Trademark Office) have grown quite strongly for Turkish residents and, to a lesser extent, for Armenian and Ukrainian ones.
- None of the Black Sea countries seem to invest significant resources in Triadic patents, indicating that they are not yet at a stage of development where they can compete with the advanced economies for S&T-driven industrial competitiveness.
- The Black Sea countries appear to invest heavily in acquiring trademarks, which give a measure of creative effort but are less directly correlated with S&T as such, according to the Global Innovation Index (2014).

7. including a growing number of commodities such as computers and other ICT goods

Figure 12.4: **GDP per capita and GERD/GDP ratio in the Black Sea countries, 2010–2013 (average)**

For economies with GDP per capita between PPP$ 2 500 and PPP$ 30 000

Note: for Georgia, state budgetary expenditure on R&D only from the National Statistics Office

Source: World Bank's World Development Indicators, as of September 2014; UNESCO Institute for Statistics, March 2015

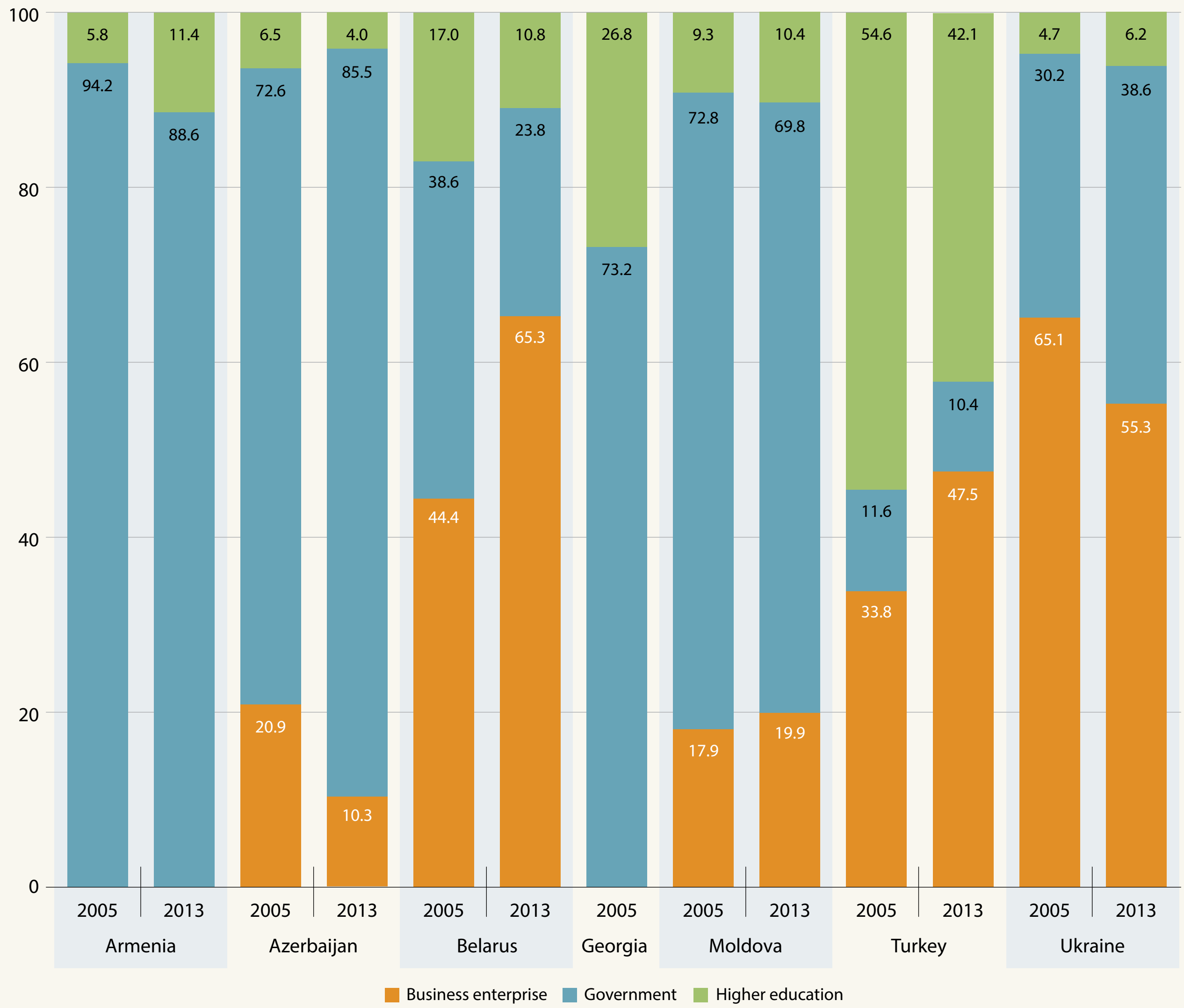
■ On the whole, the legislative and institutional framework for intellectual property protection is in place in the Black Sea countries but there is room for improvement, especially for countries which are not members of the World Trade Organization (WTO[8]), both as concerns compliance with WTO's Agreement on Trade-Related Aspects of Intellectual Property Rights (Sonnenburg *et al.*, 2012) and, in the case of Turkey, a stronger commitment to fighting counterfeiting and piracy, for instance (EC, 2014).

8. Georgia joined the WTO in 2000, Moldova in 2001, Armenia in 2003 and Ukraine in 2008. Turkey has been a member of the Global Agreement on Trade and Tariffs (the precursor to WTO) since 1951. Neither Azerbaijan, nor Belarus is a member.

Publications progressing in some countries, stagnating in others

If we measure productivity in terms of articles published in international journals, we find that Belarus, Moldova and Ukraine were at about the same level in 2013 as in 2005; this should be of concern (Figure 12.6). Armenia and Turkey have made the most progress, with Armenia having almost doubled the number of articles per million inhabitants from 122 to 215 over this period and Turkey's ratio having risen from 185 to 243 per million. If we combine researcher density and output per researcher, Turkey has clearly made the greatest progress; it also has higher population growth than its neighbours. Georgian scientists have not only increased their publication

Figure 12.5: **GERD in the Black Sea region by sector of performance, 2005 and 2013**



Note: The data for Armenia and Georgia do not show business R&D expenditure as a separate category, since official statistics tend to use the classification system inherited from Soviet times when all industrially oriented companies belonged to the state; although some companies have since been privatized, business expenditure on R&D tends to be included in public sector expenditure to preserve a time series.

Source: UNESCO Institute for Statistics, March 2015 rate from a low starting point;[9] they also top the region for a key measure of quality, the average citation rate.

All six post-Soviet states specialize in physics. Turkey's profile is more varied. It publishes most in medical sciences but also specializes in engineering. Next come publications spread more or less equally across biological sciences, chemistry and physics. Agriculture and computer sciences are a low priority for Turkish scientists but also for their neighbours. Of note is that the only discipline in which Ukraine publishes more than Turkey is astronomy.

The post-Soviet states maintain a balance between Eastern and Western partners. Armenia, Moldova and Ukraine collaborate most with Germany but the Russian Federation figures among their top four collaborators, as it does for the other post-Soviet states. Poland makes an appearance in the top five as Ukraine's fourth-closest collaborator. Within the region, only Azerbaijan counts Turkey as its closest collaborator but Turkey itself partners mostly with the USA and Western Europe.

9. Georgia has very few national scientific journals, whereas Ukraine counts more than 1 000 periodicals. Between 1995 and 2012 in particular, Ukrainian scientists were incited to publish in these national journals to further their careers; not all these journals are internationally recognized, however.

Chapter 12

Table 12.3: **High-tech merchandise exports by Black Sea countries, 2008 and 2013**

	Total in million US$*		Per capita in US$	
	2008	2013	2008	2013
Armenia	7	9	2.3	3.1
Azerbaijan	6	42[-1]	0.7	4.4[-1]
Belarus	422	769	44.1	82.2
Georgia	21	23	4.7	5.3
Moldova	13	17	3.6	4.8
Turkey	1 900	2 610	27.0	34.8
Ukraine	1 554	2 232	33.5	49.3
Other countries are given for comparison				
Brazil	10 823	9 022	56.4	45.0
Russian Federation	5 208	9 103	36.2	63.7
Tunisia	683	798	65.7	72.6

+n/-n = data refer to *n* years before or after reference year

Source: Comtrade database of the United Nations Statistics Division, July 2014

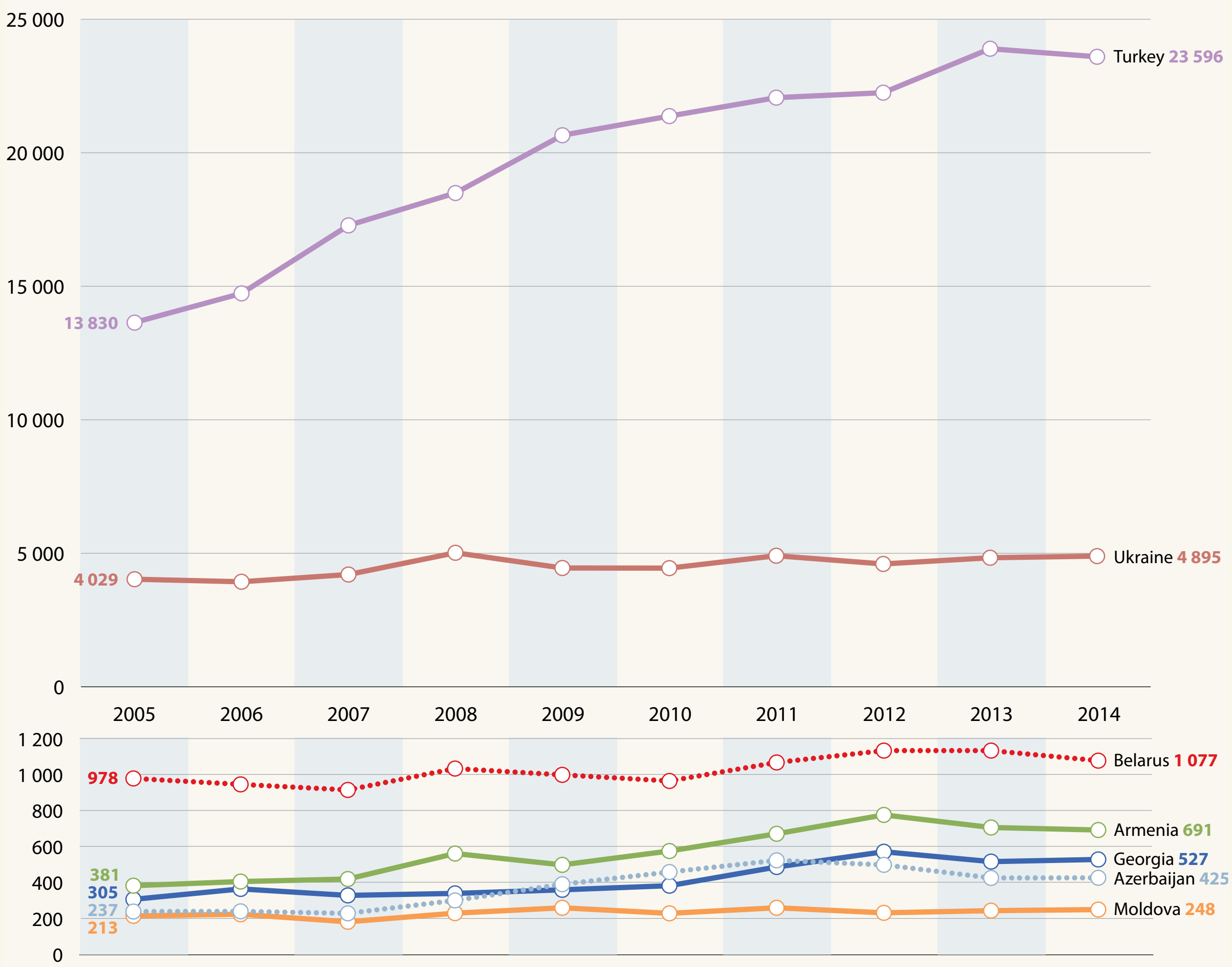
Table 12.4: **Patent applications from Black Sea countries, 2001–2012**

	National office applications						Patent applications to EPO		Patent applications to USPTO	
	Applications per billion PPP GDP, 2012			World rank			Total, 2001–2010	Ratio 2006–2010 to 2001–2006	Total 2001–2010	Ratio 2006–2010 to 2001–2006
	Utility model	Patents	Under the PCT	Utility model	Patents	Under the PCT	Number		Number	
Armenia	2.0	7.1	0.4	16	16	42	14	0.6	37	1.3
Azerbaijan	0.1	1.5	0.1	54	59	90	–	–	–	–
Belarus	7.6	11.6	0.1	6	6	74	70	1.1	93	0.8
Georgia	1.8	5.3	0.2	18	24	64	17	1.3	55	1.1
Moldova	14.2	7.7	0.3	3	14	62	14	0.4	12	2.5
Turkey	3.4	4.0	0.5	11	30	39	1 996	3.1	782	2.1
Ukraine	30.2	7.5	0.4	2	15	45	272	1.2	486	1.3

Source: National office applications from the Global Innovation Index (2014), Annex Tables 6.11, 6.12 and 6.1.3; EPO and USPTO applications from OECD Patent Statistics online, based on EPO's Worldwide Statistical Patent Database (PATSTAT)

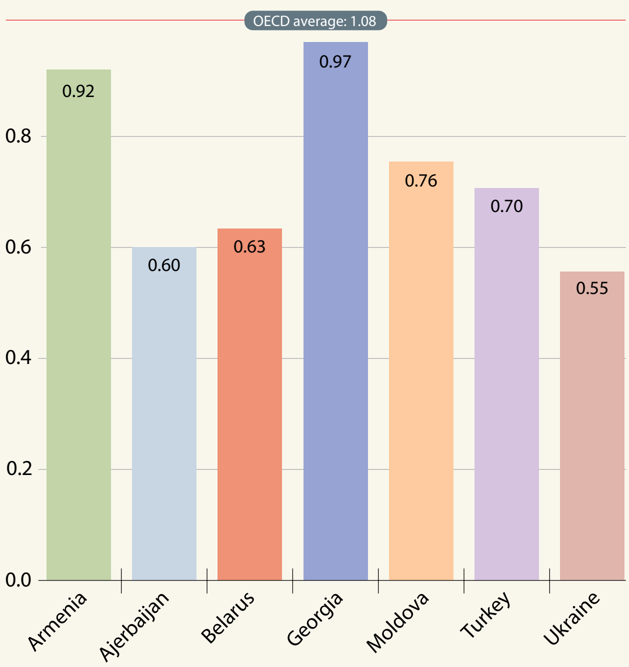
Figure 12.6: **Scientific publication trends in the Black Sea countries, 2005–2014**

Strong growth in publications in the smaller countries and Turkey



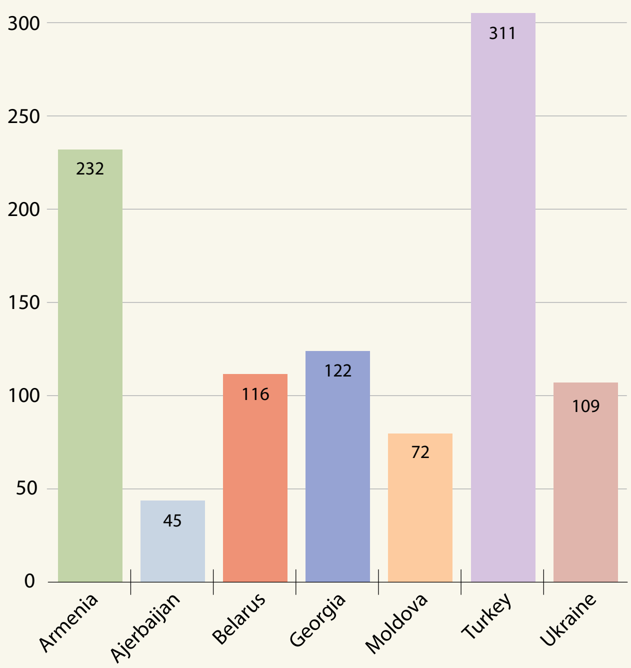
Georgia comes closest to the OECD average for the citation rate

Average citation rate, 2008–2012



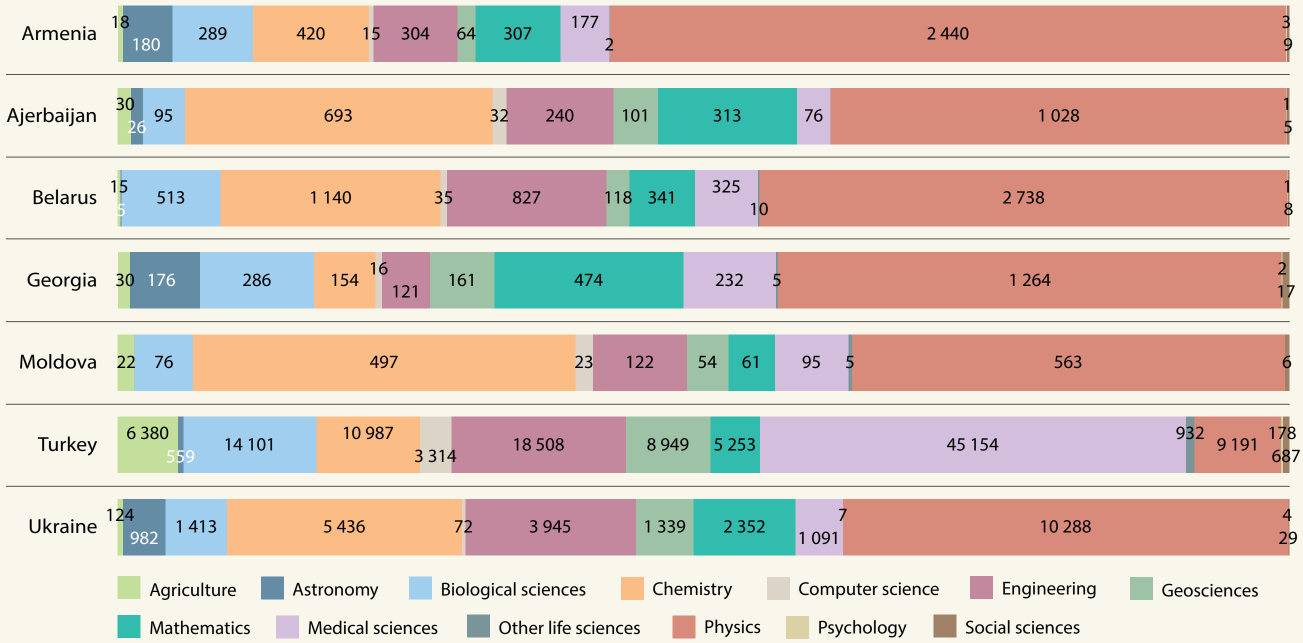
Turkey has the highest publication intensity, followed by Armenia

Publications per million inhabitants in 2014



The former Soviet states publish most in physics, Turkey most in medical sciences

Cumulative totals by field, 2008–2014



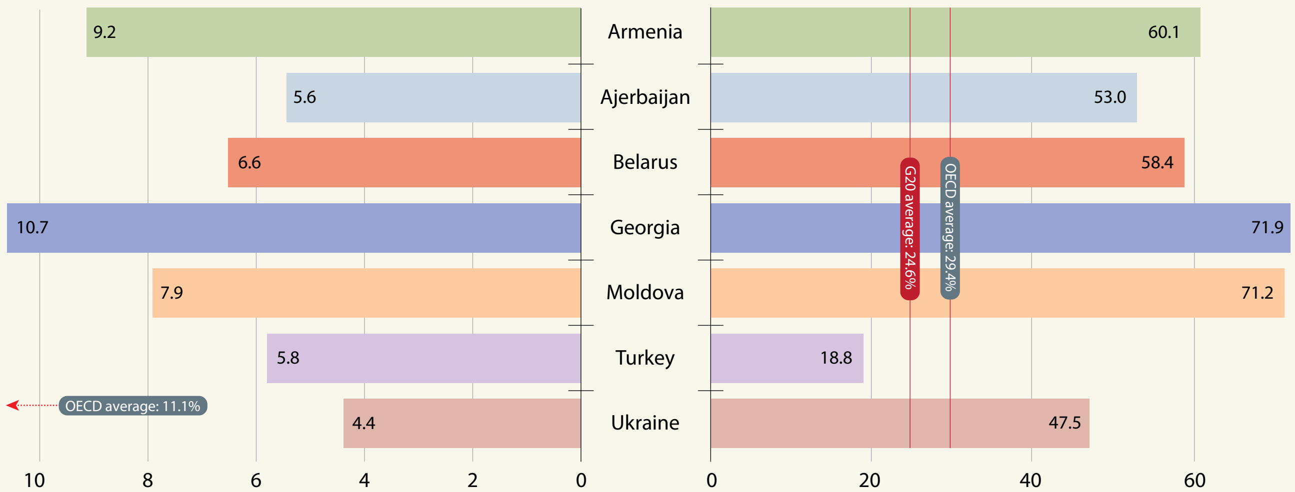
Note: : Some unclassified articles are excluded from these totals, including 28 140 for Turkey, 6 072 for Ukraine and 1 242 for Belarus.

Georgian, Armenian and Moldovan scientists score best for the 10% most-cited papers

Share of papers among 10% most-cited, 2008–2012 (%)

The former Soviet states collaborate a lot internationally, Turkey less so

Share of papers with foreign co-authors, 2008–2014 (%)



The post-Soviet states balance collaboration with Eastern and Western Europe

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Armenia	USA (1 346)	Germany (1 333)	France/Rus. Fed. (1 247)		Italy (1 191)
Azerbaijan	Turkey (866)	Russian Fed. (573)	USA (476)	Germany (459)	UK (413)
Belarus	Russian Fed. (2 059)	Germany (1 419)	Poland (1 204)	USA (1 064)	France (985)
Georgia	USA (1 153)	Germany (1 046)	Russian Fed. (956)	UK (924)	Italy (909)
Moldova	Germany (276)	USA (235)	Russian Fed. (214)	Romania (197)	France (153)
Turkey	USA (10 591)	Germany (4 580)	UK (4 036)	Italy (3 314)	France (3 009)
Ukraine	Russian Fed. (3 943)	Germany (3 882)	USA (3 546)	Poland (3 072)	France (2 451)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

COUNTRY PROFILES

ARMENIA

A need to strengthen science–industry linkages

Armenia has made a considerable effort to transform its S&T system in recent years. Three important ingredients for success are in place: a strategic vision, political will and high-level support. Building an efficient research system is a strategic objective for the Armenian authorities (Melkumian, 2014). Armenian and foreign experts highlight other advantages, such as the strong science base, a large Armenian diaspora and traditional national values that emphasize education and skills.

Nonetheless, there are still a number of hurdles to overcome before the country can build a well-functioning national innovation system. The most critical among these are the poor linkages between universities, research institutions and the business sector. This is partly a legacy of its Soviet past, when the policy focus was on developing linkages across the Soviet economy, not within Armenia. R&D institutes and industry were part of value chains within a large market that disintegrated. Two decades on, domestic businesses have yet to become effective sources of demand for innovation.

Over the past decade, the government has made an effort to encourage science–industry linkages. The Armenian ICT sector has been particularly active: a number of public–private partnerships have been established between ICT companies and universities, in order to give students marketable skills and generate innovative ideas at the interface of science and business. Examples are Synopsys Inc. and the Enterprise Incubator Foundation (Box 12.2).

Plans to become a knowledge-based economy by 2020

In Armenia, regulations governing 'public good' R&D have tended to be a step ahead of those related to the commercialization of R&D. The first legislative act was the Law on Scientific and Technological Activity (2000). It defined key concepts related to the conduct of R&D and related organizations. Next came a key policy decision, the government resolution of 2007 establishing the State Committee of Science (SCS). While being a committee within the Ministry of Education and Science, the SCS was empowered with wide-ranging responsibilities as the leading public agency for the governance of science, including the drafting of legislation, rules and regulations on the organization and funding of science. Shortly after the creation of the SCS, competitive project financing was introduced to complement basic funding of public R&D institutions; this funding has dropped over the years in relative terms. SCS is also the lead agency for the development and implementation of research programmes in Armenia (UNECE, 2014).

Box 12.2: Two public–private partnerships in Armenia's ICT sector

Synopsys Inc.

Synopsys Inc. celebrated ten years in Armenia in October 2014. This multinational specializes in the provision of software and related services to accelerate innovation in chips and electronic systems. Today, it employs 650 people in Armenia.

In 2004, Synopsys Inc. acquired LEDA Systems, which had established an Interdepartmental Chair on Microelectronic Circuits and Systems with the State Engineering University of Armenia. The Chair, now part of the global Synopsys University Programme, supplies Armenia with more than 60 microchip and electronic design automation specialists each year.

Synopsys has since expanded this initiative by opening interdepartmental chairs at Yerevan State University, the Russian–Armenian (Slavonic) University and the European Regional Academy.

The Enterprise Incubator Foundation

The Enterprise Incubator Foundation (EIF) was founded jointly in 2002 by the government and the World Bank and has since become the driving force of Armenia's ICT sector. It acts as a 'one-stop agency' for the ICT sector, dealing with legal and business aspects, educational reform, investment promotion and start-up funding, services and consultancy for ICT companies, talent identification and workforce development.

It has implemented various projects in Armenia with international companies such as Microsoft, Cisco Systems, Sun Microsystems, Hewlett Packard and Intel. One such project is the Microsoft Innovation Center, which offers training, resources and infrastructure, as well as access to a global expert community.

In parallel, the Science and Technology Entrepreneurship Programme helps technical specialists bring innovative products to market and create new ventures, as well as encouraging partnerships with established companies. Each year, EIF organizes the Business Partnership Grant Competition and Venture Conference. In 2014, five winning teams received grants for their projects of either US$7 500 or US$15 000. EIF also runs technology entrepreneurship workshops, which offer awards for promising business ideas.

Source: compiled by authors

The SCS led the preparation of three key documents which were subsequently adopted by the government in 2010: the *Strategy for the Development of Science 2011–2020*, *Science and Technology Development Priorities for 2010–2014* and the *Strategic Action Plan for the Development of Science for 2011–2015*. The *Strategy* envisages a competitive knowledge-based economy drawing on basic and applied research. The *Action Plan* seeks to translate this vision into operational programmes and instruments supporting R&D in the country.

The *Strategy* envisions that 'by 2020, Armenia is a country with a knowledge-based economy and is competitive within the European Research Area with its level of basic and applied research.' The following targets have been formulated:

- Creation of a system capable of sustaining the development of science and technology;
- Development of scientific potential, modernization of scientific infrastructure;
- Promotion of basic and applied research;
- Creation of a synergistic system of education, science and innovation; and
- Becoming a prime location for scientific specialization in the European Research Area.

Based on this strategy, the *Action Plan* was approved by the government in June 2011. It defined the following targets:

- Improve the S&T management system and create the requisite conditions for sustainable development;
- Involve more young, talented people in education and R&D, while upgrading research infrastructure;
- Create the requisite conditions for the development of an integrated STI system; and
- Enhance international co-operation in R&D.

Although the strategy clearly pursues a 'science push' approach, with public research institutes as the key policy target, it nevertheless mentions the goals of generating innovation and establishing an innovation system. However, the business sector, which is the main driver of innovation, is not mentioned. In between the *Strategy* and the *Action Plan*, the government issued a resolution in May 2010 on *Science and Technology Development Priorities for 2010–2014*. These priorities were:

- Armenian studies, humanities and social sciences;
- Life sciences;
- Renewable energy, new energy sources;
- Advanced technologies, information technologies;
- Space, Earth sciences, sustainable use of natural resources;
- Basic research promoting essential applied research.

The Law on the National Academy of Sciences (May 2011) is also expected to play a key role in shaping the Armenian innovation system. It allows the academy to carry out wider business activities concerning the commercialization of R&D results and the creation of spin-offs; it also makes provision for restructuring the National Academy of Sciences by combining institutes involved in closely related research areas into a single body. Three of these new centres are particularly relevant: the Centre for Biotechnology, the Centre for Zoology and Hydro-ecology and the Centre for Organic and Pharmaceutical Chemistry.

In addition to horizontal innovation and science policies, the government strategy focuses support schemes on selected sectors of industrial policy. In this context, the State Committee of Science invites private sector participation on a co-financing basis in research projects targeting applied results. More than 20 projects have been funded in so-called targeted branches: pharmaceuticals, medicine and biotechnology, agricultural mechanization and machine building, electronics, engineering, chemistry and particularly the ICT sphere.

Low R&D spending, shrinking researchers

GERD is low in Armenia, averaging 0.25% of GDP over 2010–2013, with little annual variation observed in recent years. This is only around one-third of the ratios observed in Belarus and Ukraine. However, the statistical record of R&D expenditure is incomplete in Armenia, as expenditure in the privately-owned business enterprises is not surveyed. With this proviso, we can affirm that the share of R&D funding from the state budget has increased since the 2008–2009 financial crisis and accounted for around two-thirds (66.3%) of GERD in 2013. In parallel, the number of researchers in the public sector has dropped by 27% since 2008, to 3 870 (2013). Female researchers accounted for 48.1% of the total in 2013. They are underrepresented in engineering and technology (33.5%) but prevalent in medical and health sciences (61.7%) and agriculture (66.7%).

A high degree of autonomy for Armenian universities

Armenia has a well-established system of tertiary education that encompasses 22 state universities, 37 private universities, four universities established under intergovernmental agreements and nine branches of foreign universities. Universities in Armenia have a high degree of autonomy in formulating curricula and setting tuition fees. Armenia joined the Bologna Process[10] in 2005 and universities are

10. The Bologna Process involves 46 European countries which have committed to creating a Higher Education Area. Three key priorities are to generalize across Europe the bachelor's–master's–PhD system, quality assurance and the recognition of qualifications. See the box in the *UNESCO Science Report 2010*, p. 150.

currently working to align the standards and quality of their qualifications. With only a few exceptions, universities tend to focus almost exclusively on teaching and do not engage in, or encourage, research by staff (UNECE, 2014).

Armenia ranks 60th out of 122 countries for education – lagging somewhat behind Belarus and Ukraine but ahead of Azerbaijan and Georgia (WEF, 2013). Armenia ranks better for tertiary enrolment (44th out of 122 countries), with 25% of the workforce possessing tertiary education (Table 12.2). It performs poorly, though, according to the workforce and employment index (113th out of 122 countries), primarily due to high unemployment and low levels of employee training.

Next steps for Armenia

- Greater focus needs to be assigned to integrating Armenian R&D institutes and businesses into global value and supply chains by further developing co-operation with leading producers as a specialized supplier of components, for instance.
- The poor statistical base and a limited evaluation culture make it difficult to obtain a clear picture of technological capabilities; this poses clear challenges for evidence-based policy making.
- R&D institutes could be restructured to increase the efficiency of resource allocation to R&D, such as by turning some of them into technical institutes supporting knowledge-intensive SMEs. These institutes should rely on a combination of public and commercial funding and co-operate closely with technoparks.
- The introduction of a system of international evaluation could serve as a basis for integrating complementary university research departments and research institutes, in order to make savings that could be used gradually to raise expenditure on education; the criteria for selecting centres of excellence would give equal weight to the institution's international and local relevance.

AZERBAIJAN

Moves to reduce dependence on commodity exports

Oil and gas extraction dominates the Azeri economy. From the early to late 2000s, its share in GDP rose from around a quarter to more than half, before receding somewhat in more recent years. Oil and gas account for around 90% of exports and the bulk of fiscal revenues (Ciarreta and Nasirov, 2012). During a period of high oil prices, growth led by energy exports enabled a sharp rise in per capita income and a dramatic fall in the measured poverty rate. Non-oil GDP also grew but, following the 2008–2009 global financial crisis, economic growth slowed considerably to about 2% per year over the period 2011–2014, according to the IMF's *World Economic Outlook* (2014).

Some observers expect Azerbaijan's oil output to pursue its decline. The European Bank for Reconstruction and Development makes this point, for instance, in its *Strategy for Azerbaijan 2014*. With the world having entered a period of lower oil prices in 2014, devising a growth strategy that is not dependent on commodity exports is becoming more of a strategic issue for Azerbaijan. One example of the government's desire to strengthen non-oil sources of growth is its decision to finance infrastructure projects through the State Oil Fund of Azerbaijan, which has received high international recognition as a sovereign wealth fund (World Bank, 2010).

An environment not yet conducive to innovation

The *National Strategy for the Development of Science in the Republic of Azerbaijan in 2009–2015* (Government of Azerbaijan, 2009) itself recognizes that Azerbaijan's S&T environment is ill-prepared to realize the country's innovative potential. GERD has not kept up with the phenomenal growth in GDP in the first decade of the century. Despite a brief surge in 2009, GERD actually contracted by 4% in real terms between 2009 and 2013, as the share of R&D performed by the business sector fell from 22% to 10%. Over the past decade, the number of Azeri researchers has stagnated, even declining in the business sector. AzStat indicates a 37% jump in total researchers in 2011–2013 but the country does not publish data in full-time equivalents.

Apart from sheer numbers, the ageing of the research body is a key issue in Azerbaijan. Already in 2008, 60% of Azeri PhD-holders were aged 60 years or more (Government of Azerbaijan, 2009). AzStat data suggest that the proportion of researchers under the age of 30 dropped from 17.5% in 2008 to 13.1% in 2013. Moreover, there is no indication of a determined educational effort to bring fresh blood to the research establishment. Tertiary enrolment as a whole has been stagnant (Table 12.2) and the number of doctoral graduates in science and engineering is dropping, as is the share of women among them; women represented 27% of the total in 2006 but only 23% by 2011. Finding qualified labour has become a serious problem for high-tech enterprises in Azerbaijan (Hasanov, 2012).

The weakness of Azerbaijan's STI effort is also reflected in its modest publication and patent record, coupled with very low exports in high-tech goods (Tables 12.3 and 12.4 and Figure 12.6). A number of qualitative issues underlie these quantitative shortcomings. According to a UNESCO Memorandum from 2009 on the *Formulation of a Science, Technology and Innovation (STI) Strategy and STI Institutional*

Capacity Building in Azerbaijan: Plan of Action, November 2009–December 2010, these issues include the following:

- STI functions are concentrated in the Azerbaijan National Academy of Sciences (ANAS) and universities have failed to develop strong R&D links with the business enterprise sector.
- Certain administrative or other hurdles constrain the expansion of private universities.
- The allocation of government funding to public universities seems to follow popular demand for certain subjects, such as business studies or international relations, and penalize studies in science and engineering disciplines.
- There appear to be special difficulties in expanding doctoral programmes in regular university departments.
- R&D equipment is obsolete and the measured productivity of research is very low.
- Financial allocations to research institutions are not transparent and there is insufficient independent evaluation.

The entire spectrum of science–industry linkages, from technology transfer offices to business incubators, technoparks and early-stage financing, remain weak in Azerbaijan (Dobrinsky, 2013). The R&D system consists largely of sector-based government laboratories and remains 'isolated from market and society' (Hasanov, 2012). Innovative SMEs are rare, as everywhere, but even larger enterprises do not seem to pursue technology-intensive activities. Only 3% of Azerbaijan's industrial output is high-tech (Hasanov, 2012). The growth of technologically intensive activity is constrained by problems in the general business environment, where Azerbaijan ranks near the bottom for Eastern Europe and Central Asia (World Bank, 2011), despite improvements in recent years.

More generally, according to Hasanov (2012), the governance of Azerbaijan's national innovation system is characterized by limited administrative capacity for policy design and implementation; the lack of an evaluation culture; an arbitrary policy-making process; a lack of quantitative targets in most of the adopted policy documents related to the promotion of innovation and a low level of awareness of recent international trends among government officials responsible for developing innovation policy.

STI has become a greater priority

In recent years, the government has sought to develop the contribution of STI to the economy, notably by inviting UNESCO's assistance in 2009 in developing an *Azerbaijan Science, Technology and Innovation Strategy*. This document was intended to build on the *National Strategy* (Government of Azerbaijan, 2009) adopted by Presidential Decree in May 2009, with ANAS being designated co-ordinator of the *Strategy*.

More recently, the government has launched a new wave of initiatives, notably by elevating responsibility for STI policy to cabinet level. In March 2014, the mandate of the former Ministry of Communications and Information Technologies was also broadened to that of Ministry of Communications and High Technologies. This development is part of a series of executive actions since 2012, including the:

- creation of a State Fund for the Development of Information Technologies (2012), which is intended to provide start-up funding[11] for innovative and applied S&T projects in ICT fields through equity participation or low-interest loans;
- announcement of the development project *Azerbaijan – 2020: Outlook for the Future* by the Presidency (July 2012), which establishes STI-related goals[12] in communications and ICTs, such as the implementation of the Trans-Eurasian Information Super Highway project or equipping the country with its own telecommunications satellites;
- presidential order on the establishment of a High Technologies Park (November 2012);
- adoption of the *Third National Strategy for Information Society Development* in Azerbaijan covering 2014–2020 (April 2014) – Azerbaijan had the greatest Internet penetration of any Black Sea country in 2013: 59% of the population (Table 12.1);
- creation of a Knowledge Fund under the auspices of the Presidency (May 2014); and the
- creation of a National Nuclear Research Centre under the new Ministry of Communications and High Technologies (May 2014).

The following constitute the current priority areas for S&T development in Azerbaijan, according to a presentation made by Bunyamin Seyidov from ANAS to a Horizon 2020 Eastern Partnership meeting in Chisinau in March 2014:

- ICTs;
- energy and environment;
- efficient utilization of natural resources;
- natural sciences;
- nanotechnologies and new materials;
- safety and risk reduction technologies;
- biotechnology;
- space research; and
- e-governance.

11. See: http://mincom.gov.az/ministry/structure/state-fund-for-development-of-information-technologies-under-mcht

12. See: www.president.az/files/future_en.pdf

Next steps for Azerbaijan

There is no doubt that Azerbaijan is aware of the need to step up its STI effort. Nor is it surprising that the country has not yet managed to overcome the 'Dutch disease' associated with a sudden surge in oil wealth (see glossary, p. 738). Although the country has suddenly been propelled to the ranks of an upper middle-income country for GDP per capita, it is still catching up in terms of modernizing its economic and institutional fabric. There is now a need to follow through on these good intentions with decisive reforms, including the following:

- The past few years have seen a vast number of laws and presidential decrees and decisions proclaimed on STI matters but few concrete improvements; it would be useful to carry out a comprehensive evaluation of past measures to identify what is preventing regulatory initiatives from being translated into action.
- The large number of STI policy documents adopted in Azerbaijan contain surprisingly few quantitative targets; it would be worthwhile to consider adopting a small number of cautious and judiciously chosen targets, in order to measure progress towards the desired goals and facilitate an *ex post* evaluation.
- The government should take decisive steps to improve the general business environment, such as by strengthening the rule of law, in order to help Azerbaijan derive economic benefits from its input into innovation.

BELARUS

A specialization in engineering and oil refining

Belarus is not well-endowed with natural resources and relies largely on imported energy and raw materials. Historically, the country has always specialized in processing; the main activities of its large industrial sector (42% of GDP in 2013) are engineering (agricultural technology and specialized heavy vehicles such as tractors) and the refining of oil supplied mainly by Russia. These sectors are heavily dependent on external demand, which is why foreign trade contributes a bigger share of GDP for this upper middle-income economy than for any other in this group (Table 12.1). With 50% of trade involving the Russian Federation, the Belarusian economy has been vulnerable to the crisis currently affecting its biggest commercial partner; for example, after the Russian ruble lost nearly 30% of its value in just a few days in December 2014, the value of the Belarus ruble fell by half.

The Belarusian authorities have followed a path of gradual transition towards a market economy. The state retains significant levers of influence over the economy and there has only been limited privatization of large enterprises. The authorities have developed initiatives in recent years to improve the business environment and promote the development of SMEs. However, state companies continue to dominate production and exports, whereas the rate of new firm creation remains low (UNECE, 2011).

Belarus is a catching-up economy that will remain dependent on imported technology for some time to come, despite having declared 20 years ago that its strategic policy objective was to develop an economy based on science and technology. Since then, more than 25 laws and presidential decrees have been introduced, some 40 governmental decrees have been issued and many other legal acts have been put in place to contribute to this stated aim. All this has created broad awareness of the importance of science and technology for the country's economic prosperity.

Ministries and other governmental bodies have developed *The Concept for the National Innovation System* on the basis of the *National Strategy 2020*, adopted in 2006, the *Technology forecast 2006–2025* and other strategic documents. *The Concept* approved by the Science and Technology Policy Committee of the Council of Ministers in 2006 recognizes the sectorial approach as being predominant in developing and implementing the country's science and innovation policy.

Scientific co-operation is growing

The government was planning to increase GERD to 1.2–1.4% of GDP by 2010 but this has not been achieved. This eliminates any likelihood of reaching the more recent target of raising GERD to 2.5–2.9% of GDP by 2015, a target ensconced in the Programme of Social and Economic Development for the Republic of Belarus covering 2011–2015 (Tatalovic, 2014).

The Belarusian R&D system is strongly dominated by technical sciences, which represent approximately 70% of GERD, whatever the source of funding (including the state's goal-oriented programmes). Sectorial ministries in Belarus each have their own established funds to finance innovation in key economic sectors, such as construction, industry, housing and so on. Arguably the most successful of these funds is that targeting ICT companies.

Only 3.6% of R&D funding was spent on international co-operation in 2012 , according to the Belarusian journal *Nauka i innovatsii* (2013). There is no specific national policy document on international collaboration in the various scientific fields. The share of GERD funded from abroad, which oscillated around 5–8% between 2003 and 2008, climbed to 9.7% on average in 2009–2013. The number of research projects with international partners has also more than doubled in the past seven years.

A skilled labour force but ageing researchers

The Belarusian R&D system reflects the legacy of its Soviet past, as privately owned business enterprises are not a major performer of R&D, in contrast to what you find in market economies. This said, the R&D system is, in principle, largely oriented towards enterprises, which buy S&T services from 'branch' research institutes. In Belarus, the latter play a bigger role in providing S&T services than the university sector. This feature has remained a strong characteristic of the Belarusian system, despite the gradual transformation taking place.

Belarus has preserved engineering competencies in large enterprises and has a skilled labour force. Although its R&D potential remains high, the deteriorating age structure, coupled with brain drain, has negatively affected actual performance. In the past ten years, the share of R&D staff aged between 30 and 39 years has halved from more than 30% to about 15% of the total. The number of those aged 60 and above has grown six-fold. The reputation of scientists and their status remain high in Belarus but the profession's appeal has waned.

The distribution of R&D staff within the country is irregular. Three-quarters of researchers are still concentrated in the capital, followed by the Minsk and Gomel regions. Relocating research personnel is costly and strongly dependent both on the availability of research infrastructure and the overall economic situation, which has not been conducive in recent years to relocation programmes.

Owing to changes in statistical methodology which now consider state enterprises operating like commercial entities as being part of the business enterprise sector, in line with the OECD's approach, business spending on R&D has risen to the detriment of government funding (down to roughly 0.45% of GDP in 2013). The role of the higher education sector remains negligible.

The number of articles published in internationally tracked journals has stagnated in recent years (Figure 12.6). Belarus is performing much better in terms of national patents. Domestic patent applications are up from fewer than 700 per year in the early 1990s to more than 1 200 in 2007–2012. For this indicator, Belarus is doing better than some of the new EU members, such as Bulgaria or Lithuania.

Next steps for Belarus

From the foregoing, it would seem advisable to consider taking the following steps:

- Complementing existing 'vertical' instruments in high-level policy documents with 'horizontal' ones cutting across firms, industries and sectors to improve linkages among the various stakeholders in innovation;
- Facilitating and encouraging access by innovative SMEs to state science and technology programmes; in addition to the development of science and technology parks, innovation-related tax incentives could be applied across all sectors and industries and incentives could be offered to foreign firms to encourage them to set up R&D centres in Belarus;
- Granting targeted tax relief for early-stage innovation by SMEs, in particular, such as subsidized loans, innovation grants or vouchers and credit guarantee schemes, which take on some of the risk borne by the innovative SME of defaulting on a loan;
- Conducting an *ex post* evaluation (which combines quantitative and qualitative assessments) of the degree to which programmes, projects and policy instruments meet policy objectives and targets; incorporating elements that facilitate subsequent *ex post* evaluation at the early stages of designing programmes, policies and related instruments; and
- Expanding the scope and outreach of regional programmes promoting science and technology to encompass regional innovative development, accompanied by the requisite additional resources.

GEORGIA

Ahead on market reforms but STI could do more to drive development

Compared with other economies at a similar stage of development, Georgia is one of the most advanced in implementing market-oriented reforms but also one of the least focused on nurturing STI for socio-economic development.

With few natural resources to speak of and hardly any legacy of heavy industry, Georgia's economy has been dominated by the agro-industry since Soviet times. As late as 2009, food and beverages represented 39% of manufacturing output and the share of agriculture in employment stood at 53% (FAO, 2012). Exports of transport services (including oil and gas via pipelines) have become important sources of revenue, representing 5–6% of GDP in the last five years, according to the World Bank. Broad-based growth is presently reducing the relative importance of these sectors, however. The Georgian economy grew by an average of 6% per year between 2004 and 2013, driven by 'a noteworthy push on structural reforms and liberalisation starting in 2004' (World Bank, 2014).

Indeed, Georgia has been one of the most resolute reformers of modern times when it comes to advancing economic freedoms and improving the business environment. The country rose 101 places in the World Bank's Doing Business Indicator between 2005 and 2011. Meanwhile, its extensive anti-corruption and administrative simplification campaign helped lower the share of the informal economy in Georgia's fast-growing GDP from 32% to 22% from 2004 to 2010 (OECD *et al.,* 2012).

Against the backdrop of this economic success story, Georgia currently presents a much more ambivalent picture when it comes to STI:

- Government funding for R&D is low and unstable – state budgetary expenditure on R&D tripled between 2009 and 2011, only to contract by two-thirds again by 2013, according to the National Statistics Office. The budget is allocated in a haphazard way as a result of institutional inertia and much of it is spent on non-scientific needs (State Audit Office, 2014).
- R&D in the business sector is not measured and there is a general lack of comparable data on STI for recent years.
- Georgia occupies a median position among the seven Black Sea countries in terms of scientific output (Figure 12.6).

The government's recent audit of the science sector (State Audit Office, 2014) makes a critical assessment of the situation, arguing that, 'science does not significantly participate in the process of economic and social development (in Georgia).' The assessment underlines the disconnect between applied research and concrete innovation and 'the private sector's lack of interest in research.' It also deplores the absence of any evaluation of publicly funded research.

In addition to its own half-hearted efforts to generate new knowledge and technology, Georgia is making little use of the technology that is globally available; despite the country's relative openness to trade, its imports of high-tech goods have stagnated at low levels, with just 6% growth over 2008–2013, according to the UN's Comtrade database.

Urgent challenges in education

The country's neglect of education is likely to constrain future growth prospects. Although the educational attainment of the adult population has been historically high in Georgia, the tertiary enrolment rate in 2013 remained 13.5 percentage points below the peak in 2005. Doctorates awarded in science and engineering slid by 44% (to a total of 92) in the five years to 2012 and enrolment at this level in these fields also fell sharply, although there has been a surge in recent years, according to the UNESCO Institute for Statistics.

Georgia also faces challenges with regard to the quality of secondary education. The performance of the country's 15 year-olds in reading, mathematics and science was comparable to that of some of the lowest-ranking countries in the OECD's Programme for International Student Assessment in 2009 (Walker, 2011). Georgia also ranks below comparable countries in the Trends in International Mathematics and Science Study survey of 2007. At the tertiary level, Georgia's inbound mobility is virtually zero, indicating serious attractiveness problems. As outbound mobility is high, brain drain is also a potential problem, according to a 2010 study by the Technopolis Group of the way in which doctoral programmes are run in EU neighbouring programmes.

Time for a strategic vision

The present STI institutional structure in Georgia began to emerge after what is known as the Revolution of Roses[13] in 2003. Cabinet-level responsibility for science policy rests within the Ministry of Education and Science (MoES), within the framework of the Law on Higher Education (2005) and the Law on Science, Technologies and their Development (2004, modified in 2006). The National Academy of Sciences was formed by merging older academies in 2007; it fulfils an advisory role in STI matters. The principal government instrument for funding public research is the Shota Rustaveli National Science Foundation, which was formed in 2010 by merging the National Science Foundation with the Foundation for Georgian Studies, Humanities and Social Sciences.

The government's own audit acknowledges that a 'strategic vision and priorities of scientific activities are not defined.' Moreover, in the absence of top-down sectorial priorities, the Rustaveli Foundation is believed to allocate project funding across fields based on the merits of each proposal in isolation. There are no data to assess the outcome of recent reforms designed to integrate public research institutions and universities and knowledge transfer offices are yet to be created on university campuses (State Audit Office, 2014).

International development partners from advanced Western economies have been active in Georgia in the past ten years and have contributed studies on the strengths, weaknesses, opportunities and threats facing STI in Georgia. One such *Constraints Analysis* was undertaken by the Government of Georgia in co-operation with the Millennium Development Challenge Corporation in 2011. These partners have also analysed specific science sectors and trends in overseas development assistance. One example is the study by Georgia's Reforms Associates in 2014 on *Analyzing Ways to Promote Research in Social Sciences in Georgia's Higher Education Institutions*, funded by USAID.

Next steps for Georgia

The government's liberal, hands-off approach to economic development has brought considerable benefits but Georgia

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13. The Revolution of Roses was characterized by widespread protests over disputed parliamentary elections which led to President Eduard Shevardnadze's forced resignation in November 2003.

would now gain from additional policies that harness STI to development. It should act upon the recommendations made by the State Audit Office (2014) and consider the following:

- There is a need to improve the availability of timely and internationally comparable data on STI input and output.
- On the education front, Georgia has key advantages on which it can capitalize, including the greatly reduced level of corruption and the absence of demographic pressure; it now needs to reverse the declining tertiary enrolment rates and address quality issues in secondary education.
- There is a need to reflect on an advisory structure on STI matters which would incorporate the perspectives of stakeholders outside government and academic circles, especially the enterprise sector, in the design and implementation of STI policies.
- The development of a national innovation strategy would improve the coherence and co-ordination of policies in different governmental spheres: education, industry, international trade, taxation, etc.

MOLDOVA

An alternative growth engine to replace remittances

Moldova has one of the lowest levels of GDP per capita in Europe and the lowest in the Black Sea region (Table 12.1). Moldova's emigrant population is among the largest in the world, in relative terms; it accounts for about 30% of the labour force. Workers' remittances are high (23% of GDP in 2011) but their contribution is expected to stagnate (World Bank, 2013), so the country needs an alternative growth engine based on exports and investment.

Moldova's economy recovered strongly from the global financial crisis, growing by more than 7% in 2010–2011, but growth has been unstable since, with GDP contracting by 0.7% in 2012 only to rebound by 8.9% in 2013, according to the IMF. This underlines Moldova's vulnerability to the Eurozone crisis and climatic events such as droughts (World Bank, 2013).

After peaking at 0.55% of GDP in 2005, GERD dropped to 0.36% in 2013, according to the UNESCO Institute for Statistics. The share of GERD performed by business enterprises has been very erratic, dropping from 18% in 2005 to 10% in 2010 before bouncing back to 20% in 2013. The low level of R&D investment means that research infrastructure remains undeveloped, although ICT networks and databases are available to researchers to some extent.

A centralized national innovation system

The Academy of Sciences is the main policy-making body in Moldova; it fulfils the role of ministry of science, as its president is a member of the government. It is also the main policy implementation body. Nearly all public R&D and innovation funding programmes are managed by the Academy through its executive body, the Supreme Council for Science and Technological Development, and its subordinated management bodies and agencies, the Centre for Fundamental and Applied Research Funding, the Centre for International Projects and the Agency for Innovation and Technology Transfer. The Consultative Council for Expertise assures the evaluation of these three funding agencies. With its 19 research institutes, the Academy is also the country's main research organization. Sectorial research institutes under certain ministries also carry out research.

The country's 32 universities also perform scientific research but not necessarily technological development. The business enterprise sector also performs R&D but only four entities[14] are accredited by the Academy of Sciences, thereby giving them access to public competitive R&D funding.

Given the trend in Moldova towards emigration and brain drain, the number of researchers per million inhabitants has stagnated at a level well below those of other Black Sea countries (Figure 12.2). The share of the population with tertiary education is relatively high but the number of new doctorate graduates per 1 000 population aged 25–34 years is less than a fifth of the EU average. Moldova has difficulty in attracting and retaining foreign students and researchers, as the education offered by local universities does not meet market expectations and generally offers unattractive conditions (Cuciureanu, 2014).

The *Innovation Strategy: Innovation for Competitiveness* developed by the Ministry of the Economy for the period 2013–2020 outlines five general objectives: adoption of an open governance model for research and innovation; strengthening entrepreneurship and innovation skills; encouraging innovation in enterprises; applying knowledge to solve societal and global problems; and stimulating demand for innovative products and services. In parallel, the *Strategy for Research and Development of the Republic of Moldova until 2020* prepared under the guidance of the Academy of Sciences and approved in December 2013 establishes an R&D investment target of 1% of GDP by 2020. Neither strategy identifies clear thematic priorities.

The government's main funding instruments are the so-called institutional projects, which allocate more than 70% of public funds in a semi-competitive mode. These competitive funding

14. Three state enterprises have been accredited, the Institute of Agricultural Engineering (Mecagro), the Research and Production Enterprise of Aquatic Biological Resources (Aquaculture Moldova) and the Research Institute for Construction (INCERCOM) and have access to public competitive R&D funding. A fourth, the Institute for Development of an Information Society, is in the process of obtaining accreditation. Source: http://erawatch.jrc.ec.europa.eu schemes include state programmes for R&D, international projects and projects for the transfer of new technologies and processes, grants for young researchers, including PhD fellowships, as well as grants for the procurement of equipment, the editing of monographs or for organizing scientific conferences.

The rest is allocated through other funding modes, such as block grants to the administration, research facilities or to subordinated agencies of the Academy of Sciences and to pay for infrastructure. In recent years, there has been a trend towards increasing the share of institutional funding at the expense of the other funding instruments.

Only the state programmes for R&D have a thematic focus (Figure 12.7). The procedure for funding policy instruments, evaluation, monitoring and reporting is identical for each thematic priority. The topics tend to be broad and government funding modest. Moreover, programme-based R&D financing has dropped by two-thirds in the past five years to an insignificant € 0.35 million in 2012.

Next steps for Moldova

Since the 2004 Law on Science and Innovation, the combination of reforms and closer ties with the EU in research and innovation have helped to prop up the national science system but have not been enough to stop its decline. A recent paper by a consultant to the Academy of Sciences recommends prioritizing the following reforms (Dumitrashko, 2014):

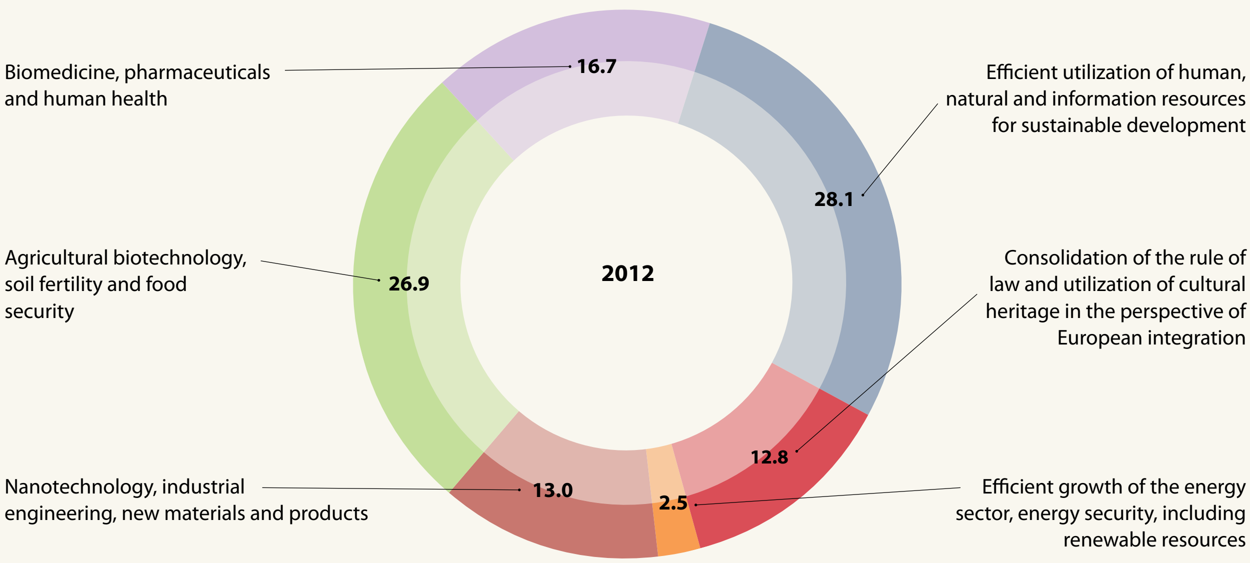
- Updating research equipment and the country's technical base;
- Designing targeted incentive schemes to encourage the young to embark on a research career, including stipends, grants and awards for young scientists, programmes for training abroad and so on;
- Greater participation in the European Research Area and other international networks;
- Accelerating technology transfer and encouraging partnerships between research institutions and the business enterprise sector.

TURKEY

Ambitious development targets to 2023

In the past decade, Turkey has experienced an economic boom that was only briefly curtailed by the global financial crisis. This has carried GDP per capita from one-third (32%) that of high-income economies in 2003 to almost half (47%) in 2013, according to the World Bank's World Development Indicators, and reduced economic inequalities (OECD, 2014, Box 12.1.) Growth has been driven by the emergence of new, first-generation enterprises in previously non-industrial, low-income parts of the country and accompanied by an expanding employment rate (OECD, 2012, Figure 2.2).

Figure 12.7: **Budget breakdown of Moldova's state programmes for R&D, by thematic priority, 2012 (%)**



Source: Cuciureanu (2014)

Table 12.5: **Key development targets for Turkey to 2018 and 2023**

	Situation in 2012	Targets to 2018	Targets to 2023
GDP per capita at market prices (US$)	10 666	16 000	25 000
Merchandise exports (US$ billions)	152	227	500
Share of world trade (%)	1.0	_	1.5
GERD/GDP ratio	0.86	1.80	3.0
Share of GERD performed by business enterprise sector (%)	43.2	60.0	_
Researchers (FTE)	72 109	176 000	_

Source: MoDev (2013); World Bank's World Development Indicators, accessed November 2014; UNESCO Institute for Statistics, March 2015

Formulated in 2008, the government's *Strategic Vision 2023* includes ambitious[15] development targets, such as achieving a GERD/GDP ratio of 3% by the time the republic celebrates its centenary in 2023 and turning Turkey into a Eurasian hub for medium- and high-tech exports (Table 12.5). It also puts the country's STI policy goals in context. To the same end, the *Tenth Development Plan* (2014–2018) establishes operational targets to 2018 such as that of raising the share of business expenditure to 60% of GERD (MoDev, 2013, Table 23), which would imply doubling the number of FTE researchers in five years.

External factors could frustrate Turkey's ambitions

Turkey's ambitions could yet be frustrated by external factors. The country's economic growth remains dependent on foreign capital flows. As much of these flows are non-FDI, growth is subject to changing perceptions of Turkey's country risk, or to swings in monetary policy in the USA or Eurozone. With many of Turkey's principal export markets appearing to be trapped in an extended period of modest growth, at best, Turkey's official development targets seem very difficult to reach. Apart from a period between 2002 and 2007 when total factor productivity growth was the main driver, it is the increases in capital and labour input which still primarily drive growth in Turkey (Serdaroğlu, 2013). Historically, growth in manufacturing has been driven mainly by greater use of technology, rather than by the generation of new technologies (Şentürk, 2010). All these reasons justify a renewed focus and re-examination of STI policies in Turkey, in order to learn from recent experience.

Some university–industry collaboration but quality is an issue

Since the release of the *UNESCO Science Report 2010*, Turkey has been pursuing the vigorous expansion of R&D which began around 2004. The R&D intensity of the economy is approaching levels found in advanced economies such as Spain or Italy, but is well below that found in fast-growing emerging market economies such as China, where the business enterprise sector contributes more than 70% of GERD. At the same time:

- Turkey has pursued its efforts to improve the quantity and quality of schooling available to the average person. For instance, there has been a significant improvement in the scores of 15 year-olds in mathematics in the OECD's Programme for International Student Assessment; this feat is attributed both to the growing wealth of the general population, which can afford better tutoring, and to the impact of education sector reforms (Rivera-Batiz and Durmaz, 2014).
- Internationally comparable opinion surveys of managers generally place Turkey below levels found in the more advanced emerging market economies, although there has been some improvement in the past five years, according to the Global Innovation Index (2014) and successive *Global Competitiveness Reports* since 2008.
- More generally, Turkey's rankings in qualitative international comparisons tend not to match its ambitions. One international survey of business executives in 25 of the principal innovative economies suggests that the gap between in-country executives' opinion of the quality of the innovation environment in Turkey and that of outsiders is one of the widest of any country (Edelman Berland, 2012).
- Whereas the percentage of women with a PhD in science and engineering fields has been improving in recent years, the gender balance between researchers has been going the other way, especially in the private sector, and remains quite low in decision-making circles. As of 2014, none of the 20 permanent members of the Supreme Council for Science and Technology was a woman.

15. See: www.tubitak.gov.tr/en/about-us/policies/content-vision-2023

A highly centralized national innovation system

The institutional structure of the Turkish STI system remains highly centralized (TÜBITAK, 2013, Figure 1.1). Key recent developments include:

- The mandate of the former Ministry of Industry and Commerce was broadened in 2011 to that of a Ministry of Science, Technology and Industry, which now oversees the Scientific and Technological Research Council of Turkey (TÜBITAK).
- The former State Planning Agency was transformed into the Ministry of Development in 2011 and is now responsible for preparing the Technological Research Sector Investment Budget, amounting to PPP$1.7 billion in 2012 (TÜBITAK, 2013), and for co-ordinating regional development agencies.
- In August 2011, the government changed the statutes of the Turkish Academy of Sciences (TUBA) by decree and increased the share of members it can appoint directly to its Science Council, fuelling concerns in the press about TUBA's future scientific independence.
- Chaired by the prime minister, the Supreme Council for Science and Technology has met five times since 2010 to review progress and foster co-ordination in STI matters. Its recent meetings have tended to focus on a single specific technology sector: energy in 2013, health in 2014.
- Current activities are governed by the *National Science, Technology and Innovation Strategy* (2011–2016), which sets the following sectorial priorities:
  - Target-based approaches in three areas with a strong R&D and innovation capacity: automotive, machinery manufacturing and ICTs;
  - Needs-based approaches in areas where acceleration is required: defence, space, health, energy, water and food.

Businesses have not grasped the government's helping hand

Turkey participates in various European research co-operation networks and is one of the founding members of the OECD. In 2014, Turkey became an Associate Member of the European Organization for Nuclear Research (CERN), where it had been an Observer since 1961. Turkey has long had close ties to Europe: it was one of the first countries to conclude an Association Agreement with the EU in 1964; it has enjoyed a customs union with the EU since 1996 and opened accession negotiations in 2005. Despite this, science diplomacy got off to a slow start with the EU's Sixth Framework Programme for Research and Innovation (2002–2006), before accelerating under the Seventh Framework Programme (2007–2013). Efforts are now being made to seize the opportunities available under the Horizon 2020 programme (2014–2020) more fully. Despite this, the Turkish innovation systems' international linkages remain limited, in terms of outcome:

- In innovation surveys, Turkey ranks lowest among OECD countries for both national and international collaboration involving firms, according to the OECD' STI Scoreboard of 2013.
- The share of GERD funded from abroad is one of the lowest in the Black Sea grouping and has not kept pace with the expansion of the country's STI effort in recent years: at just 0.8% in 2013, according to the UNESCO Institute for Statistics, it accounted for 0.01% of GDP.
- Although patenting has grown in recent years, Turkey has one of the lowest rates for cross-border ownership of patents among OECD countries and the share of business R&D funded by foreign enterprises is negligible, according to the OECD's STI Scoreboard (2013). Moreover, unlike many emerging market economies, Turkey does not take part in international trade in R&D services in any significant way.

This said, other aspects of Turkey's international linkages in STI offer promise:

- Turks are the sixth-largest national contingent for PhDs in science and engineering fields awarded to foreigners in the USA; they earned a total of 1 935 degrees in 2008–2011 (about 3.5% of all foreigners in the USA), compared to the 5 905 similar degrees awarded inside Turkey over the same period (NSB, 2014).
- Generally, Turkish international co-operation in science *per se* is much stronger than that in innovation. For instance, the USA–Turkey bilateral link is one of the more important examples of co-authorship of scientific articles, according to the OECD's STI Scoreboard (2013).

On the whole, the dynamic Turkish private sector has not grasped the government's helping hand when it comes to STI. The Turkish economy has rebounded well from the tight contraction of 2008–2009 but its export performance is not keeping up with competitors in developed country markets (OECD, 2014). Whereas the technologically more advanced regions in the northwest of the country have continued to grow and deepen their integration with the EU, thanks to the customs union, the Turkish economy's overall shift to higher-tech patenting and exports has been slow, owing partly to the rapid expansion of a 'middle ground' of enterprises specializing in relatively low-tech manufactured goods such as textiles, food, plastic and metal products in much of the country for export to developing countries (OECD, 2012). With the boom in Turkish trade with developing countries, the

EU's share of Turkish exports has been declining, particularly since 2007; this decline can also be interpreted as slower integration into EU value chains and the technological upgrading that this entails (Işik, 2012).

This said, export performance may not fully capture the ongoing technological transformation:

- The share of manufacturing employment in medium-tech sectors has been growing (OECD, 2012). Anecdotal evidence points to technology-intensive service sectors with growing excellence but few exports to speak of, one example being in-house professional software development in banking, telecommunications and so on. The share of services within business expenditure on R&D has grown strongly from around 20% in the mid-2000s to 47% in 2013, according to the latest OECD statistics.
- There is strong growth in medium-tech exports such as in automotive or machinery production, a trend that is echoed in the field of intellectual property, where the strong recent growth in patenting has been mostly in low or medium technology (Soybilgen, 2013).
- Within a considerably open economy characterized by a customs union with the EU, many Turkish enterprises can afford to import the highest-tech machinery available in their sector, develop production in keeping with global best practice and seek excellence in high-end manufacturing within seemingly low-tech sectors, such as textiles, foodstuffs or logistics.

Next steps for Turkey

Having made great strides in the level of public support for STI in the past decade, the public authorities now need to consider additional measures to interconnect better the different players participating in the Turkish innovation system to make the whole more coherent: scientists, universities, public laboratories, large or small enterprises, NGOs and so on.

Measures could include:

- making a systematic effort to involve representatives of industry in the design and implementation of government-driven schemes, from technology parks to the regional development agencies that have been set up since the late 2000s;
- reversing the declining gender balance in human resources in STI, in general, and improving it at the highest decision-making levels, such as within the Supreme Council on Science and Technology;
- moderating the tendency to pursue top-down priorities and sector-specific incentives by taking better account of the very diversified and broad-based dynamism of the Turkish private sector;
- publishing consolidated and timely data on total public support for STI, including the amount of tax incentives;
- surveying barriers to FDI in R&D, as well as the R&D activities of Turkish multinationals abroad;
- strengthening the culture of evaluation regarding public-sector initiatives in the area of STI and their outcomes, both as concerns the system as a whole and key government initiatives such as technoparks (Box 12.3) or participation in international research networks like Horizon 2020. The government should seize upon the available expertise in internationally comparable evaluations, such as the innovation reviews conducted by the OECD.

Box 12.3: **Time to assess the impact of Turkish technoparks**

Technoparks created in association with universities have been one of the Turkish government's flagship schemes to foster business incubation in recent years. The first technoparks were set up in 2001 in Ankara and Kocaeli in Turkey's traditional industrial heartland.

By 2011, there were a total of 43 technoparks, 32 of which were operational. Their number may have even climbed to 52 by 2014, according to press reports. Turkey's technoparks host some 2 500 firms, 91 of which have foreign capital. In 2013, they employed 23 000 R&D personnel and generated US$1.5 billion in exports (1% of the total).

Although this feat is impressive, recent reports have been critical of the trend towards a certain inertia, with a growing number of universities establishing technology parks only to struggle to provide them with professional management and adequate funding. Reports deplore the scarcity of performance evaluations of existing parks and the lack of published data on the cost of tax breaks and other forms of public support extended to them. A 2009 report by the State Audit Committee underlined the need for an independent evaluation and impact assessment of existing technoparks – a judgement confirmed by a more recent report by a Ministry of Science, Technology and Industry inspector (Morgül, 2012).

Source: authors; see the Association of Turkish Technology Parks: www.tgbd.org.tr/en

UKRAINE

Co-operation with the EU in S&T is a priority

All Ukrainian governments in the past decade have announced plans to restructure the economy to make it more innovative and competitive. This modernization, combined with higher living standards, is a prerequisite for adhesion to the EU, the country's long-term ambition.

The country's crucial problems, such as energy wastage, poor environmental protection and an obsolete industrial sector and infrastructure, are not going to be solved without international co-operation and the acquisition of new knowledge. Moreover, national priorities in S&T tend to have a lot in common with those of the EU.

The following priorities figured in the State Law of Ukraine on Priorities for the Development of Science and Technology (2010):

- Basic research into key scientific problems in different disciplines;
- Environmental studies;
- ICTs;
- Energy generation and energy-saving technologies;
- New materials;
- Life sciences and methods for combating the main diseases.

The share of foreign sources in R&D funding is relatively high in Ukraine, accounting for about 25% of GERD in 2010–2013. Ukrainian state statistics do not provide information about the distribution of funding by country of origin. However, it is known that a substantial share is associated with the Russian Federation, the USA, EU and China.

Ukraine concluded a new agreement with the EU on S&T co-operation in 2010 that was implemented a year later. It has opened up new opportunities for co-operation and creates framework conditions for a number of joint initiatives, such as joint research projects with EU funding, joint expeditions, the exchange of information and so on. In July 2015, the Ukrainian parliament ratified the agreement for the country's associate membership of the EU's Horizon 2020 programme (2014–2020).

Successive crises have eroded R&D spending

Successive crises have had a negative impact on the economy, in general, and R&D funding, in particular: first, there was the economic crisis of the late 2000s then depreciation of the national currency, the Ukrainian hryvnia (UAH), and, in 2013–2015, the Euromaidan Revolution followed by armed conflict. In 2009, Ukrainian exports fell by 49% over the previous year and the economy contracted by 15%. The crisis resulted from a combination of factors, including the slump in international prices for steel, which forced the metallurgy and machine-building industries to reduce wages and lay off workers, and the suspension of gas supplies by Russia in January 2009 in a dispute over Ukraine's natural gas debt. The crisis in turn affected GERD, which represented UAH 8 025 million (€ 796 million) in 2007 but had declined (in euro terms) to UAH 8 236 million (€ 680 million) by 2009. In 2010, Ukraine returned to positive growth (4.2%) and GERD had recovered to UAH 9 591 million (€ 865 million) by 2011 but R&D intensity shrank over the same period from 0.85% (2007) to 0.77% (2013) measured in PPPs. GERD is expected to decline once more in euros in 2014 (HSE, 2014).

State funding of R&D has itself fluctuated over the past decade; it accounted for 36% of GERD in 2002, 55% in 2008 and 47% in 2013. The bulk of state funding goes towards supporting the state-sponsored academies of sciences, including the National Academy of Sciences. The state has tried to involve the private sector in research projects but this has met with limited success, largely because the state itself has repeatedly failed to meet its own obligations when it comes to financing research projects.

Low-tech heavy industries form the core of the economy

The share of business funding of R&D has dropped since 2003 (36%). It hit a low of 26% in 2009 and has stagnated since (29% in 2013). The generally low level of private sector expenditure on R&D is a consequence of the specific structure of the Ukrainian economy: two-thirds of business spending on R&D is concentrated in machine-building, an industry which has seen its contribution to the national economy contract since independence in 1991, with an acceleration in its decline during the economic crisis of 2008–2009 and again during the political crisis of 2013–2015, Russia being the machine-building sector's main customer up until now. Heavy industries with low R&D intensity form the core of the national economy: ferrous metallurgy, production of basic chemicals and coal-mining.

Technoparks in decline since abolition of tax breaks

The most successful experiments in commercializing research projects were those associated with technoparks in 1999–2005. In fact, these technoparks were more evocative of 'clusters' of high-tech companies and groups of scientists and engineers who enjoyed a favourable regime for realizing their research and innovation projects. The best technoparks were those established by institutes of the National Academy of Sciences which had a strong technological orientation, such as the Paton Institute of Electric Welding and the Institute of Monocrystals. Both the institutes themselves and their registered innovation projects were entitled to tax breaks. However, since the abolition of these tax breaks in 2005, the number of innovation projects has stagnated and the role played by technoparks in national innovation has declined.

Most research bodies focus on industrial development

Research policy in Ukraine is overseen mainly by the central ministries but local bodies also have some tools at their disposal with which they can exert influence over local universities and research institutions, in particular. Local bodies can introduce tax incentives, for example, provide financial support from local budgets and allocate public land for technoparks and business incubators. Traditionally, the university sector has played a subordinate role in the national research system, as it focuses mainly on teaching. The share of GERD performed by the higher education sector has hovered between 5% and 7% since the turn of the century. There are more than 340 universities but only 163 of them performed R&D in 2013. Approximately 40 of these universities are privately owned.

The Ministry of Science and Education plays the key role in determining science policy, along with the Ministry of Economic Development and Trade, although a number of other ministries and agencies distribute state funds to specific research programmes, projects and research bodies. The total number of ministries and agencies with science budgets varied from 31 to 44 in the 2000s (UNECE, 2013).

The State Committee for Science and Technology has changed its name and functions several times since its creation in 1991, most recently in December 2010 when the majority of its departments were incorporated into the Ministry of Science and Education and other ministries or state agencies. The former special State Committee on Science, Education and Informatization became an agency in 2011 and was fully incorporated into the Ministry of Science and Education in mid-2014; this committee is directly responsible for S&T policy formulation under the ministry's supervision (UNECE, 2013).

The majority of research institutions are associated with specific economic areas and focus on industrial R&D. Formally, these organizations are subordinated to the different ministries and state agencies but, in recent years, ties with the ministries have weakened. The National Academy of Sciences and five other state-sponsored academies have traditionally been key actors in the national research system, as they receive three-quarters of the state budget devoted to R&D. Academies are responsible for basic research but also for the co-ordination of many research- and innovation-related programmes, as well as for fixing S&T priorities and the provision of scientific advice. Their situation has been complicated by the *de facto* absorption of numerous Ukrainian research institutions in Crimea by the Russian Federation since 2014, including the A.O. Kovalezsky Institute of Biology of the Southern Seas in Sebastopol and the Crimean Astrophysical Observatory in Nauchny.

The public research system currently lags behind the world average for the quantity of research articles and their impact. The number of Ukrainian publications has not yet recovered to 2008 levels and the citation rate is one of the lowest among Black Sea countries. The share of Ukrainian publications in the Web of Science declined from 0.5% in 1996–2000 to about 0.2% in 2012. Ukraine has an especially poor record in social sciences, computer sciences, life sciences – and agricultural science, despite being the world's third-biggest grain exporter in 2011, with higher than average yields (Figure 12.6). The shares of Ukrainian publications in some areas of technical sciences, such as welding and electric machines, are much higher (Zinchenko, 2013).

No long-term human resource policy for R&D

The government's long-term human resource policy in R&D could be defined as 'inertial' rather than targeted, despite the different types of special stipend[16] for scientists, the most recent of which was introduced in 2012 to finance studies abroad. Although Ukraine joined the Bologna Process, which aims to harmonize higher education across Europe, in 2005, it still preserves a mixed[17] system. In 2014, the new Minister for Education and Science announced plans to harmonize Ukrainian degrees with the three-tiered degree system: bachelor's –master's–PhD. Many scientists are of pensionable age in Ukraine. The average age of Doctors of Science is more than 61 years and that of Candidates of Science more than 53. The average age of researchers has been growing by one year every three years (Yegorov, 2013).

Concern about the relevance of higher education

Ukraine inherited a relatively well-developed education system from the Soviet era. It still preserves some positive features of this system with its emphasis on mathematics and natural sciences at school level. However, serious concerns have been raised as to the quality of S&T education since independence.

16. Young scientists may also apply for parliamentary stipends and stipends from the National Academy of Sciences. Hundreds of distinguished older scientists receive lifelong stipends from the President of Ukraine. Special monthly salaries for the members and corresponding members of the state-sponsored academies of sciences could also be considered specific stipends for scientists.

17. Bachelor's and master's degrees have been introduced but the Soviet qualification of 'specialist' has been preserved. The Soviet Candidate of Science must not only hold a master's degree but also count no fewer than five publications to his or her name. The Soviet Doctor of Science must be a Candidate of Science with substantial scientific experience and at least 20 international publications.

For one thing, as universities have limited interaction with industry, programmes do not follow the latest advances in the business world. Some high-tech sectors no longer exist, including electronics and a number of military-related enterprises in the machine-building industry. Demand for degrees in some technical disciplines has declined, especially in industry, after graduates were unable to find a job suited to their qualifications.

With the exception of agriculture, health care and services, the share of graduates in natural sciences has shrunk by one-quarter and in technical sciences by more than one-fifth since the mid-2000s. The share of students studying humanities and the arts, on the other hand, has grown by 5% and, in social sciences, business and law by as much as 45%, according to the State Statistical Office.

Between 2001 and 2012, the number of students climbed from 1.5 million to 2.5 million. This expansion will be short-lived, however. With the country's overall population declining, the number of students will likewise decline in the coming years. Nor are there many foreign students in Ukraine, although several foreign universities have established campuses in Ukraine, including Moscow State Lomonosov University, while some foreign universities have established joint programmes with their Ukrainian counterparts. Graduates receive a dual diploma from both universities. Arguably the best-known twinning programmes concern the Kiev Polytechnic Institute and several German technical universities.

Next steps for Ukraine

The government formed in 2014 has developed a series of measures to address the following key issues in Ukrainian research policy:

- Establishment of research priorities which correspond to the goals of national development;
- A clear orientation of R&D towards respecting the best EU standards, with the intention of joining the European Research Area; and
- Administrative changes to improve the governance of the R&D system.

However, policy measures outlined in different strategic documents are much less concerned with identifying specific demands for knowledge and especially with providing strategic intelligence on structural changes in the economy. Moreover, rather limited measures have been envisaged to improve knowledge circulation, to meet business knowledge demands and to increase resource mobilization in the private sector.

Ukrainian research and innovation policy with respect to industry is almost exclusively focused on direct state support for the six national academies of sciences, state-owned companies and state universities. There is a noteworthy lack of co-ordination between research policy (focusing on the quality of academic research and the provision of skilled researchers) and economic development policies, owing to a fragmentation of the responsibilities of both the state ministries and agencies and the central and regional authorities.

Box 12.4: A first for Ukraine: the Key Laboratory

In April 2011, the State Agency for Science, Innovation and Informatization created the first so-called State Key Laboratory for Molecular and Cell Biology. The idea was to provide extra funding for research in molecular and cell biology in priority areas which required collaboration among researchers from different institutions.

Research projects were selected on the basis of the evaluation by an expert group, headed by the German Nobel Prize laureate Edwin Neher. Projects were then approved by the Scientific Council, which included several prominent scholars and state officials. This procedure was designed to minimize any 'external' influence on the decision-making process and was relatively new to Ukraine.

The institutional members of the Key Laboratory were the Institute of Physiology and the Institute of Molecular Biology and Genetics, both attached to the National Academy of Sciences. It fell to the Scientific Council of the Key Laboratory, however, to select research projects on a competitive basis from among the research proposals it received from scholars, irrespective of their institutional affiliation.

Project funding was provided by the State Fund for Basic Research. In addition to these 'standard block grants,' project teams were entitled to receive extra funding via the regular budgets of their own institutes, as long as these were attached to the National Academy of Sciences.

Two projects were selected for funding in 2011– 2012 and another two in 2013. A total of UAH 2 million (*circa* €190 000) was disbursed for the latter two projects in 2013.

Funding for the laboratory dried up in 2014, as a result of the economic crisis.

Source: compiled by authors

CONCLUSION

Countries can learn from one another and from emerging economies

Most Black Sea countries still have a long way to go to catch up to dynamic middle-income countries when it comes to the STI policy environment and levels of investment in human resources, R&D and ICT infrastructure. In global comparisons, they tend to fare better for output than for input, with the notable exception of Azerbaijan and Georgia, which seem to have particular difficulties in translating their modest R&D effort into economic gains. Georgia, for instance, has a relatively strong standing in some branches of humanities but these publications do not fuel R&D and technology-driven innovation.

Most countries can look back on a strong orientation towards science and technology in their education systems and economic structures of the not too distant past. Some vestiges of this period still survive in the post-Soviet states, such as the high prevalence of graduates with technical qualifications or of publications in physical sciences and engineering. With the right sort of policies and incentives, the reorientation of these countries towards technology-intensive development would be a much less challenging prospect than for those developing countries which are still in the process of shedding their traditional agrarian socio-economic structures.

In order to make the transition to an innovation-driven economy, all the post-Soviet states situated in the Black Sea region will have no choice but to engage in fundamental reforms, including a steep increase in R&D funding. Moreover, if they are to intensify their R&D effort to any significant extent, the business sector will need stronger incentives to invest in R&D. These incentives will need to create a business-friendly environment that is conducive to a thriving market economy, not least by fighting corruption and eliminating oligarchic ownership and control structures. No traditional STI policy initiative can expect to have a decisive impact on private sector R&D if the business environment remains largely hostile to the emergence of new enterprises and market-based challenges to existing power relations.

In the case of Turkey, which has already accomplished substantial progress in the past decade for a wide range of STI indicators – be they educational attainment, researcher and R&D intensity or the number of patents – priority issues have more to do with improving co-ordination and collaboration among the various actors of the national innovation system, in addition to strengthening accountability and improving efficiency. In parallel, the targets fixed by the government for further quantitative growth translate a worthy ambition, even if some targets may be overoptimistic.

For all countries, making the various components of the national innovation landscape work as a system, rather than as disjointed parts, while maintaining sufficient flexibility remains a challenge. It is evident that Azerbaijan and Georgia, in particular, would benefit from a clearer focus on a national innovation strategy at the highest political level. As for Armenia, Belarus, Moldova and Ukraine, they would get more mileage out of their existing STI strategies by making a more determined effort to address shortcomings in the business environment.

All seven countries would benefit from a stronger culture of evaluation in the area of STI policies, not least Turkey, which has raised its level of investment in R&D by so much in recent years. This would also help countries to establish and pursue more realistic goals and targets in this area.

All countries should also make a bigger effort to converge with global best practice for STI data availability, quality and timeliness; this is especially critical for Georgia and, to a lesser extent, for Armenia and Azerbaijan.

The countries around the Black Sea have an understandable tendency to look more or less exclusively to the European Union or the Russian Federation, or to both, for partnerships in science and technology and international comparisons. It would be helpful for them to look beyond this geographical sphere, in order to get a better grasp of how S&T-related policies and performance are evolving in other emerging market economies and developing countries, some of which are becoming key international players or policy innovators. Countries around the Black Sea should also look closer to home when it comes to seizing opportunities for scientific co-operation and learning from one another's successes and failures. The present chapter has striven to point them in that direction.

KEY TARGETS FOR BLACK SEA COUNTRIES

- Azerbaijan is to double GDP per capita to US$13 000 by 2020;
- All educational institutions in Azerbaijan are to have internet access and free open education resources are to be developed by 2020;
- Belarus is to increase its GERD/GDP ratio to 2.5–2.9% of GDP by 2015, up from 0.7% in 2011;
- Turkey is to increase its GERD/GDP ratio to 3.0% of GDP by 2023, up from 0.9% in 2011;
- Industrial GERD in Turkey is to rise from 43.2% of total spending on R&D in 2011 to 60.0% by 2018;
- The number of Turkish FTE researchers is to more than double from 72 000 (2012) to 176 000 (2018).

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Boosting support for university research has become one of the most important strategic orientations of STI and education policies in the Russian Federation.

Leonid Gokhberg and **Tatiana Kuznetsova**

A Soyuz rocket taking off in Kazakhstan and heading for the International Space Station

Photo: © Vasily Smirnov / Shutterstock.com

13 · Russian Federation

Leonid Gokhberg and Tatiana Kuznetsova

INTRODUCTION

The end of long-term resource-led growth

The Russian Federation faces a variety of challenges in securing adequate investment in new knowledge and technologies and deriving socio-economic benefit from them. The *UNESCO Science Report* 2010 had observed that the global financial crisis of 2008 and the ensuing stagnation were exacerbating domestic weaknesses, such as the limited market competition and persistent barriers to entrepreneurship which were hampering the growth of the Russian economy. Despite some reforms since, these challenges have intensified since mid-2014.

The rapid growth of the Russian economy since the turn of the century had been largely fuelled by oil, natural gas and other primary products. Oil and gas alone account for more than two-thirds of exports and 16% of GDP. High oil prices have helped to improve the standard of living and accumulate large financial reserves. The growth rate slowed, however, in the aftermath of the global crisis in 2008, particularly after 2012 (Table 13.1). It has deteriorated further since mid-2014, driven by a vertiginous drop in global oil prices between June and December 2014, combined with the economic, financial and political sanctions imposed on the Russian Federation by the European Union (EU), USA and several other countries in response to events in Ukraine. This has fostered inflation and currency depreciation while curbing consumer spending. Capital outflows have become a major concern: the latest estimates are for outflows of US$ 110 billion in 2015. Growth stalled altogether in 2014 and the government predicts that GDP will contract by 2.5% in 2015 before a return to positive growth of 2.8% in 2016.

The government has been obliged to cut back on spending and to use accumulated reserves to prop up the economy, in accordance with its anti-crisis plan adopted in January 2015.[1] The difficult economic and geopolitical situation has also prompted the government to implement vital structural and institutional reforms to revitalize and diversify the economy. As early as September 2014, Prime Minister Dmitry Medvedev cautioned against the risk of reacting to the sanctions with measures that would reduce competition or stoke protectionism (Tass, 2014).

The growing urgency of innovation-led growth

Paradoxically, the rapid economic growth fuelled by the commodities boom between 2000 and 2008 actually weakened the motivation of enterprises to modernize and innovate. In the sphere of science, technology and innovation (STI), this manifested itself in a boom in imports of advanced technologies and a growing technological dependence on developed countries in certain areas, such as in pharmaceuticals and high-tech medical equipment.

In the past few years, the government has sought to reverse this trend by encouraging companies, public research institutes and universities to innovate. Some 60 state-owned companies were obliged to implement special programmes to boost innovation. As a result, their investment in R&D doubled between 2010 and 2014, rising from 1.59% to 2.02% of sales, on average. The share of innovative products in the total sales of state-owned companies consequently rose from 15.4% to 27.1%. Exports of innovative products also progressed, particularly in the aircraft industry, shipbuilding and chemicals, according to the Ministry

1. See: http://www.rg.ru/2015/01/28/plan-antikrizis-site.html

Table 13.1: **Economic indicators for the Russian Federation, 2008–2013**

Percentage change over previous year, unless otherwise stated

	2000–2007*	2008	2009	2010	2011	2012	2013
GDP	7.2	5.2	-7.8	4.5	4.3	3.4	1.3
Consumer price index	14.0	13.3	8.8	8.8	6.1	6.6	6.5
Industrial production index	6.2	0.6	-10.7	7.3	5.0	3.4	0.4
Capital investment	14.0	9.5	-13.5	6.3	10.8	6.8	0.8
Exports	21.0	34.6	-36.3	32.1	31.3	2.3	-0.8
Imports	24.2	29.4	-36.3	33.6	29.7	5.4	1.7
Consolidated public sector balance (% of GDP)	–	4.8	-6.3	-3.4	1.5	0.4	1.3
Public external debt (% of GDP)	–	2.1	2.9	2.6	2.1	2.5	2.7

*annual average growth rate

Source: Rosstat (2014); *Ministry of Finance (2014) Execution of the federal budget and budget system of the Russian Federation*. Moscow.

of Economic Development and Trade. Central to the national strategy was the decision to enlarge the government's arsenal of competitive research funding for leading federal and national research universities. Public institutes and universities also received grants to commercialize new technologies and create small innovative firms (start-ups). In parallel, the government introduced schemes to foster academic mobility and expose scientists and engineers to the best training that money could buy. For instance, public research institutes and universities received grants to enable them to invite top Russian and foreign professionals to work on their campuses.

A need for a new economy

The present conjuncture makes it difficult to tackle the domestic weaknesses outlined in the *UNESCO Science Report 2010*. These include inadequate intellectual property protection, the obsolete institutional structure of the R&D sector, the lack of autonomy of universities and the relatively weak infrastructure for research and innovation. These chronic weaknesses augment the risk of the Russian Federation falling further behind the leading countries in global development. It is this concern which has made national policy-makers particularly keen to galvanize STI-led recovery and development. Since 2010, the Russian authorities have adopted no fewer than 40 documents to regulate STI, including in the form of presidential decrees.

As early as 2012, President Putin acknowledged the need for a new economy. 'It is not acceptable for Russia to have an economy that guarantees neither stability, nor sovereignty, nor decent welfare,' he said. 'We need to create an effective mechanism to rebuild the economy and find and attract the necessary...material and human resources' (Putin, 2012). More recently, he called for a widening of import-substitution programmes in May 2014, during a presentation to the St Petersburg International Economic Forum. 'Russia needs a real technological revolution,' he said, 'serious technological renewal, the most extensive in the last half-century, massive re-equipping of our enterprises'.

In 2014 and 2015, action plans were launched in various industrial sectors, in order to produce cutting-edge technologies and reduce dependence on imports. Target products include high-tech machine tools, equipment for the oil and gas sectors, power engineering machinery, electronics, pharmaceuticals, chemicals and medical instruments. The federal Law on Industrial Policy adopted in 2014 provides a comprehensive package of supportive measures for companies, including investment contracts, R&D subsidies, preferential public procurement of the technologies produced, standardization, the creation of industrial parks and clusters and so on. A Fund for Industrial Development was established the same year to support highly promising investment projects initiated by companies.

The reforms implemented include a serious 'rationale' for partnerships with foreign countries, such as with the fellow BRICS countries – Brazil, India, China and South Africa – as well as other rapidly developing nations. At the sixth BRICS summit in Brazil in 2014, the five partners established a New Development Bank, to be hosted by China, and a Contingency Reserve Agreement (CRA) to provide them with alternatives to the World Bank and International Monetary Fund in times of economic hardship, protect their national economies and strengthen their global position. The Russian Federation is contributing US$ 18 billion to the CRA, which will be credited by the five partners with a total of over US$ 100 billion. The CRA is already operational. Currently, work is under way to develop financing mechanisms for innovative projects with the new bank's resources.

The Russian Federation is also developing co-operation with Asian partners within the Shanghai Cooperation Organisation and the Eurasian Economic Union; the latter was launched on 1 January 2015 with Belarus and Kazakhstan and has since been extended to Armenia and Kyrgyzstan. Just a day after hosting a BRICS summit in the eastern city of Ufa in July 2015, the Russian Federation hosted a summit of the Shanghai Cooperation Organisation in the same city, at which the admission of India and Pakistan was announced.[2]

A new framework for innovation policy

In May 2012, the president approved several decrees proposing directives for STI development. These decrees fix qualitative objectives that are to be measured against quantitative targets to 2018 (Table 13.2). Although the potential for developing STI is relatively high, this potential is held back by weaknesses in private investment, low scientific productivity and incomplete institutional reforms. A fundamental lack of receptiveness to innovation and poor demand from many firms and organizations for scientific achievements and new technologies still hampers progress in this area. All stakeholders in the Russian innovation system, including economic actors, feel an urgent need for institutional change and more effective implementation of government policies. There are other bottlenecks too, which, if not overcome, could condemn state initiatives to being no more than a flash in the pan.

Since 2011, a number of policy documents[2] have identified the principal orientations of national policies for science and technology, as well as related implementation mechanisms. A wider format for promoting STI in Russia was provided by the report entitled *Strategy – 2020: a New Framework for Innovation Policy*. It was drafted by leading Russian and international experts. Some of the ideas put forward in the report have since been transformed into official documents and are outlined below (Gokhberg and Kuznetsova, 2011a).

2. including the *Presidential Decree on the Approval of the Priority Areas for the Development of Science and Technology and the List of Critical Technologies* (2011), the *Strategy for Innovative Development to 2020* (2012), the *State Programme for Development of Science and Technology*, 2013–2020 and the Federal Goal-oriented Programme on Research and Development in Priority Areas of Russia's Science and Technology Complex (2012)

Table 13.2: **Objectives and quantitative targets to 2018 of the May 2012 presidential decrees in the Russian Federation**

Decree	Objectives	Quantitative targets to 2018
On long-term economic policy (No. 596)	To increase the pace and sustainability of economic growth and raise the real income of citizens	Labour productivity to grow by 150%
	To achieve technological leadership	Increase the share of high-tech industries in GDP by 130%
On measures to implement state social policy (No. 597)	To improve the conditions of employees in social sectors and science	Increase the average salary of researchers to double that of the average salary in the region
On measures to implement state policy in the field of education and science (No. 599)	To improve state policy in education and science and the training of qualified professionals to meet the requirements of the innovation economy To improve the efficiency and performance of the R&D sector	Increase total funding of public scientific foundations to 25 billion rubles Raise the GERD/GDP ratio to 1.77% (by 2015). Increase the share of GERD performed by universities to 11.4%. Boost Russia's world share of publications in the Web of Science to 2.44% (by 2015).

TRENDS IN R&D

R&D effort is primarily government-funded

Gross domestic expenditure on research and development (GERD) rose by about one-third at constant prices between 2003 and 2013. Federal budget allocations for civil R&D even tripled.[3] Nevertheless, R&D intensity remained relatively stable; in 2013, GERD accounted for 1.12% of GDP, compared to 1.15% in 2004 and 1.25% in 2009 (Figure 13.1). After rising steadily for years, state expenditure on R&D dropped slightly in 2010 as a consequence of the global financial crisis in 2008–2009 but has since recovered (Figure 13.1). The government fixed a target in 2012 of raising GERD to 1.77% of GDP by the end of 2015 (Table 3.2), which would bring it closer to the EU average: 1.92% in 2012. In absolute terms, government funding of R&D amounted to PPP$ 34.3 billion in 2013, on a par with that of Germany (PPP$ 32.1 billion) and Japan (PPP$ 35.0 billion) [HSE, 2015a].

The low share of industry-financed R&D is a perennial concern. Despite government efforts, the contribution of industry to GERD actually fell from 32.9% to 28.2% between 2000 and 2013 (Figure 13.1). This sector, which encompasses privately and publicly owned companies and large-scale industrial R&D institutes, nevertheless performs the bulk of GERD: 60% in 2013, compared to 32% for the government sector, 9% for higher education and just 0.1% for the private non-profit sector (HSE, 2015a).

The low propensity of companies to finance research is reflected in the modest place occupied by R&D in total expenditure on innovation: 20.4% overall in industry; 35.7% in high-tech sectors. On average, significantly less is spent on R&D than on the acquisition of machinery and equipment (59.1%). In EU countries, the situation is diametrically the opposite; in Sweden, the ratio is even 5:1 and, in Austria and France, about 4:1. In Russian industry, a low proportion of investment goes on acquiring new technologies (0.7%), including patent rights and licenses (0.3%). This phenomenon is characteristic of all types of economic activity and limits both the country's technological potential and its capacity to produce groundbreaking inventions (HSE, 2014b, 2015b). Normally, the generation of new knowledge and technologies would be expected to be driven by technology-based start-ups and fast-growing innovative companies, including small and medium-sized enterprises (SMEs). However, this type of company is still uncommon in the Russian Federation.

Lesser priorities: basic research and green growth

Figure 13.1 depicts a growing orientation of R&D towards the needs of industry since 2008 and a drop in non-targeted (basic) research, referred to in official statistics as the general advancement of research. The share of R&D allocated to societal issues has risen somewhat but remains modest. The thin slice of the pie directly devoted to environmental issues has shrunk further and that for energy-related research has stagnated; this is disappointing, given the growing interest globally in environmentally sustainable technologies. It also comes somewhat as a surprise, since the government has adopted a number of policies in recent years as part of an action plan for sustainable green growth that is aligned with the *Green Growth Strategy* of the Organisation for Economic Co-operation and Development (OECD, 2011).

3. The relative figures in current prices are 4.4 and 10 times.

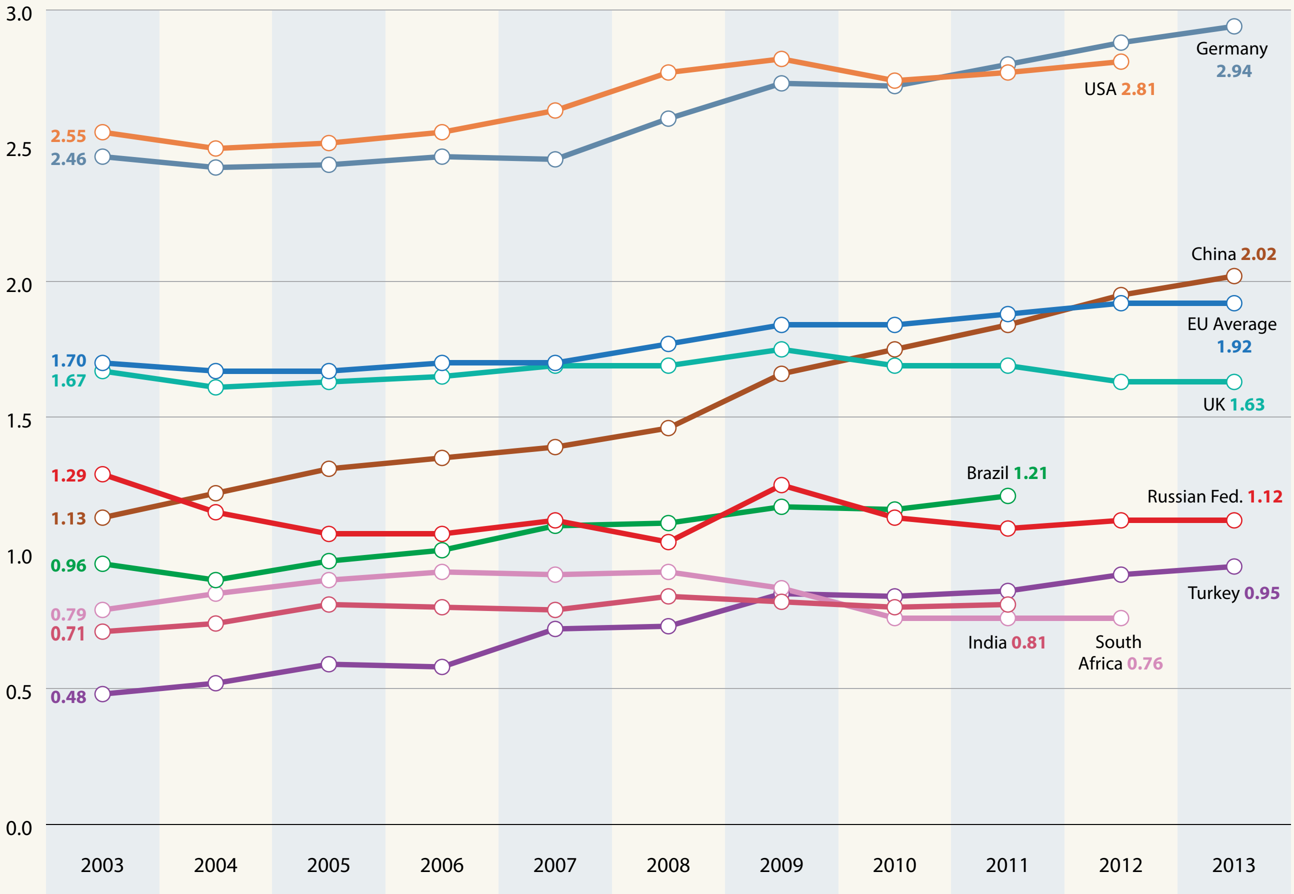
Figure 13.1: **Trends in GERD in the Russian Federation, 2003–2013**

1.29%
Russian GERD/GDP ratio in 2003

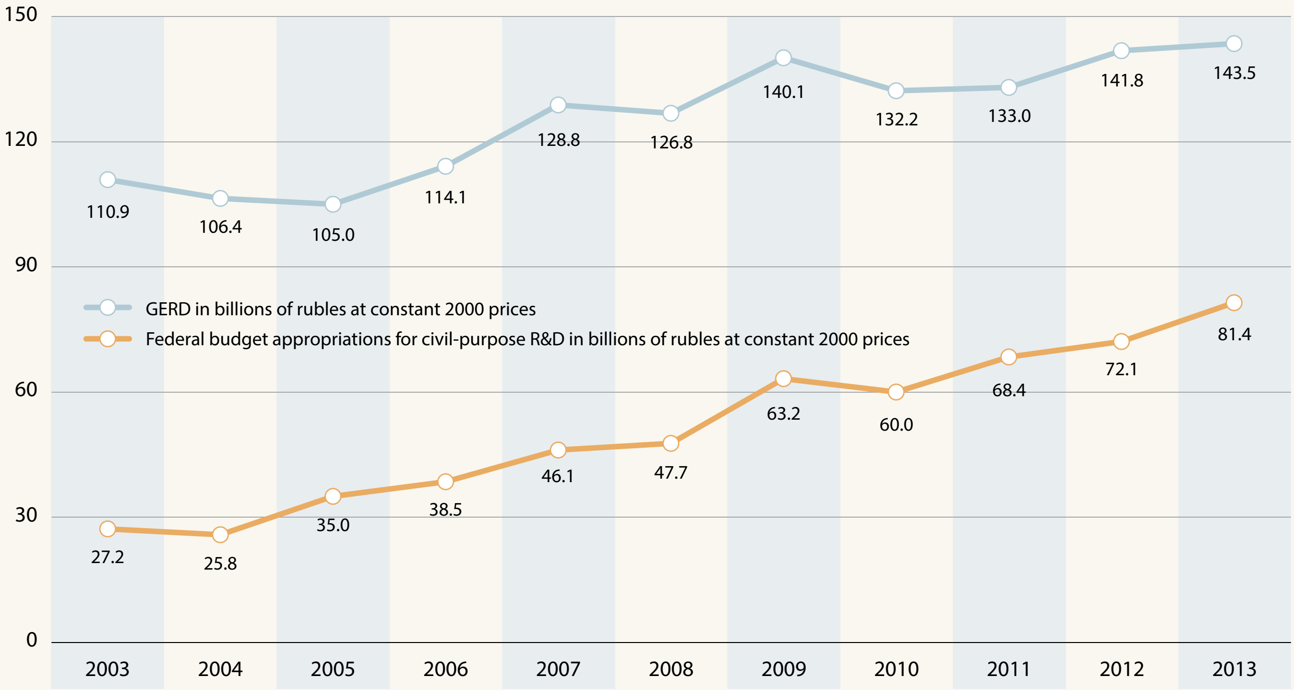
1.12%
Russian GERD/GDP ratio in 2013

The Russian Federation's R&D intensity has not progressed over the past decade

Other countries are given for comparison

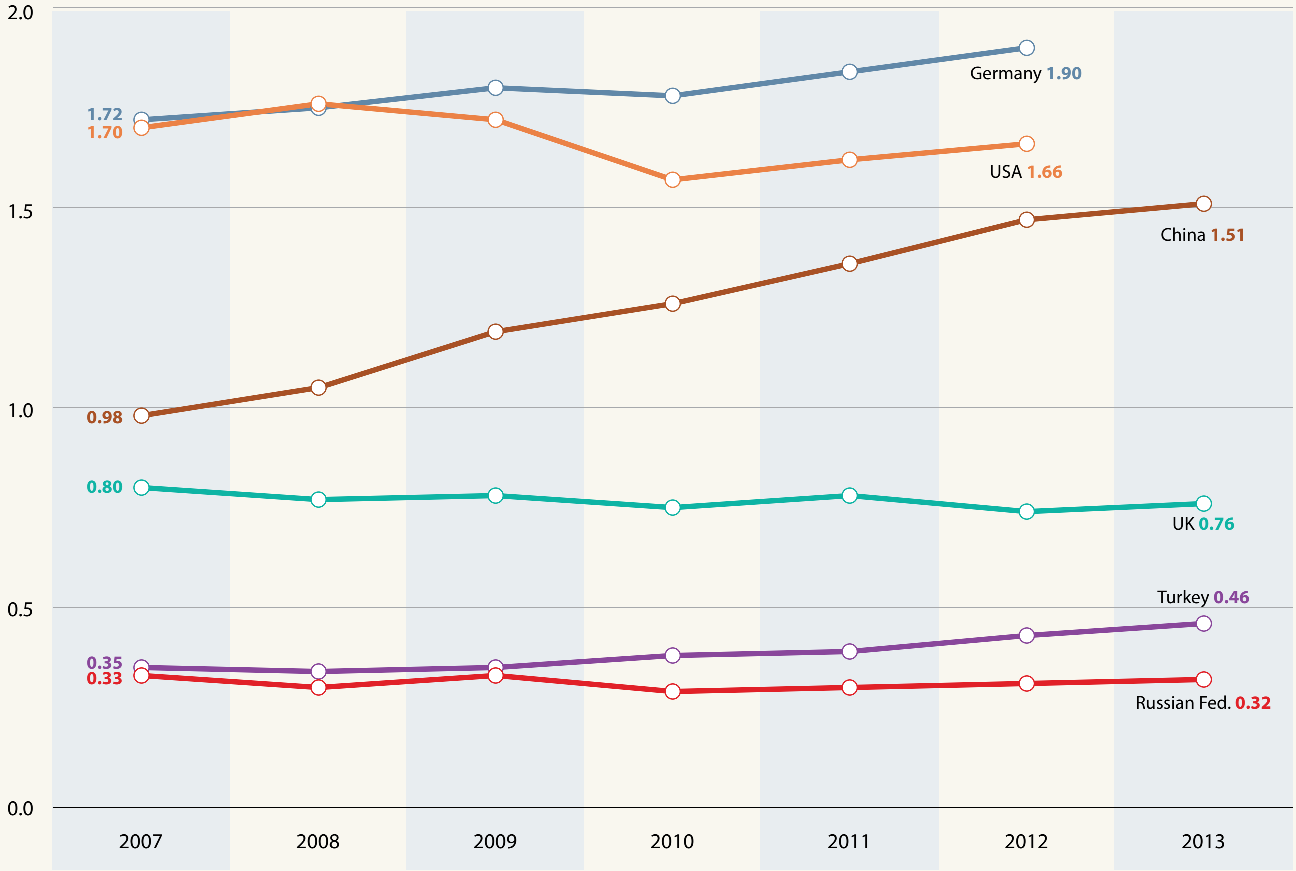


Federal budget allocations for civil-purpose R&D tripled between 2003 and 2013



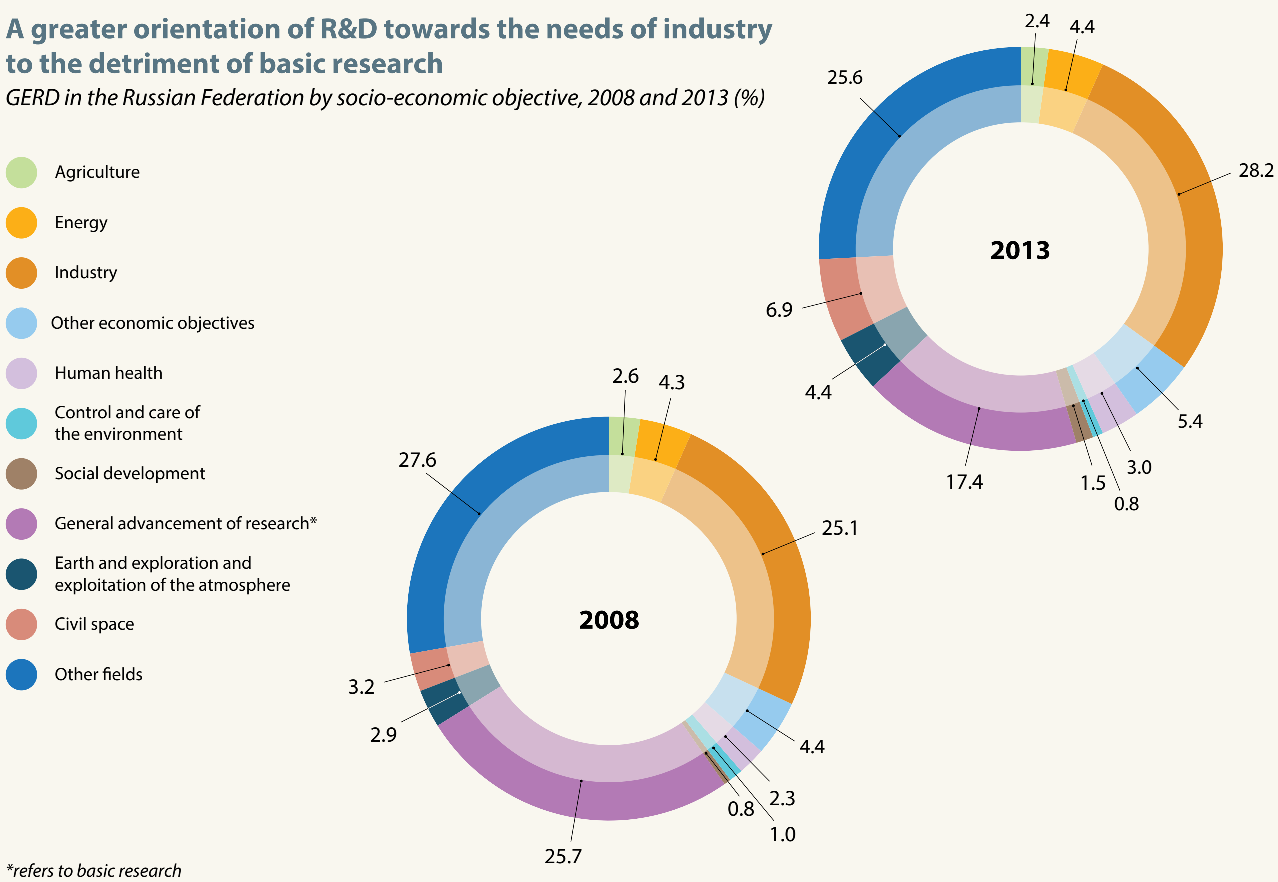
The low share of industry-financed R&D is a perennial concern

Share of GDP, other countries are given for comparison



A greater orientation of R&D towards the needs of industry to the detriment of basic research

GERD in the Russian Federation by socio-economic objective, 2008 and 2013 (%)



*refers to basic research

Source: HSE (2015a); OECD's Main Science and Technology Indicators, May 2015; for Brazil and India: UNESCO Institute for Statistics

In 2009, the government adopted *State Policy Priorities to Raise Energy Efficiency in the Electric Power Engineering Sector based on the Use of Renewable Energy Sources*, covering the period to 2020. In 2012, it adopted *Principles of the State Policy on the Ecological Development of the Russian Federation*, which is valid to 2030. The problem of green growth and social progress is addressed by four Russian technology platforms: Environmentally Clean Efficient Fuel; Technologies for Ecological Development; Biotech 2030; and Bio-energy. These platforms co-ordinate the activities of industrial companies, research centres and universities to promote R&D and technology in related areas. Collectively, these measures represent only the first leg of the journey towards sustainable growth, of course.

The modest investment so far in sustainable technologies can largely be explained by the business sector's tepid interest in green growth. Empirical data show that 60–90% of Russian companies do not use advanced general-purpose and resource-saving technologies, or alternative energy-generating technologies and have no plans to do so in the near future. Only one in four (26%) innovative enterprises are producing inventions in the environmental field. Even when companies do have recourse to environmentally friendly inventions like energy-saving technologies, this gives them virtually no competitive advantage in the domestic market. Most companies are focusing their efforts on reducing environmental pollution, in order to comply with government standards. Very few are engaged in waste recycling or in substituting raw and other materials for more environmentally friendly ones. For instance, only 17% of companies use environmental pollution control systems (HSE estimates; HSE, 2015b). This state of affairs prompted the government to adopt a series of regulations in 2012–2014 which encourage usage of the best available technologies for reducing environmental waste, saving energy and upgrading technologies through a series of positive incentives (such as tax exemptions, certification and standardization) and negative ones, such as fines for environmental damage or higher energy tariffs.

Scientific productivity is stagnating

Scientific output has stagnated in recent years (Figure 13.2). Moreover, the average citation rate for articles (0.51) is just half the G20 average. Russian scientists publish most in physics and chemistry, reflecting traditional strengths and a certain dependence on domestic research, even though one in three articles had a foreign co-author between 2008 and 2014.

Although patenting activity is relatively high and has grown by 12% since 2009 – residents filed 28 756 applications in 2013, ranking it sixth worldwide – the Russian Federation only ranks 20th worldwide for the number of applications per million inhabitants: 201. Moreover, 70% of patent applications submitted by domestic applicants contain only minor improvements to existing technologies. This suggests that the R&D sector is generally not yet ready to supply the business sector with competitive and cost-effective technologies for practical applications, or to guarantee support during the development stages of technology.

Innovation largely confined to domestic market

In the course of its transition to a market economy, the Russian Federation has become an attractive destination for foreign technologies. Between 2009 and 2013, the number of patent applications submitted in Russia by foreign applicants increased by 17% to 16 149 (HSE, 2015a; HSE, 2014b). Patent activity by Russian applicants grew more slowly. As a result, the coefficient of technological dependence increased: the ratio of foreign to domestic patent applications submitted in the Russian Federation went from 0.23 in 2000 to 0.56 in 2013. If we take into consideration the low patenting activity by Russian applicants abroad, this sends a negative signal to national policy-makers as to the competitiveness of domestic technologies in the global market.

Less than 3% of technology transfer occurs through exports. Intellectual property titles represent only roughly 3.8% of technology exports[4] and just 1.4% of companies engaged in R&D earn revenue from exports of technology. The latter generated just US$ 0.8 billion in 2013, virtually the same as in previous years, compared to US$ 2.6 billion for Canada, US$ 5.3 billion for the Republic of Korea and US$ 120.4 billion for the USA (HSE, 2015a). The Russian Federation's membership of the World Trade Organization since 2012 should help to boost technology transfer through exports and related revenue.

TRENDS IN HUMAN RESOURCES

Four in ten research personnel are support staff

Although the Russian Federation ranks 49th in the latest Global Innovation Index and 30th in the sub-index for human capital development (Cornell University *et al.*, 2014), international competition for talent is intensifying. The issue of developing skills and behavioural patterns in line with the country's development strategy has never been more pressing in the Russian Federation. Policies introduced in recent years have addressed this urgent question.

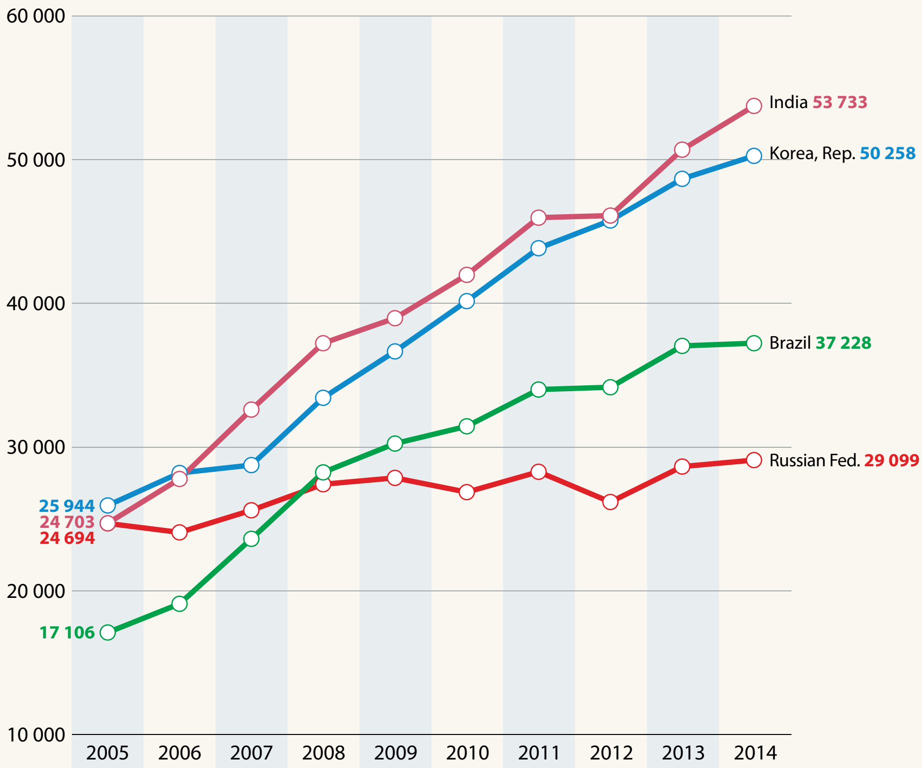
In 2013, there were 727 029 people engaged in R&D, a group encompassing researchers, technicians and support staff. Research personnel represented 1% of the labour force, or 0.5% of the total population. In absolute numbers, the Russian Federation figures among the world leaders for R&D personnel, coming only after the USA, Japan and China. However, there is an imbalance in the dynamics and structure of R&D personnel.

4. These official statistics are based on the balance of payments for technology.

Figure 13.2: **Scientific publication trends in the Russian Federation, 2005–2014**

Russian publications have grown fairly slowly since 2005

Selected large emerging market economies are given for comparison



Publications are making a small impact

0.51

Average citation rate for Russian scientific publications, 2008–2012; the G20 average is 1.02

3.8%

Share of Russian papers among 10% most cited papers, 2008–2012; the G20 average is 10.2%

33.0%

Share of Russian papers with foreign co-authors, 2008–2014; the G20 average is 24.6%

Russian scientists specialize in physics and chemistry

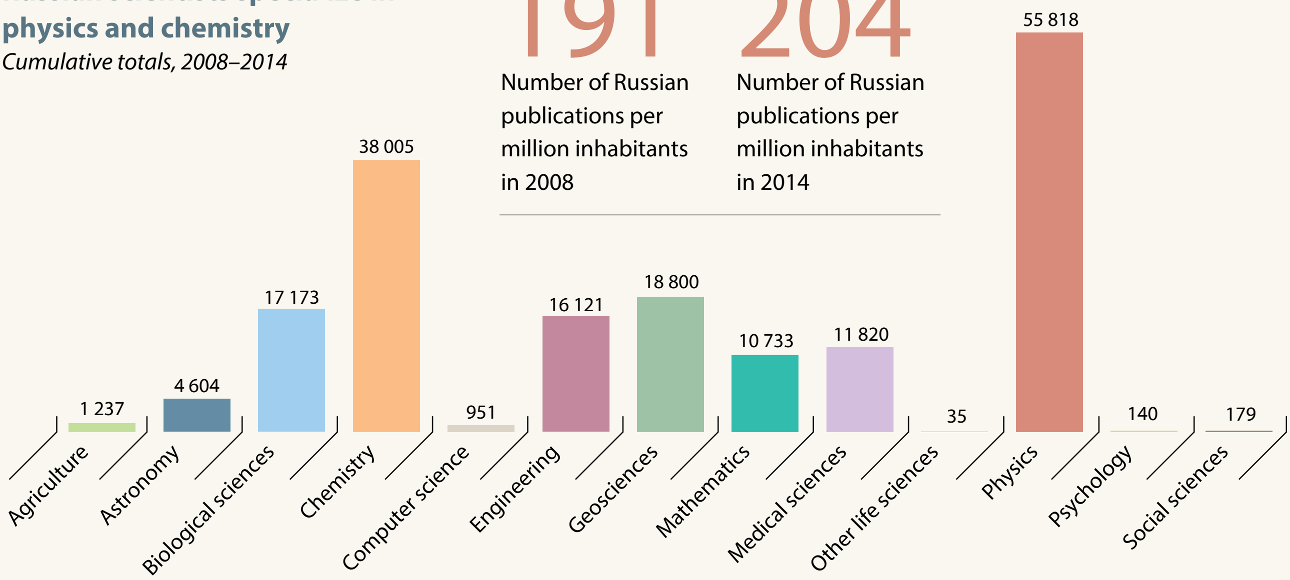
Cumulative totals, 2008–2014

191

Number of Russian publications per million inhabitants in 2008

204

Number of Russian publications per million inhabitants in 2014



Note A further 18 748 publications are unclassified.

Germany and the USA are the Russian Federation's principal partners

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Russian Fed.	Germany (17 797)	USA (17 189)	France (10 475)	UK (8 575)	Italy (6 888)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

Researchers (by head count) account for little more than half of R&D personnel (369 015) and support staff 41%, compared to just 8.4% for technicians. The large share of support staff can be explained by the dominance of R&D institutes, which have traditionally tended to function in isolation from both universities and enterprises and required labour-intensive services to maintain the premises and manage the institution's finances. The Russian Federation ranks 21st globally for the number of people engaged in R&D per 10 000 employees but 29th for the number of researchers. Over two-thirds of R&D personnel are employed by state-owned organizations (HSE, 2015a).

In the *UNESCO Science Report 2010*, we observed a worrying inversion of the age pyramid in the research population.[5] Between 2010 and 2013, there were some signs of improvement. The proportion of researchers under the age of 40 rose to more than 40% and has since stabilized at this level. This trend reflects absolute growth in two age groups: scientists under the age of 30 and those aged between 30 and 39 years. After a long period of growth, the share of researchers over the age of 60 has at last stabilized in recent years at roughly 25% of the total (HSE, 2015a).

A hike in researchers' salaries to spur productivity

In 2012–2013, several roadmaps were adopted to improve the attractiveness of careers in research, in order to stimulate productivity, redress the age pyramid and give research a greater economic impact. These documents introduced a new remuneration system primarily for researchers employed by public research institutes and universities. The corresponding target indicators were established by the Presidential Decree on Measures to Implement State Social Policy (2012). As for the implementation schedule, it is controlled by the government.

The action plan fixes the target of raising researchers' salaries to at least 200% of the average wage in the region where the researcher is based by 2018. There are also similar plans to raise the salaries of teachers in universities and other institutions offering higher education programmes. Currently, research institutes and universities receive annual subsidies from the federal budget to enable them to increase salaries, as happens also for secondary schools, hospitals and agencies managing social security. The average salary of researchers tends to be rather high in Russian research hubs like the Moscow region,[6] thereby contributing to the unequal distribution of R&D potential across the country. Reaching the aforementioned target in these research hubs may turn out to be problematic, as raising salaries that are already fairly generous will mean allocating substantial additional funding to R&D. Whatever their status, all regions may find it hard to reach the '200%' target, on account of budget shortfalls and the slowdown in the pace at which institutional reform is being implemented in the R&D sector. Of note is that (Gerschman and Kuznetsova, 2013):

> *In order to prevent the rise in researchers' salaries from becoming a goal in itself without any strong connection to their performance and the socio-economic impact of their work, the action plan also introduces performance-related pay mechanisms, implying that researchers will be regularly evaluated on their productivity.*

One in four adults holds a university degree

Russia has long had a relatively high level of education. In recent years, interest in pursuing higher education has not waned. On the contrary, a Russian could expect to spend 15.7 years in the education system in 2013, up from 13.9 years in 2000. According to the 2010 population census, more than 27 million people over the age of 15 years hold university degrees, up from 19 million in 2002. This represents about 23% of the adult population, compared to 16% in 2002. In the 20–29-year age group, the percentage is as high as 28%, although this is down from 32% in 2002. At 55%, the overall proportion of the population with some form of tertiary education – including those with non-degree qualifications – is well above that of any member of the Organisation for Economic Co-operation and Development (OECD). Moreover, the number of people enrolled in higher education per 1 000 inhabitants has risen sharply in the past decade from 162 in 2002 to 234 in 2010.

The rise in student rolls can partly be attributed to the hike in government spending on education in recent years (Figure 13.3). Federal expenditure on higher education has remained stable at about 0.7% of GDP and 3.7% of overall federal budget appropriations but public expenditure on education as a whole has climbed to 4.3% of GDP, or 11.4% of the consolidated budget (federal and regional levels). This has enabled spending per tertiary student to double since 2005 (HSE, 2014a, 2014d).

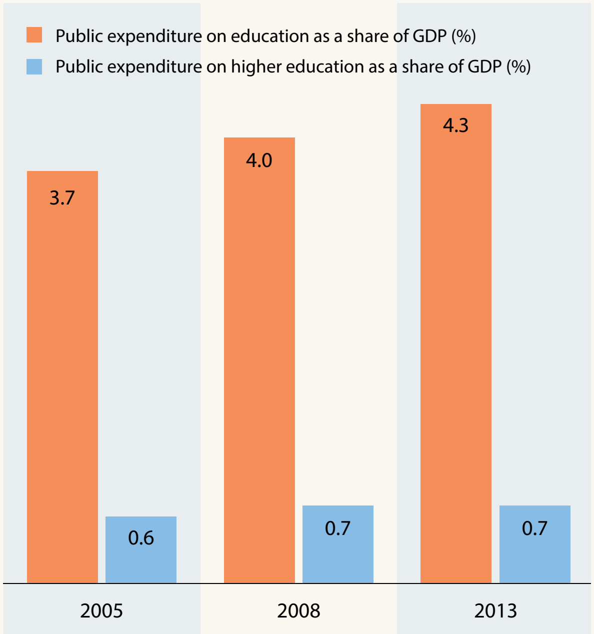
Training scientists becoming a core mission of research universities

As of the 2013/2014 academic year, 5.6 million students were enrolled in the country's tertiary institutions, 84% of which were state-owned: 2.8% of students were studying natural sciences, physics and mathematics; more than 20% engineering; 31% economics and management; and a further 20% humanities.

5. Between 2002 and 2008, there was absolute growth in the number of researchers aged 70 years and above. Simultaneously, the ranks thinned for such creative age groups as 40–49 year-olds (down by nearly 58%) and 50–59 year-olds (down by 13%). In 2008, researchers were 49 years old, on average, compared to 40 years old for those working in the national economy as a whole.

6. Roughly 60% of Russian researchers work in Moscow, the Moscow Region and St Petersburg. Six other regions together account for a further 20% of researchers: Nizhny Novgorod, Ekaterinburg, Novosibirsk, Rostov, Tyumen and Krasnodar.

Figure 13.3: **Public expenditure on education in the Russian Federation 2005, 2008 and 2013**



Source: HSE (2014a, 2014d)

Postgraduate programmes that confer a Candidate of Science degree (equivalent to a PhD) lead to the highest scientific degree, the Doctor of Science. In 2013, some 1 557 institutions offered postgraduate programmes in science and engineering, almost half of which (724) were universities and other tertiary institutions and the remainder research institutes. Some 38% of these institutions (585) also hosted doctoral courses, including 398 universities. Women made up just under half (48%) of the 132 002 postgraduate and 4 572 doctoral students in science and engineering. Most of the postgraduates (89%) and Doctor of Science candidates (94%) specializing in scientific disciplines are on the university payroll. The dominance of universities in postgraduate training is nothing new but the share of postgraduate students trained by research institutes was nearly three times higher in the early 1990s (36.4% in 1991) than today. This means that the education of highly qualified scientists is increasingly becoming a core mission of Russian universities. Engineering, economics, law, medicine and pedagogy are the preferred broad disciplines for postgraduate study.

Boosting university research a top priority

The higher education sector has a long-standing research tradition that dates back to the Soviet Union. About seven out of ten universities perform R&D today, compared to half in 1995 and four out of ten in 2000, as noted in the *UNESCO Science Report 2010*. However, universities still occupy a fairly lowly position when it comes to the generation of new knowledge: in 2013, they performed just 9% of GERD. Although this is up from 7% in 2009 and on a par with China (8%), it remains less than in either the USA (14%) or Germany (18%). Although university staff are still insufficiently engaged in R&D, the situation has improved in recent years: the proportion of professors and teaching staff conducting research rose from 19% to 23% between 2010 and 2013 (HSE, 2014a, 2015a).

Boosting support for university research has become one of the most important strategic orientations of STI and education policies in the Russian Federation. This process has been under way for almost a decade. One of the first steps was the National Priority Project for Education, initiated in 2006. Over the next two years, 57 higher education institutions received competitive grants from the federal budget for the purposes of implementing innovative educational programmes and high-quality research projects, or acquiring research equipment.

Between 2008 and 2010, 29 institutions received the coveted label of national research university. The aim is to turn these 29 national research universities into centres of excellence. In parallel, eight federal universities are being turned into 'umbrella' institutions for regional education systems. This status entitles them to large-scale government support but there are strings attached – in return, they are expected to produce high-quality research, education and innovation.

Currently, the magnitude of support given to higher education and its main orientations are determined by the Presidential Decree on Measures to Implement State Policy in the Field of Education and Science (2012) and the State Programme for the Development of Education[7] (2013–2020). The presidential decree anticipates that universities will be performing 11.4% of GERD by 2015 and 13.5% by 2018 (Table 13.2). Moreover, the level of engagement of university staff in R&D has become a major criterion for proficiency testing and professional advancement.

TRENDS IN STI GOVERNANCE

Higher education must adapt to economic needs

Despite undeniable success in boosting university research in recent years, one urgent problem remains: the discrepancy between the structure and quality of professional training, on the one hand, and current economic needs, on the other (Gokhberg *et al*., 2011; Kuznetsova, 2013). This is reflected not only in the composition of educational programmes, graduate specializations and diplomas but also in the relatively small scale and low level of applied research, experimental development and innovation performed by universities.

7. This programme provides schools, colleges and universities with full-scale financing for equipment procurement, offers subsidies to the best secondary schools and technical colleges, finances advanced teachers' training, etc.

In recent years, one of the most important steps towards modernizing higher education has been the adoption of the Federal Law on Education in 2012; it outlined the contours of a modern system respectful of international practices and standards, new developments in educational programmes and technologies, as well as new teaching methods and approaches to conducting experimental development and innovation.

Aligning degrees with the Bologna Process

In accordance with the *Bologna Declaration* (1999), which launched the process of developing a European Higher Education Area, the various echelons of the Russian higher education system have been aligned with the International Standard Classification of Education to give:

- at the undergraduate level, the bachelor's degree;
- at the postgraduate level, specialist training leading to a diploma or a master's degree;
- postgraduate study for academic staff leading to a Candidate of Science degree, equivalent to a PhD.

New legislation has raised the standards for a PhD and made the process more transparent. University consortia and networking have been introduced into educational curricula and universities have been given the right to set up small innovative firms to commercialize their intellectual property. Students may also apply for scholarships or earmarked loans to cover the costs of their education.

New funding mechanisms to boost training and research

The 5/100 Programme was adopted[8] in 2013 to raise the global competitiveness of Russian universities to the point where five of them figure in the top 100 (hence the programme's name) and the remainder in the top 200 of global university rankings. In 2013–2015, 15 leading universities[9] were selected on a competitive basis to receive earmarked subsidies to help raise their global competitiveness in both science and education. To this end, a total of over 10 billion rubles (RUB, *circa* US$ 175 million) were earmarked for 2013–2014 and RUB 40 billion for 2014–2016. The selection criteria included the university's publication output, international research collaboration, academic mobility and the quality of strategic programmes. These 15 universities are subject to a performance evaluation each year.

The Presidential Programme for Advanced Training of Engineers was launched in 2012. It offers training programmes and internships in leading research and engineering centres at home and abroad, with a focus on strategic industries. Between 2012 and 2014, the programme enabled 16 600 engineers to obtain higher qualifications and 2 100 to train abroad; the programme involved 96 tertiary institutions located in 47 regions. The 'customers' of this programme were 1 361 industrial companies which seized this opportunity to develop their long-term partnerships with tertiary institutions.[10]

The Russian Science Foundation[11] is a non-profit organization set up in 2013 to expand the spectrum of competitive funding mechanisms for research in Russia. The foundation received RUB 48 billion in state funding for 2013–2016. R&D-performing institutions may apply for grants to fund their large-scale projects in basic or applied research. To obtain a regular grant, applicants must include young scientists in their project team and guarantee that at least 25% of the grant will be spent on the salaries of young researchers. In 2015, the Russian Science Foundation launched a special grants programme to support postdocs and introduced short- to medium-term internships to increase academic mobility (Schiermeier, 2015). A total of 1 100 projects received funding in 2014, one-third of which were in life sciences. Among the thematic priorities announced for the next call for proposals in 2015 are: new approaches to identifying the mechanisms behind infectious diseases, advanced industrial biotechnologies, neurotechnologies and neurocognitive research.

In recent years, the government has augmented its arsenal for stimulating research funding. A special government programme has been offering 'megagrants' to universities and research centres since 2010 to help them attract leading scientists. So far, the programme has seduced 144 world-class researchers, half of them foreigners, including several Nobel laureates. All the invitees have been selected to lead new laboratories with a total staff of more than 4 000 scientists at 50 top Russian universities; this has led to the publication of 1 825 scientific papers, more than 800 of which have appeared in scientific journals indexed by the Web of Science. Just 5% of applications were submitted by women, which explains why only 4 of the 144 megagrants went to principal investigators who were women (Schiermeier, 2015). A total of RUB 27 billion in public funding has been allocated to the megagrants programme over 2010–2016, with recipient universities contributing about 20% of the budget.

In parallel, the government has increased funding for 'old' state foundations[12] which focus on basic research and humanities, as well as for innovative SMEs (Gokhberg *et al.,* 2011). It has

8. as one means of realizing the goals in the *Presidential Decree on Measures to Implement State Policy in the Field of Education and Science* (no. 599)

9. including St Petersburg Polytechnic, the Far-East Federal University and three national research universities: the Higher School of Economics; Moscow Institute of Physics and Technology; and Moscow Institute of Engineering and Physics

10. See: http://engineer-cadry.ru

11. not to be confused with the Russian Foundation for Basic Research, set up in 1993 to issue grants for basic research

12. The Russian Foundation for Basic Research, the Russian Foundation for Humanities and the Foundation for Assistance to Small Innovative Enterprises were all set up in the early 1990s.

also introduced grants to develop research networks and co-operation between universities and the national academies of science and industry, within the framework of the State Programme for the Development of Science and Technology for 2013–2020. Leading universities participating in this programme are expected to raise the share of their budget devoted to technology transfer from 18% to 25% between 2012 and 2020.

A Basic Research Programme has been designed for 2013–2020 to co-ordinate national efforts. It is part of the overarching State Programme for the Development of Science and Technology and contains specific provisions for selecting priorities in basic research and for an open public evaluation of scientific achievements. These provisions include the presentation of the programme's results in a freely accessible database and the mandatory publication of open-access articles on the internet.

Funding mechanisms to stimulate business R&D

Since 2010, the government has also introduced a number of schemes to stimulate innovation in the business sector. These include:

- programmes that make it mandatory for state-owned enterprises to develop innovation strategies and co-operate with universities, research institutes and small innovative businesses; to qualify for this programme, state-owned enterprises must raise their spending on R&D and actively produce innovative products, processes or services;
- a Federal Law on Public Procurement (2013) providing for the purchase of high-tech and innovative products by the state and promoting state procurement of goods and services from SMEs;
- state technology-oriented programmes supporting particular industrial sectors (aircraft, shipbuilding, electronics, pharmaceuticals, etc.) and overarching areas, such as biotechnology, composite materials, photonics, industrial design and engineering; and the
- Small and Medium-sized Enterprise Development Programme covering 2013–2020, which includes the distribution of federal budget subsidies to cofinance regional SME development, support local clusters of engineering and prototyping centres and provide credit guarantees through the national system of guarantor institutions, the core of which is the new Credit Guarantee Agency (est. 2014).[13]

In 2015, two schemes were announced to drive technological development. The first is the National Technology Initiative; it introduces a new long-term model for achieving technological leadership by creating novel technology-based markets, such as in non-piloted drones and automobiles for the industrial and services sectors, neurotechnological products, network-based solutions for customized food delivery and so on; technological projects will be coupled with support for the training of schoolchildren and students in these promising areas. The second scheme targets major traditional sectors and consists in funding a series of national technological projects with a high innovation component through public–private partnerships, with a focus on smart power engineering, agriculture, transport systems and health services, among other areas.

A key issue for businesses concerns how to demonstrate tangible results from their research. One possible mechanism would be for the state to allocate budgetary funds to businesses on the condition that expenses be cofinanced by interested companies and that effective partnerships be established between research institutes, universities and business enterprises (Gokhberg and Kuznetsova, 2011a; Kuznetsova *et al.*, 2014). It is also important to ensure co-ordination between government programmes targeting STI and programmes implemented by institutions oriented towards development, in order to build the so-called 'innovation lift' needed to carry novel technologies, products and services along the entire innovation chain from the initial idea to the market. It goes without saying that it would be vital to monitor the performance of these programmes in order to make timely adjustments.

Tackling the insufficient carry-over of patents into the economy

The national intellectual property market is still at the developmental stage, with research output taking years to impact the economy: only 2–3% of all current patents are in use and patenting tends to be done more intensively than licensing of intellectual property. This is a pity, as it is precisely during commercialization that the real competitive advantages emerge, such as income from the use of protected inventions and the accumulation of know-how. In the Russian Federation, however, the development of intellectual property is often disconnected from specific consumer needs and industrial demand.

Hence the need to improve the legislative framework for intellectual property. The main regulation in this area comes from Section VI of the Civil Code, which is specifically devoted to issues related to intellectual property and the enactment of legislation. New norms developed in this area over the period 2009–2014 include:

13. In 2015, it was renamed the Federal Corporation for the Development of Small and Medium Enterprises, a public company with 100% state ownership.

- assigning intellectual property rights generated by public research to the Russian Federation and establishing the principle of the free transfer of intellectual property from the public sector to industry and society, making it easier for research centres and universities to deal with licenses or other forms of commercialization of intellectual property;
- regulating the conditions, amount and procedures relative to the payment of fees to authors for the creation and commercialization of in-service research results and technologies; and
- establishing an exhaustive list of the conditions under which the state may obtain exclusive rights to the fruit of intellectual creativity.

An action plan adopted by the government in 2014 contains additional measures for protecting intellectual property rights at the 'pre-patent' stage and on the internet and introduces specialized patent courts, as well as better professional training in this area. Steps are also being taken gradually to improve the conditions under which R&D is capitalized upon, including by placing intellectual property on company balance sheets. This is particularly important for SMEs, as it allows them to increase their balance sheet value, for example, or to attract investment and use their exclusive rights as a pledge to obtain credits.

New tax incentives to foster innovation

All fiscal affairs have been governed by a single document since 2008, the Russian Tax Code. The most important amendments in recent years concern new rules for calculating R&D expenditure and classifying certain specific types of spending by organizations as R&D expenditure, along with new regulations concerning the creation of reserves for forthcoming expenditure.

New tax incentives have been introduced since 2011 in favour of innovative SMEs, start-ups and spin-off companies, in particular:

- Zero tax (for three years) on profits channelled into developing intellectual property; in parallel, taxes on transactions involving intellectual property have been removed;
- Benefits and extensions to patent duty payment deadlines are offered to SMEs, as well as to individual inventors (enterprises);
- Residents of the Skolkovo Innovation Centre have been given a 'tax holiday' for up to ten years (Box 13.1).

In the near future, there are plans to introduce tax incentives for individuals, such as business agents, inventors or entrepreneurs, who invest in projects developing innovation (or innovative companies) and for companies desirous to expand their intangible assets.

Box 13.1: **Skolkovo Innovation Centre: a temporary tax haven near Moscow**

The Skolkovo Innovation Centre is currently under construction in the city of Skolkovo, near Moscow. This high-tech business complex has been designed to attract innovative companies and nurture start-ups in five priority areas: energy efficiency and energy saving; nuclear technologies; space technologies; biomedicine; and strategic computer technologies and software.

The complex was announced by the president in November 2009. It consists mainly of a technological university and a technopark and is headed by Russian oligarch Viktor Vekselberg and co-chaired by former Intel head Craig Barrett. In order to woo potential residents, a bill according the residents of Skolkovo special legal, administrative and fiscal privileges was adopted by the State Duma (parliament) in September 2010.

The law granted residents substantial benefits for up to ten years, including exemption from income tax, value-added tax and property taxes, as well as reduced insurance premiums of 14% rather than the going rate of 34%.

The law also made provision for the establishment of the Skolkovo Fund to support development of the university and thereby give personnel the skills that companies need. One of the centre's biggest partners is the Massachusetts Institute of Technology in the USA.

Once corporations and individuals become 'residents' of the city, they are entitled to apply for grants from the fund. Residents also have access to the centre's legal and financial infrastructure. In 2010, the government published a decree granting highly skilled foreign nationals who secured employment at Skolkovo a three-year work visa.

The Skolkovo Innovation Centre is financed primarily from the Russian federal budget. Its budget has increased steadily since 2010 and amounted to RUB 17.3 billion in 2013. A brand new motorway has been built linking Skolkovo to Moscow.

Today, more than 1 000 companies from 40 Russian regions have set up shop in Skolkovo. In 2013, 35 agreements were signed with major global and domestic companies, including Cisco, Lukoil, Microsoft, Nokia, Rosatom and Siemens. Industrial partners plan to open 30 R&D centres in Skolkovo, which would create more than 3 000 jobs.

Source: compiled by authors

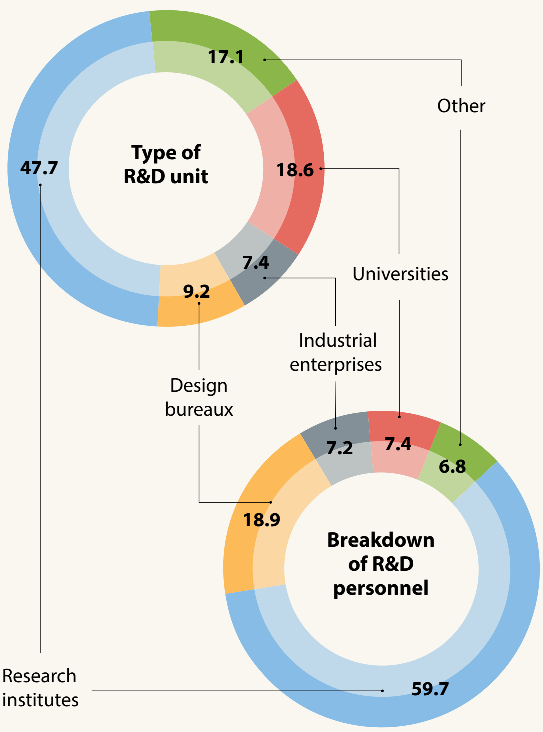
See also: http://economy.gov.ru/minec/press/interview/20141224

Restructuring to reinvigorate research

The institutional structure of the Russian R&D sector is not yet fully adapted to the market economy. As described in *The UNESCO Science Report 2010*, in the Soviet era, basic research was conducted predominantly by the research institutes of the state academies of science and major universities, whereas applied research and experimental development were concentrated mostly in branch institutions, design bureaux and specialized units of industrial enterprises. All R&D organizations were state-owned. Nowadays, most of the so-called industrial R&D in Russia is performed by large companies or legally independent research institutes. Industrial enterprises and design bureaux are mostly privately owned or semi-private organizations. This said, seven out of ten R&D-performing institutions are still state-owned, including universities and enterprises in which the government has a share of the capital. As already noted, small companies in the R&D sector are underrepresented, especially in comparison with other industrial nations (HSE, 2015a).

Unaffiliated research institutes and design bureaux tend to dominate institutions of higher education and enterprises when it comes to R&D: they represented 48% and 9% of all R&D units respectively and employed three-quarters of all R&D personnel in 2013 (Figure 13.4). Industrial enterprises account for just 7.4% of all R&D units, compared to 18% for institutions offering higher education (HSE, 2015a). The government's desire to optimize the institutional structure of research triggered a long-awaited reform of the state academies of science[14] in 2013 that will have far-reaching consequences for Russian science (Box 13.2).

Figure 13.4: **Breakdown of R&D units in the Russian Federation by type and personnel, 2013 (%)**



Source: HSE (2015a)

In parallel, the government is pursuing its plans to expand the network of state research centres (they now number 48) and to create a new network of large-scale national research centres. The first of these national research centres resulted, in 2009, from the subordination of three R&D institutes to the Kurchatov Research Centre, which specializes in nuclear energy and a broader spectrum of convergent[15] technologies. The second centre on a similar scale was established in the aircraft sector in 2014 by attaching several R&D institutes to the Central Aero-hydrodynamic Institute, renowned for aeronautic research. The Krylov Research Centre for Shipbuilding and the Research Institute for Aviation Materials are the next candidates on the list. To monitor the efficiency of national research infrastructure and identify avenues for targeted support, new arrangements were introduced in 2014 to assess the performance of public research institutions in the civil sector regularly.

Eight priority areas and critical technologies identified

The Russian Federation has an established system for identifying priorities so that resources can be distributed effectively to a limited number of fields, taking into account national objectives and both internal and external challenges. The current list encompasses eight priority areas and 27 critical technologies based on the results of a foresight exercise conducted in 2007–2010. This list was approved by the president in 2011. These research priorities have been chosen to address global challenges, ensure national competitiveness and promote innovation in key areas; they are being used to design governmental programmes for R&D and to streamline funding for other policy initiatives. Two of the eight priority areas concern defence and national security. The remaining six focus on civil-purpose science and technology; their share of total funding is broken down as follows:

- Transport systems and space (37.7%);
- Safe and efficient energy systems (15.6%);
- ICTs (12.2%);
- Environmental management (6.8%);
- Life sciences (6.0%); and
- Nanotechnology (3.8%).

14. Prior to the reform of 2013, there were six Russian academies: the Academies of Sciences; Medical Sciences; Agricultural Sciences; Education; the Arts; and Architecture and Construction Services.

15. such as bionanotechnology, neurobiology, bioinformatics, etc.

Box 13.2: **Reform of the Academy of Sciences**

The reform of the Russian Academy of Sciences had been debated for over a decade. Since the late 1990s, the academy had functioned as a quasi-ministry, managing federal property and overseeing the network of institutions which carried out the bulk of basic research in Russia. In 2013, the six academies comprising this sector accounted for 24% of the Russian Federation's research institutions, about one-fifth of R&D personnel, 36% of researchers and 43% of all researchers with Candidate and Doctor of Science degrees. They thus grouped a highly qualified labour force.

However, many of the institutions attached to the academy had developed a top-heavy age pyramid, with about one-third of researchers being over the age of 60 (34% in 2013), including about 14% over 70. The academies were also accused of low productivity – they received 20–25% of government research funding –and a lack of transparency. There was certainly a conflict of interest, in so far as some of those in charge of the academy and the distribution of resources among subsidiary institutes also happened to head these same institutes. Critics also reproached the academies for a lack of prioritization and weak ties to universities and industry.

The Russian Academies of Sciences, Agricultural Sciences and Medical Sciences attracted the most criticism, as they grouped about 96% of the research institutes placed under the academies, 99% of the academies' funding and 98% of their researchers in 2013. A series of 'soft' reforms in recent years had ironed out some problems, such as the introduction of rotation for managerial posts, greater internal mobility, a mandatory retirement age and teaching requirements and the expansion of competitive grants.

In September 2013, the government's long-awaited reform got under way with the adoption of a law stipulating the merger of the Russian Academy of Sciences with the two smaller academies for medical and agricultural sciences. The Russian Academy of Sciences was entitled to keep its name. A month later, the government passed a law establishing the Federal Agency for Research Organizations, with direct reporting lines to the government.

These two laws served the immediate objective of establishing a system with two nodes of power divided between the Russian Academy of Sciences, on the one hand, and the Federal Agency for Research Organizations, on the other. The functions of co-ordinating basic research, evaluating research results across the entire public research sector and providing expert advice remain the preserve of the Russian Academy of Sciences, whereas the management of the academy's finances, property and infrastructure now falls to the Federal Agency for Research Organizations.

The more than 800 institutes that used to belong to the three academies of sciences are now formally the property of the Federal Agency for Research Organizations, even though they may still bear the label of one of the academies. This network remains extensive: the 800 institutes employ about 17% of researchers and produce nearly half of the country's international scientific publications.

Source: Gokhberg *et al.* (2011), HSE (2015a), Stone (2014)

In 2014, work began on updating this list, once the government had approved the findings of the most recent foresight exercise, *Foresight – 2030,* conducted between 2012 and 2014 (HSE, 2014c). The report's recommendations are intended to serve as early-warning signals for the strategic planning of enterprises, universities, research institutes and government agencies.

Growing exports of nanoproducts

The *UNESCO Science Report 2010* underscored the significance of the Russian *Strategy for Nano-industry Development* (2007) and predicted that 'by 2015, all the necessary conditions will be in place for large-scale manufacturing of new nanotechnology-related products and for Russian nanotech companies to enter global markets'. It also predicted that the sales of nanotechnology-related products would grow by seven or eight times between 2009 and 2015. According to the state corporation Rusnano, as of 2013, over 500 companies were engaged in manufacturing nanotech products, the sales from which exceeded RUB 416 billion (more than US$ 15 billion). This is 11% over the target fixed in 2007 and means that the industry has grown 2.6 times since 2011. Almost one-quarter of nanotech products are exported. Moreover, export earnings doubled between 2011 and 2014 to RUB 130 billion.

By the end of 2013, Rusnano was supporting 98 projects and had established 11 centres for technological development and transfer (nanocentres) and four engineering companies in different regions. These specialize in composite materials, power engineering, radiation technologies, nano-electronics, biotechnology, optics and plasma technologies, ICTs and so on. Substantial achievements have been made in such areas as nanoceramics, nanotubes, composites and both hybrid and medical materials. Since its inception in 2011, the Centre for Nanotechnology and Nanomaterials in Saransk (Republic of Mordovia) has begun manufacturing unique nanopincers for microscopes that allow particles on a scale of 30 nanometers to be captured; this is a real breakthrough, with a multitude of potential applications in electronics and medicine (Rusnano, 2013, 2014). The centre has also patented special anticorrosion coatings, among other inventions.

Although the production of nanomaterials has grown considerably, Russian scientific output in nanotechnologies does not seem to be progressing as quickly as in a number of other economies (see Figure 15.5); nor does Russian scientific activity seem to have translated, as yet, into a significant amount of patented inventions (Figure 13.5).

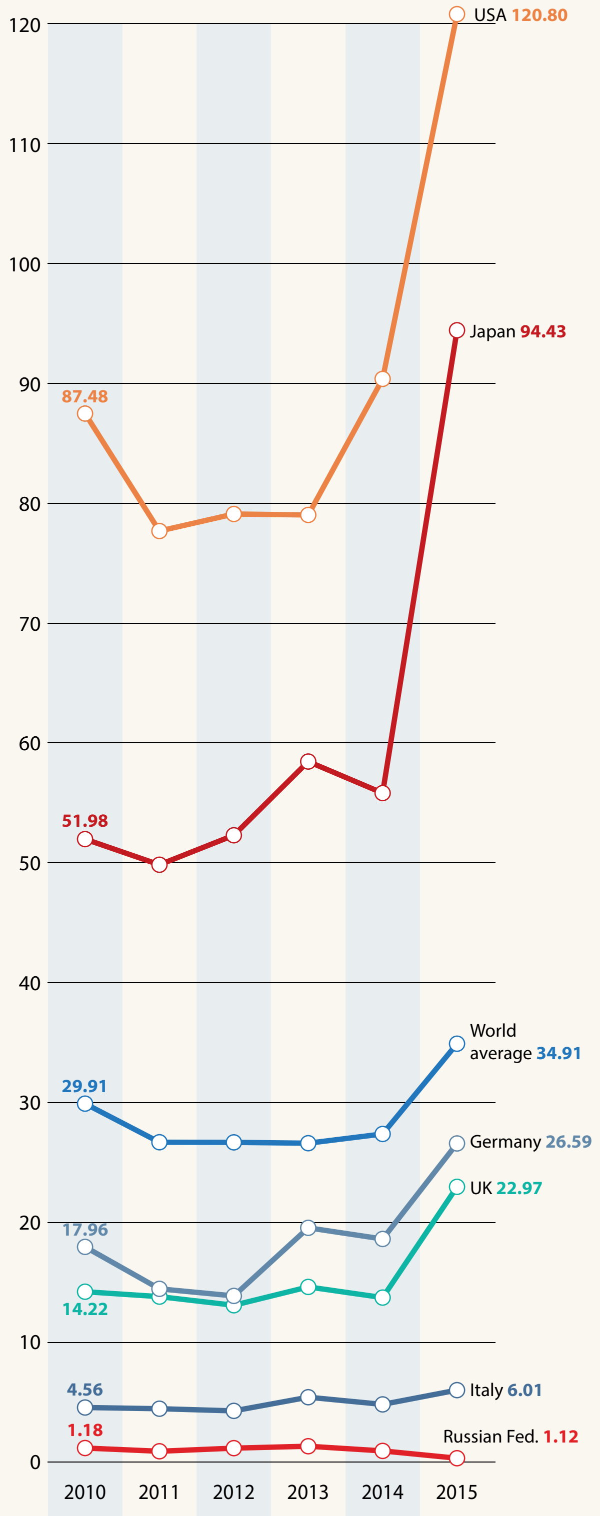
The advent of the State Roscosmos Corporation

The space industry has traditionally been considered a national priority. In terms of funding, the Russian space industry is the third-biggest after those of the USA and EU. The Russian Federation retains technological advantages in cosmonautics, rocket engines and carrier rockets. Prospective areas for R&D identified by *Foresight – 2030* include: carrier rocket technologies and acceleration block structural components, such as composite nanomaterials; spacecraft onboard engines, drives and energy storage systems; digital electronics and satellite navigation systems; new-generation environmentally friendly engines and safe fuels; clusters of small-format spacecraft for remote exploration of the Earth; and the deployment of broadband telecommunication systems (HSE, 2014c). These orientations are being taken into account in the design of a new Federal Space Programme covering the period to 2025; the new programme's priorities refer to 'social space' (the space industry as an engine of socio-economic development), basic space research and piloted cosmonautics (a new generation of space stations). It is also envisaged to complete the deployment of the International Space Station.

In recent years, the Russian space industry has faced growing global competition. At the same time, the industry's structure and organization have become outdated and inefficient, a verdict confirmed by several failed launches. This state of affairs led the government to launch a reform in 2013 to integrate more than 90 state-owned industrial enterprises and R&D centres into a single United Rocket and Space Corporation. The next stage of this ongoing reform got under way in 2015 with the merger of this corporation with the Federal Space Agency. The aim is to concentrate R&D, manufacturing and land infrastructure in the newly established State Roscosmos Corporation, which is to become a hub for the strategic planning and decision-making needed to overcome existing problems. There are strong hopes that this move will enhance horizontal linkages to avoid a dispersion of the procurement, performance and regulatory functions and 'reinforce competition'. A similar approach was successfully tried earlier by the nuclear energy corporation Rosatom.

Figure 13.5: **Nanotechnology patents in the Russian Federation, 2011–2015**

Number of patents per 100 nano-articles



Note: Data concern the ratio of nanotechnology patents to nano-articles (USPTO patents per 100 articles). The data for 2015 cover the period to the end of March.

Source: Thomson Reuters' Web of Science; USPTO

Along with this reform of the public space sector, new players are gradually changing the traditional centralized landscape. These are several private start-up companies based at Skolkovo (Box 13.1), including Dauria Aerospace, Lepton Company (St Petersburg) and Sputniks. These start-ups are targeting the production of microsatellites and space instruments, as well as the commercialization of remote sensing technologies for weather forecasting, environmental monitoring and exploration of natural resources.

Developing technologies to 'shrink' distances

The development of transport systems has two key motivations: to strengthen the global reach of domestic technologies and ensure continuity across the Russian Federation's vast territory through the development of regional aviation hubs and high-speed railways.

Foresight – 2030 suggests some orientations for specific transport sectors. It recommends that the aircraft industry focus its technological portfolio on reducing the weight of planes, on the use of alternative fuels (biofuel, condensed and cryogenic fuel), the development of 'smart' cabins for pilots with front windshield-based information panels and new composite (non-metal) materials, coatings and constructions (HSE, 2014c). The Sukhoi Superjet 100 (SSJ) is one example of recent technological progress; this new-generation regional aircraft is equipped with advanced technologies and meets the demand of both domestic and global civil aviation markets. A novel integrated power system for regional and long-haul aircraft is also being developed by Snecma (the French Safran Group) and Saturn (Russian Federation).

The state programme for the shipbuilding industry was adopted in 2013. This sector is experiencing a renaissance. More than 200 enterprises are engaged in manufacturing vehicles for maritime and inland cargo shipping, equipment for exploiting oil and gas reserves on the continental shelf, commercial and scientific shipping. The United Shipbuilding Corporation (est. 2007) is the largest company in this sector; this fully state-owned company encompasses 60 enterprises and accounts for about 80% of the domestic shipbuilding industry's turnover, with exports to 20 countries.

According to *Foresight – 2030* and a special report on *Foresight for Shipbuilding* (Dekhtyaruk *et al.,* 2014), research objectives for this industry principally concern the following areas: the development of composite materials based on nanotechnologies, organic and non-organic synthesis, metallurgy and thermal treatment; construction using novel materials and coatings; techniques to maximize the economic performance of vehicles; the construction of high-performance propulsion systems for small vessels based on the novel principles of energy generation, storage and conversion; high-performance tools and systems for ensuring the safety and durability of ships and vessels, including modern radio-electronic equipment based on nanotechnologies; and the design of highly automated smart adjustable systems for industrial production.

A stronger focus on alternative energy and energy efficiency

Given the energy sector's key contribution to GDP and exports, any changes have an immediate impact on national competitiveness. You could say that, when the energy sector sneezes, the Russian economy catches a cold. In 2014, the government launched the Energy Efficiency and Development programme to tackle the challenges facing the sector, including low energy efficiency, high extraction costs for fuel and the predominant orientation towards traditional sources of energy. Within this programme, funds have been earmarked for the development of electric power engineering and the oil, gas and coal industries – but also alternative energy sources. Since 2010, four technological platforms have been put in place for an Intellectual Energy System (smart system), Environmentally Neutral and Efficient Heat and Power Engineering, Advanced Technologies for Renewable Energy and Small Distributed Generation Systems.

There have been some noteworthy achievements in the field of alternative energy in recent years. High-performance separators, turbines and allied equipment are being used in the construction of new geothermal power stations in Kamchatka and Kurils, for instance. Mini-power plants using biogas generated from waste have also been built in many regions. Engines are also being produced for wind farms and small hydropower plants. In 2013, a complex engineering project got under way to develop the Prirazlomnaya ice-strengthened platform, offering a strong impetus for the exploitation of the Arctic shelf.

A cluster of projects are developing energy-efficient technologies at Skolkovo (Box 13.2). These focus on reducing energy consumption in industry, housing and municipal infrastructure. For example, the New Energy Technologies company is developing efficient thermos-electric generators for the direct conversion of thermal energy into electricity, based on nanostructured membranes and highly efficient solar converters derived from organic polymers. Meanwhile, the Wormholes Implementation company is creating intelligent systems for the monitoring and optimal exploitation of wells, in order to increase the efficiency of oil extraction and oil field development.

Foresight – 2030 identifies 14 thematic areas for highly-promising applied R&D related to energy. These include specific technologies for the efficient prospecting and extraction of fossil fuels, effective energy consumption, bio-energy, storage of electric and thermal energy, hydrogen-based power generation, deep processing of organic fuels, smart energy systems, high-power fourth-generation water-cooled nuclear reactors and optimizing energy and fuel transportation (HSE, 2014c).

A series of pilot innovative territorial clusters

In the past five years, the government has taken steps to strengthen institutional infrastructure for the commercialization and transfer of technology. In 2012, it launched a series of pilot innovative territorial clusters to promote value-added production chains and drive growth in the regions. Initially, 25 clusters were selected on a competitive basis out of nearly a hundred applications. The applicants were cluster consortia grouping industry, research institutes and universities supported by local administrations. The clusters represent a variety of regions stretching from Moscow to the Far East; they specialize in areas ranging from high-tech (ICTs, biotechnology, nuclear energy, etc.) to the more traditional manufacturing sectors of the automotive, shipbuilding, aircraft and chemical industries.

In 2013, the 14 best-prepared clusters received funding from federal and regional authorities on a 50:50 basis (matching principle); in 2014, a further 11 clusters were earmarked for support. The next stage of the national cluster policy will involve creating broader regional cluster programmes and cluster development centres to ensure co-ordination and networking.

Technology platforms to support industry

The first technology platforms were set up in Russia in 2010. They serve as a communication tool to unite the efforts by the state, businesses and the scientific communities to identify challenges, develop strategic research programmes and implementation mechanisms and encourage promising commercial technologies, new goods and services in specific economic sectors. There are currently 34 technology platforms across the country involving over 3 000 organizations: 38% concern businesses, 18% universities, 21% research institutes and the remainder NGOs, business associations and so on. In many cases, the platforms' strategic research programmes have been inspired by the recommendations of *Foresight – 2030* (HSE, 2014c).

Two key tools used to regulate the activity of these platforms are the co-ordination with government technology-oriented programmes and the provision of interest-free loans for innovative projects from the Russian Technology Development Fund, which was renamed the Foundation for Industrial Development in 2014.

Among the best-performing platforms are Medicine of the Future; Bio-industry and Bioresources – BioTech2030; Bio-energy; Environmentally Neutral and Efficient Heat and Power Engineering; Advanced Technologies for Renewable Energy; Technologies for Hydrocarbon Extraction and Use; Hydrocarbon Deep Processing; Photonics; and Aviation Mobility.

All 34 platforms will be evaluated to assess their level of support for industry; the list of platforms will then be adjusted accordingly. State support will only be renewed for those platforms that have demonstrated a high potential and tangible results.

Engineering centres being created at leading universities

Research and federal universities, state research centres and academic institutes form the core of the country's federal centres for collaborative use of scientific equipment, the first of which appeared in the mid-1990s. Since 2013, these centres have been brought together in a network of 357 entities to improve their effectiveness. Their funding comes from the Federal Goal-oriented Programme for Research and Development in Priority Areas. Centres can obtain annual subsidies of up to RUB 100 million (*circa* US$ 1.8 million) for a maximum of three years for a specific project.

Since 2013, a related pilot project to create engineering centres at leading technological universities has got under way. Its objective is to advance university-led development and the provision of engineering and training services. Support comes from budgetary subsidies that offset some of the expenses incurred in carrying out projects in engineering and industrial design: in 2013, each centre received RUB 40–50 million, for a total of RUB 500 million in subsidies.

Red tape holding back technopark development

There are currently 88 technoparks. The main tools of public support for these are the programme for The Creation of High-Tech Technoparks in the Russian Federation (2006) and, since 2009, an annual competitive programme for SMEs. Technoparks mostly specialize in ICTs, medicine, biotechnology, instrument-making and mechanical engineering but one-third (36%) exhibit a cross-sectorial specialization.

Technopark policies are fraught with problems, owing to some 'grey areas' in legislation and organizational procedures. According to the Russian Association of Technoparks in High-Tech Sectors, only 15 technoparks are actually effective.[16] The remainder are in the planning, construction or winding-up stages. The main reason for this is the excessive length of time taken by regional authorities to establish the titles to plots of land and to give town-planning permission, or to render decisions on funding.

16. Some technoparks have failed to achieve prescribed objectives related to the creation of highly skilled jobs, turnover in goods manufacturing, services rendered to resident businesses, etc. See: http://nptechnopark.ru/upload/spravka.pdf

More bridges needed between special zones and the exterior

Special economic zones date back to 2005, when the government decided to instigate a favourable regime for innovative entrepreneurship at the local level. Certain locations were identified specifically to encourage the development of new high-tech businesses and high-tech exports.

By 2014, five such zones were in operation in St Petersburg, Dubna, Zelenograd, Tomsk and the Republic of Tatarstan. These five zones host a total of 214 organizations. Each one benefits from a preferential regulatory environment, such as a zero property tax for the first ten years or other tax benefits, free customs regimes, preferential leasing terms, the opportunity to buy plots of land and state investment in the development of innovation, engineering, transport and social infrastructure. In order to increase the efficiency of these policy instruments, particular attention should be paid to arriving at a critical mass of organizations and to strengthening linkages between residents and the external environment.

TRENDS IN INTERNATIONAL SCIENTIFIC CO-OPERATION

Towards a Common Space for Research and Education with the EU

In recent years, the Russian Federation has made a concerted effort to integrate the international scientific community and develop international co-operation in science and technology. A crucial aspect of this co-operation lies in its ties with the EU, international organizations and regional economic associations.

There has been fruitful scientific collaboration with the EU over the past decade, as confirmed by the extension for another five years of the Agreement on Co-operation in Science and Technology between the European Community and the Russian government in 2014. A roadmap for establishing a Common Space for Reasearch and Education is currently being implemented, involving, *inter alia*, the stepping up of collaboration in space research and technologies. The Agreement for Co-operation between the European Atomic Energy Community and the Russian government in the field of controlled nuclear safety (2001) is currently in force. A joint declaration on the Partnership for Modernization was signed at the Russian Federation–EU summit in 2010.

The Russian Federation also participates in a number of European research centres, including the European Organization for Nuclear Research (CERN) in Switzerland, the European Synchrotron Radiation Facility in France and European X-ray Free Electron Laser in Germany. It is a major stakeholder in several international megascience projects, including the ongoing construction of both the International Thermonuclear Experimental Reactor in France and the Facility for Antiproton and Ion Research in Germany. The Russian Federation also hosts the Joint Institute for Nuclear Research in Dubna, which employs over 1 000 researchers from the Russian Federation and further afield and receives nearly the same number of temporary foreign visitors each year.

Following fairly active participation in the EU framework programmes for research and innovation in the past, Russian research centres and universities are liable to participate in the EU's current Horizon 2020 programme (2014–2020), as members of international consortia. This co-operation is being co-ordinated by a joint committee; in parallel, joint working groups have been set up to manage field-specific joint research calls that are cofinanced by the allied EU and Russian programmes.

The Russian Federation is also developing bilateral ties with European countries through international organizations and projects, such as the UK Science and Innovation Network or the Russian–French collaboration on climate change.

In 2014, a wide array of activities were set in motion as part of the Russian–EU Year of Science. These include the launch of joint projects such as Interact (Arctic research), Supra (next-generation pilot simulators), Diabimmune (diabetic and auto-immune illness prophylactics) and Hopsa/Apos (efficient supercomputing for science and industry) [Ministry of Education and Science, 2014].

Political tensions are affecting some areas of co-operation

Economic sanctions imposed on the Russian Federation by the EU in 2014 are limiting co-operation in certain areas, such as dual-use military technologies, energy-related equipment and technologies, services related to deep-water exploration and Arctic or shale oil exploration. The sanctions may ultimately affect broader scientific co-operation.[17]

Over the past 20–25 years, there has also been significant co-operation with the USA in key areas such as space research, nuclear energy, ICTs, controlled thermonuclear fusion, plasma physics and the fundamental properties of matter. This co-operation has involved leading universities and research organizations on both sides, including Moscow State University and Saint Petersburg University, Brookhaven and Fermi national laboratories and Stanford University. The level of mutual trust was such that the USA even relied on Russian spacecraft to transport its astronauts to the International Space Station after its own space shuttle programme was wound up in 2011.

17. See: http://europa.eu/newsroom/highlights/special-coverage/eu_sanctions/index_en.htm#5

However, these contacts with the USA are now being affected by the recent political tensions over Ukraine. For example, joint efforts to secure nuclear materials actually ceased when the US Department of Energy announced the termination of co-operation in April 2014. For the time being, co-operation between the Russian Federation and the USA is being maintained at the level of particular research centres and universities. This approach was approved, for example, by a meeting of the Skolkovo Scientific Advisory Council in November 2014 in Stanford (USA). At this meeting, several areas were selected for joint activities, namely brain and other bioscience research, molecular diagnostics, environmental monitoring and the forecasting of natural and technogenic emergencies.

Growing collaboration with Asia

Collaboration with the Association of Southeast Asian Nations currently targets joint activities in such high-tech sectors as the commercial development of space (space tourism), prospecting and extraction of minerals (including the use of space technology), materials engineering, medicine, computing and telecommunications. Collaborative projects are also being carried out in the field of renewable energy, biotechnology, atomic energy and education. In 2014, Viet Nam hosted a large-scale presentation of export-oriented Russian technologies. This resulted in a series of concrete agreements to initiate projects in the field of navigation technologies, agricultural biotechnology, energy and pharmaceuticals. An agreement was also reached in 2011 for the development of nuclear energy in Viet Nam using Russian technologies and equipment.

The Republic of Korea is co-operating with the Russian Federation in Antarctic exploration. This joint activity got under way in 2012; it includes the construction of a second Korean science station, assistance with the training of professionals in ice navigation, accompanying the Korean ice-breaker Araon, information exchange and joint research on living organisms found in low-temperature environments. The two countries have also been deepening their co-operation in the pharmaceutical sector since 2013; Russia's Chemical Diversity Research Institute and SK Biopharmaceuticals, on the one hand, and the Korean Pasteur Institute, on the other, have been collaborating on pre-clinical research, clinical trials, new drugs to treat tuberculosis, etc. Moreover, the Russian High-tech Centre ChimRar is currently setting up a joint biotechnology business to engage in research and develop innovative preparations to treat diseases which attack the central nervous system, together with the Korean firm Dong-A Pharmaceutical Co. Ltd.

Dynamic bilateral collaboration with China stems from the Treaty on Good Neighbourliness, Friendship and Co-operation signed by the two countries in 2001, which has given rise to regular four-year plans for its implementation. The treaty provides the basis for about 40 collaborative projects, as well as student exchanges at the secondary and tertiary levels and the joint organization of conferences and symposia, among other forms of co-operation. Dozens of joint large-scale projects are being carried out. They concern the construction of the first super-high-voltage electricity transmission line in China; the development of an experimental fast neutron reactor; geological prospecting in the Russian Federation and China; and joint research in optics, metal processing, hydraulics, aerodynamics and solid fuel cells. Other priority areas for co-operation include industrial and medical lasers, computer technology, energy, the environment and chemistry, geochemistry, catalytic processes, new materials, including polymers, pigments, etc. One new priority theme for high-tech co-operation concerns the joint development of a new long-range civil aircraft. To date, the aircraft's basic parameters have been elaborated, as well as a list of key technologies and a business plan which has been submitted for approval.

The Russian Federation and China are also co-operating in the field of satellite navigation, through a project involving Glonass (the Russian equivalent of GPS) and Beidou (the regional Chinese satellite navigation system). They have also embarked on a joint study of the planets of our Solar System. A resident company of Skolkovo, Optogard Nanotech (Russian) and the Chinese Shandong Trustpipe Industry Group signed a long-term deal in 2014 to promote Russian technologies in China. In 2014, Moscow State University, the Russian Venture Company and the China Construction Investment Corporation (Chzhoda) also signed an agreement to upscale co-operation in developing technologies for 'smart homes' and 'smart' cities' (see also Box 23.1).

We are seeing a shift in Russo–Chinese collaboration from knowledge and project exchanges to joint work. Since 2003, joint technoparks have been operating in the Chinese cities of Harbin, Changchun and Yantai, among others. Within these technoparks, there are plans to manufacture civilian and military aircraft, space vehicles, gas turbines and other large equipment using cutting-edge innovation, as well as to mass-produce Russian technologies developed by the Siberian Branch of the Russian Academy of Sciences.

In the past few years, the government has removed a number of administrative barriers to closer international co-operation with its partners. For example, the visa application process has been simplified, along with labour and customs regulations, to promote academic mobility and flows of research equipment and materials related to collaborative projects.

CONCLUSION

A need for longer-term horizons in policy-making

Despite the current complex economic and geopolitical situation, the Russian Federation has the firm intention of consolidating its national innovation system and pursuing international co-operation. In January 2015, the Minister of Education and Science, Dmitry Livanov, told *Nature* magazine as much. 'There will be no substantial reductions in the level of science funding caused by the current economic situation', he said. 'I strongly believe that scientific co-operation should not depend on temporary changes in the economic and political situation. After all, the generation of new knowledge and technologies is a mutually beneficial process' (Schiermeier, 2015).

The rapidly changing landscape of science and technology – with supply and demand for innovation shifting incessantly – is obliging policy-makers to address longer-term horizons and tackle emerging challenges. In a context of rapidly evolving global economic and geopolitical climates, coupled with growing international competition, both the government and public and private companies need to adopt more active investment strategies. To this end, future policy reforms in the Russian Federation should incorporate:

- preferential support for competitive centres of excellence, taking into account international quality standards for research and the centres' potential for involvement in global networks; research priorities should be influenced by the recommendations of *Foresight – 2030*;
- better strategic planning and long-term technology foresight exercises; an important task for the near future will be to ensure the consistency of foresight studies, strategic planning and policy-making at the national, regional and sectorial levels and that national priorities are translated into targeted action plans;
- greater financial support for the research of leading universities and research institutes, together with incentives for them to collaborate with businesses and investment bodies;
- further development of competitive research funding, coupled with a regular assessment of the effectiveness of budget spending in this area;
- stimuli for technological and organizational innovation in industry and the services sector, including subsidies for innovative companies – particularly those engaged in import substitution – tax deductions for companies investing in high-tech companies, a wider range of incentives for companies to invest in R&D, such as tax rebates and corporate venture funds; and
- regular appraisals of specific institutional mechanisms to support innovation, such as the technology platforms, and monitoring of their funding levels and performance.

STI will obviously develop most intensively in those sectors where resources are concentrated, such as in fuel and energy, traditional high-tech manufacturing and so on. At the same time, we expect to see future STI intensity around newly emerging competitive industries where the conditions for global competition have already been met, such as in advanced manufacturing, nanotechnology, software engineering and neurotechnology.

In order to strengthen domestic STI in a globally competitive environment, Russia needs to establish a climate conducive to investment, innovation, trade and business, including through the introduction of tax incentives and lighter customs regulations. The National Technology Initiative adopted in 2015 has been devised to ensure that Russian companies capture their share of future emerging markets.

It is of vital importance that administrative barriers blocking the entry to markets and the development of start-ups be removed; the intellectual property market must also be further liberalized by gradually reducing the role of the state in managing intellectual property and enlarging the class of owners, with the introduction of support measures to raise demand for innovation. Some of these issues have been addressed in the action plan adopted in 2015 to implement *The Russian Federation's Strategy for Innovative Development to 2020* – the impact of which will be discussed in the next edition of the *UNESCO Science Report*.

KEY TARGETS FOR THE RUSSIAN FEDERATION

- Raise labour productivity by 150% by 2018;
- Increase the share of high-tech industries in GDP by 130% between 2011 and 2018;
- Raise export revenue from nanotech products to RUB 300 billion by 2020;
- Raise GERD from 1.12% of GDP in 2012 to 1.77% by 2018;
- Raise the average salary of researchers to 200% of the average salary in the region where the researcher is based by 2018;
- Raise the share of GERD performed by universities from 9% in 2013 to 11.4% by 2015 and 13.5% by 2018;
- Increase total funding of public scientific foundations to RUB 25 billion by 2018;
- Boost Russia's world share of publications in the Web of Science from 1.92% in 2013 to 2.44% by 2015.

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Progress in Central Asia is being hampered by the low level of investment in research and development.

Nasibakhon Mukhitidinova

A 'flying machine' on display at the Tashkent Innovation Fair in 2014
Photo: © Nasibakhon Mkhitidinova

14 · Central Asia

Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan

Nasibakhon Mukhitdinova

INTRODUCTION

A quick recovery from the global financial crisis

The Central Asian economies have emerged relatively unscathed from the global financial crisis of 2008–2009. Uzbekistan has recorded consistently strong growth over the past decade (over 7%) and Turkmenistan[1] even flirted with growth of 15% (14.7%) in 2011. Although Kyrgyzstan's performance has been more erratic, this phenomenon was visible well before 2008 (Figure 14.1).

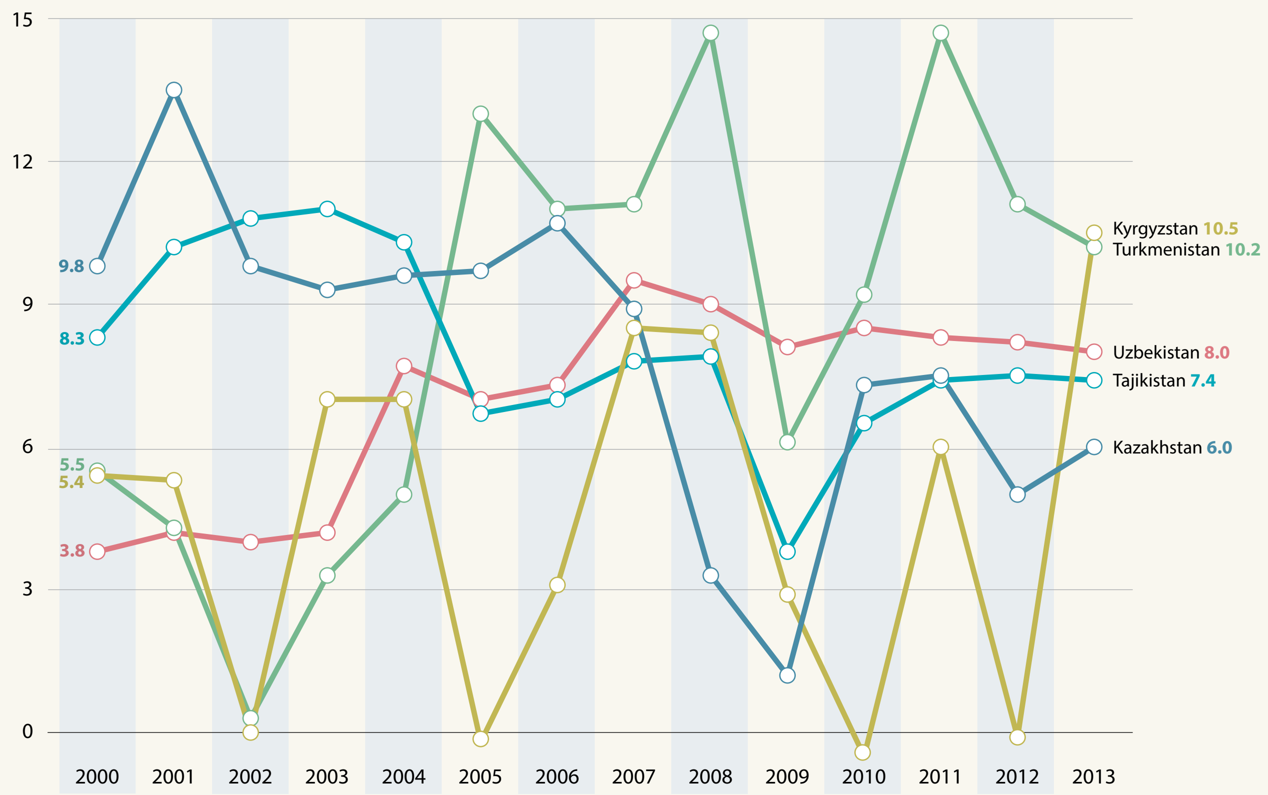
The republics which have fared best have surfed on the wave of the commodities boom. Kazakhstan and Turkmenistan have abundant oil and natural gas reserves and Uzbekistan's own reserves make it more or less self-sufficient. Kyrgyzstan, Tajikistan and Uzbekistan all have gold reserves and Kazakhstan has the world's largest uranium reserves. Fluctuating global demand for cotton, aluminium and other metals (except gold) in recent years has hit Tajikistan hardest, since aluminium and raw cotton are its chief exports – the Tajik Aluminium Company is the country's primary industrial asset. In January 2014, the Minister of Agriculture announced the government's intention to reduce the land cultivated by cotton to make way for other crops. Uzbekistan and Turkmenistan are major cotton exporters themselves, ranking fifth and ninth respectively worldwide for volume.

Although both exports and imports have grown impressively over the past decade, the countries remain vulnerable to economic shocks, owing to their reliance on exports of raw materials, a restricted circle of trading partners and a negligible manufacturing capacity. Kyrgyzstan has the added disadvantage of being considered resource poor, although it does have ample water. Most of its electricity is generated by hydropower.

The Kyrgyz economy was shaken by a series of shocks between 2010 and 2012. In April 2010, President Kurmanbek

1. Turkmenistan had reduced its external debt to just 1.6% of GDP by 2012 (down from 35% in 2002) and Uzbekistan's external debt is just 18.5% of GDP (2012). Kazakhstan's external debt has remained relatively stable at 66% (2012), whereas Tajikistan's external debt has climbed to 51% (up from 36% in 2008) and Kyrgyzstan's remains high at 89%, after dropping to 71% in 2009. Source: Sescric database, accessed July 2014.

Figure 14.1: **GDP growth trends in Central Asia, 2000–2013** (%)



Source: World Bank (2014) *Global Economic Prospects,* Table A1.1, p. 100

Bakiyev was deposed by a popular uprising, with former minister of foreign affairs Roza Otunbayeva assuring the interim presidency until the election of Almazbek Atambayev in November 2011. Food prices rose two years in a row and, in 2012, production at the major Kumtor gold mine fell by 60% after the site was perturbed by geological movements. According to the World Bank, 33.7% of the population was living in absolute poverty in 2010 and 36.8% a year later.

A region of growing strategic importance

Former Soviet states, the Central Asian republics share a common history and culture. Situated at the crossroads of Europe and Asia, rich in mineral resources, they are of growing strategic importance. All five are members of several international bodies, including the Organization for Security and Co-operation in Europe, the Economic Cooperation Organization and the Shanghai Cooperation Organisation.[2]

Moreover, all five republics are members of the Central Asia Regional Economic Cooperation (CAREC) Program, which also includes Afghanistan, Azerbaijan, China, Mongolia and Pakistan. In November 2011, the 10 member countries adopted the *CAREC 2020 Strategy*, a blueprint for furthering regional co-operation. Over the next decade, US$ 50 billion is being invested in priority projects in transport, trade and energy to improve members' competitiveness.[3] The landlocked Central Asian republics are conscious of the need to co-operate in order to maintain and develop their transport networks and energy, communication and irrigation systems. Only Kazakhstan and Turkmenistan border the Caspian Sea and none of the republics has direct access to an ocean, complicating the transport of hydrocarbons, in particular, to world markets.

Kyrgyzstan and Tajikistan have been members of the World Trade Organization since 1998 and 2013 respectively, which Kazakhstan is also keen to join. Uzbekistan and Turkmenistan, on the other hand, have adopted a policy of self-reliance. Symptomatic of this policy is the lesser role played by foreign direct investment. In Uzbekistan, the state controls virtually all strategic sectors of the economy, including agriculture, manufacturing and finance, foreign investors being relegated to less vital sectors like tourism (Stark and Ahrens, 2012).

On 29 May 2014, Kazakhstan signed an agreement with Belarus and the Russian Federation creating the Eurasian Economic Union. They were joined by Armenia in October 2014 and by Kyrgyzstan in December 2014. The Union came into effect on 1 January 2015, four years after the initial Customs Union had removed trade barriers between the three founding countries. Although the agreement focuses on economic co-operation, it includes provision for the free circulation of labour and unified patent regulations, two dispositions which may benefit scientists.[4]

Central Asian snow leopards not for tomorrow

Since gaining independence two decades ago, the republics have gradually been moving from a state-controlled economy to a market economy. The ultimate aim is to emulate the Asian Tigers by becoming the local equivalent, Central Asian snow leopards. However, reform has been deliberately gradual and selective, as governments strive to limit the social cost and ameliorate living standards in a region with a population growing by 1.4% per year on average.

All five countries are implementing structural reforms to improve competitiveness. In particular, they have been modernizing the industrial sector and fostering the development of service industries through business-friendly fiscal policies and other measures, to reduce the share of agriculture in GDP (Figure 14.2). Between 2005 and 2013, the share of agriculture dropped in all but Tajikistan, where it progressed to the detriment of industry. The fastest growth in industry was observed in Turkmenistan, whereas the services sector progressed most in the other four countries.

Public policies pursued by Central Asian governments focus on buffering the political and economic spheres from external shocks. This includes maintaining a trade balance, minimizing public debt and accumulating national reserves. They cannot totally insulate themselves from negative exterior forces, however, such as the persistently weak recovery of global industrial production and international trade since 2008.

According to Spechler (2008), privatization has proceeded fastest in Kazakhstan, with two-thirds of all firms being privately owned by 2006. Prices are almost completely market-based and banking and other financial institutions are much better established than elsewhere in the region. The government can dialogue with private enterprises through Atameken, an association of more than 1 000 enterprises from different sectors, and with foreign investors through the Foreign Investors' Council, set up in 1998. Kazakhstan nevertheless remains attached to state-led capitalism, with state-owned companies remaining dominant in strategic industries. When the global financial crisis hit in 2008, the Kazakh government reacted by stepping up its involvement in the economy, even though it had created a wealth fund, Samruk–Kazyna, the same year to further the privatization of state-controlled businesses (Stark and Ahrens, 2012).

2. See Annex 1 for the membership of international bodies mentioned here, p. 736.

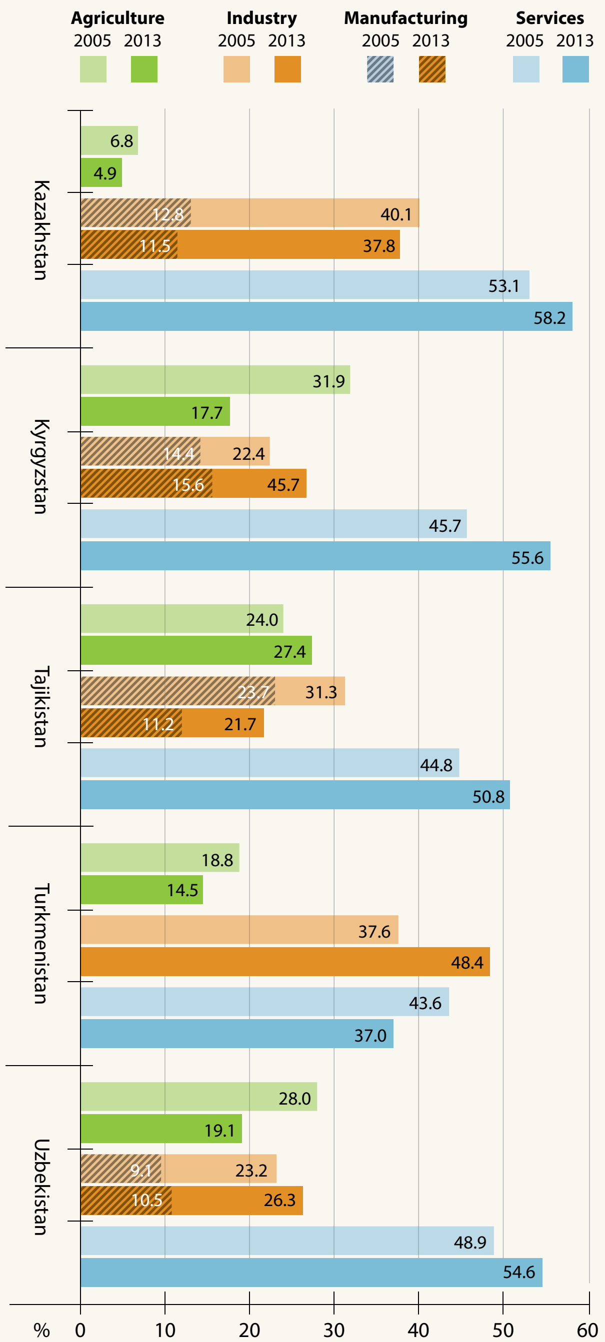
3. CAREC was founded in 1997. It partnered with six multilateral institutions in 2003 to help mainstream regional co-operation in transport, trade and energy, including infrastructure development: the Asian Development Bank (providing the secretariat since 2001); European Bank for Reconstruction and Development; International Monetary Fund; Islamic Development Bank; UNDP and; World Bank.

4. When the Eurasian Economic Union came into effect on 1 January 2015, the Eurasian Economic Community ceased to exist.

High literacy and medium development

Despite high rates of economic growth in recent years, GDP per capita in Central Asia was higher than the average for developing countries only in Kazakhstan in 2013 (PPP$ 23 206) and Turkmenistan (PPP$ 14 201). It dropped to PPP$ 5 167 for Uzbekistan, home to 45% of the region's population, and was even lower for Kyrgyzstan and Tajikistan.

Figure 14.2: **GDP in Central Asia by economic sector, 2005 and 2013** (%)



Note: For Turkmenistan, the most recent data are for 2012.

Source: World Bank's *World Development Indicators*, September 2014

All adult Central Asians are literate and a person born today can expect to live 67.8 years on average. UNDP considers Central Asia as having a medium level of human development. Kazakhstan's ranking in the Human Development Index improved by as much as 13 points between 2009 and 2013, compared to 7 points for Turkmenistan and 5 for Uzbekistan. Kyrgyzstan's ranking actually dropped 5 points.

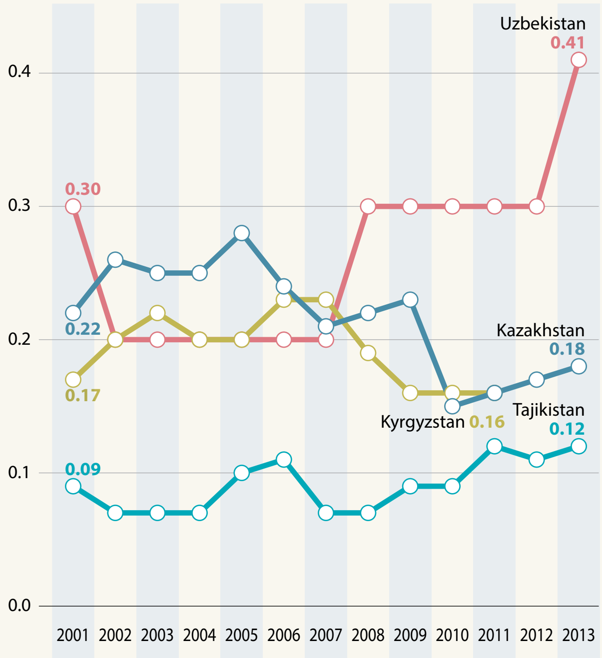
In 2013, the Earth Institute made an effort to measure the extent of happiness in 156 countries. Kazakhs (57th), Turkmens (59th) and Uzbeks (60th) were found to be happier than most, unlike the Kyrgyz (89th) and, above all, Tajiks (125th).

TRENDS IN EDUCATION AND RESEARCH

Persistently low investment in R&D

Common among the Central Asian republics is the persistently low investment in R&D. In the past decade, Kazakhstan and Kyrgyzstan have struggled to maintain gross domestic expenditure on R&D (GERD) at 0.2% of GDP. Uzbekistan's R&D effort intensified in 2013 to 0.4% of GDP (Figure 14.3). Kazakhstan has announced plans to hoist its own GERD/GDP ratio to 1% by 2015 (see p. 373), a target that will be hard to attain as long as annual economic growth remains strong.

Figure 14.3: **Trends in GERD/GDP ratio in Central Asia, 2001–2013**



Note: Data are unavailable for Turkmenistan.

Source: UNESCO Institute for Statistics database, July 2014; for Uzbekistan, Committee for Co-ordination of Science and Technology Development

Chapter 14

A focus on university and research infrastructure

The governments of Central Asia have adopted the same policy of gradual, selective reforms when it comes to science and technology (S&T). Only two research institutions opened in the region between 2009 and 2014, bringing the total to 838. Both are situated in Uzbekistan (see p. 386).

The other countries actually halved the number of their research institutions between 2009 and 2013. This is because centres set up during the Soviet period to solve national problems have become obsolete with the development of new technologies and changing national priorities. Kazakhstan and Turkmenistan are both building technology parks and grouping existing institutions to create research hubs. Bolstered by strong economic growth in all but Kyrgyzstan, national development strategies are focusing on nurturing new high-tech industries, pooling resources and orienting the economy towards export markets.

Three universities have been set up in Central Asia in recent years to foster competence in strategic economic areas: Nazarbayev University in Kazakhstan (first student intake in 2011), Inha University in Uzbekistan, specializing in ICTs, and the International Oil and Gas University in Turkmenistan (2014 for both). Countries are not only bent on increasing the efficiency of traditional extractive sectors; they also wish to make greater use of ICTs and other modern technologies to develop the business sector, education and research. Internet access varies widely from one country to another. Whereas every second Kazakh (54%) and one in three Uzbeks (38%) were connected in 2013, this proportion is as low as 23% in Kyrgyzstan, 16% in Tajikistan and just 10% in Turkmenistan.

Box 14.1: **Three neighbourhood schemes**

The following three programmes illustrate how the European Union (EU) and Eurasian Economic Community have been encouraging Central Asian scientists to collaborate with their neighbours.

STI International Cooperation Network for Central Asia (IncoNet CA)

IncoNet CA was launched by the EU in September 2013 to encourage Central Asian countries to participate in research projects within Horizon 2020, the EU's eighth research and innovation funding programme (see Chapter 9). The focus of the research projects is on three societal challenges considered as being of mutual interest to both the EU and Central Asia, namely: climate change, energy and health. IncoNet CA builds on the experience of earlier EU projects which involved other regions, such as Eastern Europe, the South Caucasus and the Western Balkans (see Chapter 12).

IncoNet CA focuses on twinning research facilities in Central Asia and Europe. It involves a consortium of partner institutions from Austria, the Czech Republic, Estonia, Germany, Hungary, Kazakhstan, Kyrgyzstan, Poland, Portugal, Tajikistan, Turkey and Uzbekistan. In May 2014, the EU launched a 24-month call for applications from twinned institutions – universities, companies and research institutes – for funding of up to € 10 000 to enable them to visit one another's facilities to discuss project ideas or prepare joint events like workshops. The total budget within IncoNet CA amounts to € 85 000.

Innovative Biotechnologies Programme

The Innovative Biotechnologies Programme (2011–2015) involves Belarus, Kazakhstan, the Russian Federation and Tajikistan. Within this programme established by the Eurasian Economic Community, prizes are awarded at an annual bio-industry exhibition and conference. In 2012, 86 Russian organizations participated, plus three from Belarus, one from Kazakhstan and three from Tajikistan, as well as two scientific research groups from Germany.

Vladimir Debabov, Scientific Director of the Genetica State Research Institute for Genetics and the Selection of Industrial Micro-organisms in Russia, stressed the paramount importance of developing bio-industry. 'In the world today, there is a strong tendency to switch from petrochemicals to renewable biological sources,' he said. 'Biotechnology is developing two to three times faster than chemicals.'

Centre for Innovative Technologies

The Centre for Innovative Technologies is another project of the Eurasian Economic Community. It came into being on 4 April 2013, with the signing of an agreement between the Russian Venture Company (a government fund of funds), the Kazakh JSC National Agency and the Belarusian Innovative Foundation. Each of the selected projects is entitled to funding of US$ 3–90 million and is implemented within a public–private partnership. The first few approved projects focused on supercomputers, space technologies, medicine, petroleum recycling, nanotechnologies and the ecological use of natural resources. Once these initial projects have spawned viable commercial products, the venture company plans to reinvest the profits in new projects.

The venture company is not a purely economic structure; it has also been designed to promote a common economic space among the three participating countries.

Source: www.inco-ca.net; www.expoforum.ru/en/presscentre/2012/10/546; www.gknt.org.by

All three new universities teach in English and work with partner universities in the USA, Europe or Asia on academic programme design, quality assurance, faculty recruitment and student admissions.

International co-operation is also a strong focus of the research institutes and hubs set up in recent years (Boxes 14.1–14.5). The mandate of these centres reflects a will to adopt a more sustainable approach to environmental management. Centres plan to combine R&D in traditional extractive industries, for instance, with a greater use of renewable energy, particularly solar.

In June 2014, the headquarters of the International Science and Technology Center (ISTC) were moved to Nazarbayev University in Kazakhstan, three years after the Russian Federation announced its withdrawal from the centre. Permanent facilities within the new Science Park at Nazarbayev University should be completed by 2016. ISTC was established in 1992 by the European Union (EU), Japan, the Russian Federation and the USA to engage weapons scientists in civilian R&D projects[5] and to foster technology transfer. ISTC branches have been set up in the following countries party to the agreement: Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan and Tajikistan (Ospanova, 2014).

Countries at different stages of education reform

Kazakhstan devotes less to education (3.1% of GDP in 2009) than either Kyrgyzstan (6.8% in 2011) or Tajikistan (4.0% in 2012) but the needs are greater in the latter two countries, which have lower standards of living. Both Kyrgyzstan and Tajikistan have introduced national strategies to correct such structural weaknesses as ill-equipped schools and universities, inadequate curricula and poorly trained teaching staff.

Kazakhstan has made great strides in improving the quality of education over the past decade. It now plans to generalize quality education by raising the standard of all secondary schools to the level of its Nazarabayev Intellectual Schools by 2020, which foster critical thinking, autonomous research and proficiency in Kazakh, English and Russian. The Kazakh government has also pledged to increase university scholarships by 25% by 2016. The higher education sector performed 31% of GERD in 2013 and employed more than half (54%) of researchers (Figure 14.5). The new Nazarbayev University has been designed as an international research university (see p. 378).

Kazakhstan and Uzbekistan are both generalizing the teaching of foreign languages at school, in order to facilitate international ties. Kazakhstan and Uzbekistan have both adopted the three-tier bachelor's, master's and PhD degree system, in 2007 and 2012 respectively, which is gradually replacing the Soviet system of Candidates and Doctors of Science (Table 14.1). In 2010, Kazakhstan became the only Central Asian member of the Bologna Process, which seeks to harmonize higher education systems in order to create a European Higher Education Area.[6] Several higher education institutions in Kazakhstan (90 of which are private) are members of the European University Association.

5. In the past 20 years, ISTC has provided competitive funding for about 3 000 projects in basic and applied research in energy, agriculture, medicine, materials science, aerospace, physics, etc. Scientists from member countries interact with one another, as well as with international centres such as the European Organization for Nuclear Research (CERN) and with multinationals that include Airbus, Boeing, Hitachi, Samsung, Philips, Shell and General Electric (Ospanova, 2014).

6. Other non-European Union members of the Bologna Process include the Russian Federation (since 2003), Georgia and Ukraine (since 2005). The applications for membership by Belarus and Kyrgyzstan have not been accepted.

Table 14.1: **PhDs obtained in science and engineering in Central Asia, 2013 or closest year**

	PhDs		PhDs in science				PhDs in engineering			
	Total	Women %	Total	Women %	Total per million population	Women PhDs per million population	Total	Women %	Total per million population	Women PhDs per million population
Kazakhstan (2013)	247	51	73	60	4.4	2.7	37	38	2.3	0.9
Kyrgyzstan (2012)	499	63	91	63	16.6	10.4	54	63	—	—
Tajikistan (2012)	331	11	31	—	3.9	—	14	—	—	—
Uzbekistan (2011)	838	42	152	30	5.4	1.6	118	27	—	—

Note: PhD graduates in science cover life sciences, physical sciences, mathematics and statistics, and computing; PhDs in engineering also cover manufacturing and construction. For Central Asia, the generic term of PhD also encompasses Candidate of Science and Doctor of Science degrees. Data are unavailable for Turkmenistan.

Source: UNESCO Institute for Statistics, January 2015

Table 14.2: **Central Asian researchers by field of science and gender, 2013 or closest year**

	Total researchers (HC)				Researchers by field of science (HC)											
					Natural Sciences		Engineering and technology		Medical and health sciences		Agricultural sciences		Social sciences		Humanities	
	Total researchers	Per million pop.	Number of women	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)
Kazakhstan (2013)	17 195	1 046	8 849	51.5	5 091	51.9	4 996	44.7	1 068	69.5	2 150	43.4	1 776	61.0	2 114	57.5
Kyrgyzstan (2011)	2 224	412	961	43.2	593	46.5	567	30.0	393	44.0	212	50.0	154	42.9	259	52.1
Tajikistan (2013)	2 152	262	728	33.8	509	30.3	206	18.0	374	67.6	472	23.5	335	25.7	256	34.0
Uzbekistan (2011)	30 890	1 097	12 639	40.9	6 910	35.3	4 982	30.1	3 659	53.6	1 872	24.8	6 817	41.2	6 650	52.0

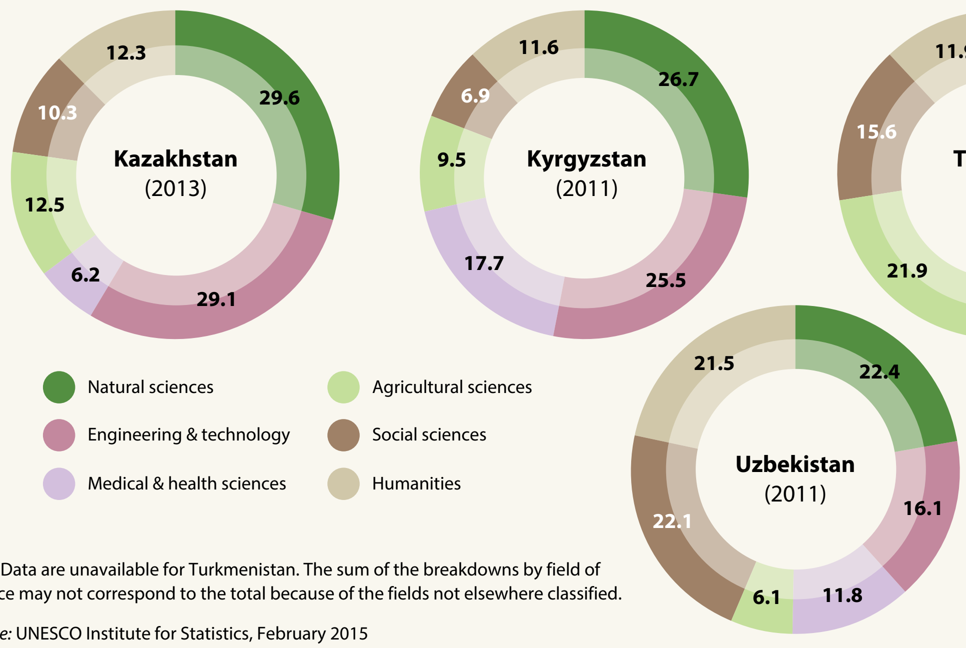
Note: Data are unavailable for Turkmenistan. The sum of the breakdowns by field of science may not correspond to the total because of the fields not elsewhere classified.

Source: UNESCO Institute for Statistics, February 2015

Kazakhstan is the only Central Asian country where the business enterprise and private non-profit sectors make any significant contribution to R&D (Figure 14.5). Uzbekistan is in a particularly vulnerable position, with its heavy reliance on higher education: three-quarters of researchers are employed by the university sector, at a time when many are approaching retirement age and 30% of the younger generation hold no degree qualification at all.

Kazakhstan, Kyrgyzstan and Uzbekistan have all maintained a share of women researchers above 40% since the fall of the Soviet Union. Kazakhstan has even achieved gender parity, with Kazakh women dominating medical and health research and representing some 45–55% of engineering and technology researchers in 2013 (Table 14.2). In Tajikistan, however, only one in three scientists (34%) was a woman in 2013, down from 40% in 2002. Although policies are in place to give Tajik women equal rights and opportunities, these are underfunded and poorly understood (see p. 381). Turkmenistan has offered a state guarantee of equality for women since a law adopted in 2007 but the lack of available data makes it impossible to draw any conclusions as to the law's impact on research.

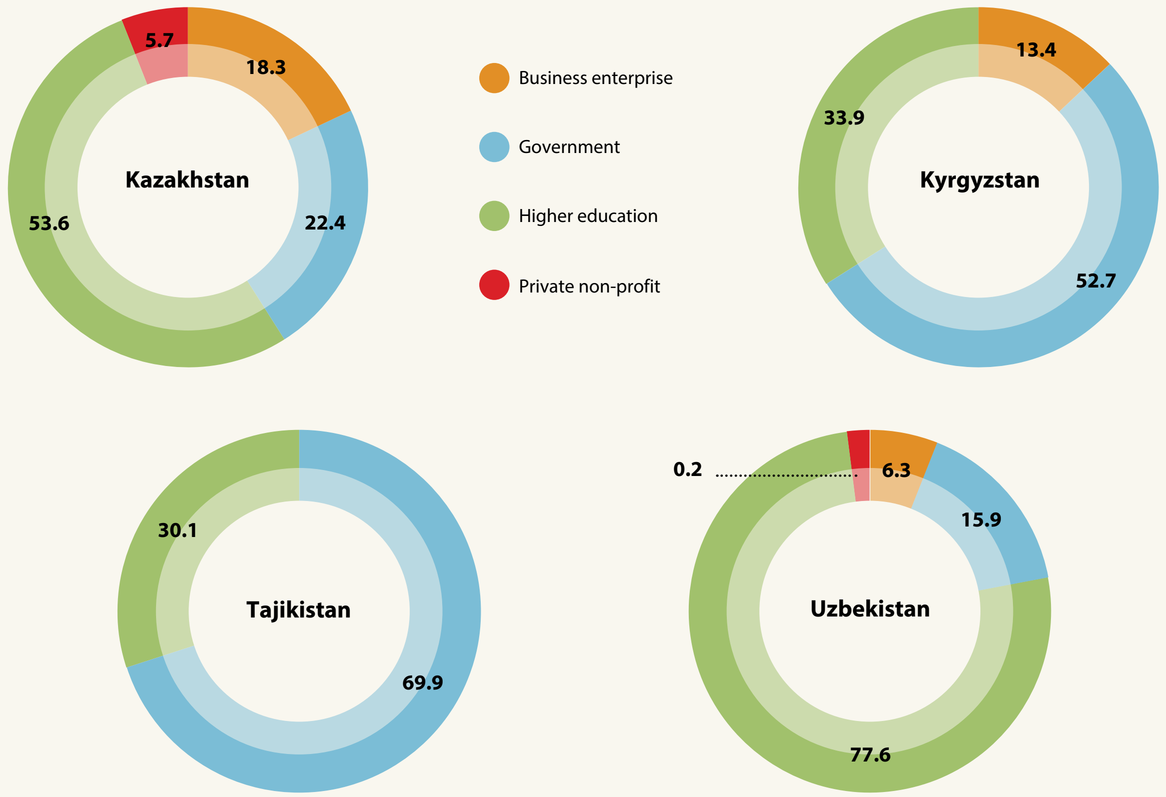
Figure 14.4: Central Asian researchers by field of science, 2013 (%)



Note: Data are unavailable for Turkmenistan. The sum of the breakdowns by field of science may not correspond to the total because of the fields not elsewhere classified.

Source: UNESCO Institute for Statistics, February 2015

Figure 14.5: **Central Asian researchers by sector of employment (HC), 2013** (%)



Note: For Kyrgyzstan and Uzbekistan, the most recent data are for 2011. Data are unavailable for Turkmenistan.

Source: UNESCO Institute for Statistics, February 2015

Kazakhstan leads the region for scientific productivity

Despite persistently low investment in R&D among the Central Asian republics, national development strategies are nonetheless focusing on developing knowledge economies and new high-tech industries. Trends in scientific productivity are useful indicators of whether these strategies are having an impact or not. As Figure 14.6 shows, the number of scientific papers published in Central Asia grew by almost 50% between 2005 and 2013, driven by Kazakhstan, which overtook Uzbekistan over this period. Kazakhstan and Uzbekistan both specialize in physics, followed by chemistry, which also happens to be Tajikistan's speciality. Kyrgyzstan, on the other hand, publishes most in geosciences and Turkmenistan most in mathematics. Articles related to agriculture trail far behind and are almost non-existent in computer sciences.

Of note are the strong international ties of Central Asian scientists – but not with each other. At least two out of every three articles were co-authored by foreign partners in 2013. The biggest change has occurred in Kazakhstan, suggesting that international partnerships have driven the steep rise in Kazakh publications recorded in the Science Citation Index since 2008. The three main partners of Central Asian scientists are based in the Russian Federation, Germany and the USA, in that order. Kyrgyz scientists are the only ones who publish a sizeable share of their articles with their peers from another Central Asian country, namely Kazakhstan.

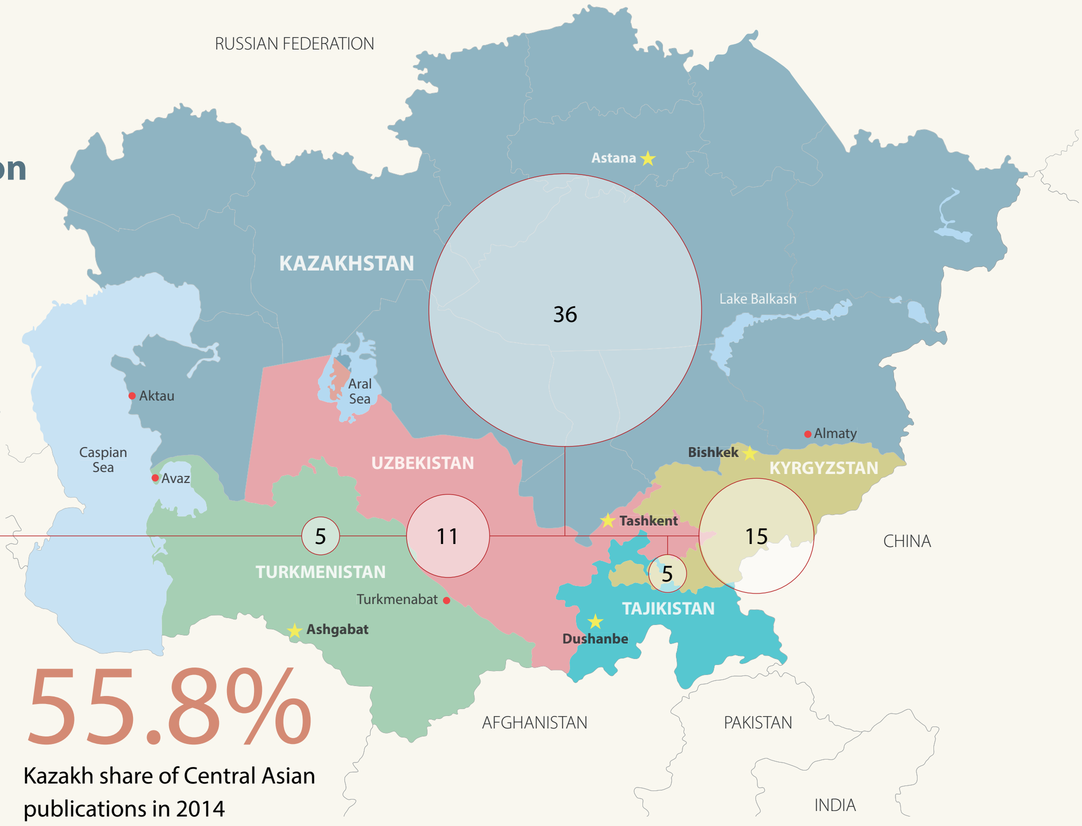
The number of patents registered at the US Patent and Trademark Office is minimal. Kazakh inventors were granted just five patents by this office between 2008 and 2013 and Uzbek inventors three. No patents at all were recorded for the other three Central Asian republics.

Kazakhstan is Central Asia's main trader in high-tech products. Kazakh imports nearly doubled between 2008 and 2013, from US$ 2.7 billion to US$ 5.1 billion. There has been a surge in imports of computers, electronics and telecommunications; these products represented an investment of US$ 744 million in 2008 and US$ 2.6 billion five years later. The growth in exports was more gradual – from US$ 2.3 billion to US$ 3.1 billion – and dominated by chemical products (other than pharmaceuticals), which represented two-thirds of exports in 2008 (US$ 1.5 billion) and 83% (US$ 2.6 billion) five years later.

Figure 14.6:
Scientific publication trends in Central Asia, 2005–2014

Kazakhstan publishes most but output remains modest

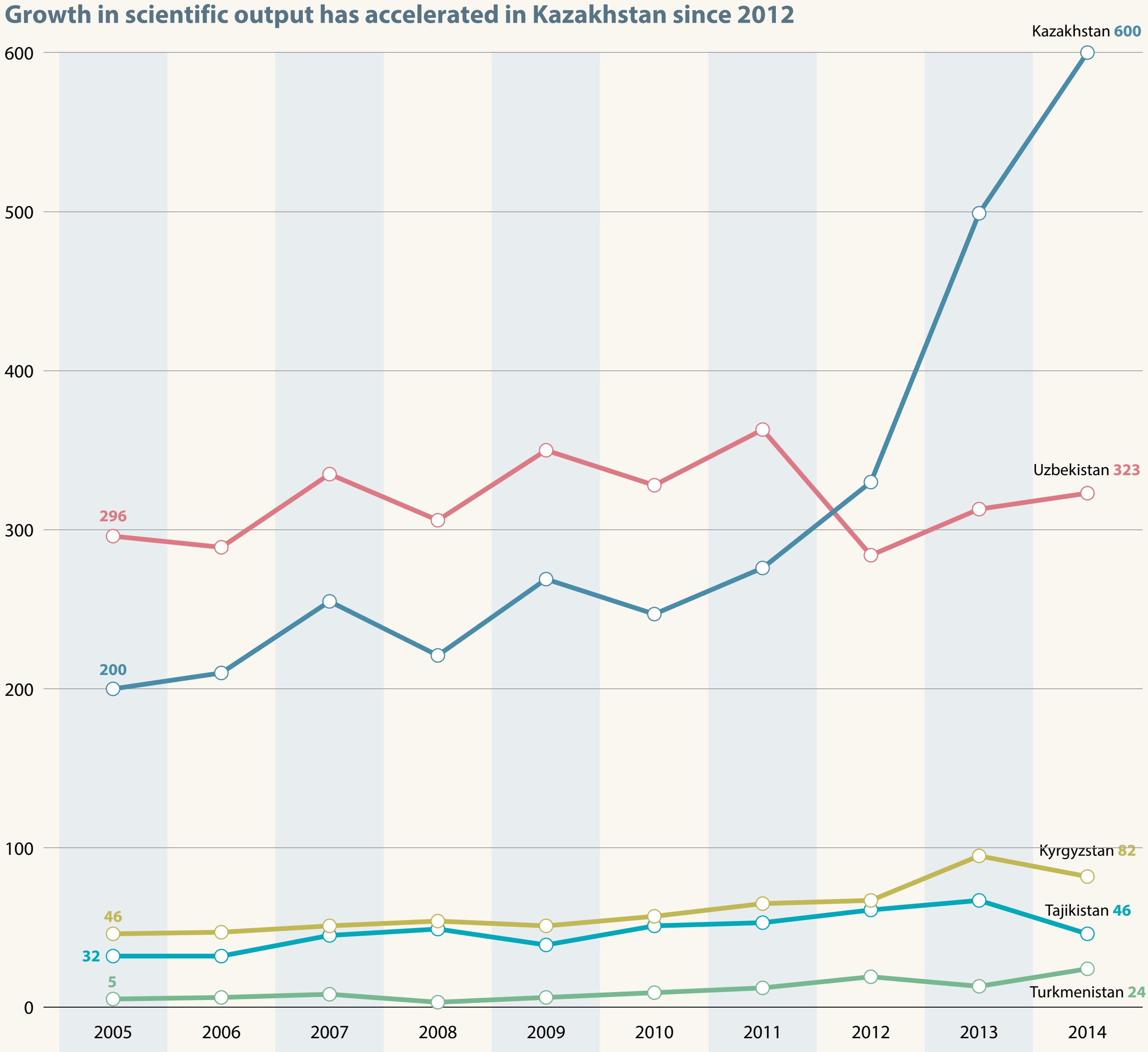
Publications per million inhabitants, 2014



34.5%
Kazakh share of Central Asian publications in 2005

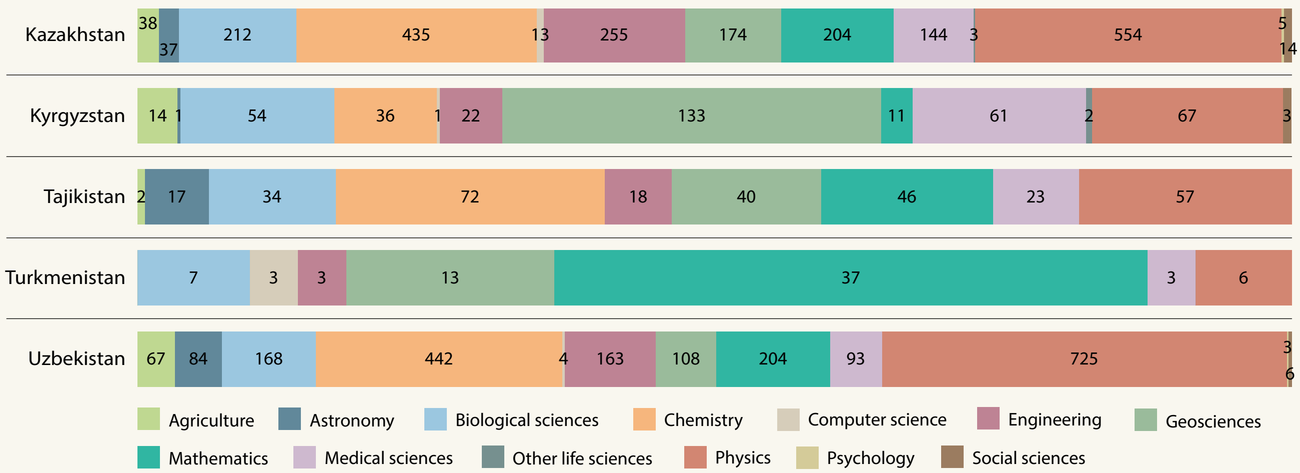
55.8%
Kazakh share of Central Asian publications in 2014

Growth in scientific output has accelerated in Kazakhstan since 2012



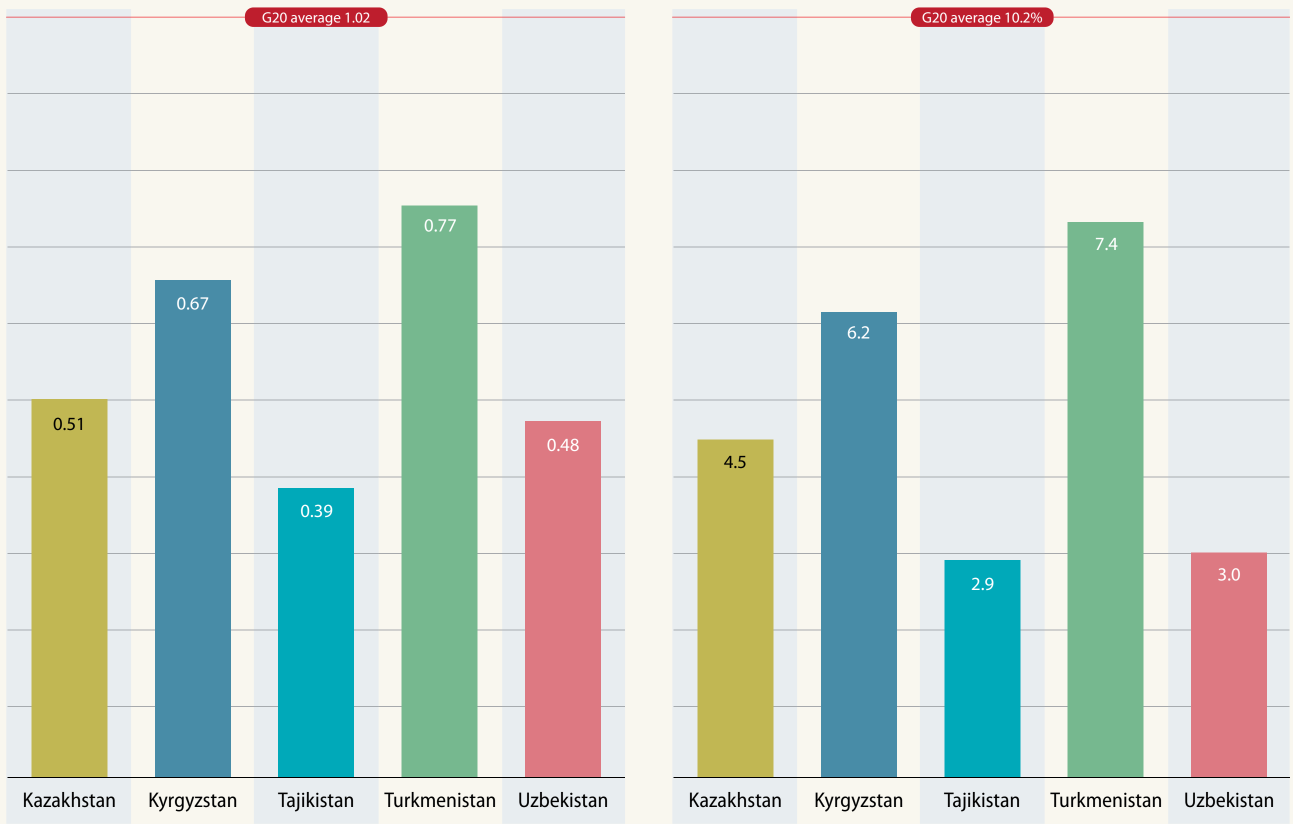
The most prolific countries – Kazakhstan and Uzbekistan – specialize in physics and chemistry

Cumulative totals by field, 2008–2014



Note: Totals exclude unclassified articles.

The average citation rate is low



The Russian Federation, Germany and the USA are the region's top partners

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Kazakhstan	Russian Fed. (565)	USA (329)	Germany (240)	UK (182)	Japan (150)
Kyrgyzstan	Russian Fed. (99)	Turkey/Germany (74)		USA (56)	Kazakhstan (43)
Tajikistan	Pakistan (68)	Russian Fed. (58)	USA (46)	Germany (26)	UK (20)
Turkmenistan	Turkey (50)	Russian Fed. (11)	USA/Italy (6)		China/Germany (4)
Uzbekistan	Russian Fed. (326)	Germany (258)	USA (198)	Italy (131)	Spain (101)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

KAZAKHSTAN

Little industrial R&D

Kazakhstan devoted 0.18% of GDP to research and development (R&D) in 2013, down from 0.23% in 2009 and a decadal high of 0.28% in 2005. The economy has grown faster (Figure 14.1) than gross domestic expenditure on R&D (GERD), which only progressed from PPP$ 598 million to PPP$ 714 million between 2005 and 2013.

In 2011, the business enterprise sector financed half of all research (52%), the government one-quarter (25%) and higher education one-sixth (16.3%). Since 2007, the share of the business sector in research has progressed from 45%, to the detriment of the government share, down from 37%. The share of the private non-profit sector has climbed from barely 1% in 2007 to 7% four years later.

Research remains largely concentrated in the country's largest city and former capital, Almaty, home to 52% of R&D personnel (UNECE, 2012). As we have seen, public research is largely confined to institutes, with universities making only a token contribution. Research institutes receive their funding from national research councils under the umbrella of the Ministry of Education and Science. Their output, however, tends to be disconnected from market needs.

Few industrial enterprises in Kazakhstan conduct R&D themselves. Investment in R&D by the business enterprise sector represented just 0.05% of GDP in 2013. Even those engaged in modernizing their production lines feel disinclined to invest in the purchase of products resulting from R&D**.** Only one in eight (12.5%) manufacturing firms was active in innovation[7] in 2012, according to a survey by the UNESCO Institute for Statistics.

Paradoxically, enterprises spent 4.5 times more on scientific and technological services in 2008 than in 1997, suggesting a growing demand for R&D products. Most enterprises prefer to invest in 'turnkey' projects which embody technological solutions in imported machinery and equipment. Just 4% of firms purchase the license and patents that come with this technology (Government of Kazakhstan, 2010).

A fund for science to accelerate industrialization

In 2006, the government set up the Science Fund within the State Programme for Scientific Development 2007–2012, in order to encourage market-oriented research by fostering collaboration with private investors. According to the United Nations Commission for Europe (UNECE, 2012), about 80% of the funds disbursed go to research institutes. The fund provides grants and loans for projects in applied research in priority areas for investment, as identified by the government's High Scientific Technology Committee, which is headed by the prime minister. For the period 2007–2012, these were:

- hydrocarbons, mining and smelting sectors and correlated service areas (37%);
- biotechnologies (17%);
- information and space technologies (11%);
- nuclear and renewable energy technologies (8%);
- nanotechnologies and new materials (5%);
- other (22%).

The State Programme for Scientific Development 2007–2012 stipulated that the Science Fund should channel 25% of all science funding by 2010 (UNECE, 2012). However, after the global financial crisis hit in 2008, the government's contribution to the fund dropped. The fund adapted by offering more flexible terms, such as interest- and tax-free loans, and by extending the loan period up to 15 years. In parallel, Kazakh scientists were encouraged to reach out to Western partners.

A law which could transform Kazakh science

In February 2011, Kazakhstan adopted the Law on Science. Encompassing education, science and industry, the law propelled leading researchers to the highest echelons of the decision-making process. It established national research councils in priority areas, comprised of both Kazakh and foreign scientists. The decisions adopted by national research councils are executed by the Ministry of Education and Science and line ministries.

The law prioritized the following areas: energy research; innovative technologies in the processing of raw materials; ICTs; life sciences; and basic research (Sharman, 2012).

It introduced three streams of research funding:

- basic funding to support scientific infrastructure, property and salaries;
- grant funding to support research programmes; and
- programme-targeted funding to resolve strategic challenges.

The originality of this funding framework is that public research institutions and universities may use the funding to invest in scientific infrastructure and utilities, information and communication tools and to cover staffing costs. Funding is disbursed via calls for proposals and tenders.

7. Firms qualify as active in innovation if their activity has led to the implementation of a product or process innovation, or if the firm is performing ongoing innovation or has recently abandoned innovation.

The Law on Science established a system of peer review for research grant applications from universities and research institutes. These competitive grants are examined by the national research councils. The government also plans to increase the share of funding for applied research to 30% and that for experimental development to 50%, leaving 20% for basic research. The law introduced a change to the tax code which reduces corporate income tax by 150% to compensate for businesses' R&D expenditure. In parallel, the law extends intellectual property protection. In addition, public and private enterprises are eligible for state loans, so as to encourage the commercialization of research results and attract investment.

In order to ensure coherence, independence and transparency in the management of STI projects and programmes, the government created the National Centre for State Scientific and Technical Expertise in July 2011. A joint stock company, the centre runs the national research councils, monitors ongoing projects and programmes and evaluates their impact, while maintaining a project database.

Long-term planning for coherent development

The *Kazakhstan 2030 Strategy* was adopted by presidential decree in 1997. Apart from national security and political stability, it focuses on growth based on an open-market economy with a high level of foreign investment, as well as on health, education, energy, transport communication infrastructure and professional training.

After the first medium-term implementation plan expired in 2010, Kazakhstan rolled out a second plan to 2020. It focuses on accelerating diversification of the economy through industrialization and infrastructure development; the development of human capital; better social services, including housing; stable international relations; and stable interethnic relations.[8]

Two programmes underpin the *Strategic Plan to 2020*, the State Programme for Accelerated Industrial and Innovative Development and the State Programme for Educational Development, both adopted by decree in 2010. The latter is designed to ensure access to quality education and fixes a number of targets (Table 14.3). The former focuses on the twin goals of diversifying the economy and improving Kazakhstan's competitiveness by creating an environment more conducive to industrial development and developing priority economic sectors, including via effective interaction between the government and business sectors. Kazakhstan's economic priorities to 2020 are agriculture, mining and metallurgical complexes, the energy sector, oil and gas, engineering, information and communication technologies (ICTs), chemicals and petrochemicals. One of the most ambitious targets of the State Programme for Accelerated Industrial and Innovative Development is to raise the country's GERD/GDP ratio to 1% by 2015 (Table 14.3).

UNECE (2012) observes that innovation expenditure more than doubled in Kazakhstan between 2010 and 2011, representing KZT 235 billion (*circa* US$ 1.6 billion), or around 1.1% of GDP. Some 11% of the total was spent on R&D. This compares to about 40–70% of innovation expenditure in developed countries. UNECE (2012) attributes this augmentation to a sharp rise in product design and the introduction of new services and production methods over this period, to the detriment of the acquisition of machinery and equipment which has traditionally made up the bulk of Kazakhstan's innovation expenditure. Training costs represented just 2% of innovation expenditure, a much lower share than in developed countries.

Using innovation to modernize the economy

Within the State Programme for Accelerated Industrial and Innovative Development, a law was adopted in January 2012 to provide state support for industrial innovation; it establishes the legal, economic and institutional bases for industrial innovation in priority sectors of the economy and identifies means of state support.

Within the same programme, the Ministry of Industry and New Technologies has developed an *Inter-industry Plan* to stimulate innovation through the provision of grants, engineering, services, business incubators and so on.

The Council on Technology Policy, established in 2010 within the same programme, is responsible for formulating and implementing the state policy on industrial innovation. The National Agency for Technological Development – established in 2011 – co-ordinates technology programmes and government support. It carries out foresight exercises and planning, monitors programmes, maintains a database on innovation projects and their commercialization, manages relevant infrastructure and co-operates with international bodies to obtain information, education and funding.

The main focus of innovation policy for the first three years (2011–2013) is to make enterprises more efficient through technology transfer, technological modernization, the development of business acumen and the introduction of relevant technologies. The following two years will be devoted to developing new competitive products and processes for manufacture. The focus will be on developing project finance, including through joint ventures. In parallel, efforts will be made to organize public events, such as seminars and exhibitions, to expose the public to innovation and to innovators.

8. According to the 2009 census, Kazakhs make up 63% of the population and ethnic Russians 24%. Small minorities (less than 3%) make up the remainder, including Uzbeks, Ukrainians, Belarusians and Tatars.

Table 14.3: **Kazakhstan's development targets to 2050**

KAZAKHSTAN 2030 STRATEGY Targets to 2020		**KAZAKHSTAN 2050 STRATEGY** Targets to 2050
State Programme for Educational Development, 2011–2020	State Programme for Accelerated Industrial and Innovative Development, 2011–2014	
■ Kazakhstan to possess the requisite human resources for the development of a diversified economy and infrastructure; ■ Completion of transition to a 12-year education model; ■ 100% of 3–6 year olds to be provided with pre-school education; ■ 52% of teachers to hold a bachelor's or master's degree (or equivalent); ■ 90% of secondary schools to use an e-learning system; ■ Secondary schools to be of the same quality as the Nazarbayev Intellectual Schools, teaching Kazakh, Russian and English, and fostering critical thinking, autonomous research and a deep analysis of information; ■ 80% of university graduates who complete education under the government grant scheme to be employed in their field of specialization in their first year after graduation; ■ The leading universities to enjoy academic and managerial autonomy; two of them to rank among the world's 100 best (Shanghai list); ■ 65% of universities to pass independent national accreditation in accordance with international standards; ■ Government scholarships for university students to increase by 25% [by 2016].	■ Kazakhstan to figure among the 50 most competitive countries in the world with a business climate conducive to foreign investment in non-primary economic sectors; ■ The economy to grow in real terms by more than one-third in relation to 2009; annual GDP growth to attain no less than 15% (KZT 7 trillion in real terms); ■ The population living beneath the poverty line to drop to 8%; ■ Contribution of manufacturing sector to increase to at least to 12.5% of GDP; ■ Share of non-primary exports to increase to at least 40% of total exports [by 2014]; ■ Labour productivity in manufacturing to grow by a factor of no less than 1.5; ■ GERD to represent 1% of GDP [by 2015]; ■ 200 new technologies to be in use; ■ Two centres with industrial expertise, three design bureaux and four technology parks to open; ■ Share of innovative activity in enterprises to increase to 10% by 2015 and 20% by 2020; ■ Basic research to represent 20% of all research; applied research 30%; and technological development 50%, in order to favour the introduction of innovative technologies; ■ Number of internationally recognized patents to increase to 30.	■ Kazakhstan to figure among the top 30 developed nations; ■ Kazakhstan to increase per capita GDP from US$ 13 000 in 2012 to US$ 60 000; ■ With the urban population due to rise from 55% to 70% of the total, towns and cities are to be linked by high-quality roads and high-speed transport (trains); ■ Small and medium-sized businesses are to produce up to 50% of GDP, compared to 20% at present; ■ Kazakhstan to be a leading Eurasian centre of medical tourism (possible introduction of universal medical insurance); ■ Annual GDP growth to reach at least 4%, with the volume of investment rising from 18% to 30%; ■ Non-resource goods to represent 70% of exports and the share of energy in GDP to be halved; ■ GERD to rise to 3% of GDP to allow for the development of new high-tech sectors; ■ As part of the shift to a 'green economy', 15% of acreage to be cultivated with water-saving technologies; agrarian science to be developed; experimental agrarian and innovation clusters to be established; drought-resistant GM crops to be developed [by 2030]; ■ Launch of a research centre on future energy and the green economy [by 2017]; ■ Launch of a Geological Cluster of Schools at Nazarbayev University [by 2015], see Box 14.3.

Box 14.2: The Caspian Energy Hub

The Caspian Energy Hub is under construction on a site of 500–600 ha in the Kazakh city of Aktau; it will form part of a cluster planned for Asia and the Middle East, with a similar hub already existing in Qatar.

The project's main objectives are to improve staff training and develop the energy sector's scientific potential, while modernizing infrastructure to serve the oil and gas industries better. The hub will comprise a specialized laboratory, a Centre for Geophysical Data Analysis, a Centre for Oil and Gas Technologies and an administrative pole responsible for state security and environmental protection. The site will also host an international technical university. Three foreign universities plan to set up campuses there: Colorado University and the University of Texas at Austin in the USA and Delft University in the Netherlands.

The project was launched in May 2008 by two joint stock companies, the Kazakhstan Holding for the Management of State Assets (Samruk) and the Sustainable Development Fund (Kazyna), which were subsequently merged in October 2008. Other partners include the PFC Energy international consulting company, the Gulf Finance House investment company and the Mangystau investment company. Samruk–Kazyna is charged with modernizing and diversifying the Kazakh economy by attracting investment to priority economic sectors, fostering regional development and strengthening inter-industry and inter-regional links.

Oil and gas represent 60–70% of Kazakh exports. A 2% reduction in oil revenue in 2013, subsequent to a drop in prices, cost the Kazakh economy US$ 1.2 billion, according to Ruslan Sultanov, Director-General of the Centre for Development of Trade Policy, a joint stock company of the Ministry of the Economy and Budget Planning. More than half (54%) of processed products were exported to Belarus and the Russian Federation in 2013, compared to 44% prior to the adoption of the Customs Union in 2010.

Source: www.petroleumjournal.kz

Between 2010 and 2012, technological parks were set up in the east, south and north Kazakhstan oblasts (administrative units) and in the capital, Astana. A Centre for Metallurgy was also established in the east Kazakhstan oblast, as well as a Centre for Oil and Gas Technologies within the new Caspian Energy Hub (Box 14.2).

The Centre for Technology Commercialization has been set up as part of the Parasat National Scientific and Technological Holding, a joint stock company established in 2008 that is 100% state-owned. The centre supports research projects in technology marketing, intellectual property protection, technology licensing contracts and start-ups. The centre plans to conduct a technology audit in Kazakhstan and to review the legal framework regulating the commercialization of research results and technology.

'Strong business, strong state'

In December 2012, the Kazakh president announced the *Kazakhstan 2050 Strategy* with the slogan 'Strong Business, Strong State.' This pragmatic strategy proposes sweeping socio-economic and political reforms to hoist Kazakhstan among the top 30 economies by 2050.

In his January 2014 state of the nation address, the president observed[9] that 'OECD members have covered a journey of deep modernization. They also demonstrate high levels of investment, research and development, labour efficiency, business opportunities and standards of living. These are the standards for our entrance into the ranks of the 30 most developed nations.' Promising to explain the strategy's goals to the population in order to ensure public support, he stressed that 'the well-being of ordinary citizens should serve as the most important indicator of our progress.'

At the institutional level, he pledged to create an atmosphere of fair competition, justice and rule of law and to 'shape and implement new counter-corruption strategies.' Promising local governments more autonomy, he recalled that 'they must be accountable to the public.' He pledged to introduce principles of meritocracy into human resources policy for state-owned enterprises and companies.

The president recognized the 'need to update relationships between the state and NGOs and the private sector' and announced a privatization programme. A list of state enterprises to be privatized was to be drawn up by the government and the Samruk–Kazyna sovereign wealth fund in the first half of 2014.

The first stage of the *2050 Strategy* focuses on making a 'modernization leap' by 2030. The aim is to develop traditional industries and create a processing industrial sector. Singapore and the Republic of Korea are cited as models. The second stage to 2050 will focus on achieving sustainable development via a shift to a knowledge economy

9. The information here on the *2050 Strategy* is taken from the president's address: www.kazakhembus.com/in_the_news/president-nursultan-nazarbayevs-2014-the-state-of-the-nation-address reliant on engineering services. High value-added goods are to be produced in traditional sectors during this second stage. In order to smooth the transition to a knowledge economy, there will be a reform of laws related to venture capital, intellectual property protection, support for research and innovation and commercialization of scientific results. Knowledge and technology transfer will be a key focus, with the establishment of R&D and engineering centres, in co-operation with foreign companies. Multinational companies working in major oil and gas, mining and smelting sectors

Box 14.3: **An international research university for Kazakhstan**

Nazarbayev University is a public research university founded in Astana in 2009 by the President of Kazakhstan, who chairs the Supreme Board of Trustees. The first intake of students dates from 2011.

By law, the Supreme Board oversees not only the university but also Kazakhstan's first endowment fund, the Nazarbayev Fund, which ensures sustainable funding for the university, and the 20 or so Nazarbayev Intellectual Schools which supply most of the university's students. Pupils are selected for these elite English-language secondary schools – and later for admission to Nazarbayev University – by University College London. Although students may apply directly for undergraduate programmes, most students choose first to complete a one-year programme at the Centre for Preparatory Studies run by University College London. All undergraduate courses are free to students, some of whom receive a stipend. The university also offers scholarships to selected international students.

The university faculty and other staff are recruited internationally and the language of instruction is English. In 2012, the three undergraduate schools counted a cumulative roll of 506 students, 40% of whom were women: the School of Science and Technology (43% of admissions in 2012), School of Engineering (46%) and the School of Humanities and Social Sciences (11%). The university's *Strategy for 2013–2020* aims to offer a full complement of graduate programmes by 2014 and to increase the undergraduate student roll to 4 000 and the number of graduates to 2000 by 2020, 15% of whom should be pursuing a doctoral degree by this time. The university has adopted the three-tier degree system (bachelor's, master's and PhD) in line with the European Union's Bologna Process to harmonize national education systems.

A particularity of the university is that each school twins with one or more partner institutions on curriculum and programme design, quality assurance, faculty recruitment and student admissions. The School of Science and Technology partners with the Carnegie Mellon University (USA), the School of Engineering with University College London, and the School of Humanities and Social Sciences with the University of Wisconsin–Madison (USA).

The three graduate schools welcomed their first cohort of students in 2013: the Graduate School of Education partners with Cambridge University (UK) and the University of Pennsylvania (USA); the Graduate School of Business with Fuqua School of Business at Duke University (USA) and the Graduate School of Public Policy with Lee Kuan Yew School of Public Policy at the National University of Singapore.

According to the *Strategy for 2013–2020*, a School of Medicine will open in 2015, in partnership with the University of Pittsburgh (USA). A School of Mining and Geosciences is also on the cards. Together with a Centre for Geological Research, it will form a Geological Cluster of Schools at Nazarbayev University, in partnership with the Colorado School of Mines in the USA. This cluster is part of the government's Kazakhstan *2050 Strategy*.

Nazarbayev University hosts several research centres, in addition to the research conducted by faculty and students: the Centre for Education Policy, the Centre for Life Sciences and the Centre for Energy Research. The research priorities of the latter for *2013–2020* include renewable energy and energy efficiency and energy sector modelling and analysis. Established in 2010, the Centre for Energy Research was renamed the Nazarbayev University Research and Innovation System two years later. In line with Kazakhstan's 2030 and 2050 strategies, the university is also establishing a Centre for Growth and Competitiveness with an initial focus on developing research excellence in global value chain analysis.

One hindrance to innovation in Kazakhstan has been the lack of geographical proximity between innovation hubs and the country's main universities. In January 2012, the president announced the construction of the Innovation Intellectual Cluster, which aims to surround the university gradually with a belt of high-tech companies. The hub encircling the university consists of a business incubator, technopark, research park, prototyping centre and commercialization office.

In 2012, the university published the first issue of *The Central Asian Journal of Global Health*, a peer-reviewed scientific journal developed in partnership with the University of Pittsburgh.

Source: www.nu.edu.kz

will be encouraged to create industries to source required products and services. Technology parks will be reinforced, such as the new Innovative Intellectual Cluster at Nazarbayev University in Astana (Box 14.3) and the Alatau Information Technology Park in Almaty.

Fifteen years to become a knowledge economy

In its *2050 Strategy*, Kazakhstan gives itself 15 years to evolve into a knowledge economy. New sectors are to be created during each five-year plan. The first of these, covering the years 2010–2014, focused on developing industrial capacity in car manufacturing, aircraft engineering and the production of locomotives, passenger and cargo railroad cars. During the second five-year plan to 2019, the goal is to develop export markets for these products.

To enable Kazakhstan to enter the world market of geological exploration, the country intends to increase the efficiency of traditional extractive sectors such as oil and gas. It also intends to develop rare earth metals, given their importance for electronics, laser technology, communication and medical equipment.

The second five-year plan coincides with the development of the *Business 2020* roadmap for small and medium-sized enterprises (SMEs), which will make provision for the allocation of grants to SMEs in the regions and for micro-credit. The government and the National Chamber of Entrepreneurs also plan to develop an effective mechanism for helping start-ups.

During subsequent five-year plans to 2050, new industries will be established in fields such as mobile, multi-media, nano- and space technologies, robotics, genetic engineering and alternative energy. Food processing enterprises will be developed with an eye to turning the country into a major regional exporter of beef, dairy and other agricultural products. Low-return, water-intensive crop varieties will be replaced with vegetable, oil and fodder products. As part of the shift to a 'green economy' by 2030, 15% of acreage will be cultivated with water-saving technologies. Experimental agrarian and innovational clusters will be established and drought-resistant genetically modified crops developed.

In his speech of January 2014, the president said that highways were currently under construction to link Kazakh cities and turn Kazakhstan into a logistics hub linking Europe and Asia. 'The Western Europe–Western China corridor is nearly completed and a railway line is being built to Turkmenistan and Iran to gain access for goods to ports in the Gulf,' the president said. 'This should increase the capacity of Kazakhstan's port in Aktau and simplify export-import procedures. Upon completion, the 1 200 km-long Zhezkazgan–Shalkar–Beineu railway will connect the east and west of the country, providing access to the Caspian and Caucasus regions in the west and to the Chinese port of Lianyungang on the Pacific coast in the east.'

The traditional energy sector is also to be developed. Existing thermal power stations, many of which already use energy-saving technologies, will be equipped with clean energy technologies. A research centre on future energy and the green economy is to be established by the time Expo 2017 takes place. Environmentally friendly fuel and electric vehicles are to be introduced in public transportation. A new refinery will also be established to produce gas, diesel and aviation fuels. Endowed with the world's biggest uranium reserves, Kazakhstan also plans to set up nuclear power plants[10] to satisfy the country's growing energy needs.

In February 2014, the National Agency for Technological Development[11] signed an agreement with the Islamic Corporation for the Development of the Private Sector and a private investor for the establishment of the Central Asia Renewable Energy Fund. Over the next 8–10 years, the fund will invest in Kazakh projects for renewable and alternative energy sources, with an initial endowment of US$ 50–100 million, two-thirds of which is to come from private and foreign investment (Oilnews, 2014).

KYRGYZSTAN

A technologically dependent country

The Kyrgyz economy is oriented primarily towards agricultural production, mineral extraction, textiles and the service industry. There is little incentive to create knowledge- and technology-based industries. The insufficient rate of capital accumulation also hampers structural changes designed to boost innovation and technology-intensive industries. Every key economic sector is technologically dependent on other countries. In the energy sector, for instance, all technological equipment is imported from abroad and many of its assets are in foreign[12] hands.

10. Kazakhstan's sole nuclear power plant was decommissioned in 1999 after 26 years of service. According to the IAEA, a joint venture with the Russian Atomstroyexport envisages developing and marketing innovative small and medium-sized reactors, starting with a 300 MWe Russian design as a baseline for Kazakh units.

11. This agency is a joint stock company, like many state bodies.

12. If we take the example of the Russian Federation, three partly state-owned companies have recently invested in Krygzystan's hydropower, oil and gas industries. In 2013, RusHydro began building the first of a series of hydroelectric dams that it will manage. In February 2014, Rosneft signed a framework agreement to buy 100% of Bishkek Oil and a 50% stake in the sole aviation fuel provider at the country's second-biggest airport, Osh International. The same year, Gazprom came closer to acquiring 100% of Kyrgyzgaz, which operates the country's natural gas network. In return for a symbolic investment of US$ 1, Gazprom will assume US$ 40 million in debt and invest 20 billion rubles (*circa* US$ 551 million) in modernizing Kyrgyz gas pipelines over the next five years. Gazprom already provides most of the country's aviation fuel and has a 70% share in the retail gasoline market (Satke, 2014).

Kyrgyzstan needs to invest heavily in priority sectors like energy to improve its competitiveness and drive socio-economic development. However, the low level of investment in R&D, both in terms of finance (Figure 14.3) and human resources, is a major handicap. In the 1990s, Kyrgyzstan lost many of the scientists it had trained during the Soviet era. Brain drain remains an acute problem and, to compound matters, many of those who remain are approaching retirement age. Although the number of researchers has remained relatively stable over the past decade (Table 14.2), research makes little impact and tends to have little application in the economy. R&D is concentrated in the Academy of Sciences, suggesting that universities urgently need to recover their status as research bodies. Moreover, society does not consider science a crucial driver of economic development or a prestigious career choice.

A need to remove controls on industry

The government's *National Strategy for Sustainable Development* (2013–2017)[13] recognizes the need to remove controls on industry in order to create jobs, increase exports and turn the country into a hub for finance, business, tourism and culture within Central Asia. With the exception of hazardous industries where government intervention is considered justified, restrictions on entrepreneurship and licensing will be lifted and the number of permits required will be halved. Inspections will be reduced to a minimum and the government will strive to interact more with the business community. The state reserves the right, however, to regulate matters relating to environmental protection and conservation of ecosystem services. By 2017, Kyrgyzstan hopes to figure in the Top 30 of the World Bank's Doing Business ranking and no lower than 40th in the global ranking for economic freedom or 60th for global enabling trade. By combining a systematic fight against corruption with legalizing the informal economy, Kyrgyzstan hopes to figure among the Top 50 least corrupt countries in Transparency International's Corruption Perceptions Index by 2017.

Better intellectual property protection

In 2011, the government devoted just 10% of GDP to applied research, the bulk of funding going to experimental development (71%). The State Programme for the Development of Intellectual Property and Innovation (2012–2016) sets out to foster advanced technologies, in order to modernize the economy. This programme will be accompanied by measures to improve intellectual property protection and thereby enhance the country's reputation as concerns the rule of law. A system will be put in place to counter trafficking in counterfeit goods and efforts will be made to raise public awareness of the role and importance of intellectual property. During the first stage (2012–2013), specialists were trained in intellectual property rights and relevant laws were adopted. The government is also introducing measures to increase the number of bachelor's and master's degrees in S&T fields.

Improving the quality of education

Kyrgyzstan spends more on education than most of its neighbours: 6.8% of GDP in 2011. Higher education accounts for about 15% of the total. According to the government's *Review of the Cost-Effectiveness of the Education system of Kyrgyzstan*, there were 52 institutions offering higher education in 2011.

Many universities are more interested in chasing revenue than providing quality education; they multiply the so-called 'contract' student groups who are admitted not on merit but rather for their ability to afford tuition fees, thereby saturating the labour market with skills it does not want. The professionalism of faculty is also low. In 2011, six out of ten faculty held only a bachelor's degree, 15% a master's, 20% a Candidate of Science degree, 1% a PhD and 5% a Doctor of Science (the highest degree level).

The *National Education Development Strategy* (2012–2020) prioritizes improving the quality of higher education. By 2020, the target is for all faculty to have a minimum master's qualification and for 40% to hold a Candidate of Science and 10% either a PhD or Doctor of Science degree. The quality assurance system is also to be revamped. In addition, the curriculum will be revised to align it with national priorities and strategies for the region's economic development. A teacher evaluation system will be introduced and there will be a review of existing funding mechanisms for higher education.

TAJIKISTAN

Strong economic growth without greater R&D intensity

Tajikistan has recorded strong growth in recent years, thanks to various economic reforms, including the development of new sectors such as hydropower and tourism and effective measures to promote macro-economic stability. GERD increased by 157% between 2007 and 2013 (to PPP$ 20.9 million, in constant 2005 PPP$) but the GERD/GDP ratio barely improved, rising from 0.07% to 0.12% over the same period (Figure 14.3).

The country has considerable assets: in addition to freshwater and diverse mineral resources, it has relatively large expanses of undeveloped land suitable for agriculture and environmentally friendly crops, a relatively inexpensive labour force and a strategic geographical position thanks to its border with China, making it a place of transit for merchandise and transportation networks.

13. See http://gov.kg; www.nas.aknet.kg

Conditions not yet in place for a market economy

The country also faces several challenges, including widespread poverty; the need to develop the rule of law; the high cost of combating drug trafficking and terrorism on its border; low Internet access (16% in 2013) and a small domestic market. The government sector is not structured to meet the demands of a market economy and development plans and strategies are neither interconnected nor vertically integrated. Potential partners in the private sector and civil society are insufficiently implicated in the development process. To compound matters, the modest allocation of financial resources is frequently inadequate to reach the goals set forth in national strategic documents. The country is also plagued by inadequate statistics.

These factors affect the implementation of the *National Development Strategy* for 2005–2015, which was designed by President Emomalii Rahmon to help the country meet the Millennium Development Goals. In education, the *National Development Strategy* focuses on an institutional and economic reform of the education system and on boosting the education sector's potential to provide services. Key problems to overcome include widespread malnutrition and illness among children, leading to absenteeism; poorly qualified teaching staff; lowly paid teachers, which affects morale and encourages corruption; a shortage of up-to-date textbooks; ineffective evaluation methods; and inadequate curricula at all levels of education for meeting the demands of the modern world, including an absence of science-based curricula at some levels.

Education increasingly dependent on aid

According to projections, the number of secondary school pupils could rise by 40% between 2005 and 2015. A recent survey revealed a lack of 600 000 places for schoolchildren, no heating or running water in one-quarter of schools and no toilets in 35%. Internet access is rare, even in schools equipped with computers, owing to frequent electricity cuts and a shortage of trained staff. In recent years, the gender gap in school attendance has increased for pupils in grades 9–11 particularly, in favour of boys.

Although state spending on education rose from 3.4% to 4.0% of GDP between 2007 and 2012, it remains well beneath 1991 levels (8.9%). Only 11% of this expenditure went to higher education in 2012, after peaking at 14% in 2008.

The education system is thus becoming increasingly dependent on 'unofficial payments' and international aid. Administrative barriers hamper the establishment of effective public–private partnerships, limiting private sector participation at pre-school and vocational and university levels, in particular. It seems unlikely that Tajikistan will reach the target ensconced in its *National Development Strategy* of privatizing 30% of these institutions by 2015.

Only time will tell whether Tajikistan can reach other key targets for 2015. These include providing all pupils with adequate textbooks, involving local communities more in problem-solving, decentralizing education funding, retraining 25% of teachers annually and founding at least 450 new schools, all of which are to be equipped with heating, water and sanitation, along with the renovated schools. At least 50% of schools are also to be given access to the internet.

Plans to modernize the research environment

Tajikistan can still count on a fairly strong core of human resources in science but the meagre resources available for R&D are spread too thinly across a wide range of areas. Research is disconnected from problem-solving and market needs. Moreover, research institutions have weak linkages to educational institutions, making it hard to share facilities such as laboratories. The poor distribution of ICTs also hampers international scientific co-operation and information-sharing.

Conscious of these problems, the government intends to reform the science sector. There are plans to conduct an inventory and analysis of research topics at scientific institutions in order to enhance their relevance. Targeted programmes will be adopted for basic and applied research in critical areas for scientific and economic development; at least 50% of scientific projects will have some practical application. Scientists will be encouraged to apply for competitive grants proposed by the government and international organizations and foundations, and contract research will be gradually introduced for high-priority R&D in all the sciences. Related scientific facilities will be renovated and equipped, including with internet access. A scientific information database is also being set up.

Tajikistan hosted its first forum of inventors in October 2014 in Dushanbe, entitled From Invention to Innovation. Run by the National Centre for Patents and Information of the Ministry of Economic Development and Trade, in partnership with international organizations, the forum discussed the private sector's needs and fostered international ties.

Equal on paper but not in practice

If Kazakhstan, Kyrgyzstan and Uzbekistan have all maintained a share of women researchers above 40% (even gender parity in Kazakhstan's case) since the fall of the Soviet Union, only one in three Tajik scientists (33.8%) was a woman in 2013, down from 40% in 2002. Although policies are in place[14] to give women equal rights and opportunities, these are underfunded and poorly understood by public employees at all levels of government. There is also little co-operation among the state, civil society and the business world when

14. A government programme identified basic directions for state policy in maintaining equal rights and opportunities for men and women over the period 2001–2010, and a March 2005 law guarantees these rights and opportunities.

it comes to implementing the national gender policy. As a result, women often find themselves excluded from public life and decision-making processes, even though they are increasingly a household breadwinner.

As part of current administrative reform within the *National Development Strategy*, gender considerations are to be taken into account in the drafting of future budgets. Existing legislation will be amended to support gender equality objectives and ensure equal access for men and women to secondary and higher education, loans, information, consulting services and, in the case of entrepreneurs, to venture capital and other resources. The policy will also focus on eliminating gender stereotypes in the public consciousness and preventing violence against women.

TURKMENISTAN

Social safety nets to cushion market transition

Turkmenistan has been undergoing rapid change – with little social upheaval – since the election of President Gurbanguly Berdimuhammadov in 2007 (re-elected in 2012), following the death of 'president for life' Sparamurat Niyazov. Turkmenistan has been moving towards a market economy since this policy was enshrined in the Constitution in 2008; in parallel, however, the government offers a minimum wage and continues to subsidize a wide range of commodities and services, including gas and electricity, water, wastewater disposal, telephone subscriptions, public transportation (bus, rail and local flights) and some building materials (bricks, cement, slate). Economic liberalization policies are being implemented gradually. Thus, as the standard of living has risen, some subsidies have been removed, such as those for flour and bread in 2012.

Today, Turkmenistan has one of the fastest-growing economies in the world. By introducing a fixed exchange rate of US$ 1 to 2.85 Turkmen manat in 2009, the president caused the 'black' foreign exchange market to disappear, making the economy more attractive to foreign investment. A fledgling private sector is emerging with the opening of the country's first iron and steel works and the development of a chemical industry and other light industries in construction, agro-food and petroleum products. Turkmen gas is now exported to China and the country is developing one of the largest gas fields in the world, Galkinish, with estimated reserves of 26 trillion m^3 of gas. Avaz on the Caspian Sea has been turned into a holiday resort, with the construction of dozens of hotels which can accommodate more than 7 000 tourists. In 2014, some 30 hotels and holiday homes were under construction.

The country has embarked on a veritable building boom, with the construction of 48 kindergartens, 36 secondary schools, 25 sports academies, 16 stadiums, 17 health centres, 8 hospitals, 7 cultural centres and 1.6 million m^2 of housing[15] in 2012 alone. Across the country, roads, shopping centres and industrial enterprises are all under construction. Turkmenistan's railway transport and metropolitan trains have been fully upgraded and the country is buying state-of-the-art aircraft.

At the same time, schools around the country are being renovated, 20-year old textbooks replaced and modern multimedia teaching methods introduced. All schools, universities and research institutes are being equipped with computers, broadband and digital libraries. Internet has only been available to the public since 2007, which explains why just 9.6% of the population had access to it in 2013, the lowest proportion in Central Asia.

A better respect for the rule of law

In the political arena, President Berdimuhammadov has restored the legislative powers of the *Mejlis*, the Turkmen parliament, and made it obligatory for parliament to approve certain ministerial appointments, such as those of the ministers of justice and the interior. The first multi-party parliamentary elections took place in 2013, allowing a second party, the Party of Industrialists and Entrepreneurs, to enter the *Mejlis* for the first time.

Laws have been introduced giving greater freedom to the media and punishing torture and other criminal acts committed by state officials. Movement within the country has also become easier with the removal of identity checkpoints – at one time there were no fewer than 10 between Ashgabat and Turkmenabat. Nowadays, someone travelling abroad need only present their passport once, a development which should facilitate the mobility of scientists.

A president keen to revive Turkmen science

The current president is far more committed to science than his predecessor. In 2009, he restored the Turkmen Academy of Sciences and its reputed Sun Institute, both dating from the Soviet era (Box 14.4). In 2010, he also determined 12 priority areas for R&D (*UNESCO Science Report 2010*, p. 245):

- Extraction and refining of oil and gas and mining of other minerals;
- Development of the electric power industry, with exploration of the potential use of alternative sources of energy: sun, wind, geothermal and biogas;
- Seismology;
- Transportation;
- The development of ICTs;

15. See: www.science.gov.tm/organisations/classifier/high_schools

- Automation of production;
- Conservation of the environment and, accordingly, introduction of non-polluting technologies that do not produce waste;
- Development of breeding techniques in the agricultural sector;
- Medicine and pharmaceuticals;
- Natural sciences; and
- Humanities, including the study of the country's history, culture and folklore.

Several of the academy's institutes were merged in 2014: the Institute of Botany was merged with the Institute of Medicinal Plants to become the Institute of Biology and Medicinal Plants; the Sun Institute was merged with the Institute of Physics and Mathematics to become the Institute of Solar Energy; and the Institute of Seismology merged with the State Service for Seismology to become the Institute of Seismology and Atmospheric Physics.[16]

In 2011, construction began of a technopark in the village of Bikrova near Ashgabat. It will combine research, education, industrial facilities, business incubators and exhibition centres. The technopark will house research on alternative energy sources (sun, wind) and the assimilation of nanotechnologies. The same year, the president signed a decree creating the National Space Agency,[17] which will be responsible for monitoring the Earth's orbit, launching satellite communication services, conducting space research and operating an artificial satellite over Turkmenistan's territory.

International co-operation with major scientific and educational centres abroad is being encouraged, including long-term scientific collaboration. International scientific meetings have been held in Turkmenistan regularly since 2009 to foster joint research and the sharing of information and experience.

The Turkmen State Institute of Oil and Gas was founded in 2012 before being transformed into the International Oil and Gas University a year later. Built on a 30-hectare site which includes a Centre for Information Technology, it can accommodate 3 000 students. This brings the number of training institutes and universities in the country to 16, including one private institution.

The government has also introduced a series of measures to encourage young people to pursue a career in science or engineering. These include a monthly allowance throughout their degree course for students enrolled in S&T fields and a special fund targeting the research of young scientists in priority areas for the government, namely: the introduction of innovative technologies in agriculture; ecology and the rational use of natural resources; energy and fuel savings; chemical technology and the creation of new competitive products; construction; architecture; seismology; medicine and drug production; ICTs; economics; and the humanities. It is hard to gauge the impact of government measures in favour of R&D, though, since Turkmenistan does not make data available on higher education, R&D expenditure or researchers.

16. See: www.turkmenistan.ru/en/articles/17733.html

17. See: http://en.trend.az/news/society/1913089.html

Box 14.4: **Turkmenistan's Sun Institute**

Although Turkmenistan is blessed with abundant oil and gas reserves and produces enough electric power for its own needs, it is difficult to lay power lines in the Kopet Dag mountains or arid parts of the country: about 86% of Turkmenistan is desert. Local generation of wind and solar energy gets around this problem and creates jobs.

Scientists at the Sun Institute are implementing a number of long-term projects, such as the design of mini-solar accumulators, solar batteries, wind and solar photovoltaic plants and autonomous industrial mini-biodiesel units. These units will be used to develop arid areas and the territory around the Turkmen Lake, as well as to foster tourism in Avaz on the Caspian seashore.

In isolated parts of the country, 'sun' scientists are working on schemes to pump water from wells and boreholes, recycle household and industrial wastes, produce biodiesel and organic fertilizers and raise 'waste-free' cattle. Their achievements include solar drying and desalination units, the cultivation of algae in solar photobioreactors, a 'solar' furnace for high-temperature tests, solar greenhouses and a biogas production unit. A wind and energy unit has been installed on Gyzylsu Island in the Caspian Sea to supply water to the local school.

Within the Tempus project, 'sun' scientists have been trained (or retrained) since 2009 at the Technical University Mountain Academy of Freiberg (Germany). 'Sun' scientists are also studying the possibility of producing silicon from the Karakum sands for photovoltaic converters, thanks to a grant from the Islamic Development Bank.

Source: www.science.gov.tm/en/news/20091223news_alt_ener/

One of the first laws adopted under Berdimuhammadov's presidency offered a state guarantee of equality for women, in December 2007. Some 16% of parliamentarians are women but there are no data on women researchers. A group of women scientists have formed a club to encourage women to choose a career in science and increase the participation of women in state S&T programmes and in decision-making circles. The current chair is Edzhegul Hodzhamadova, Senior Researcher at the Institute of History of the Academy of Sciences. Club members meet with students, deliver lectures and give interviews to the media. The club is endorsed by the Women's Union of Turkmenistan, which has organized an annual meeting of more than 100 women scientists on National Science Day (12 June) ever since the day was instituted in 2009.

UZBEKISTAN

A fledgling innovation system

The anti-crisis package covering 2009–2012 helped Uzbekistan weather the financial crisis by injecting funds into strategic economic sectors. As specified by presidential decree in December 2010, these sectors were, for 2011–2015: energy, oil and gas; the chemical, textile and automobile industries; non-ferrous metals; engineering; pharmaceuticals; high-quality processing of agricultural products ; and construction materials. These sectors tend to involve large companies equipped with design bureaux and laboratories. There are, however, also specialized state institutions which actively promote innovation. These include the: the Agency for Technology Transfer (since 2008), focusing on technology transfer to the regions; the Scientific and Technical Information State Unitary Enterprise, placed under the Committee for the Co-ordination of Science and Technology Development (since 2009); and the Intellectual Property Agency of Uzbekistan (since 2011).

The government has also decreed free industrial zones (FIZ) to foster the modernization of all economic sectors. The Navoi region became the first FIZ in December 2008. It was followed by Angren in the Tashkent region in April 2012 and Djizak in the Sirdary region in March 2013. The enterprises established in these FIZ have already produced some inventions and are involved in public–private partnerships through which they co-finance projects in innovation with the Fund for the Reconstruction and Development of Uzbekistan, set up in May 2006. The national innovation system in Uzbekistan is still in its formative years, however. There is at best a tenuous relationship between science and industry and almost no commercialization of research results.

In 2012, the Committee for the Co-ordination of Science and Technology Development formulated eight priorities for R&D to 2020, based on the needs of industry (CCSTD, 2013):

- Constructing an innovative economy by strengthening the rule of law;
- Energy and resource savings;
- Development of renewable energy use;
- Development of ICTs;
- Agriculture, biotechnology, ecology and environmental protection;
- Medicine and pharmacology;
- Chemical technologies and nanotechnologies; and
- Earth sciences: geology, geophysics, seismology and raw mineral processing.

The first of the eight R&D priorities merits greater explanation. The ultimate goal of the ongoing legal reform in Uzbekistan is to harness innovation to solving socio-economic problems and enhancing economic competitiveness. Innovation is perceived as a means of democratizing society. The contours of the draft law on innovation and innovative activity were first outlined in the presidential decree of January 2011 devoted to deepening democratic reforms, including by strengthening the status of local representatives. This draft bill also sets out to create an effective mechanism for the testing, deployment and commercial development of promising scientific work. It outlines additional incentives and rewards for enterprises developing innovative projects, especially in high-tech industries. In 2014, the draft law was subjected to public scrutiny to encourage debate.

In Uzbekistan, state support (financial, material and technical) for innovation is provided directly to specific programmes and projects, rather than to the individual research institutions and hierarchical structures. One of the most effective elements of this scheme is the principle of equity financing, which allows for a flexible combination of budgetary funds with funding from industry and the regions. This ensures that there is a demand for the research being undertaken and that the results will lead to products and processes. It also creates bridges between the public research sector and industrial enterprises. Researchers and industrialists can also discuss ideas at the country's annual innovation fairs (see photo, p. 364). Between 2008 and 2014:

- 26% of the proposals vetted concerned biotechnologies, 19% new materials, 16% medicine, 15% oil and gas, 12% chemical technologies and 13% energy and metallurgy;
- more than 2 300 agreements were signed for experimental development for more than 85 billion Uzbek soms (UZS), equivalent to US$ 37 million;
- based on these contracts, 60 new technologies were introduced and 22 product types went into production;

Table 14.4: **Uzbekistan's most active research organizations, 2014**

Physics and Astronomy	Energy
Institute of Nuclear Physics RT-70 Observatory SPU Physical–Technical Institute (Physics–Sun) Institute of Polymers, Chemistry and Physics Institute of Applied Physics, National University of Uzbekistan	Institute of Energy and Automation Tashkent State Technical University Fergana Polytechnic Institute Karshi Engineering Economic Institute Biochemistry, genetics and molecular biology
Chemical Sciences	**Biochemistry, Genetics and Molecular Biology**
Institute of Bio-organic Chemistry *(named after Academician Sadykov)* Institute of General and Inorganic Chemistry Institute of Chemistry and Plant Substances Institute of Polymers, Chemistry and Physics	Centre of Genomics and Bioinformatics Institute of Plant and Animal Genofund Institute of Genetics and Plant Experimental Biology Institute of Microbiology

Source: compiled by author

- the new products generated UZS 680 billion (almost US$ 300 million), providing US$ 7.8 million in import substitution.

Securing a new generation of researchers

In 2011, three-quarters of Uzbek researchers were employed in higher education and just 6% in the business enterprise sector (Figure 14.5). With most university researchers nearing retirement, this imbalance imperils Uzbekistan's research future. Almost all holders of a Candidate of Science, Doctor of Science or PhD are more than 40 years old and half are aged over 60; nearly one in four researchers (38.4%) holds a PhD degree, or its equivalent, the remainder holding a bachelor's or master's degree (60.2%).

In July 2012, a presidential decree abolished the system of Candidate of Science and Doctor of Science degrees inherited from the Soviet system,[18] replacing it with the three-tier degree system comprised of bachelor's, master's and PhD degrees. Whereas those with a bachelor's degree used to be barred from postgraduate studies in the old system, they will now be able apply for a course leading to a master's degree. This should incite young people to study science.

In December 2012, a second presidential decree focused on improving proficiency in foreign languages, beginning with the 2013/2014 academic year. English teaching, in particular, will be introduced into secondary schools and certain university courses will be taught in English, especially engineering and specialized areas, such as law and finance, in order to foster international information exchange and scientific co-operation. Students from remote rural areas will be able to specialize in foreign language teaching at university on the recommendation of local public authorities. Television and radio programmes designed to teach children and teenagers foreign languages will be broadcast widely. Universities will be given greater access to international multimedia resources, specialized literature, newspapers and magazines.

Inha University in Tashkent opened its doors to students in October 2014. Specializing in ICTs, this new university is the result of collaboration with Inha University in the Republic of Korea and will adopt similar academic programmes. Initially, 70 students are being selected for the Department of Information and Communication Engineering and a further 80 for the Department of Computer Science and Engineering. All lectures are given in English.

In order to improve training, the first cross-sectorial youth laboratories were created by the Academy of Sciences in 2010, in promising fields such as genetics and biotechnology; advanced materials; alternative energy and sustainable energy; modern information technology; drug design; and technology, equipment and product design for the oil and gas and chemical industries. These fields were chosen by the academy to reflect the strengths of Uzbek science (Figure 14.6 and Tables 14.2 and 14.4). The Academy of Sciences has also revived the Council of Young Scientists.

More problem-solving research

In order to re-orient academic research towards problem-solving and ensure continuity between basic and applied research, the Cabinet of Ministers issued a decree in February 2012 re-organizing more than 10 institutions of the Academy of Sciences. For example, the Mathematics and Information Technology Research Institute was subsumed under the National University of Uzbekistan and the Institute for Comprehensive Research on Regional Problems of Samarkand was transformed into a problem-solving laboratory on environmental issues within Samarkand State University. Some have remained attached to the Academy of Sciences, such as the Centre of Genomics and Bioinformatics (Table 14.4 and Box 14.5).

18. For an explanation of the Soviet system of higher education, see Figure 14.3 on p. 220 of the *UNESCO Science Report* 2010.

Box 14.5: **Uzbek and US scientists add economic value to cotton fibre**

A recent study could potentially have a multibillion-dollar impact on the global cotton industry and help cotton farmers fend off increasing competition from synthetic fibres.

Published in January 2014 in *Nature Communications*, the study is the result of collaboration between biologists at the Uzbek Centre of Genomics and Bioinformatics, the Texas A&M University (USA) and the US Department of Agriculture's Office of International Research Programs, which provided most of the funding.

'Sustainability and biosecurity of cotton production are pivotal for the Uzbek economy because agriculture accounts for [19%] of the country's GDP', says lead author Prof. Ibrokhim Abdurakhmonov, who received his master's degree in plant breeding from Texas A&M University in 2001 and is now director of the Centre of Genomics and Bioinformatics at the Academy of Sciences in his native Uzbekistan.

The overwhelming majority of cotton harvested worldwide is upland cotton *(Gossypium hirsutum)*. A cotton called *Gossypium barbadense* is more desirable because of its longer fibres and greater strength but it is late-maturing, low-yielding and more difficult to grow because it requires a dry climate and is less resistant to pathogens and pests.

'For a long time, cotton breeders have been trying to develop upland cotton with the fibre qualities of *G. barbadense* cotton,' says Alan Pepper, an associate professor in the Texas A&M Department of Biology and a co-author of the paper. 'Globally, everybody is trying to do it. Economically, it is a huge deal because every millimetre you add to fibre length adds that much to the price of cotton when the farmer sells it.'

The researchers' method increased the length of the fibre by at least 5 mm, or 17%, compared to the control plants in their experiment. 'This was pure basic science – kind of a shot-in-the-dark experiment,' says Pepper.

He acknowledges that the results of the research are, technically, genetically modified organisms (GMOs). But he makes a key distinction. A major criticism of GMOs, Pepper notes, focuses on cases where genes from other species – even bacterial ones – have been added to an organism to achieve a desired trait. 'What we are doing is a little different. We are not actually adding a gene from another species. We are just taking the genes that are there and we are knocking down the effect of one of those genes that is already in the plant.'

'The increased value of longer and stronger lint would be at least US$ 100 per acre more income,' says Abdurakhmonov. 'Our anticipation of possible improvement of resistance to abiotic stresses [such as high winds or drought] further adds to its commercial potential.'

In December 2013, Prof. Abdurakhmonov was named 'researcher of the year' by the International Cotton Advisory Committee for this 'gene knockout technology,' which is being patented in Uzbekistan, the USA and elsewhere. Research is being conducted in order to apply this technology to other crops.

Uzbekistan accounts for about 10% of global cotton fibre exports, behind the USA, India, China and Brazil. It is currently using revenue from cotton-growing to diversify its economy.

Source: www.bio.tamu.edu (press release); see also http://genomics.uz

In March 2013, two research institutes were created by presidential decree to foster the development of alternative energy sources, with funding from the Asian Development Bank and other institutions: the SPU Physical–Technical Institute (Physics Sun Institute) and the International Solar Energy Institute.

CONCLUSION

Progress hampered by low investment in R&D

Most of the Central Asian republics have managed to maintain stable economic growth throughout the global financial crisis and even some of the highest annual growth rates in the world. They are still in the process of transition to a market economy, however. Progress is being hampered by the low level of investment in R&D and, in Kyrgyzstan and Turkmenistan in particular, by very low levels of internet access.

The republics are all adopting structural and administrative reforms to reinforce the rule of law, modernize traditional sectors of the economy, introduce new technologies, strengthen related skills and create an environment more conducive to innovation, such as by strengthening intellectual property protection and providing incentives for innovative enterprises. Increasingly, government policies are opting for a more sustainable development path, including for extractive industries.

In order to attain the objectives outlined in their respective development plans, governments in Central Asia need to:

- strengthen co-operation – which is vital for sharing R&D results – by developing a common regional network for scientific and technical information, and creating a database in priority research areas: renewable energy, biotechnology, new materials, etc.;

- establish a support centre for STI using a common methodological approach to ensure unified legislative frameworks and the development of standard tools to assess STI policy implementation;
- provide one another with foreign direct investment, in order to diversify sources of R&D funding and foster intraregional co-operation in areas of common interest, including renewable energy, biotechnology, biodiversity conservation and medicine;
- develop more infrastructure to foster innovation: science and technology parks, special industrial zones, business incubators for start-ups and spin-offs, etc.; and
- co-operate in training highly qualified specialists for the knowledge economy: managers and engineers for innovative projects; intellectual property lawyers, including as concerns international law, patent marketers and so on.

KEY TARGETS FOR CENTRAL ASIA

- Raise Kazahkstan's GERD/GDP ratio to 1% by 2015;
- Raise the share of innovative activity in Kazakh enterprises to 10% by 2015 and 20% by 2020;
- Carry the weight of the Kazakh manufacturing sector to 12.5% of GDP by 2020;
- Reduce the share of the Kazakh population living below the poverty line to 8% by 2020;
- Cultivate 15% of the acreage in Kazakhstan with water-saving technologies and develop drought-resistant genetically modified crops by 2030;
- Place Kyrgyzstan among the top 30 countries for doing business by 2017 and the 50 least corrupt by 2017;
- Ensure that all Kyrgyz faculty members hold at least a master's degree and 10% a PhD or Doctor of Science degree by 2020;
- Privatize 30% of Tajik pre-schools, vocational schools and universities by 2015;
- Equip 50% of Tajik schools with internet access by 2015;
- Ensure that 50% of Tajik scientific projects are in applied fields by 2015.

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Indirectly, international sanctions have had some benefits for science, technology and innovation in Iran.

Kioomars Ashtarian

Professor Maryam Mirzakhani speaking at the International Congress of Mathematicians in Seoul (Republic of Korea) in 2014, where she was awarded the Field's Medal, the Nobel equivalent for mathematics

Photo: © International Mathematical Union

15 · Iran

Kioomars Ashtarian

INTRODUCTION

Sanctions have reshaped public policy in Iran

In the *UNESCO Science Report 2010,* we discussed how high oil receipts had stimulated consumerism but divorced science from socio-economic needs, favouring a science push rather than a technology pull. In more recent years, Iran has been less able to rely on oil receipts, as the embargo has tightened its grip: oil exports shrank by 42% between 2010 and 2012, dropping from 79% to 68% of total exports.

This predicament has reshaped Iranian public policy. The transition from a resource-based economy to a knowledge economy was already programmed in the *Vision 2025* document adopted in 2005. However, it has taken the hardening of sanctions – and a change of government – for policy-makers to make this transition a priority.

Four of the resolutions adopted by the United Nations Security Council since 2006 include progressively tough sanctions. Since 2012, the USA and European Union (EU) have imposed additional restrictions on Iranian oil exports and on enterprises and banks accused of circumventing the sanctions. The embargo is designed to persuade Iran to stop enriching uranium, which can be used for both civilian and military purposes.

Iran has always insisted on the civil nature of its nuclear programme[1] and its compliance with the Nuclear Non-Proliferation Treaty. Civil nuclear science is a source of national pride, in much the same way that Iranians are proud of their prowess in nanotechnology, stem cell technology and satellite technology. There was extensive coverage in the national press when Maryam Mirzakhani (*see photo*) became the first woman and the first Iranian in 2014 to be awarded the Fields Medal, the Nobel equivalent for mathematics.

President Hassan Rouhani took office in 2013 with the intention of dialoguing with the West. He rapidly initiated a new round of negotiations with the contact group, made up of the five permanent members of the United Nations Security Council plus Germany (known as the P5+1). The first concrete sign of a drop in tensions came in November 2013 with the conclusion of an interim arrangement with the P5+1. Shortly thereafter, the EU General Court announced that it would be annulling sanctions against the Central Bank of Iran. Another interim agreement in mid-2014 has allowed oil exports to climb back gradually to 1.65 million barrels per day. A final agreement was signed on 14 July 2015 and rapidly endorsed by the United Nations Security Council, paving the way to the lifting of sanctions.

1. Iran currently has a single nuclear reactor, located in Bouchehr.

Iran trades with the East ...

Between 2010 and 2012, non-oil exports rose by 12%, as Iran sought to cushion the economic impact of sanctions by limiting cash sales. Iran was able to import gold, for instance, in exchange for exporting goods to other countries. China is one of Iran's biggest customers but owes an estimated US$ 22 billion for oil and gas supplies which cannot be paid due to banking sanctions. In late 2014, China was planning to invest an equivalent sum in electricity and water projects as a way of circumventing the restrictions.

Like China, the Russian Federation is one of Iran's main trading partners.In October 2014, the Iranian agriculture minister met with his Russian counterpart on the sidelines of a Shanghai Cooperation Organization meeting in Moscow to discuss a new trade deal, whereby Iran would export vegetables, protein and horticultural products to the Russian Federation, in exchange for imports of some engineering and technical services, cooking oil and grain products. In September 2014, the Iranian Mehr news agency reported that Iran had signed a US$ 10 billion agreement with Russia for the design and construction of four new thermal[2] power plants, as well as facilities for the transfer of electricity.

The sanctions have caused a distinct shift in Iran's trading partners from West to East. Since 2001, China's exports to Iran have increased almost sixfold. The EU, on the other hand, accounted for almost 50% of Iranian trade in 1990 but, today, represents just 21% of Iranian imports and less than 5% of its exports.

... but conducts science with East and West

Scientific collaboration, on the other hand, has remained largely oriented towards the West. Between 2008 and 2014, the top four partners for scientific co-authorship were, in descending order, the USA, Canada, the UK and Germany (Figure 15.1). In 2012, researchers from Iran began participating in the project to build an International Thermonuclear Experimental Reactor[3] in France by 2018, which is developing nuclear fusion technology. In parallel, Iran is stepping up its collaboration with developing countries. Malaysia is Iran's fifth-closest collaborator in science and India ranks tenth, after Australia, France, Italy and Japan.

This said, just one-quarter of Iranian articles have a foreign co-author. There is a lot of scope for the development of twinning between universities for teaching and research, as well as student exchanges (Hariri and Riahi, 2014). Ties with Malaysia

2. There are different types of thermal power plant: nuclear, geothermal, coal-driven, biomass-burning, etc.

3. This project is funded by the European Union (*circa* 45% of the budget), China, India, Japan, the Republic of Korea and the USA.

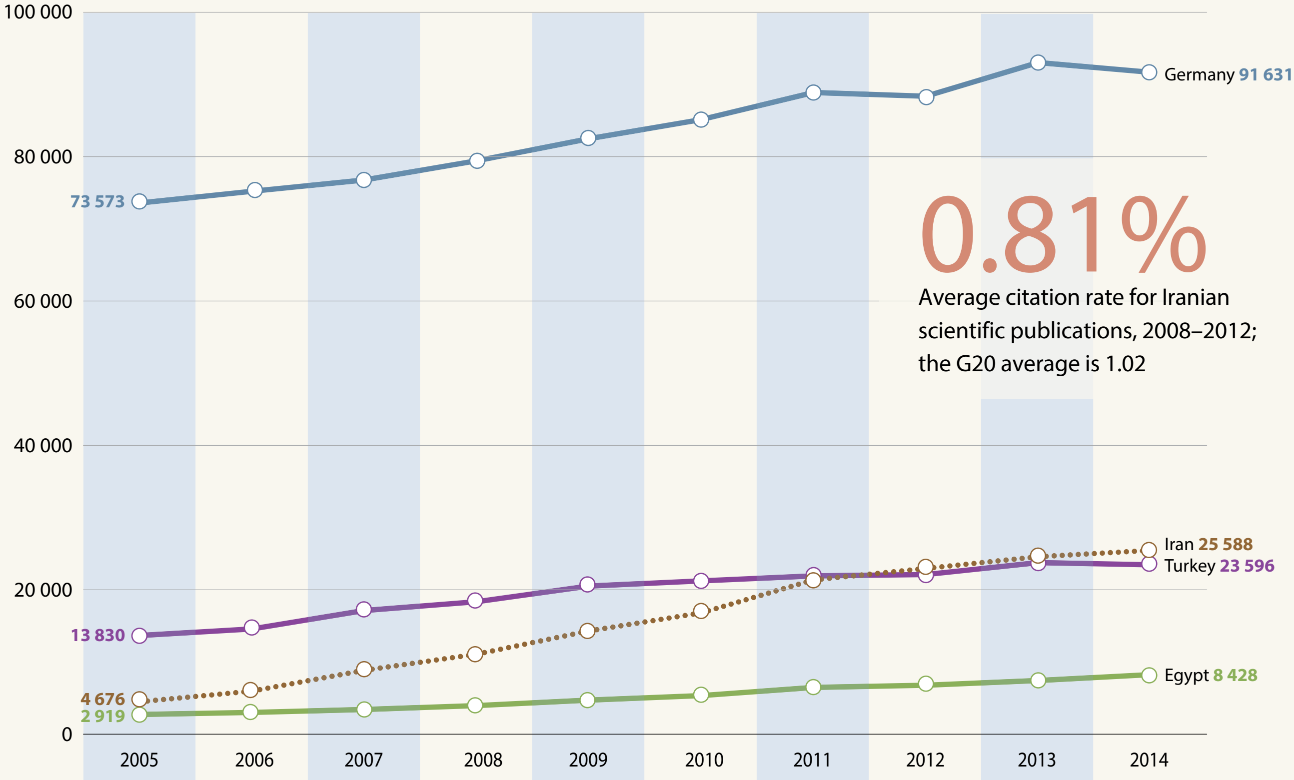
Figure 15.1: **Scientific publication trends in Iran, 2005–2014**

7.4%

Average share of Iranian papers among 10% most cited papers, 2008–2012; the G20 average is 10.2%

Strong growth in Iranian publications

Countries with a similar population are given for comparison

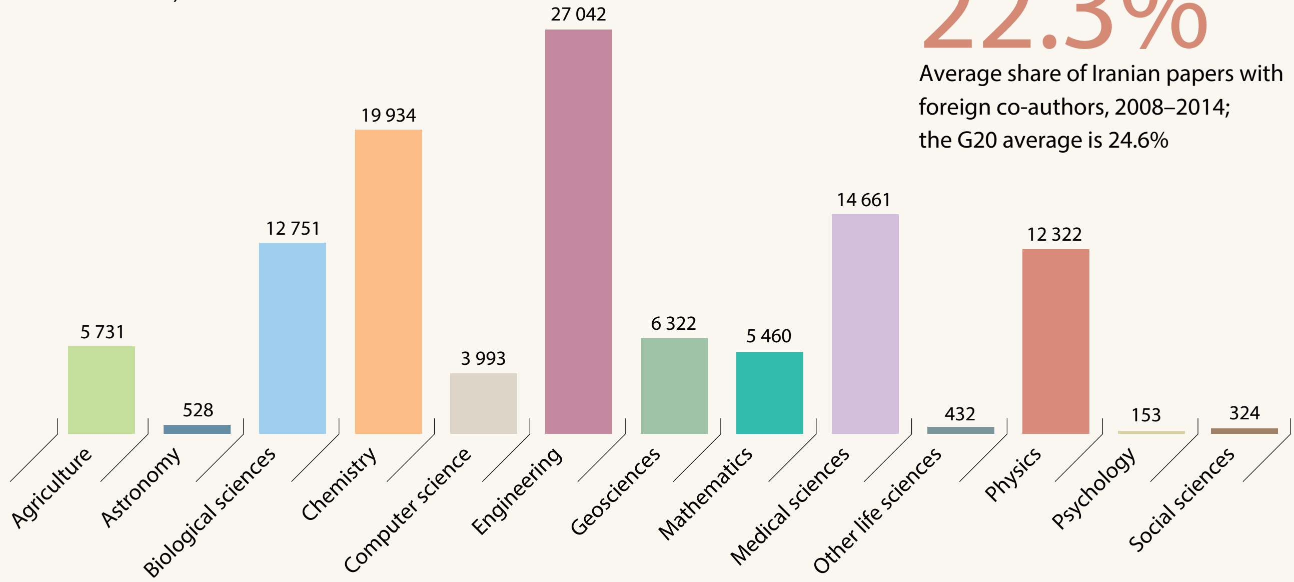


0.81%

Average citation rate for Iranian scientific publications, 2008–2012; the G20 average is 1.02

Iranians now publish most in engineering, followed by chemistry

Cumulative totals, 2008–2014



22.3%

Average share of Iranian papers with foreign co-authors, 2008–2014; the G20 average is 24.6%

Note: Totals exclude unclassified articles

The USA is Iran's top collaborator

Main foreign partners between 2008 and 2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Iran	USA (6 377)	Canada (3 433)	UK (3 318)	Germany (2 761)	Malaysia (2 402)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

are already strong. In 2012, one in seven international students in Malaysia was of Iranian origin (see Figure 26.9). In addition to being one of the rare countries which do not impose visas on Iranians, Malaysia is a Muslim country with a similar level of income. There were about 14 000 foreign students at Iranian universities in 2013, most of whom came from Afghanistan, Iraq, Pakistan, Syria and Turkey. The *Fifth Five-Year Economic Development Plan* has fixed the target of attracting 25 000 foreign students by 2015 (Tehran Times, 2013). In a speech[4] delivered at the University of Tehran in October 2014, President Rouhani recommended establishing an English-language university to attract more foreigners.

Iran is collaborating on international projects via the Organization of Islamic States' Standing Committee on Scientific and Technological Cooperation (COMSTECH). Moreover, in 2008, Iran's Nanotechnology Initiative Council established an Econano network[5] to promote the scientific and industrial development of nanotechnology among members of the Economic Cooperation Organization (see Annex I, p. 736).

Iran hosts several international research centres, including the following established within the past five years under the auspices of the United Nations: the Regional Centre for Science Park and Technology Incubator Development (UNESCO, est. 2010), the International Centre on Nanotechnology for Water Purification (UNIDO, est. 2012) and the Regional Educational and Research Centre for Oceanography for Western Asia (UNESCO, est. 2014).

An economy under pressure

According to Mousavian (2012), the sanctions have slowed Iran's industrial and economic growth, considerably limited foreign investment and triggered national currency devaluation, hyperinflation, declining GDP and, last but not least, a dip in oil and gas production and exports. The sanctions have hit the private sector particularly hard, increasing the costs of finance companies and the credit risk of banks, eroding foreign-exchange reserves and restricting companies' access to foreign assets and export markets. Knowledge-based enterprises have also had limited access to high-quality equipment, research tools, raw materials and technology transfer (Fakhari *et al.,* 2013).

Two other variables have affected Iran's economy: populist policies, which fuelled inflation, and the reform of energy and food subsidies. Some analysts argue[6] that this combination did more harm to the economy than the sanctions and global financial crisis put together (see, for example, Habibi, 2013). They posit that populist policies created an anti-expert discourse, citing President Mahmoud Ahmadinejad's decision to place the Management and Planning Organization under his direct control[7] in 2007. This venerable institution dated from 1948 and was responsible for preparing Iran's medium- and long-term development plans and policies, along with evaluating their implementation.

In January 2010, parliament introduced a reform to remove the energy subsidies which dated from the Iran–Iraq war of the 1980s. These subsidies were costing about 20% of GDP each year and had made Iran one of the most energy-intensive countries in the world. The International Monetary Fund (IMF) has described the reform as 'one of the most courageous moves to reform subsidies in an energy-exporting country' (IMF, 2014).

To cushion the impact on households, the subsidies were replaced by targeted social assistance of the equivalent of about US$ 15 per month that was extended to more than 95% of Iranians. Enterprises were also promised subsidized loans to help them adopt new, energy-saving technologies and credit lines to mitigate the impact of higher energy prices on their production (IMF, 2014). Ultimately, most of these loans have not materialized.[8]

Between 2010 and 2013, inflation climbed from 10.1% to 39.3%, according to the Iranian Statistical Centre. By 2013, the economy had slipped into recession (-5.8%), after growing by 3% in 2011 and 2012. Unemployment remained high but stable, at 13.2% of the the labour force in 2013.

A new team at the economy's bedside

President Rouhani is considered a moderate. Shortly after his election in June 2013, he stated in parliament that 'there must be equal opportunities for women,' before going on to appoint two women vice-presidents and the first woman spokesperson in the Ministry of Foreign Affairs. He has also pledged to expand internet access (26% in 2012). In an interview with NBC News[9] in September 2013, he said that 'we want the people, in their private lives, to be completely free. In today's world, having access to information and the right of free dialogue and the right to think freely is a right of all peoples, including Iranians. The people must have full access to all information worldwide.' In November 2014, he reinstated the Management and Planning Organization.

4. President Rouhani said that 'scientific evolution will be achieved by criticism […] and the expression of different ideas. […] Scientific progress is achieved, if we are related to the world. […] We have to have a relationship with the world, not only in foreign policy but also with regard to the economy, science and technology. […] I think it is necessary to invite foreign professors to come to Iran and our professors to go abroad and even to create an English university to be able to attract foreign students.'

5. See : http://econano.ir

6. See, for example : http://fararu.com/fa/news/213322

7. The Management and Planning Organization was renamed the Presidential Deputy for Strategic Monitoring.

8. The Hi-Tech Development Fund has meanwhile been helping some enterprises to adopt energy-saving technologies. See (in Persian): www.hitechfund.ir

9. See : http://english.al-akhbar.com/node/17069

President Rouhani's domestic priorities are to create an environment more conducive to business and to tackle the acute problems of high unemployment, hyperinflation and inadequate purchasing power: GDP per capita amounted to PPP$ 15 586 (in current prices) in 2012, less than the previous year (PPP$ 16 517).

In 2014, the president instituted two major projects. The first was the *Second Phase of the Subsidy Reform Plan* initiated by his predecessor, which entailed a 30% price rise on petrol. His second major project has been the *Health Overhaul Plan*. This plan reduces the cost of treatment for patients in state-run hospitals from 70% to 5% in rural areas and 10% in urban areas. About 1.4 million patients have been admitted to state-run hospitals since the plan's inception. Some 3 000 specialists have been employed by the ministry to work in vulnerable regions, 1 400 of whom had taken up their positions by the end of 2014. According to Iran's health minister, the plan is not facing any financial problems in its first two years of operation but some health policy experts worry that the government may not be able to pursue this policy for long, owing to the high cost. Six million people have received health insurance since the plan's implementation, according to the health minister, most of them from the poorer echelons of society.

According to the Iranian economic journalist Saeed Leylaz, 'the country's economic condition was not predictable in the past government but the current government has managed to stabilize the economy. This helped make people reluctant to buy dollars for the purpose of saving. The government has also reduced political tensions and refrained from impulsive acts in the economy' (Leylaz, 2014).

Iran's economic outlook is brighter, thanks partly to the resumption of negotiations with the P5+1. The Iranian Central Bank announced growth of 3.7% in 2014, inflation was down to 14.8% and the unemployment rate down to 10.5%. Non-oil exports are growing. Iran nevertheless remains highly dependent on oil. The *Wall Street Journal* estimated that Iran needed a crude oil brent of US$ 140 in 2014 to balance its budget, the year world oil prices tumbled from US$ 115 to US$ 55 between June and December (see Figure 17.2).

Fluctuating global oil prices have spawned fresh challenges. Iran has recently been using new technologies like hydroconversion in its terminals to diversify its oil products. The sharp decline in the price of crude oil since 2014 may prevent the government from investing as much as it would like in research and development (R&D) into advanced oil extraction technologies. An alternative would be for Iran to develop these technologies jointly with Asian oil companies.

TRENDS IN STI GOVERNANCE

Sanctions precipitating shift to a knowledge economy

They say that every cloud has a silver lining. Indirectly, international sanctions have had some benefits for science, technology and innovation (STI):

- *Firstly,* they have accelerated the shift from a resource-based economy to a knowledge economy. There tends to be a weak link between the oil industry and other socio-economic sectors. Companies deprived of oil and gas revenue have shown a propensity to export technical and engineering services to neighbouring countries. According to a report by the Mehr news agency in November 2014 which cited the deputy energy minister for international affairs, Iran currently exports water and technological power services worth over US$ 4 billion to more than 20 countries.[10]
- *Secondly,* the sanctions have helped to reconcile R&D with problem-solving and public interest research, after years of high oil receipts had divorced science from socio-economic preoccupations.
- *Thirdly*, the sanctions have helped small and medium-sized enterprises (SMEs) develop their businesses by erecting barriers to foreign imports and encouraging knowledge-based enterprises to localize production. With unemployment high and Iranians well-educated, they have had no difficulty recruiting trained staff.
- *Fourthly,* by isolating Iranian companies from the outside world, the sanctions have forced them to innovate.
- *Last but not least,* the sanctions have persuaded policy-makers of the need to embrace the knowledge economy.

The government's policy of developing a knowledge economy is reflected in its *Vision 2025* document adopted in 2005, which offers a recipe for turning Iran into the number one economy in the region[11] and one of the top 12 economies in the world by 2025.

Vision 2025 foresees an investment of US$ 3.7 trillion by 2025 to achieve this goal, nearly one-third of which (US$ 1.3 trillion) is to come from foreign sources. Much of this amount is to go towards supporting investment in R&D by knowledge-based firms and the commercialization of research results. A law was passed in 2010 to provide an appropriate funding mechanism, the Innovation and Prosperity Fund, which became effective in 2012 (see p. 394).

10. including Afghanistan, Azerbaijan, Ethiopia, Iraq, Kenya, Oman, Pakistan, Sri Lanka, Syria, Tajikistan and Turkmenistan

11. *Vision 2025* defines this region as encompassing: Afghanistan, Armenia, Azerbaijan, Bahrain, Egypt, Georgia, Iran, Iraq, Israel, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Lebanon, Oman, Pakistan, Palestine, Qatar, Saudi Arabia, Syria, Tajikistan, Turkey, Turkmenistan, United Arab Emirates, Uzbekistan and Yemen.

Given the persistently low level of foreign direct investment (FDI) – just 0.8% of GDP in 2013 – coupled with Iran's economic woes, several of *Vision 2025's* goals seem unrealistic. A classic example is the target of raising gross domestic expenditure on R&D (GERD) to 4% of GDP by 2025. Other goals seem within reach, such as that of tripling the number of scientific articles to 800 per million population (Table 15.1).

In 2009, the government adopted a *National Master Plan for Science and Education* to 2025 which reiterates the goals of *Vision 2025*. It lays particular stress on developing university research and fostering university–industry ties to promote the commercialization of research results.

A focus on fostering innovation and excellence

The country's successive five-year development plans set out to realize collectively the goals of *Vision 2025*. Adopted by law, these plans also provide the most important institutional basis for STI policy in Iran. The current *Fifth Five-Year Economic Development Plan* covers the period from 2010 to 2015. The chapters relative to higher education and STI policy complement those of the *National Master Plan for Science and Education*.

Under the section on social affairs, the *Fifth Five-Year Economic Development Plan* speaks of developing indicators to measure the quality of the air, food and the environment in general, and undertakes to reduce health-threatening pollution. It also vows to reduce the population's share of health costs to 30% by 2015.

The *Fifth Development Plan* has two main thrusts relative to STI policy. The first is the 'islamization of universities,' which has become a political topic in Iran. The second thrust is to secure second place for Iran in the region in science and technology (S&T) by 2015, which would place it behind Turkey.

The notion of the islamization of universities is open to broad interpretation. The aim seems to be to nationalize scientific knowledge in the humanities and bring it into line with Islamic values, while developing student morals and spirituality. According to Article 15 of the *Plan*, university programmes in the humanities are to be modified as part of this strategy and students are to be taught the virtues of critical thinking, theorization and multidisciplinary studies. A number of research centres are also to be developed in the humanities.

Table 15.1: **Key targets for education and research in Iran to 2025**

	Situation in 2013	Vision 2025 targets
Share of adults with at least a bachelor's degree	–	30%
Share of PhD holders among total students	1.1%$^{-1}$	3.5%
Researchers (FTE) per million population	736^{-3}	3 000
Government researchers (share of total researchers)	33.6%$^{-5}$	10%
Researchers in business enterprise sector (share of total researchers)	15.0%$^{-5}$	40%
Share of researchers employed by universities*	51.5%$^{-5}$	50%
Full-time university professors per million population	1 171	2 000
Scientific articles per million population	239	800
Average citations per publication **	0.61^{-2}	15
Number of Iranian journals with an impact factor of more than 3	–	160
Number of national patents	–	50 000
Number of international patents	–	10 000
Public expenditure on education as a share of GDP	3.7%	7.0%
Public expenditure on higher education as a share of GDP	1.0%$^{-1}$	–
GERD/GDP ratio	0.31%$^{-3}$	4.0%
Share of GERD financed by business enterprise sector	30.9%$^{-5}$	50%
Share of articles among 10% most cited worldwide	7.7%$^{-2}$	–
Number of articles among 10% most cited worldwide	1 270^{-2}	2 250
Number of Iranian universities in top 10% worldwide	0	5

*includes religious centres

**average relative citations; the OECD average in 2011 was 1.16

-n/+n refers to *n* years before reference year

Source: for 2025 targets: Government of Iran (2005) *Vision 2025*; for current situation, Statistical Centre of Iran and UNESCO Institute for Statistics

The following strategies have been devised to secure second place for Iran in S&T in the region:

- a comprehensive system is to be put in place for monitoring, evaluating and ranking institutions of higher education and research institutes. The Ministry of Science, Research and Technology and the Ministry of Health and Medical Education have been entrusted with this task. Researchers will be evaluated on the basis of criteria such as their scientific productivity, their involvement in applied R&D or the problem-solving nature of their work;
- in order to ensure that 50% of academic research is oriented towards socio-economic needs and problem-solving, promotion is to be tied to the orientation of research projects. In addition, mechanisms are to be put in place to enable academics to enrol in further education, take sabbaticals and explore new research opportunities. Research and technology centres are also to be set up on campus and universities are to be encouraged to develop linkages with industry;
- The number of university graduate programmes in applied disciplines is to increase;
- Each university is to be endowed with an academic board that oversees implementation of the academic programme;
- Laboratories in applied science are to be set up and equipped at universities, other educational institutions, in science and technology parks and business incubators by public research institutions and their subsidiaries;
- The GERD/GDP ratio is to increase by 0.5% each year to attain 3% by 2015;
- FDI is to account for 3% of GDP by 2015;
- Scientific ties are to be developed with prestigious international educational and research institutions;
- An integrated monitoring and evaluation system is to be put in place for S&T;
- Major indicators of S&T are to be incorporated in government planning, including the volume of revenue generated by exports of medium-tech and high-tech goods, the share of GDP per capita derived from S&T, the number of patents, the share of FDI in scientific and technological activities, the cost of R&D and the number of knowledge-based companies.

The following priorities focus on technology diffusion and support for knowledge-based companies:

- Priority is to be given in the annual R&D budget of ministries to financing demand-driven research and to supporting the development of private and co-operative SMEs which commercialize knowledge and technology and turn them into export products; the government is to encourage the private sector to set up business incubators and science and technology parks and to encourage foreign parties to invest in technology transfer and R&D, in partnership with domestic companies; foreign investors are also to be encouraged to finance patents; the government is to support the establishment of totally private knowledge-based companies by universities; innovators and leaders in science are to receive targeted financial and intellectual support from the government to support the commercialization of their inventions; the government is to make provisions for the payment of patent application costs at both national and international levels and, lastly, to make arrangements for the commercial release of their product or service (Articles 17 and 18);
- The Ministry of Communications and Information Technology is to develop the necessary infrastructure, such as the installation of fibre optics, to ensure broadband internet access, to enable universities, research bodies and technological institutions to network and share information and data on their respective research projects, intellectual property issues and so on (Article 46);
- A National Development Fund (Articles 80–84) is established to finance efforts to diversify the economy; preserve part of oil and gas rents for future generations; and increase the return on income from accumulated savings; by 2013, the Fund was receiving 26% of oil and gas revenue – the ultimate goal is to reserve 32% of this revenue for the Fund (IMF, 2014);
- New campuses are to be launched in special economic zones by public and private Iranian universities and international leading universities (Article 112);
- Closer ties are to be forged between small, medium-sized and large businesses and, in parallel, industrial clusters are to be set up. Private sector investment is to be encouraged to develop the value chain of downstream industries (petrochemicals, basic metals and non-metallic mineral products), with an emphasis on the establishment of professional industrial estates and the development of closer linkages between industry and science and technology parks to develop capacity for industrial design, procurement, innovation and so on (Article 150).

The pivotal role of the Innovation and Prosperity Fund

The Innovation and Prosperity Fund functions under the Deputy for Science and Technology. It was established in 2012 to support investment in R&D by knowledge-based firms and the commercialization of research results.

According to the Fund's president, Behzad Soltani, 4 600 billion Iranian rials (*circa* US$ 171.4 million) had been allocated to 100 knowledge-based companies by late 2014. Sorena Sattari, Vice-President for Science and Technology, declared[12] on 13 December 2014 that, 'in spite of the difficulties the country is confronting, 8 000 billion rials have been attributed to the Innovation and Prosperity Fund for 2015.'

The Innovation and Prosperity Fund is the primary policy instrument for ensuring the implementation of Articles 17 and 18 of the *Fifth Five-Year Economic Development Plan:*

- National organizations wishing to conduct problem-solving research may apply for the allocation of facilities and partnering to the Secretariat of the Working Group for the Assessment and Identification of Knowledge-based Companies and Institutions and Supervision of Project Implementation.
- Universities wishing to set up fully private companies may also apply to the fund; as of December 2014, public and private universities from four Iranian provinces had applied to establish knowledge-based companies in special economic zones (Article 112): Tehran, Isfahan, Yazd and Mashhad. These applications are still under review, according to the Supreme Council of Science, Research and Technology.
- The fund also supports SMEs by offering tax incentives and paying partial costs of commercializing knowledge and technology; it also covers part of the interest on bank loans contracted for the purchase of equipment, the setting up of production lines, testing and marketing, etc.;
- The fund also offers financial support to private companies wishing to set up business incubators and science and technology parks then facilitates the establishment of these centres through such measures as the provision of rent-free premises and tax incentives.

The fund is also intended to encourage foreign parties to invest in technology transfer and R&D but this ambition has been somewhat thwarted by the international sanctions; foreign companies may still invest in patents, however.

Innovators and leaders in science receive intellectual and financial support from the National Elites Foundation, which was set up[13] in 1984. In December 2013, a new department was created within the foundation, called the Deputy of International affairs. It aims to harness the talent of non-resident Iranians to improve domestic capacity in S&T and take advantage of the experience of the diaspora. The foundation tailors its services to four different groups: Iranian PhD graduates from the world's top universities; Iranian professors teaching in the world's top universities; Iranian experts and managers heading the world's top scientific centres and companies in technological fields and, lastly, non-resident Iranian investors and entrepreneurs who have succeeded in technological fields. The eligibility criteria were revised in 2014 to include groups as well as individuals and research expertise and experience as well as academic performance. The selection of elites has also been delegated to the universities. Additional incentive measures have been introduced, such as grants for research visits to top universities abroad and research grants from day one of a faculty member's career.

Enter the 'economy of resistance'

On 19 February 2014, the Supreme Leader Ayatollah Ali Khamenei introduced, by decree, what he termed Iran's 'economy of resistance.' This economic plan outlines strategies for making Iran more resilient to sanctions and other external shocks. It essentially reasserts the goals of *Vision 2025*, which is why some key provisions will sound familiar.

Coming when it did, some analysts see the economy of resistance as an endorsement of the new government's comprehensive economic reform, after the previous administration's relative indifference towards *Vision 2025* caused it to veer off course. For Khajehpour (2014a), a managing partner at Atieh, a group of strategic consulting firms based in Tehran, Iran 'has all the resources that an economy would need to play a much more significant role on the international stage. The missing links are in the areas of responsible and accountable policy-making, legal transparency and modern institutions.'

Key provisions of the 'economy of resistance' include (Khajehpour (2014a):

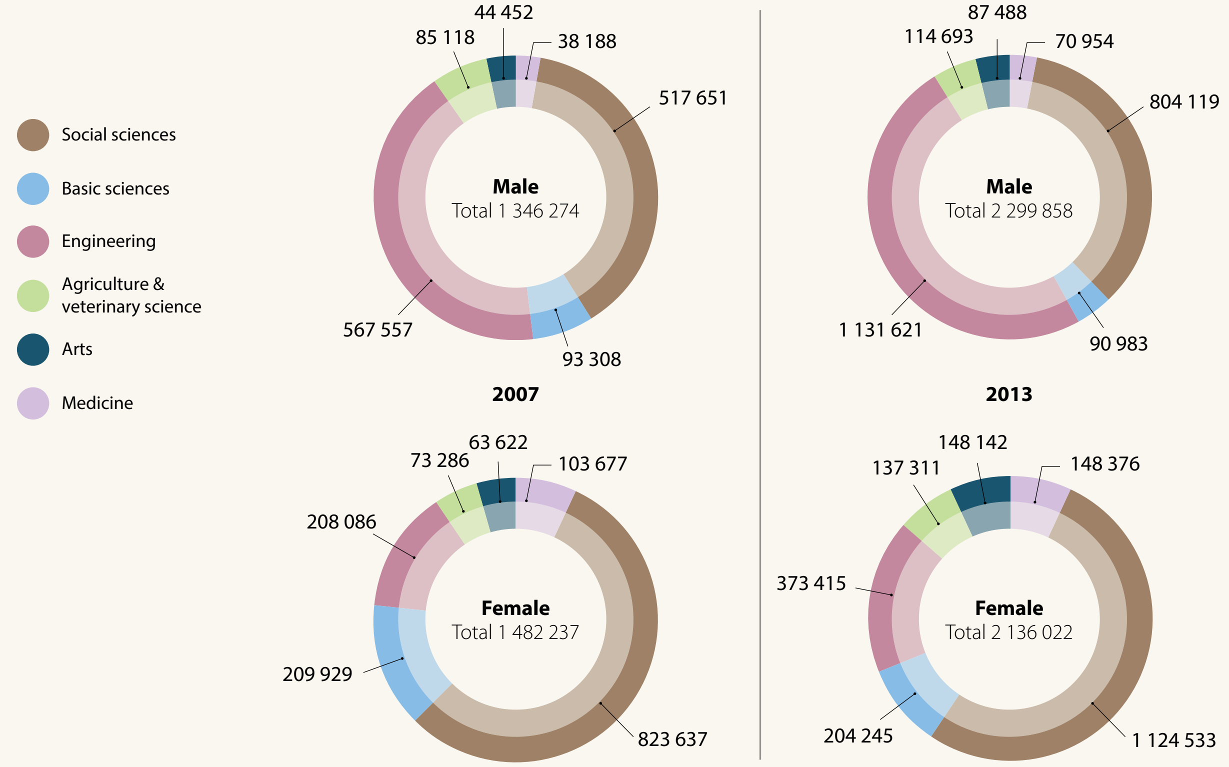
- promoting a knowledge-based economy through the drafting and implementation of a comprehensive scientific plan for the country and the promotion of innovation, the ultimate goal being to become the top knowledge-based economy in the region;
- utilizing the reform of subsidies to optimize energy consumption in the country, increase employment and domestic production and promote social justice;
- promoting domestic production and consumption, especially in strategic products and services, to reduce dependence on imports, while improving the quality of domestic production;
- providing food and medicine security;
- promoting exportable goods and services through legal and administrative reform, while promoting FDI for export purposes;

12. See (in Persian): www.nsfund.ir/news

13. See: http://en.bmn.ir

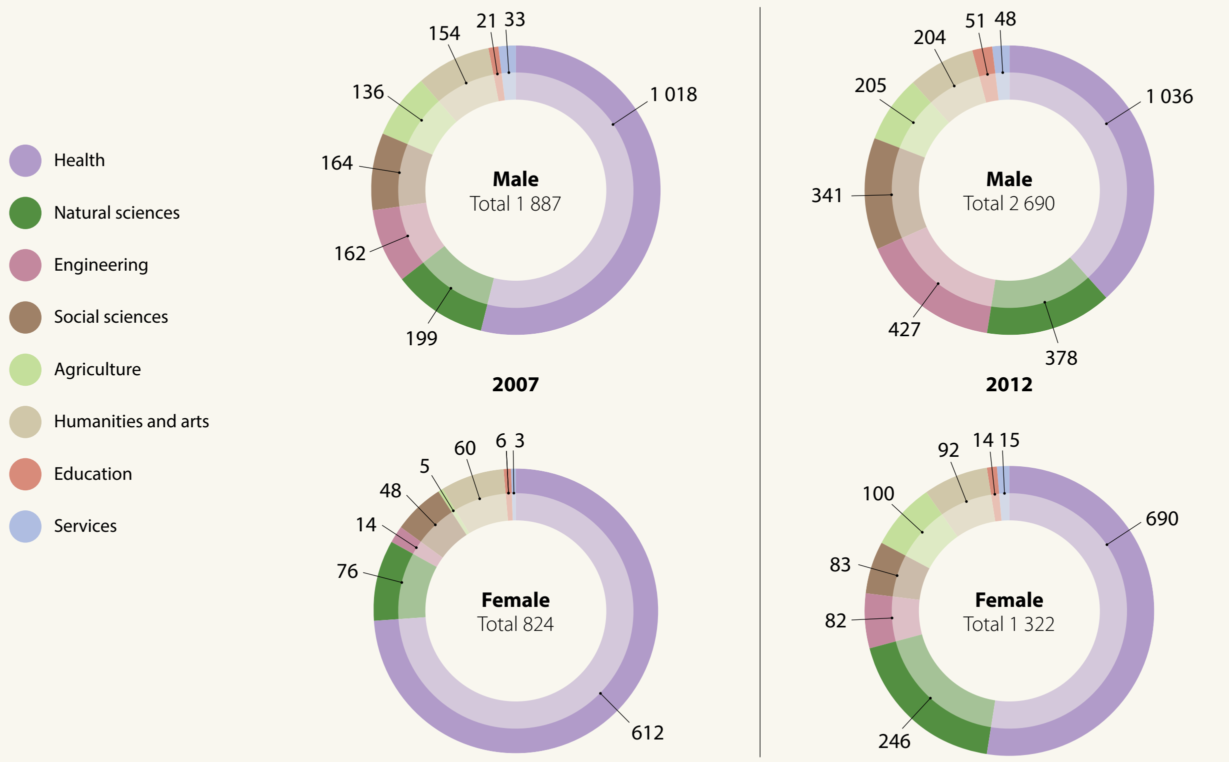
Figure 15.2: **Students enrolled in Iranian universities, 2007 and 2013**

Both public and private universities



Source: Iranian Statistical Centre (2014) *Statistical Yearbook*

Figure 15.3: **PhD graduates in Iran by field of study and gender, 2007 and 2012**



Source: UNESCO Institute for Statistics

- increasing the economy's resistance through regional and international economic collaboration, especially with neighbours but also through diplomacy;
- increasing oil and gas value-added exports;
- implementing reforms to rationalize government costs, increase tax revenues and reduce dependency on oil and gas export revenue;
- increasing the share of the National Development Fund from oil and gas export revenues;
- increasing transparency in financial matters and avoiding activities that pave the way for corruption.

TRENDS IN HUMAN RESOURCES AND R&D

Strong growth in students but no rise in R&D intensity

Between 2005 and 2010, policy-makers focused on increasing the number of academic researchers, in line with *Vision 2025.* To this end, the government raised its commitment to higher education to 1% of GDP in 2006 and has since maintained this level, even as public expenditure on education overall has slipped from 5.1% (2006) to 3.7% (2013) of GDP.

The result has been a steep rise in tertiary enrolment. Between 2007 and 2013, student rolls swelled from 2.8 million to 4.4 million in the country's public and private universities (Figure 15.2). There were more women students than men in 2007 but their proportion has since dropped back slightly to 48%. Some 45% of students were enrolled in private universities in 2011 (UIS, 2014).

Enrolment has progressed in most fields, with the exception of natural sciences where it has remained stable. The most popular fields are social sciences (1.9 million students) and engineering (1.5 million). There are more than 1 million men studying engineering and more than 1 million women studying social sciences. Women also make up two-thirds of medical students.

The number of PhD graduates has progressed at a similar pace (Figure 15.3). Natural sciences and engineering have proved increasingly popular among both sexes, even if engineering remains a male-dominated field. In 2012, women made up one-third of PhD graduates, being drawn primarily to health (40% of PhD students), natural sciences (39%), agriculture (33%) and humanities and arts (31%). According to the UNESCO Institute for Statistics, 38% of master's and PhD students were studying S&T fields in 2011 (UIS, 2014).

Although data are not readily available on the number of PhD graduates choosing to stay on as faculty, the relatively modest level of GERD would suggest that academic research suffers from inadequate funding. A study by Jowkar *et al.* (2011) analysed the impact of 80 300 Iranian articles published between 2000 and 2009 in Thomson Reuter's Science Citation Index Expanded; it found that about 12.5% of these publications were funded and that the citation rate of funded publications was higher in almost all subject fields. The greatest share of funded publications came from universities subordinate to the Ministry of Science, Research and Technology.

Even though one-third of GERD came from the business sector[14] in 2008, this contribution remains too small to nurture innovation effectively – it represents just 0.08% of GDP. GERD even dropped between 2008 and 2010 from 0.75% to 0.31% of GDP. In this context, the target identified in the *Fifth Five-Year Development Plan* (2010–2015) of devoting 3% of GDP to R&D by 2015 looks elusive, to say the least.

According to the UNESCO Institute for Statistics, the number of full-time equivalent (FTE) researchers rose from 711 to 736 per million inhabitants between 2009 and 2010. This corresponds to an increase of more than 2 000 researchers, from 52 256 to 54 813.

Businesses are performing more R&D than before

In 2008, half of researchers were employed in academia (51.5%), one-third in the government sector (33.6%) and just under one in seven in the business enterprise sector (15.0%).

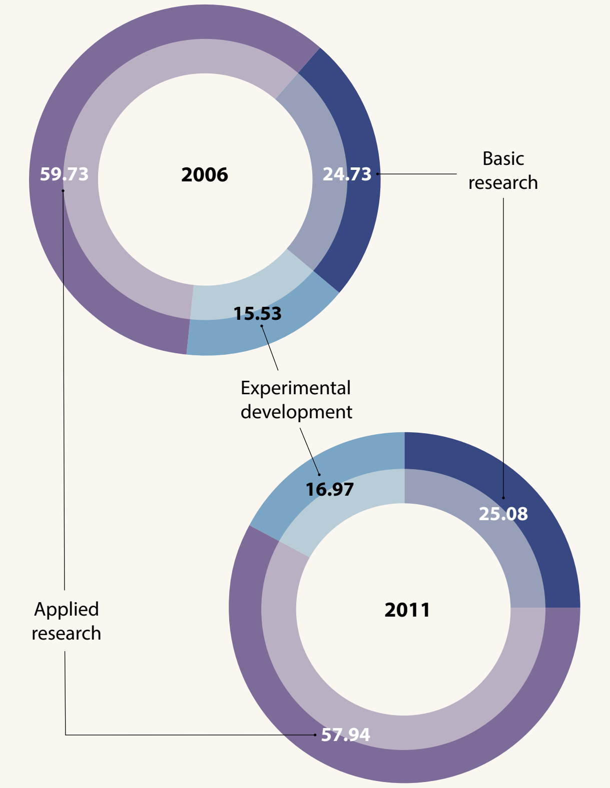
Between 2006 and 2011, the number of firms declaring R&D activities more than doubled, however, from 30 935 to 64 642. Once more recent data become available, we may find that the business enterprise sector has been hiring more researchers than before. So far, there has been little change in the focus of industrial R&D, with firms still conducting mainly applied research (Figure 15.4).

More articles but few technological spin-offs

One priority of STI policy in recent years has been to encourage scientists to publish in international journals. Again, this is in line with *Vision 2025*. As we have seen, the share of internationally co-authored articles has remained relatively stable since 2002. The volume of scientific articles has augmented considerably, on the other hand, even quadrupling by 2013 (Figure 15.1). Iranian scientists now publish widely in international journals in engineering and chemistry, as well as in life sciences and physics. Contributing to this trend is the fact that PhD programmes in Iran now require students to have publications in the Web of Science. Women contribute only about 13% of articles, with a focus on chemistry, medical sciences and social sciences, according to Davarpanah and Moghadam (2012).

14. Data are unavailable for a more recent breakdown by sector.

Figure 15.4: **Focus of Iranian firms by type of research, 2006 and 2011 (%)**



Source: Iranian Statistical Centre

This productivity gain has had little effect on the production of technology, however. In nanotechnology, for instance, Iranian scientists and engineers were only granted four patents by the European Patent Office between 2008 and 2012. The lack of technological output results mainly from three shortcomings in the innovation cycle. The first among these shortcomings is the failure to co-ordinate executive and legal power structures to strengthen intellectual property protection and the wider national innovation system, despite this being a key policy objective for over a decade now. In the *Third Five-Year Development Plan, 2000–2004,* the co-ordination of all scientific activities was entrusted to the Ministry of Science, Research and Technology, to avoid overlap with other ministries (health, energy, agriculture, etc.). The post of Presidential Deputy for Science and Technology[15] was likewise created in 2005 to centralize the budget and planning of all S&T activities. Little has been done since, however, to improve co-ordination between administrative bodies in the executive branch and judiciary.

The past few years have witnessed persistent inattention to problem-solving in decision-making and little effort to improve the country's inadequate system of intellectual property protection. These two shortcomings do more to weaken the national innovation system than either the lack of available venture capital or the international sanctions.

Why the persistent inattention to problem-solving, despite a plethora of documents? This is because public policy in Iran combines strategic planning with poetic idealism. Official policy documents are a mixture of declarations of intent and copious recommendations – even though, when everything is a priority, nothing is. A more complex and detailed alternative is required, a planning model that does not elaborate recommendations until the issues and related policy questions have first been clearly defined and the legal context analysed, a model which comprises an implementation plan and a rigorous monitoring and evaluation system.

PRIORITY AREAS FOR R&D

Most high-tech companies are state-owned

Some 37 industries trade shares on the Tehran Stock Market. These industries include the petrochemical, automotive, mining, steel, iron, copper, agriculture and telecommunications industries, a unique situation in the Middle East.

Most of the companies developing high technology in Iran are state-owned. The Industrial Development and Renovation Organization (IDRO) controls about 290 of them. IDRO has also set up special purpose companies in each high-tech sector[16] to co-ordinate investment and business development. In 2010, IDRO set up a capital fund to finance the intermediary stages of product- and technology-based business development.

Some 80% of state-owned firms are due to be privatized over the ten years to 2014, further to an amendment to Article 44 of the Constitution in 2004. In May 2014, Tasnim News Agency quoted Abdollah Pouri Hosseini, the head of the Iran Privatization Organization, as saying that Iran would be privatizing 186 state-run companies in the new year (beginning 21 March 2014 in Iran). Twenty-seven of these companies have a market value each in excess of US$ 400 million, he said. Several key industries remain largely state-owned, however, including the automotive and pharmaceutical industries (Boxes 15.1 and 15.2).

Iran's R&D priorities are reflected in their share of government outlay (Table 15.2). In basic and applied science, the priority fields

15. In Iran, each vice-president has several deputies. Under the Vice-President for Science and Technology, for instance, there is a Deputy for Science and Technology, a Deputy for Management Development and Resources and a Deputy for International Affairs and Technological Exchange.

16. These entities are the Life Science Development Company, Information Technology Development Centre, Iran InfoTech Development Company and the Emad Semiconductor Company.

are dense matter, stem cells and molecular medicine, energy recycling and conversion, renewable energies, cryptography and coding. The priority technological industries are aerospace, ICTs, nuclear technology, nanotechnology and microtechnologies, oil and gas, biotechnology and environmental technologies.

In aerospace, Iran manufactures aeroplanes, helicopters and drones. It is currently developing its first wide-body plane[17] to improve seating capacity, as the country only has about nine aircraft per million population. The industry plans to shift its focus from 59-seaters to planes that can seat 90–120 passengers, as long as it can import the relevant technical knowledge.

Meanwhile, the Iranian Space Agency has built a number of small satellites that are launched into low-Earth orbit using a locally produced carrier rocket called Safir. In February 2012, Safir transported its biggest satellite yet, weighing 50 kg (Mistry and Gopalaswamy, 2012).

17. After purchasing the production license for the An-140 from Ukraine in 2000, Iran built its first Iran-140 commercial passenger plane in 2003.

A growing role in biotechnology and stem cell research

Research in biotechnology has been overseen by the Iranian Biotechnology Society since 1997. Iran maintains three important health research[18] facilities. Two of these, the Pasteur Institute and the National Research Centre for Genetic Engineering and Biotechnology, study human pathologies. The third, the Razi Institute for Serum and Vaccines, studies both human and animal diseases. The Razi and Pasteur Institutes have been developing and producing vaccines for humans and livestock since the 1920s. In agricultural biotechnology, researchers are hoping to improve crop resistance to pests and disease. The Persian Type Culture Collection is a subordinate of the Biotechnology Research Centre in Tehran, which falls under the umbrella of the Iranian Research Organization for Science and Technology (IROST); it provides services to both private industry and academia.

18. See: www.nti.org/country-profiles/iran/biological

Box 15.1: **Automobiles dominate Iranian industry**

After oil and gas, the automotive industry is Iran's biggest, accounting for about 10% of GDP and employing about 4% of the labour force. There was a boom in local car manufacturing between 2000 and 2013, driven by high import duties and a growing middle class. In July 2013, sanctions imposed by the USA prevented Iranian companies from importing the vehicle parts upon which domestic cars rely; this caused Iran to cede its place to Turkey as the region's top vehicle manufacturer.

The Iranian car market is dominated by Iran Khodro (IKCO) and SAIPA, which are subsidiaries of the state-owned Industrial Development and Renovation Organization. SAIPA (standing for *Société anonyme iranienne de production automobile)* was founded in 1966 to assemble French Citroën cars under license for the Iranian market. IKCO was founded in 1962 and, like SAIPA, assembles European and Asian cars under license, as well as its own brands.

In 2008 and 2009, the government spent over US$ 3 billion on developing infrastructure to enable vehicles to run on compressed natural gas. The aim was to reduce costly petrol imports due to an insufficient refining capacity in Iran. With the world's biggest natural gas reserves after the Russian Federation, Iran rapidly became the world leader for the number of vehicles running on natural gas: by 2014, there were over 3.7 million on the road.

In 2010, the government reduced its participation in both companies to about 20% but the deals were annulled the same year by the Iranian Privatization Organization.

IKCO is the biggest car manufacturer in the Middle East. In 2012, it announced that it would henceforth be reinvesting at least 3% of company sales revenue in R&D.

For years, Iranian carmakers have used nanotechnology to increase customer satisfaction and safety by providing such comforts as anti-stain dashboards, hydrophobic glass planes and anti-scratch paint. In 2011, the Nanotechnology Initiative Council announced plans to export to Lebanon a series of 'home-made' nano-based engine oils manufactured by the Pishgaman–Nano-Aria Company (PNACO); these nano-based oils reduce engine erosion, fuel consumption and engine temperature. In 2009, researchers at Isfahan University of Technology developed a strong but light nanosteel as resistant to corrosion as stainless steel for use in road vehicles but also potentially in aircraft, solar panels and other products.

The sanctions imposed in 2013 hit exports particularly hard, which had doubled to about 50 000 cars between 2011 and 2012. This prompted IKCO to announce plans in October 2013 to begin selling 10 000 cars a year to the Russian Federation. Traditional export markets include Syria, Iraq, Algeria, Egypt, Sudan, Venezuela, Pakistan, Cameroon, Ghana, Senegal and Azerbaijan. In 2014, French car-makers Peugeot and Renault resumed their traditional business with Iran.

Source: http://irannano.org; Rezaian (2013); Press TV (2012)

Table 15.2: **Government outlay for R&D in Iran by major agency, 2011**

	R&D centre	Budget (million rials)
Deputy for Science and Technology		1 484 125
Supports the following R&D centres	Nanotechnology Initiative Council	482 459
	Centre for the Development of Knowledge-Based Companies	110 000
	Biotechnology Research Centre	100 686
	Centre for the Development of Drugs and Traditional Medicine	90 000
	Centre for Stem Cell Research	75 000
	Centre for New Energy Development	65 000
	Centre for ICT Development and Microelectronics	60 000
	Centre for Cognitive Science	56 274
	Centre for Water, Drought, Erosion and Environmental Management	50 000
	Centre for Software Technologies	10 000
Ministry of Science, Research and Technology		1 356 166
	Iranian Space Agency	85 346
	Iranian Research Organization for Science and Technology	357 617
Ministry of Defence		683 157
Ministry of Health and Medical Training		656 152
Ministry of Industry		–
	Industrial Development and Renovation Organization	536 980
	Iranian Fisheries Research Organization	280 069
	Iran Aviation Industries Organization	156 620
Ministry of Energy		38 950
	Atomic Energy Organization	169 564
	Research Institute of the Petroleum Industry	480 000
	Renewable Energy Organization (SUNA)	12 000
Ministry of Information and Communication Technology		440 000
Ministry of Agriculture		86 104
Other		33 147 411
	95 universities and 72 institutions affiliated to the Ministry of Science, Research and Technology	
	84 universities and 16 institutions affiliated to the Ministry of Health and Medical Training	
	22 universities and institutions affiliated to the Ministry of Defence	
	32 science and technology parks	
	184 institutions affiliated to the Ministries of Industry and Agriculture	
	23 institutions affiliated to the Presidency	
	63 other organizations	
Total		**41 069 680**

Note: The three following centres were established in 2014 under the Deputy for Science and Technology: the Centre for Oil, Gas and Coal Research; Centre for the Optimization of Energy and the Environment; and the Centre for Knowledge-based Marine Companies. The budget for each ministry does not cover the universities and other institutions associated with it.

Source: www.isti.ir; compiled by author with input from the National Research Institute for Science Policy

Box 15.2: The ups and downs of Iran's pharmaceutical industry

There are currently 96 local manufacturers in Iran which produce some 30 billion units of medicine worth about US$ 2 billion per year. Local production covers about 92% of the Iranian market but does not include high-quality drugs needed for the specific treatment of diabetes, cancer, etc. These drugs need to be imported, at a cost of about US$ 1.5 billion. As the market volume represents US$ 3.5 billion, this means that 43% of demand is met through imports.

Of the 96 local companies, about 30 control 85% of the market. The biggest four players are Daroupakhsh, Jaberebne Hayyan, Tehran Shimi and Farabi, in descending order. These four companies alone account for more than 20% of the market. Local manufacturers still rely on outdated production lines, making the cost of pharmaceutical manufacturing relatively high in Iran and thus expensive for consumers.

Foreign pharmaceutical companies in Iran usually operate either directly through their branch offices or through dealerships with Iranian pharmaceutical companies authorized to sell their products.

In Iran, per capita expenditure on medicine stood at US$ 46 in 2011. The pharmaceutical industry has a profit margin of about 14%. This is three times the profit margin of the Iranian automotive industry. Most pharmaceutical companies are state-owned or quasi-governmental entities, although some are listed on the Tehran Stock Exchange. The private sector's share of the market only amounts to about 30%. Pharmaceutical companies export drugs to about 30 countries, for a market value of US$ 100 million per year.

Under the Ministry of Health and Medical Education, it is the Department of Foods and Drugs which is directly responsible for supervising pharmaceutical companies. The government tends to make all strategic decisions and monitors standards, quality and the payment of subsidies to recipient companies.

In recent years, there has been a growing emphasis on local production and exports to regional markets. Export destinations include Afghanistan, Iraq, Yemen, the United Arab Emirates and Ukraine.

Although the pharmaceutical sector is not included in the sanctions regime – even US pharmaceutical companies can easily apply for licenses from the US Treasury's Office of Foreign Assets Control to export goods to Iran – it is severely undermined by the blanket banking sanctions. Iranian importers complain that Western banks have been declining to enter into transactions related to pharmaceutical imports into Iran. In fact, it is the banking and insurance sanctions which have been the main irritant for all Iranian businesses.

Some Western companies have also reduced their business dealings with Iranian pharmaceutical companies out of fear of contravening the sanctions. This is limiting imports of high-tech machinery, equipment and medicine, including essential drugs for diseases such as cancer, diabetes and multiple sclerosis. Imports from US and European drug-makers were down by 30% in 2012, forcing Iranian companies to import drugs of a lower standard from Asia. The shortage has also pushed up prices, as substitution is not an option in the highly patented world of pharmaceuticals, putting many drugs beyond the reach of the average Iranian. The sanctions also leave Iran short of the hard currency needed to pay for Western drugs.

Source: Khajehpour (2014b); Namazi (2013)

Iranian scientists publish less in agricultural sciences than in medical sciences, although the number of articles has progressed considerably in both fields since 2005. Iran is a growing destination for medical tourism in the Middle East. The Royan Institute, for instance, is a beacon for infertile couples (Box 15.3).

Iran has become a hub for nanotech

Nanotech research has taken off in Iran since the Nanotechnology Initiative Council (NIC)[19] was founded in 2002 (Figure 15.5). NIC's budget increased considerably between 2008 and 2011, from 138 million to 361 million rials; NIC received a lesser endowment in 2012 (251 million rials) but this has since rebounded to 350 million rials (2013).

NIC is tasked with determining the general policies for the development of nanotechnology in Iran and with co-ordinating their implementation. It provides facilities, creates markets and strives to help the private sector develop relevant R&D activities.

There are several nanotechnology research centres in Iran:

- the Nanotechnology Research Centre at Sharif University (est. 2005), which established Iran's first doctoral programme in nanoscience and nanotechnology;
- the Nanotechnology Research Centre at Mashhad University of Medical Sciences within the Mashhad Bu Ali Research Institute (est. 2009);

19. See: www.irannano.org

Box 15.3: The Royan Institute: from infertility treatments to stem cell research

The Royan Institute was founded by Dr Saeid Kazemi Ashtiani in 1991 as a public non-profit research institute for reproductive biomedicine and infertility treatments. It publishes the *Cell Journal* and the *Iranian Journal of Fertility and Sterility,* both of which are indexed in Thomson Reuters' Web of Science. The institute has its own annual prize, the Royan International Research Award.

The Royan Institute is administered by the Jihad Daneshgahi *(jihad* here means sacred effort in a scientific domain), which itself comes under the supervision of the Council of the Cultural Revolution. The institute is officially non-governmental but is, in fact, part of the higher education system and thus government-funded.

In 1998, the institute was approved by the Ministry of Health as a cell-based research centre. Today, it employs 46 scientists and 186 laboratory technicians in three separate institutes: the Royan Institute for Stem Cell Biology and Technology; the Royan Institute for Reproductive Biomedicine; and the Royan Institute for Animal Biotechnology.

One of the institute's first achievements was the birth of a child conceived using *in vitro* fertilization techniques in 1993. A decade later, the institute set up a stem cell research department. In 2003, it developed human embryonic cell lines for the first time. In 2004, researchers succeeded in obtaining insulin-producing cells from human embryonic stem cells. Adult stem cells have been used to treat corneal injuries (to the eye) and myocardial infarctions (heart attacks) in humans.

In 2011, the Royan Institute set up a Stem Cell Bank and a cell-therapy pre-hospital. A year later, the first healthy child was born after being treated for beta-thalassemia, a disease caused by a defect in the gene responsible for producing haemoglobin, an iron-rich protein contained in red blood cells. About 5% of the world's population are healthy carriers of a gene for haemoglobin disorders but these are most common in Asia, the Middle East and the Mediterranean Basin.

Among other achievements, one could cite the birth of the first cloned sheep in Iran in 2006 and that of the first cloned goat in 2009.

The Royan Institute established the Cord Blood Bank in Iran in 2005. In November 2008, the Bank announced that US$ 2.5 billion would be invested in stem cell research over the next five years and that stem cell research centres would be opened in all major cities.

Source: www.royaninstitute.org; PressTV (2008)

- the Medical Nanotechnology and Tissue Engineering Research Centre at the Shahid Beheshti University of Medical Sciences;
- the Nanotechnology Research Centre at Jondi Sapoor University (est. 2010); and
- the Zanjan Pharmaceutical Nanotechnology Research Centre at Zanjan University of Medical Sciences (est. 2012).

Iran's nanotechnology programme is characterized by the following features (Ghazinoory *et al*., 2012):

- policy-making is a top-down process led by the government;
- the programme is futuristic (forward-looking);
- it relies heavily on promotional efforts to stimulate an interest in nanotechnology among policy-makers, experts and the general public, including an annual Nanotechnology Festival in Tehran; the NIC has created a Nano Club[20] for school students and a Nano Olympiad;
- it places emphasis on making all the links in the value chain;
- it makes wide usage of financial support as an incentive;
- it is supply-based, as opposed to needs-based, and relies on Iran's domestic capabilities.

In nanotech, quantity still outstrips quality

One of NIC's missions has been to hoist Iran among the top 15 countries in this field. It has succeeded admirably, as Iran ranked seventh worldwide by 2014 for the volume of papers related to nanotechnology (Figure 15.5). Iran has also progressed rapidly for the number of papers per million inhabitants. In the past decade, 143 nanotech companies have been established in eight industries.

Despite this feat, the average citation rate has dropped since 2009 and few patents are being granted to inventors, as yet. Moreover, the number registered with the European Patent Office and US Patents and Trademark Office dropped from 27 to 12 between 2012 and 2013 after steady growth since 2008.

20. See: nanoclub.ir

Table 15.3: **Growth in Iran's science and technology parks, 2010–2013**

	2010	2011	2012	2013
Number of science and technology parks	28	31	33	33
Number of business incubators	98	113	131	146
Patents generated by science and technology parks	310	321	340	360
Knowledge-based companies established in science and technology parks	2 169	2 518	3 000	3 400
Research personnel working in science and technology parks	16 139	16 542	19 000	22 000

Source: author, based on communication with Ministry of Science, Research and Technology, 2014

A growing network of parks and incubators

Since 2010, five science and technology parks have been set up, along with 48 business incubators (Table 15.3). Whereas some parks specialize, others group a wide spectrum of companies. For instance, the Persian Gulf Science and Technology Park (also known as the Knowledge Village) was set up in 2008; it nurtures companies in all of the following fields: information, communication and electronic technology; nanotechnology; biotechnology; oil, gas and petrochemical; maritime industry; agriculture and the date palm industry; fishing industry and aquatic species; and the food industry.

A survey of about 40 firms established in science and technology parks in Iran's East Azarbaijan Province in 2010 found a correlation between the level of investment in R&D and the extent of innovation; it also revealed that, the longer SMEs had been established in the park, the more innovative they were. On the other hand, the most dynamic firms were not necessarily those with the greatest number of researchers (Fazlzadeh and Moshiri, 2010).

CONCLUSION

Science *can* grow under an embargo

We claimed in the *UNESCO Science Report 2010* that Iranian STI policy was characterized by a science push rather than a technology pull. Today, we could say that STI policy is characterized by a sanctions push rather than a science pull. The increasingly tough sanctions regime since 2011 has oriented the Iranian economy towards the domestic market. By erecting barriers to foreign imports, the sanctions have encouraged knowledge-based enterprises to localize production.

Iran reacted to the sanctions in 2014 by adopting an 'economy of resistance' – a term encompassing both economic policy and STI policy. Policy-makers are being challenged to look beyond extractive industries to the country's human capital for wealth creation, now that they have come to realize that Iran's future lies in the transition to a knowledge economy.

Iranian education policy used to focus on Iran's strength in basic sciences. This focus, together with other factors like the petrodollars windfall, had divorced science from socio-economic needs, as we saw in the *UNESCO Science Report 2010*. The deteriorating economic situation, coupled with a surge in the number of graduate students and the difficulties they encounter in finding work, has created a fertile terrain for a greater focus on applied sciences and technology. In this context, the government's limited budget is being directed towards supporting small innovative businesses, business incubators and science and technology parks, the type of enterprises which employ graduates. In parallel, the Ministry of Science, Research and Technology plans to develop more interdisciplinary university courses and a Master of Business Administration degree, in order to make university curricula more responsive to socio-economic needs.

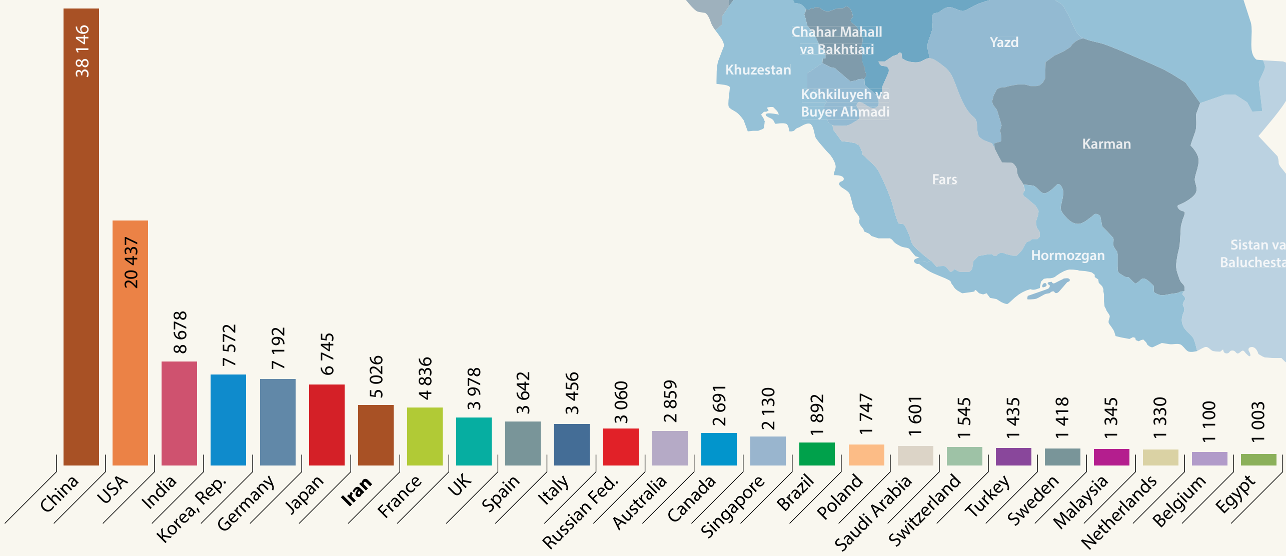
The sanctions have had one unanticipated, yet welcome effect. With the state no longer able to rely on petrodollars to oil the wheels of a sprawling administration, the government has embarked upon reform to reduce institutional costs, introduce a more disciplined budgeting system and improve science governance.

Iran's experience offers a unique perspective. More than any other factor, the growing importance of STI policy in Iran is a consequence of the tougher international sanctions. Science *can* grow under an embargo. This realization offers hope for a brighter future in Iran.

Figure 15.5: **Trends in nanotechnology in Iran**

Iran is now ranked seventh worldwide for the number of nanotech-related papers

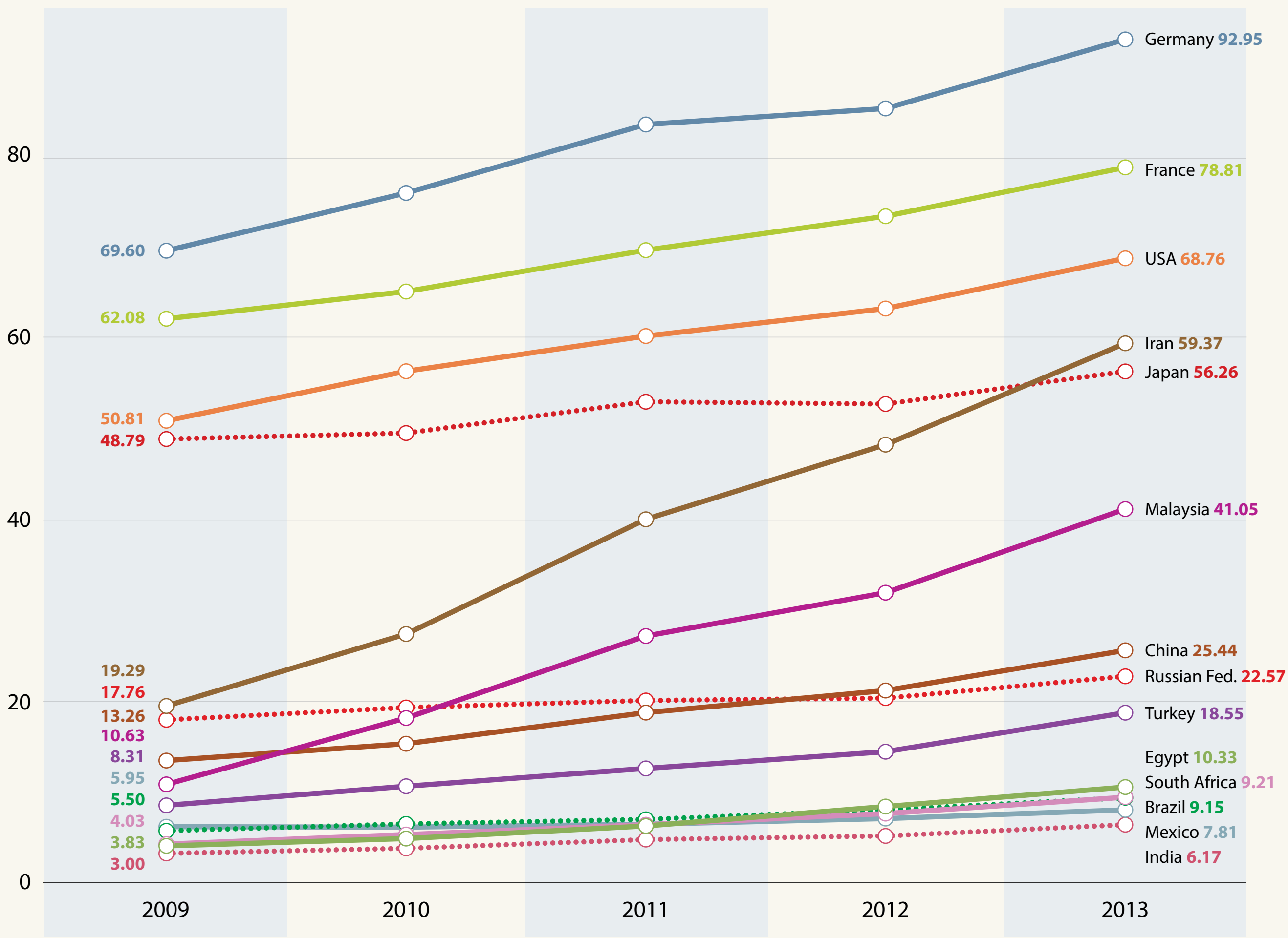
Top 25 for volume of nanotechnology-related papers, 2014



Note: The total for China does not include Taiwan, China , which recorded 3 139 papers in this database in 2014.

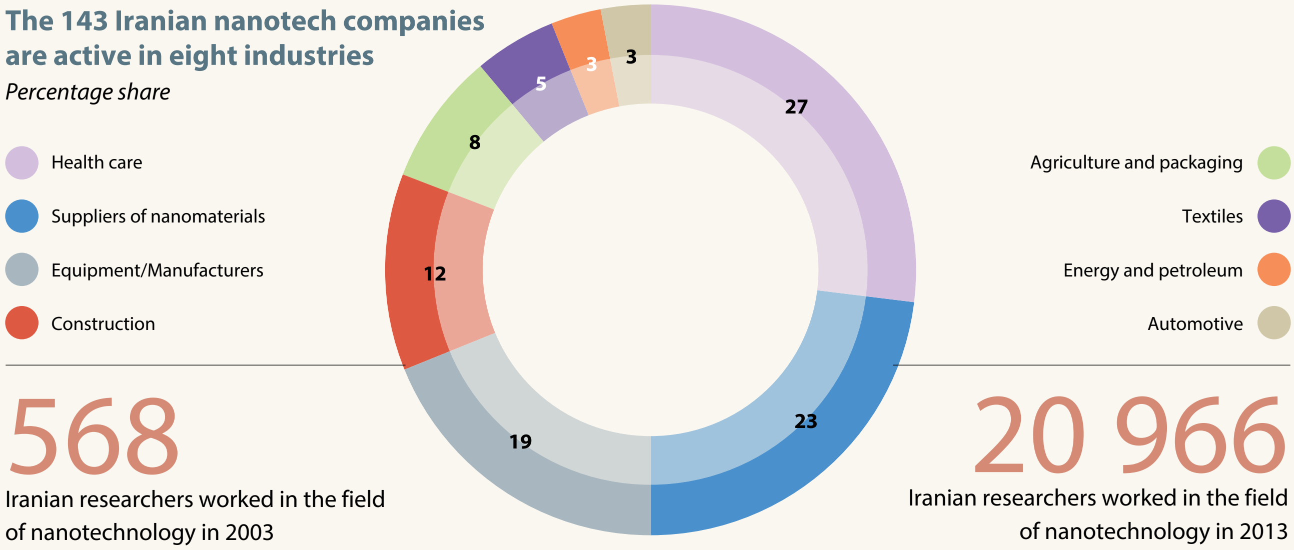
Iran performs well for the number of nanoarticles per million inhabitants

Other countries are given for comparison



The 143 Iranian nanotech companies are active in eight industries

Percentage share



568

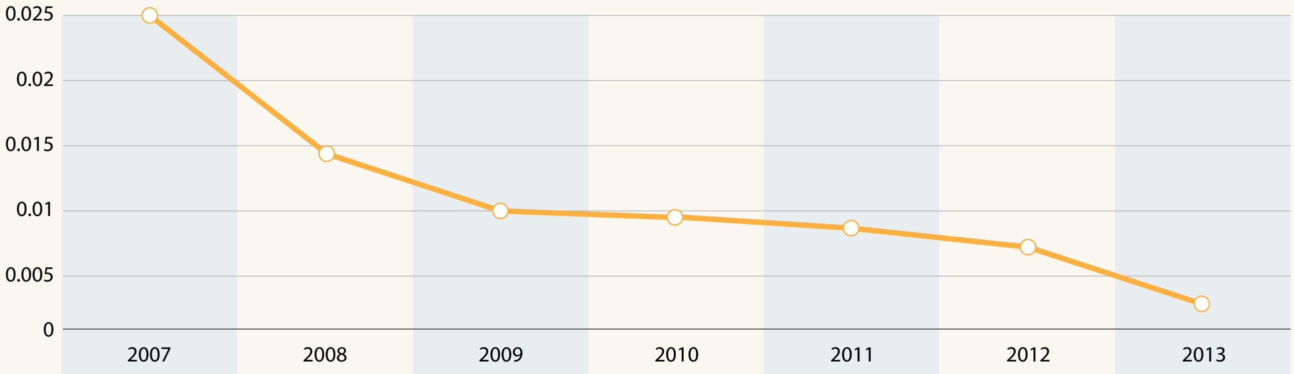
Iranian researchers worked in the field of nanotechnology in 2003

20 966

Iranian researchers worked in the field of nanotechnology in 2013

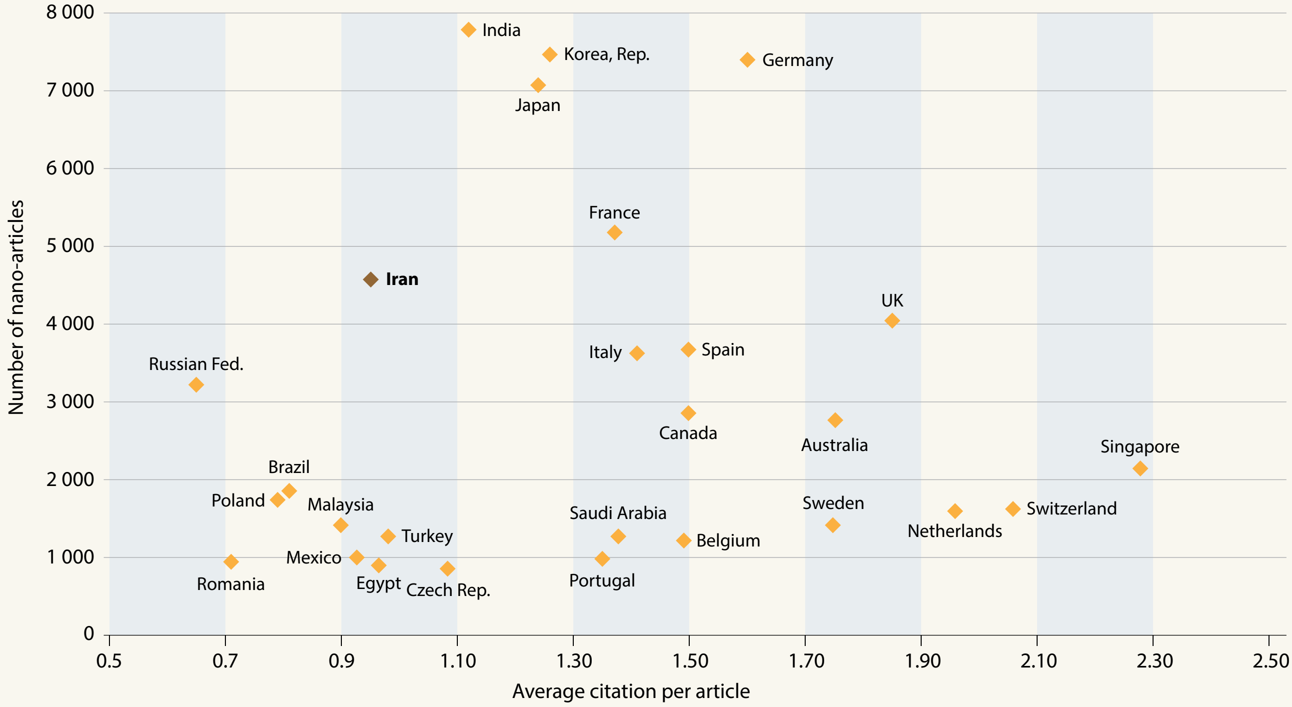
Patents are not keeping pace with growth in publications…

Number of nanotech patents from Iran registered by EPO and USPTO per 100 scientific articles



… and quality does not yet match quantity in Iran

Average citations of Iranian nanotech articles, in comparison with those of other leading countries, 2013



Source: statnano.com (January 2015), based on data from Thomson Reuters' Web of Science, Science Citation Index Expanded, and records from European Patent Office and US Patents and Trademark Office

Chapter 15

KEY TARGETS FOR IRAN

- Raise the GERD/GDP ratio to 3% by 2015 and to 4% by 2025;
- Carry business expenditure on R&D to 50% of GERD by 2025;
- Raise the share of researchers employed by the business enterprise sector to 40% by 2025;
- Increase the number of full-time university professors per million population from 1 171 in 2013 to 2 000 in 2025;
- Raise FDI to 3% of GDP by 2015;
- Privatize 80% of state-owned firms between 2004 and 2014;
- Publish 800 scientific articles in international journals per million population by 2025, compared to 239 in 2013.

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ACKNOWLEDGMENTS

The author wishes to thank the following people from the National Research Institute for Science Policy in Iran for their assistance in compiling information and data for the present chapter: Akram Ghadimi, Faculty Member, Fariba Niksiar, Responsible for International Relations and Azita Manuchehri Qashqaie, Researcher. Thanks go also to Ali Khajeh Naiini for his assistance in compiling tables.

Israel needs to prepare for tomorrow's science-based industries.

Daphne Getz and **Zehev Tadmor**

A miniaturized device developed in Professor Moshe Shoham's robotics laboratory at the Technion Institute of Technology in Haifa. Based on micro-electro-mechanical systems technology, the tiny robot can theoretically be guided inside the body via an external controller to perform a variety of medical tasks in a much less invasive way than currently possible. *Photo: © Technion Institute of Technology*

16 · Israel

Daphne Getz and Zehev Tadmor

INTRODUCTION

A geopolitical landscape in rapid mutation

Since the Arab Spring of 2011, the political, social, religious and military realities of the Middle East have been profoundly remodelled through regime change, civil war and the emergence of opportunistic politico-military sects like Da'esh (see Chapter 17). In Israel's wider neighbourhood, relations between the Western powers and Iran could be at a turning point (see p. 387). In the past five years, there has been no tangible progress towards a peaceful solution to the Israeli–Palestinian conflict, a state of affairs which may have negative repercussions for Israel's international and regional collaboration, as well as its progress in STI. Despite the tensions, there are instances of academic collaboration with neighbouring Arab countries (see p. 427).

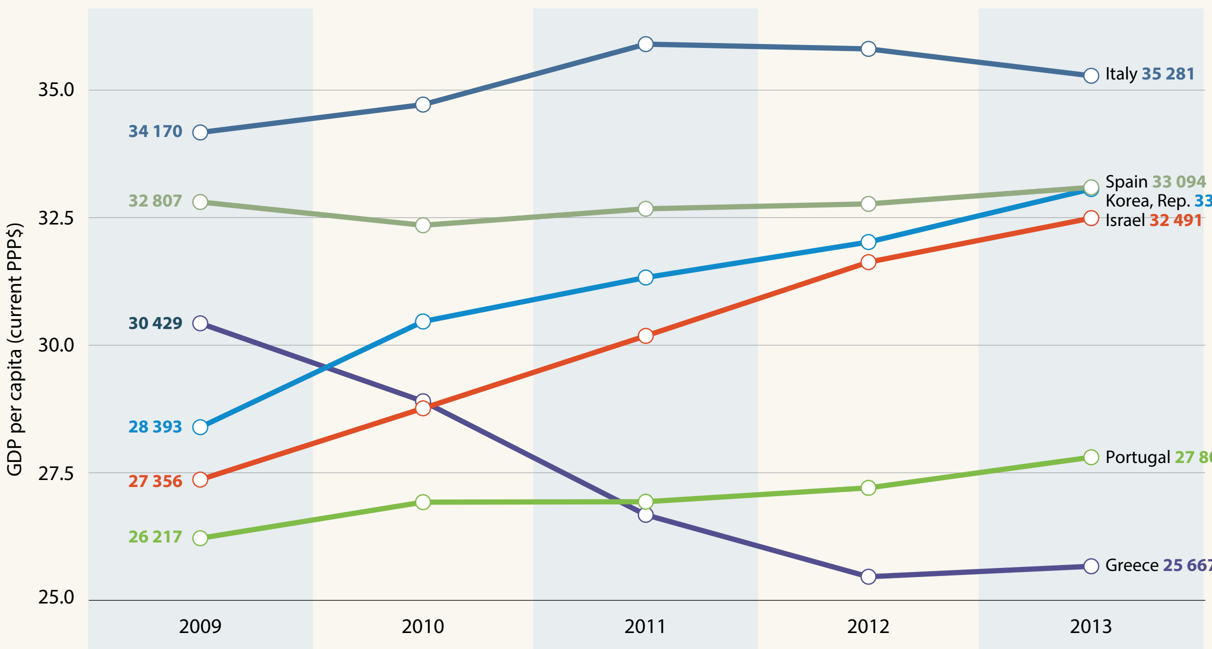
At home, the political leadership was renewed in the March 2015 elections. In order to obtain a ruling majority in the Knesset – the Israeli parliament –, the re-elected Prime Minister Binyamin Netanyahu has formed a coalition government with *Kulanu* (10 seats), *United Torah Judaism* (6 seats), *Shas* (7 seats) and *Bayit Yehudi* (8 seats), which, together with his own *Likud* party (30 seats), gives him a ruling majority of 61 seats in the Knesset. For the first time, a coalition of Arab–Israeli parties has obtained 14 out of the 120 seats in the new Knesset, making it the third-largest bloc in Israel's political landscape after the *Likud* and the *Zionist Camp* (Labour) party led by Isaac Herzog (24 seats). Arab Israelis are thus in a unique position to influence the legislative process, including as concerns issues related to STI.

No lasting impact of global financial crisis

The Israeli economy grew by 28% between 2009 and 2013 to PPP$ 261.9 billion and GDP per capita progressed by 19% (Figure 16.1). This impressive performance reflects the dominance of the medium- and high-tech sector, which constitutes the country's main growth engine and contributes 46% of Israeli exports (2012). This sector is dominated by information and communication technologies (ICTs) and high-tech services. Given its reliance on international markets and venture capital, the Israeli business enterprise sector was fairly exposed to the global financial crisis of 2008–2009. The Israeli economy has sailed through the crisis mainly due to a balanced fiscal policy and conservative measures in the real-estate market. On the R&D front, government subsidies[1] introduced in 2009 have helped high-tech firms to weather the storm, leaving them relatively unscathed.

1. There was a 12% increase in funding from government sources and international funds.

Figure 16.1: **GDP per capita in Israel, 2009–2013**
In thousands of current PPP$, other countries are given for comparison



Source: World Bank's World Development Indicators, May 2015

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Data released by the Central Bureau of Statistics in 2011 reveal that the manufacturing sector cut back its R&D expenditure by 5% and the services sector by 6% between 2008 and 2009. Each of these sectors performed about 30% of R&D in 2008 (UNESCO, 2012). As the business enterprise sector performs 83–84% of gross domestic expenditure on R&D (GERD), the cutbacks in the business enterprise sector caused the GERD/GDP ratio to falter in 2010 (3.96% of GDP). Israel has nevertheless managed to hold on to its place as world leader for R&D intensity, even if it is now being trailed by the Republic of Korea (Figure 16.2).

OECD membership has boosted investor confidence

Israel's admission to the Organisation for Economic Co-operation and Development (OECD) in 2010 has strengthened investors' confidence in the Israeli economy. Since its admission to this exclusive club, Israel has further opened up its economy to international trade and investment by lowering tariffs, adopting international standards and improving the domestic regulatory environment for business[2]. Israel now meets the OECD's policy framework for market openness, including as concerns efficient regulation and intellectual property. Israel's regulatory reforms have already led to significant growth in the influx of foreign direct investment (FDI) [OECD, 2014]. This inflow of FDI (Table 16.1) has given the Israeli high-tech sector greater access to much-needed capital which, in turn, has had a positive effect on Israeli GDP, which rose from PPP$ 204 849 million to PPP$ 261 858 million (in current prices) between 2009 and 2013.

Table 16.1: **FDI inflows to Israel and outflows, 2009–2013**

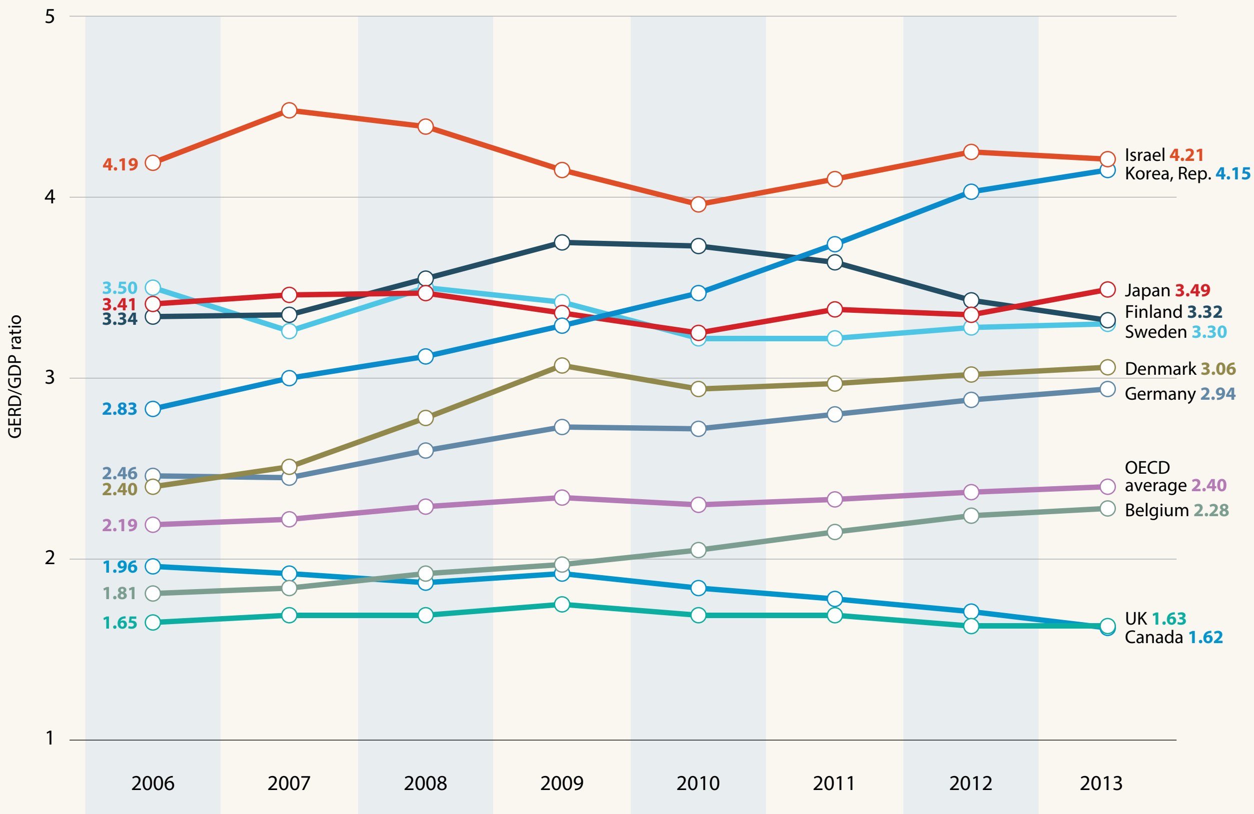
	FDI inflow	FDI outflow	FDI inflow	FDI outflow
	In current US$ millions		Share of GDP (%)	
2009	4 438	1 695	2.2	0.8
2010	5 510	9 088	2.5	4.1
2011	9 095	9 165	3.9	3.9
2012	8 055	3 257	3.2	1.3
2013	11 804	4 670	4.5	1.8

Source: Central Bureau of Statistics

2. See: www.oecd.org/israel/48262991.pdf

Figure 16.2: **Trends in Israel's GERD/GDP ratio, 2006–2013**

Other countries and regions are given for comparison



Note: The data for Israel exclude defence R&D.

Source: Getz *et al.* (2013), updated

Israel's binary economy threatens social equity and lasting growth

Israel's 'binary economy' consists of a relatively small, yet world-class high-tech sector which serves as the 'locomotive' of the economy, on the one hand, and the much larger but less efficient traditional industrial and services sectors, on the other hand. The economic contribution of the flourishing high-tech sector does not always spill over into other sectors of the economy.

Over time, this 'binary economic structure' has led to a well-paid labour force living at the 'core' of the country, namely the Tel Aviv metropolitan area, and a poorly paid labour force living primarily on the periphery. The growing socio-economic gap that has resulted from the structure of the economy and the concentration of wealth among the upper 1% is having a destabilizing effect on society (Brodet, 2008).

This duality is underpinned by a low rate of labour force participation, compared to other OECD economies, although the rate did rise from 59.8% to 63.7% between 2003 and 2013, thanks to improvements in the level of education (Fatal, 2013): as of 2014, 55% of the Israeli labour force had 13 or more years of schooling and 30% had studied for 16 years or more (CBS, 2014). The low rate of labour force participation in the general population stems mainly from low levels of participation by ultra-orthodox men and Arab women. The unemployment rate is also higher among Arabs than Jews, particularly among Arab women (Table 16.2).

Table 16.2: **Characteristics of Israel's civilian labour force, 2013**

	Total adult population*	Civilian labour force ('000s)	Civilian labour force (%)	Share of unemployed (%)
Total	**5 775.1**	**3 677.8**	**64**	**6.2**
Jewish	4 549.5	3 061.8	67	5.8
Arabs	1 057.2	482.8	46	9.4
Males	**2 818.3**	**1 955.9**	**69**	**6.2**
Jewish	2 211.9	1 549.8	70	5.8
Arab	530.8	344.4	65	8.2
Females	**2 956.7**	**1 722.0**	**58**	**6.2**
Jewish	2 337.6	1 512.0	65	5.8
Arab	526.4	138.4	26	12.4

Source: Central Bureau of Statistics

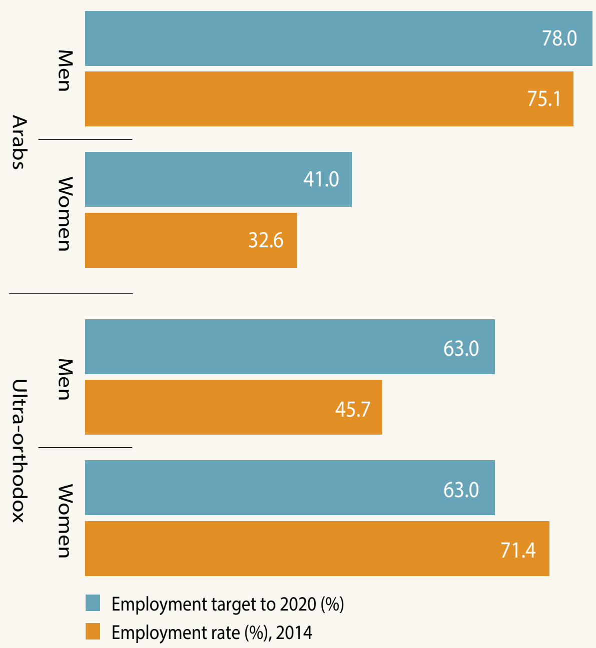
The latter phenomenon is attributable to the insufficient integration of Arab citizens into wider Israeli society, partly owing to their geographic remoteness and inadequate infrastructure; a lack of the social networks needed to find suitable employment; and discriminatory practices in certain segments of the economy.

To drive sustainable and long-lasting economic growth, it will be crucial for Israel to integrate its minority populations into the labour market. This realization prompted the government to fix a series of targets in December 2014 for raising the participation rate of minorities (Figure 16.3).

The country's transition from a semi-socialist economy in the 1980s to a free market economy has been accompanied by a rise in inequality, as illustrated by the steady rise in the Gini index (see the glossary, p. 738). As of 2011, nearly 42% of gross monthly income in Israel was concentrated in households which made up 20% of the population (the 2 top deciles). The Israeli middle class, occupying deciles 4–7, accounted for only 33% of gross income. Inequality after taxes and transfer payments has increased even more sharply, as the government has steadily reduced welfare benefits since 2003 (UNESCO, forthcoming).

The duality of the Israeli economy is also reflected in the low labour productivity, calculated as GDP per working hour. Israel

Figure 16.3: **Employment targets to 2020 for Israeli minorities**



Note: The employment targets were fixed in 2010 by a special committee charged with examining Israel's Employment Policy. The target for the employment rate for ultra-orthodox women was reached before 2014.

Source: General Accountant (2014) *Managing the Fiscal Policy Goals*. Ministry of Finance (in Hebrew)

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ranks 26th out of 34 OECD countries for this indicator and has been gradually slipping in the ranking since the 1970s (Ben David, 2014), even though it boasts some of the world's leading universities and cutting-edge high-tech firms.

Labour productivity in Israel varies strongly in technological intensity. In medium- and high-tech industries, labour productivity is significantly higher than in other manufacturing industries. In the services sector, the highest levels of production per employee are to be found in knowledge- and technology-intensive industries, such as the computer industry, R&D services and communications. The medium- and high-tech manufacturing sectors account for about 13% of GDP and 7% of total employment, even though their output contributes 46% of industrial exports, as mentioned earlier. The main industries in the manufacturing sector are chemical and pharmaceutical products, computers, electronics and optical products (Getz *et al.*, 2013).

Those industrial and services sectors that are classified as using low technologies or medium–low technologies account for the greater part of production and employment in the business sector, yet they suffer from low productivity per employee (Figure 16.4). The key to sustainable, long-term economic growth will lie in improving productivity in traditional industries and in the services sector (Flug, 2015). This can be achieved by giving firms incentives to innovate, assimilate advanced technologies, implement the requisite organizational changes and adopt new business models to raise the share of exports in their output (Brodet, 2008).

The government hopes to raise industrial-level productivity – the value added by each employee – from PPP$ 63 996 in 2014 to PPP$ 82 247 by 2020.

TRENDS IN R&D

Still the world leader for R&D intensity

Israel tops the world for R&D intensity, reflecting the importance of research and innovation for the economy. Since 2008, however, Israel's R&D intensity has weakened somewhat (4.2% in 2014), even as this ratio has experienced impressive growth in the Republic of Korea, Denmark, Germany and Belgium (Figure 16.2) [Getz *et al.*, 2013]. Business expenditure on R&D (BERD)[3] continues to account for ~84% of GERD, or 3.49% of GDP. The share of higher education in GERD has decreased since 2003 from 0.69% of GDP to 0.59% of GDP (2013). Despite this drop, Israel ranks 8th among OECD countries for this indicator.

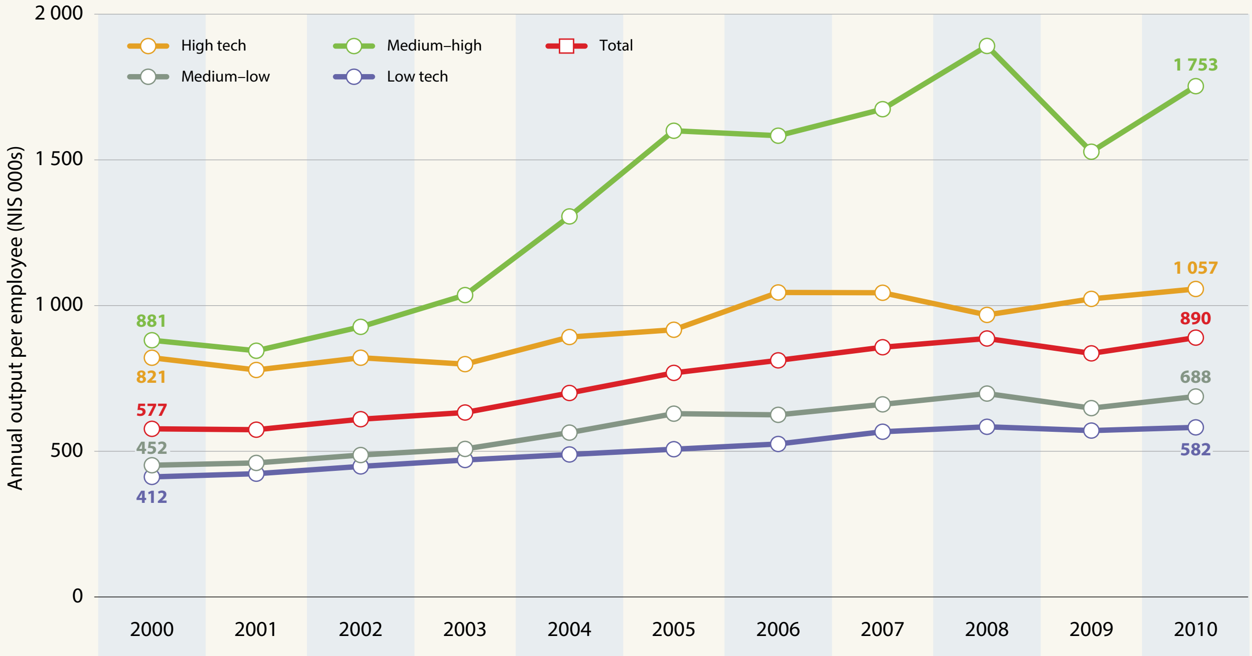
The lion's share of GERD (45.6%) in Israel is financed by foreign companies (Figure 16.5), reflecting the large scale of activity by foreign multinational companies and R&D centres in the country.

The share of foreign funding in university-performed R&D is also quite significant (21.8%). By the end of 2014, Israel had received € 875.6 million from the European Union's (EU's) Seventh Framework Programme for Research and Innovation (2007–2013),

3. refers to GERD performed by the business enterprise sector

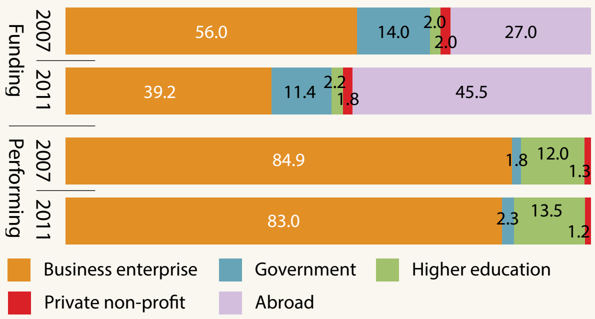
Figure 16.4: **Annual output per employee in Israel, 2000–2010**

In thousands of NIS, breakdown by technological intensity



Source: Central Bureau of Statistics

Figure 16.5: **GERD in Israel by funding and performing sectors, 2007 and 2011 (%)**

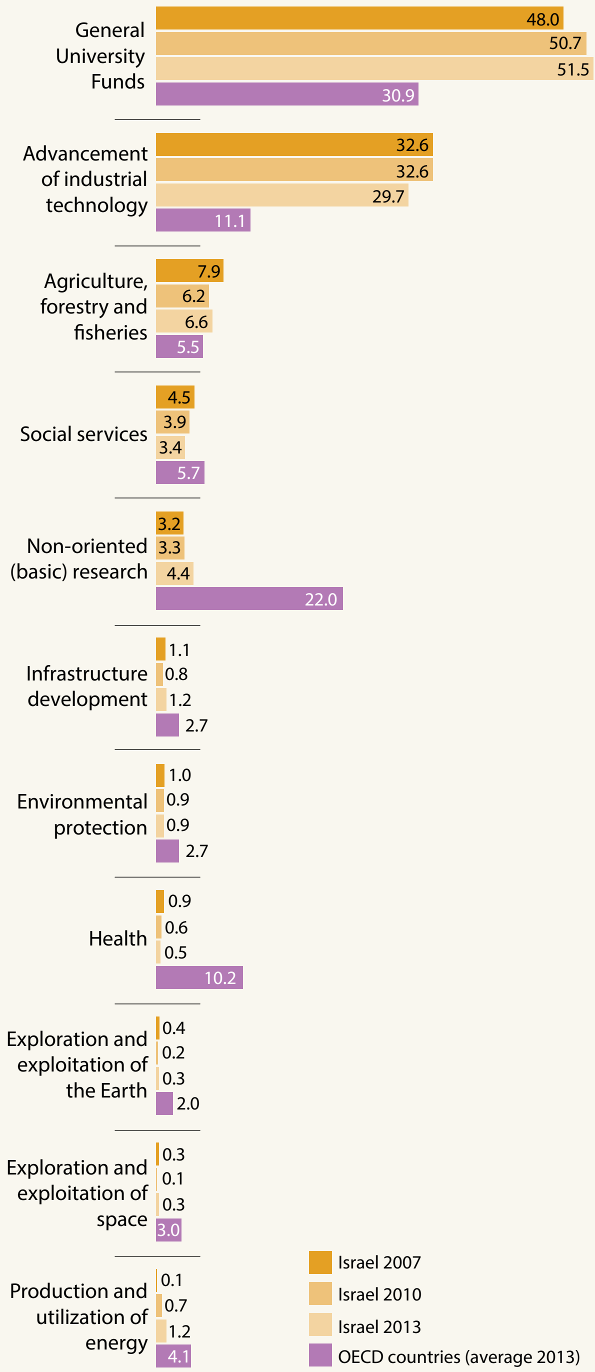


Note: Excluding defence R&D.

Source: Central Bureau of Statistics

Figure 16.6: **Israeli government outlay for R&D by major socio-economic objective, 2007, 2010 and 2013 (%)**

The OECD is given for comparison



Note: The data for Israel do not include defence R&D. The data for Israel diverge strongly from those for the OECD in two categories: health and non-oriented research. The low percentage for health can be explained by the fact that, in Israel, R&D in hospitals is assigned to the business sector and not to the government sector. The high percentage for non-oriented research for the OECD (22%) and the low percentage for Israel (4.4%) can be explained by the fact that the OECD indicator encompasses a variety of subjects.

Source: adapted from Getz *et al.* (2013)

70% of which had gone to universities. Its successor, Horizon 2020 (2014–2020), has been endowed with nearly € 80 billion in funding, making it the EU's most ambitious research and innovation programme ever. As of February 2015, Israel had received € 119.8 million from the Horizon 2020 programme.

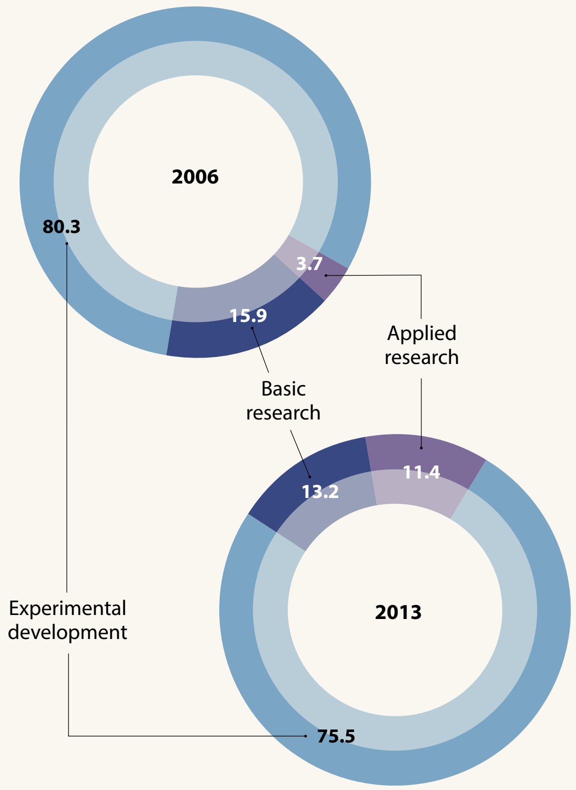
In 2013, more than half (51.8%) of government spending was allocated to university research and an additional 29.9% to the development of industrial technologies. R&D expenditure on health and the environment has doubled in absolute terms in the past decade but still accounts for less than 1% of total government GERD (Figure 16.6). Israel is unique among OECD countries in its distribution of government support by objective. Israel ranks at the bottom in government support of research in health care, environmental quality and infrastructure development.

University research in Israel is largely grounded in basic research, even though it also engages in applied research and partnerships with industry. The increase in General University Funds and non-oriented research should thus provide a significant boost to basic research in Israel, which only accounted for 13% of research in 2013, compared to 16% in 2006 (Figure 16.7).

In 2012, there were 77 282 full-time equivalent (FTE) researchers, 82% of whom had acquired an academic education, 10% of whom were practical engineers and technicians and 8% of whom held other qualifications. Eight out of ten (83.8%) were employed in the business sector, 1.1% in the government sector, 14.4 % in the higher education sector and 0.7% in non-profit institutions.

In 2011, 28% of senior academic staff were women, up by 5% over the previous decade (from 25% in 2005) [Figure 16.8]. Although the representation of women has increased, it remains very low in engineering (14%), physical sciences (11%), mathematics and computer sciences (10%) relative to education (52%) and paramedical occupations (63%).

Figure 16.7: **GERD in Israel by type of research, 2006 and 2013 (%)**



Note: The data do not include defence R&D.

Source: UNESCO Institute for Statistics, June 2015

TRENDS IN STI GOVERNANCE

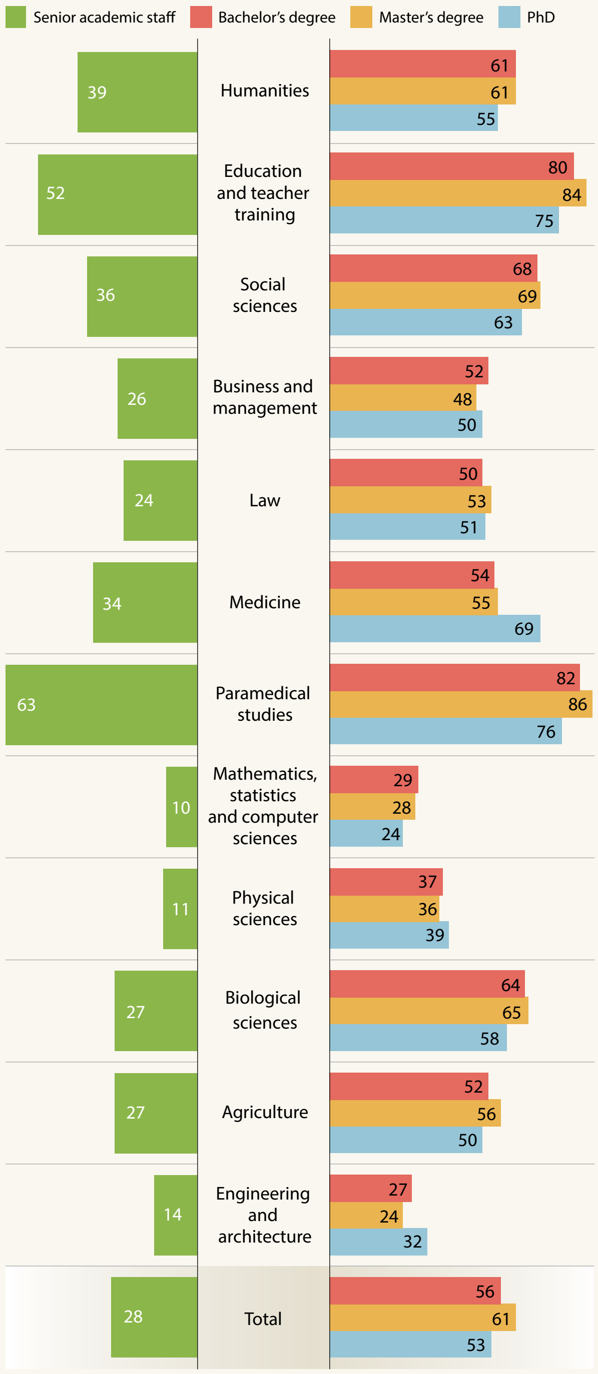
A six-year plan to revamp higher education

Israel's higher education system is regulated by the Council for Higher Education and its Planning and Budgeting Committee. The Israeli higher education system operates under a multi-year plan agreed upon by the Planning and Budgeting Committee (PBC) and the Ministry of Finance. Each plan determines policy objectives and, accordingly, the budgets to be allocated in order to achieve these objectives. The annual government allocation to universities totalled about US$ 1 750 million in 2015, providing 50–75% of their operating budgets. Much of the remainder of their operating budget (15–20%) comes from annual student tuition fees, which are uniform at about US$ 2 750 per year.

The *Sixth Higher Education Plan* (2011–2016) makes provision for a 30% rise in the Council for Higher Education's budget. The *Sixth Plan* changes the budgeting model of the PBC by placing greater emphasis on excellence in research, along with quantitative measures for the number of students. Under this model, 75% of the committee's budget (NIS 7 billion over six years) is being allocated to institutions offering higher education.

In the 2012/2013 academic year, there were 4 066 faculty members. The targets fixed by the PBC for faculty recruitment are ambitious: universities are to recruit another 1 600 senior faculty within the six-year period – about half of whom will occupy new positions and half will replace faculty expected to retire. This will constitute a net increase of more than 15%

Figure 16.8: **Share of women among Israeli university students (2013) and senior academic staff (2011) (%)**



Source: Central Bureau of Statistics

in university faculty. In colleges, another 400 new positions are to be created, entailing a 25% net increase. The new faculty will be hired via the institutions' regular recruitment channels, some in specific research areas, through the Israeli Centres of Research Excellence programme described below (Box 16.1).

The increase in faculty numbers will also reduce the student-to-faculty ratio, the target being to achieve a ratio of 21.5 university students to every faculty member, compared to 24.3 at present, and 35 students for every faculty member in colleges, compared to 38 at present.

This massive increase in the number of faculty positions, alongside the upgrading of research and teaching infrastructure and the increase in competitive research funds, should help Israel to staunch brain drain by enabling the best Israeli researchers at home and abroad to conduct their academic work in Israel, if they so wish, at institutions offering the highest academic standards.

The new budgeting scheme described above is mainly concerned with the human and research infrastructure in universities. Most of the physical development (e.g. buildings) and scientific infrastructure (e.g. laboratories and expensive equipment) of universities comes from philanthropic donations, primarily from the American Jewish community (CHE, 2014). This latter source of funding has greatly compensated for the lack of sufficient government funding for universities up until now but it is expected to diminish significantly in the years to come. Unless the government invests more in research infrastructure, Israel's universities will be ill-equipped and insufficiently funded to meet the challenges of the 21st century. This is very worrying.

Renewed interest in academic R&D

The *Sixth Higher Education Plan* launched the Israeli Centres of Research Excellence (I-CORE) programme in 2011 (Box 16.1). This is perhaps the strongest indication of a reversal in government policy, as it reflects a renewed interest in funding academic R&D. This novel programme envisions the establishment of cross-institutional clusters of top researchers in specific fields and returning young Israeli scientists from abroad, with each centre being endowed with state-of-the-art research infrastructure. The *Sixth Plan* invests NIS 300 million over six years in upgrading and renovating academic infrastructure and research facilities.

Although Israel does not have an 'umbrella type' STI policy for optimizing priorities and allocating resources, it does implement, *de facto*, an undeclared set of best practices combining bottom-up and top-down processes via government offices, such as those of the Chief Scientist or the Minister of Science, Technology and Space, as well as *ad hoc* organizations like the Telem forum (see p. 420). The procedure for selecting research projects for the Israeli centres of research excellence is one example of this bottom-up process (Box 16.1).

Box 16.1: **Israeli Centres of Research Excellence**

The Israeli Centres of Research Excellence (I-CORE) programme was launched in October 2011. It is run jointly by the Council for Higher Education's Planning and Budgeting Committee and the Israel Science Foundation.

So far, 16 centres have been established in two waves across a wide spectrum of research areas: six specialize in life sciences and medicine, five in the exact sciences and engineering, three in social sciences and law and two in humanities. Each centre of excellence has been selected via a peer review process conducted by the Israel Science Foundation. By May 2014, around 60 young researchers had been absorbed into these centres, many of whom had previously worked abroad.

The research topics of each centre are selected through a broad bottom-up process comprising of consultations with the Israeli academic community, in order to ensure that they reflect the genuine priorities and scientific interests of Israeli researchers.

I-CORE is funded by the Council for Higher Education, the host institutions and strategic business partners, with a total budget of NIS 1.35 billion (US$ 365 million).

The original goal was to set up 30 centres of research excellence in Israel by 2016. However, the establishment of the remaining 14 centres has provisionally been shelved, for lack of sufficient external capital.

In 2013–2014, the Planning and Budgeting Committee's budget for the entire I-CORE programme amounted to NIS 87.9 million, equivalent to about 1% of the total for higher education that year. This budget appears to be insufficient to create the critical mass of researchers in various academic fields and thus falls short of the programme's objective. The level of government support for the centres of excellence has grown each year since 2011 as new centres have been established and is expected to reach NIS 93.6 million by 2015–2016 before dropping to 33.7 million in 2017–2018. According to the funding model, government support should represent one-third of all funding, another third being funded by the participating universities and the remaining third by donors or investors.

Source: CHE (2014)

A shortage of professionals looms

During the 2012/2013 academic year, 34% of bachelor's degrees were obtained in S&T fields in Israel. This compares well with the proportion in the Republic of Korea (40%) and most Western countries (about 30% on average). The proportion of Israeli graduates in S&T fields was slightly lower at the master's level (27%) but dominated at PhD level (56%).

There is a visible ageing of scientists and engineers in some fields. For instance, about three-quarters of researchers in the physical sciences are over the age of 50 and the proportion is even higher for practical engineers and technicians. The shortage of professional staff will be a major handicap for the national innovation system in the coming years, as the growing demand for engineers and technical professionals begins to outpace supply.

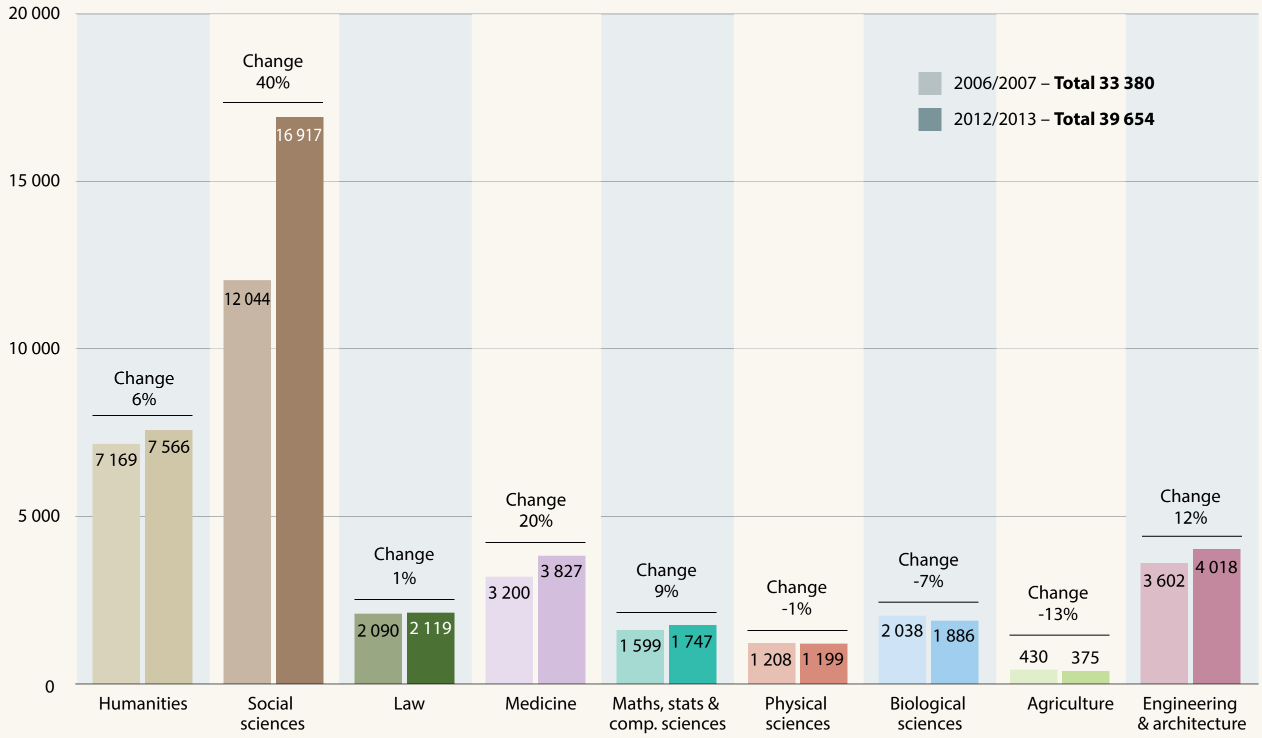
Israel has offered virtually universal access to its universities and academic colleges since the wave of Jewish immigration from the former Soviet Union in the 1990s prompted the establishment of numerous tertiary institutions to absorb the additional demand (CHE, 2014). However, the Arab and ultra-orthodox minorities still attend university in insufficient numbers. The *Sixth Higher Education Plan* places emphasis on encouraging minority groups to enrol in higher education. Two years after the *Mahar* programme was implemented in late 2012 for the ultra-orthodox population, student enrolment had grown by 1 400. Twelve new programmes for ultra-orthodox students have since been established, three of them on university campuses. Meanwhile, the Pluralism and Equal Opportunity in Higher Education programme addresses the barriers to integration of the Arab minority in the higher education system. Its scope ranges from providing secondary-school guidance through preparation for academic studies to offering students comprehensive support in their first year of study, a stage normally characterized by a high drop-out rate. The programme renews the *Ma'of* fund supporting outstanding young Arab faculty members. Since the introduction of this programme in 1995, the *Ma'of* fund has opened tenure track opportunities for nearly 100 Arab lecturers, who act as role models for younger Arab students embarking on their own academic careers.

Living on the fruits of the past?

One of the main criticisms of the current state of the higher education system is that Israel is living on the 'fruits of the past', that is to say, on the heavy investment made in primary, secondary and tertiary education during the 1950s, 1960s and 1970s (Frenkel and Leck, 2006). Between 2007 and 2013, the number of graduates in physical sciences, biological sciences and agriculture dropped, even though the total number of university graduates progressed by 19% (to 39 654) [Figure 16.9].

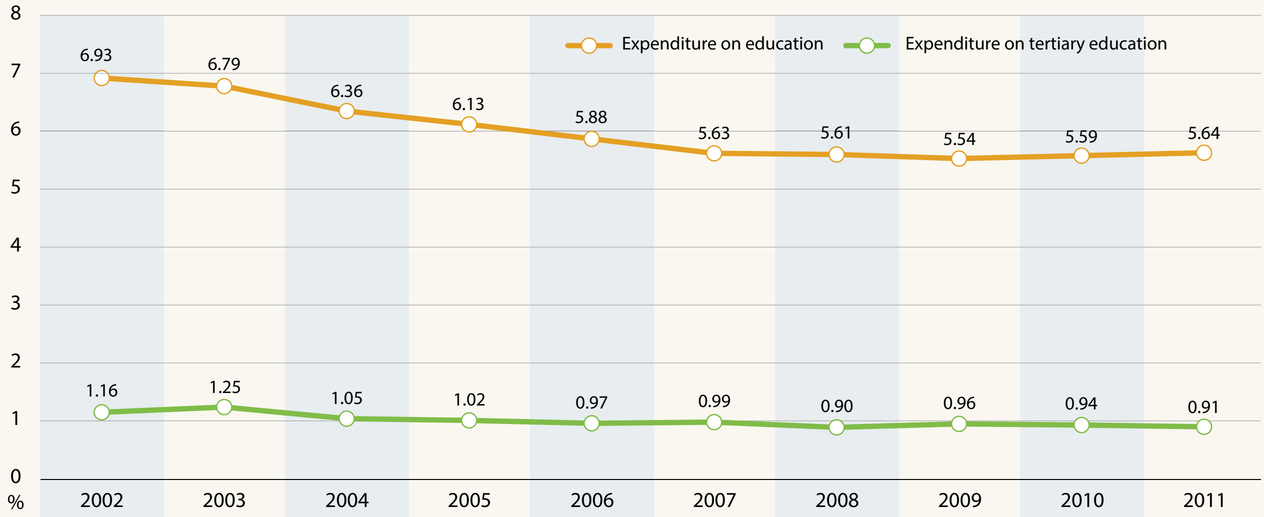
Recent data reveal that Israeli educational achievements in the core curricular subjects of mathematics and science

Figure 16.9: **University graduates in Israel, by field of study, 2006/2007 and 2012/2013**



Source: Central Bureau of Statistics

Figure 16.10: **Education spending in Israel as a share of GDP, 2002–2011 (%)**



Source: UNESCO Institute for Statistics, April 2015

are low in comparison to other OECD countries, as revealed by the exam results of Israeli 15-year olds in the OECD's Programme for International Student Assessment. Public spending on primary education has also fallen below the OECD average. The public education budget accounted for 6.9% of GDP in 2002 but only 5.6% in 2011. The share of this budget going to tertiary education has remained stable at 16–18% but, as a share of GDP, has passed under the bar of 1% (Figure 16.10). There is concern at the deteriorating quality of teachers at all levels of education and the lack of stringent demands on students to strive for excellence.

Research universities: the backbone of higher education

Seven research universities around the country form the 'backbone' of Israel's higher education system: the Hebrew University of Jerusalem, Technion – Israel Institute of Technology, Tel- Aviv University, Weizmann Institute of Science, Bar-Ilan University, University of Haifa and Ben Gurion University of the Negev.

The first six ranked among the world's top 500 universities[4] in 2014 in the Shanghai Ranking[5]. These six also ranked in the top 200 World Universities in Computer Science[6] for the same year. Three Israeli research universities rank among the top 75 in mathematics and four among the top 200 in physics and chemistry.

Over the 2007–2014 period, Israeli projects benefiting from the European Research Council's Starting Grants (see Box 9.1) recorded a success rate of 17.6% for 142 funded projects, placing Israel second after Switzerland. During the years 2008–2013, Israel ranked ninth for the European Research Council's Advanced Grants (85 funded projects), reflecting a 13.6% success rate. Since 2009, two Israeli academics have won the Nobel Prize: Professor Ada E. Yonath in 2009 for her studies on the structure and function of the ribosome and Professor Dan Shechtman in 2011 for his discovery of quasicrystals in 1984. This brings the total number of Israelis who have won the Nobel Prize in one of the sciences to eight.

The volume of publications is stagnating

The number of Israeli publications has stagnated over the past decade. Consequently, the number of Israeli publications per million inhabitants has also declined: between 2008 and 2013, it dropped from 1 488 to 1 431; this trend reflects a relative constancy in scholarly output in the face of relatively high population growth (1.1% in 2014) for a developed country and near-zero growth in the number of FTE researchers in universities.

Israeli publications have a high citation rate and a high share of papers count among the 10% most-cited (Figure 16.11). Also of note is that the share of papers with foreign co-authors is almost twice the OECD average, which is typical of small countries with developed science systems. Israeli scientists collaborate mostly with the USA and EU but there has been strong growth in recent years in collaboration with China, India, the Republic of Korea and Singapore.

Between 2005 and 2014, Israeli scientific output was particularly high in life sciences (Figure 16.11). Israeli universities do particularly well in computer science but publications in this field tend to appear mostly in conference proceedings, which are not included in the Web of Science.

4. The Hebrew University of Jerusalem and the Technion figured among the top 100, Tel Aviv University and the Weizmann Institute among the top 200.

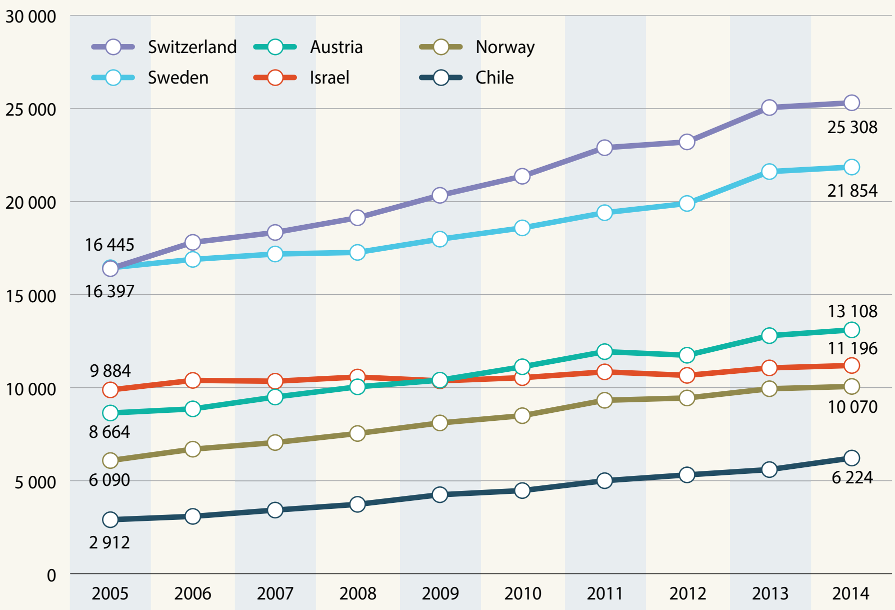
5. Shanghai Academic Ranking of World Universities, 2014

6. The Technion and Tel Aviv University ranked among the top 20, the Hebrew University and Weizmann Institute among the top 75.

Figure 16.11: **Scientific publication trends in Israel, 2005–2014**

Israeli publications have grown slowly since 2005

Countries of a similar economic size are given for comparison



1.15

Average citation rate for Israeli scientific publications 2008–2012; the OECD average is 1.08

11.9%

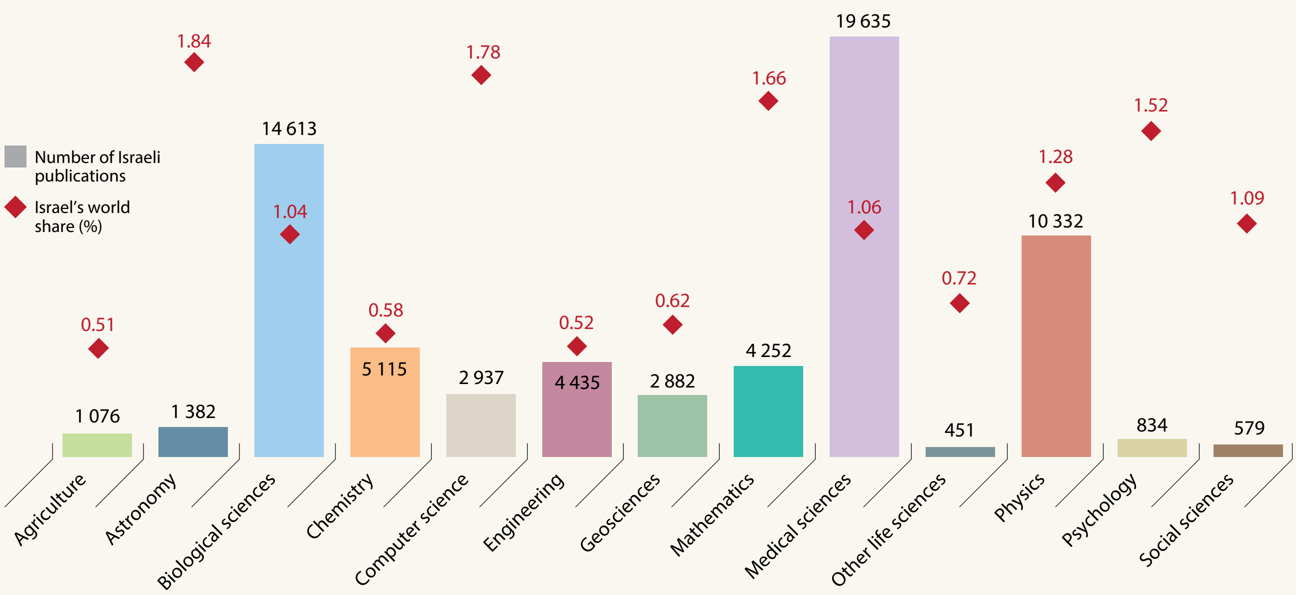
Share of Israeli papers among 10% most cited papers 2008–2012; OECD average is 11.1%

49.3%

Share of Israeli papers with foreign co-authors 2008–2014; the OECD average is 29.4%

Israel specializes in life sciences and physics

Cumulative totals by field, 2008–2014



Note: A further 6 745 papers are unclassified. Israel accounts for 0.1% of the global population.

Israeli scientists collaborate mostly with the USA and EU countries

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Israel	USA (19 506)	Germany (7 219)	UK (4 895)	France (4 422)	Italy (4 082)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

Four priority research areas which will impact daily life

The Israeli Science Foundation is the main source of research funding in Israel and receives administrative support from the Academy of Sciences and Humanities. The foundation provides competitive grants in three areas: exact sciences and technology; life sciences and medicine; and humanities and social sciences. Complementary funding is provided by binational foundations, such as the USA–Israel Binational Science Foundation (est. 1972) and the German–Israeli Foundation for Scientific Research and Development (est. 1986).

The Ministry of Science, Technology and Space funds thematic research centres and is responsible for international scientific co-operation. The Ministry's National Infrastructure Programme aims to create a critical mass of knowledge in national priority fields and to nurture the younger generation of scientists. Investment in the programme mainly takes the form of research grants, scholarships and knowledge centres. Over 80% of the ministry's budget is channelled towards research in academic institutions and research institutes, as well as towards revamping scientific infrastructure by upgrading existing research facilities and establishing new ones.

In 2012, the ministry resolved to invest NIS 120 million over three years in four designated priority areas for research: brain science; supercomputing and cybersecurity (Box 16.2); oceanography; and alternative transportation fuels. An expert panel headed by the Chief Scientist in the Ministry of Science, Technology and Space chose these four broad disciplines in the belief that they would would be likely to exert the greatest practical impact on Israeli life in the near future.

A rise in funding for space research

In 2012, the Ministry of Science, Technology and Space substantially increased its investment in the civil space programme administered by the Israel Space Agency (ISA). ISA's planned budget came to NIS 180 million for three years: NIS 65 million was allocated to fostering university–industry co-operation and NIS 90 million to joint international projects. In 2013, ISA signed contracts for a cumulative value

Box 16.2: **Israel launches cyber security initiative**

In 2013, hackers presumably used a cyber virus to shut down a major tunnel system in Israel for eight hours, causing massive traffic jams. Cyber attacks are a growing threat in Israel and worldwide.

In November 2010, the Israeli prime minister entrusted a task force with responsibility for formulating national plans to place Israel among the top five countries in the world for cyber security.

Less than a year later, on 7 August 2011, the government approved the establishment of the National Cyber Bureau to promote the Israeli cyber defence industry. The bureau is based in the Prime Minister's Office. The National Cyber Bureau allocated NIS 180 million (*circa* US$ 50 million) over 2012–2014 to encourage cyber research and dual military–civilian R&D; the funding is also being used to develop human capital, including through the creation of cyber security centres at Israeli universities that are funded jointly by the National Cyber Bureau and the universities themselves.

In January 2014, the prime minister launched CyberSpark, Israel's cyber innovation park, as part of plans to turn Israel into a global cyber hub. Located in the city of Beer-Sheva to foster economic development in southern Israel, CyberSpark is a geographical cluster of leading cyber companies, multinational corporations and universities, involving Ben Gurion University of the Negev, technology defence units, specialized educational platforms and the national Cyber Event Readiness Team.

About half of the firms in CyberSpark are Israeli, mostly small to medium-sized. Multinational companies operating in CyberSpark include EMC2, IBM, Lockheed Martin and Deutsche Telekom. PayPal recently acquired the Israeli start-up CyActive and has since announced plans to set up its second Israeli R&D centre in CyberSpark, with a focus on cyber security. This acquisition is just one of the many Israeli cybersecurity start-ups acquired by multinational companies in the past few years. Major acquisitions of Israeli start-ups in 2014 include Intellinx, purchased by Bottomline Technologies, and Cyvera, purchased by Palo Alto Networks.

The National Cyber Bureau recently estimated that the number of Israeli cyber defence companies had doubled in the past five years to about 300 by 2014. Israeli companies account for an estimated 10% of global sales, which currently total an estimated US$ 60 billion.

Total R&D spending on cyber defence in Israel quadrupled between 2010 and 2014 from US$ 50 million to US$ 200 million, bringing Israel's spending to about 15% of global R&D spending on cyber defence in 2014.

Cyber security technologies are exported by Israel in accordance with the Wassenaar Arrangement, a multilateral agreement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies.

Source: National Cyber Bureau; CyberSpark; Ministry of the Economy; Ziv (2015)
See: www.cyberspark.org.il

of NIS 88 million. The rest of the budget will be utilized in the coming years.

The aim of the national space programme is to enhance Israel's comparative advantage and place it among the world's top five countries in the field of space research and exploration. Israel plans to use its expertise in miniaturization and digitization to capture 3–5% of the US $ 250 billion global space market and generate US$ 5 billion in sales within ten years.

Over the next five years, ISA will be focusing on:

- joining the European Space Agency as a full or associate member;
- initiating and promoting two micro-research satellites;
- developing in-house knowledge, in order to increase the manufacturing capabilities of space systems and subsystems in Israel.

The ministry is also promoting collaboration with other leading countries in the field of space, including the USA, France, India, Italy, Japan and the Russian Federation, through co-operative ventures with the business sector.

Making science more approachable

Another objective of the ministry has been to bring the general public closer to science, particularly those living on Israel's periphery and the younger generation, by making science more approachable. This is done via science museums and annual events run by universities and science institutions, such as Researchers' Night.

Another tool used by the ministry has been the establishment of eight R&D centres since the 1980s on the country's geographical and social peripheries to spur local development and deepen community engagement in S&T. These centres have been established with the specific aim of drawing young, leading scientists to these parts of the country, along with raising the level of local education and fostering economic development. These R&D centres focus on finding solutions to local challenges.

A wealth of new funding programmes

The main ongoing programmes managed by the Office of the Chief Scientist within the Ministry of the Economy are: the Research and Development Fund; Magnet Tracks (est. 1994, Table 16.3); Tnufa (est. 2001) and the Incubator Programme (est.1991). Since 2010, the Office has initiated several new programmes (OCS, 2015):

- *Grand Challenges Israel (since 2014)*: an Israeli contribution to the Grand Challenges in Global Health programme, which is dedicated to tackling global health and food security challenges in developing countries; Grand Challenges Israel is offering grants of up to NIS 500 000 at the proof of concept/feasibility study stage.
- *R&D in the field of space technology (2012*): encourages R&D to find technological solutions in various fields.
- *Technological Entrepreneurship Incubators (2014)*: encourages entrepreneurial technology and supports start-up technology companies.
- *Magnet – Kamin programme (2014)* provides direct support for applied research in academia that has potential for commercial application.
- *Cyber – Kidma programme* (2014): promotes Israel's cybersecurity industry.
- *Cleantech – Renewable Energy Technology Centre (2012)*: supports R&D through projects involving private–public partnerships in the field of renewable energy.
- *Life Sciences Fund (2010*)**:** finances the projects of Israeli companies, with emphasis on biopharmaceuticals; established together with the Ministry of Finance and the private sector.
- *Biotechnology – Tzatam programme* (2011): provides equipment to support R&D in life sciences. The Chief Scientist supports industrial organizations and the PBC provides research institutions with assistance.
- *Investment in high-tech industries (2011)*: encourages financial institutions to invest in knowledge-based industries, through a collaboration between the Office of the Chief Scientist and the Ministry of Finance.

Another source of public research funding is the Forum for National Research and Development Infrastructure (*Telem*). This voluntary partnership involves the Office of the Chief Scientist of the Ministry of the Economy and the Ministry of Science, Technology and Space, the Planning and Budgeting Committee and the Ministry of Finance. *Telem* projects focus on establishing infrastructure for R&D in areas that are of common interest to most Telem partners. These projects are financed by the *Telem* members' own resources.

Regular evaluations of policy instruments

The country's various policy instruments are evaluated by the Council for Higher Education, the National Council for Research and Development, the Office of the Chief Scientist, the Academy of Sciences and Humanities and the Ministry of Finance.

In recent years, the Magnet[7] administration in the Office of the Chief Scientist has initiated several evaluations of its own policy instruments, most of which have been carried out by independent research institutions. One such evaluation was carried out in 2010 by the Samuel Neaman Institute; it concerned the *Nofar* programme within the Magnet directorate.

7. Magnet is the acronym, in Hebrew, for Generic Pre-Competitive R&D.

Table 16.3: **Grants by the Israeli Office of the Chief Scientist, by R&D programme, 2008–2013, NIS**

Programme (year of creation)	2008	2009	2010	2011	2012	2013
Research and Development Fund (1984)	1 009.0	1 245.0	1 134.0	1 027.0	1 070.0	1 021.0
Magnet (1994)	159.0	199.0	159.0	187.0	134.0	138.0
Users Association (1995)	3.2	2.7	0.8	3.2	0.7	1.6
Magneton (2000)	31.1	30.8	32.9	26.8	28.0	23.8
R&D in Large Companies (2001)	71.0	82.0	75.0	63.0	55.0	59.0
Nofar (2002)	5.0	7.8	6.9	7.6	6.9	6.2
Traditional Industries Support (2005)	44.9	79.5	198.3	150.0	131.0	80.8
R&D Centres (2010)	4.6	14.8	10.9	7.6	8.6	8.2
Cleantech (2012)	65.4	95.4	100.7	81.9	84.4	105.6

Source: Office of the Chief Scientist, 2015

Nofar tries to bridge basic and applied research, before the commercial potential of a project has caught the eye of industry. The main recommendation was for *Nofar* to extend programme funding to emerging technological domains beyond biotechnology and nanotechnology (Getz *et al.*, 2010). The Office of the Chief Scientist accepted this recommendation and, consequently, decided to fund projects in the fields of medical devices, water and energy technology and multidisciplinary research.

An additional evaluation was carried out in 2008 by Applied Economics, an economic and management research-based consultancy, on the contribution of the high-tech sector to economic productivity in Israel. It found that the output per worker in companies that received support from the Office of the Chief Scientist was 19% higher than in 'twin' companies that had not received this support (Lach *et al.*, 2008). The same year, a committee headed by Israel Makov examined the Office of the Chief Scientist's support for R&D in large companies. The committee found economic justification for providing incentives for these companies (Makov, 2014).

Universities apply for 10% of Israeli patents

Since the 1990s, the traditional dual mission of universities of teaching and research has broadened to include a third mission: engagement with society and industry. This evolution has been a corollary of the rise of the electronics industry and information technology services, along with a surge in the number of R&D personnel following the wave of immigration from the former Soviet Union.

Israel has no specific legislation regulating the transfer of knowledge from the academic sector to the general public and industry. Nevertheless, the Israeli government influences policy formulation by universities and technology transfer by providing incentives and subsidies through programmes such as Magnet and Magneton (Table 16.3), as well as through regulation.

There were attempts in 2004 and 2005 to introduce bills encouraging the transfer of knowledge and technology for the public benefit but, as these attempts failed, each university has since defined its own policy (Elkin-Koren, 2007).

All Israeli research universities have technology transfer offices. Recent research conducted by the Samuel Neaman Institute has revealed that, in the past decade, the universities' share of patent applications constituted 10–12% of the total inventive activity of Israeli applicants (Getz *et al.*, 2013). This is one of the highest shares in the world and is largely due to the intensive activity of the universities' technology transfer offices.

The Weizmann Institute's technology transfer office, Yeda, has been ranked the third-most profitable[8] in the world (Weinreb, 2013). Through exemplary university–industry collaboration, the Weizmann Institute of Science and Teva Pharmaceutical Industries have discovered and developed the Copaxone drug for the treatment of multiple sclerosis. Copaxone is Teva's biggest-selling drug, with US$ 1.68 billion in sales in the first half of 2011 (Habib-Valdhorn, 2011). Since the drug's approval by the US Food and Drug Administration (FDA) in 1996, it is estimated that the Weizmann Institute of Science has earned nearly US$ 2 billion in royalties from the commercialization of its intellectual property. An additional revolutionary drug for the treatment of Parkinson's disease, Azilect, was developed by scientists from the Technion – Israel Institute of Technology. The drug was commercialized by the Technion Technology Transfer Office and the manufacturing license was given to Teva Pharmaceutical Industries. In 2014, the US Food and Drug Administration approved the Azilect label for treatment at all stages of

8. About 10–20% of the Weizmann Institute's annual budget of US$ 470 million comes from its commercialization company Yeda, which has a number of bestseller products. Yeda's annual income has been estimated at US$ 50–100 million (Weinreb, 2013).

Parkinson's disease. This means that the drug may be used alone, or in combination with other drugs, to treat Parkinson's disease.

Sustainability more visible in STI policy

In recent years, sustainability and environmental considerations have been increasingly taken into account in the formulation of general STI policies. Both internal and external forces are responsible for this trend. Among key internal drivers are the shortage of available land for development and the need for problem-solving to cope with population[9] growth. Among the external drivers are international and regional environmental agreements signed by Israel, such as the *Kyoto Protocol* to rein in climate change (1997) and the *Barcelona Convention for Protection against Pollution in the Mediterranean Sea* (1976), which set new environmental standards and benchmarks (Golovaty, 2006; UNESCO, forthcoming). It is the Ministry of Environmental Protection which is responsible for formulating an integrated nationwide policy to protect the environment.

Sustainability and environmental policies are being promoted through various legislative tools, including the Green Growth Act (2009) and Greenhouse Gas Emissions Reduction Act (2010), as well as through economic and R&D incentives. The government is targeting both the public and private sectors, with a focus on mitigating environmental hazards and maximizing efficiency by developing novel technologies in such fields as renewable energy or water treatment. A scheme has been initiated jointly by the Water Authority and the Ministry of Economics to match the investment cost of applying innovative water technologies; the government contributes 70%, the entrepreneur 15% and the local water utility a further 15%. Israel has one of the world's greatest capacities for desalination and the highest rate of water recycling. It has also developed a wide range of water-efficient technologies for agriculture. Some 85% of Israeli households use solar energy to heat water, equal to 4% of Israel's energy capacity. In 2014, Israel topped the rankings of the Global Cleantech Innovation Index, with 300 domestic companies active in this sector. In parallel, Israel is developing a non-renewable source of energy, natural gas, to ensure greater energy independence (Box 16.3).

Targets for more sustainable development

Since 2008, the government has fixed a number of quantifiable targets for the country's sustainable development:

- a 20% reduction in electricity consumption by 2020 (government decision of September 2008);
- 10% of electricity to be generated from renewable sources by 2020, including a 5% milestone in 2014, which has not been met (government decision of January 2009);
- a 20% reduction in greenhouse gas emissions by 2020 over and above the target to 2020 for the 'business as usual' scenario (government decision of November 2010);
- A national plan for green growth is to be established covering the period 2012–2020 (government decision of October 2011).

9. Since peaking at 2.5% in 2007 after a wave of immigration, the annual population growth rate has dropped to a more sustainable rate of 1.1% (2014).

Box 16.3: Natural gas: a chance to develop technologies and markets

Since 1999, large reserves of natural gas have been discovered off Israel's coast. This fossil fuel has become the primary fuel for electricity generation in Israel and is gradually replacing oil and coal. In 2010, 37% of electricity in Israel was generated from natural gas, leading to savings of US$ 1.4 billion for the economy. In 2015, this rate is expected to surpass 55%.

In addition, the usage of natural gas in industry – both as a source of energy and as a raw material – is rapidly expanding, alongside the requisite infrastructure. This is giving companies a competitive advantage by reducing their energy costs and lowering national emissions.

Since early 2013, almost the entire natural gas consumption of Israel has been supplied by the Tamar field, an Israeli–American private partnership. The estimated reserves amount to about 1 000 BCM, securing Israel's energy needs for many decades to come and making Israel a potentially major regional exporter of natural gas. In 2014, initial export agreements were signed with the Palestinian Authority, Jordan and Egypt; there are also plans to export natural gas to Turkey and the EU via Greece.

In 2011, the government asked the Academy of Sciences and Humanities to convene a panel of experts to consider the full range of implications of the most recent discoveries of natural gas. The panel recommended encouraging research into fossil fuels, training engineers and focusing research efforts on the impact of gas production on the Mediterranean Sea's ecosystem. The Mediterranean Sea Research Centre of Israel was established in 2012 with an initial budget of NIS 70 million; new study programmes have since been launched at the centre to train engineers and other professionals for the oil and gas industry.

Meanwhile, the Office of the Chief Scientist, among others, plans to use Israel's fledgling natural gas industry as a stepping stone to building capacity in advanced technology and opening up opportunities for Israeli innovation targeting the global oil and gas markets.

Source: IEC (2014); EIA (2013)

In order to reach these targets, the government has introduced a national programme to reduce greenhouse gas emissions. Its total budget for the period 2011–2020 amounts to NIS 2.2 billion (US$ 0.55 billion); in 2011–2012, NIS 539 million (US$ 135 million) was allocated to the following measures:

- Reduction of residential consumption of electricity;
- Support for emissions reduction projects in the industrial, commercial and public sectors;
- Support for innovative, environment-friendly Israeli technologies (NIS 40 million);
- Promotion of green construction, green building codes and related training;
- Introduction of educational programmes on energy efficiency and emissions reduction; and
- Promotion of energy efficiency regulation and energy surveys.

In May 2013, the programme became a casualty of national budget cuts and was suspended for three years. It is scheduled to resume in 2016 for a period of eight years. In its first three years of operation, the project generated NIS 830 million (US$ 207 million) in economic benefits:

- A reduction of 442 000 tons of greenhouse gases per year, with an annualized economic benefit of NIS 70 million;
- A reduction in electricity generation of 235 million kWh per year, with an annualized economic benefit of NIS 515 million; and
- A reduction in pollutant emissions and consequential health problems valued at NIS 244 million.

In 2010, the government launched a voluntary greenhouse gas emissions registry. As of 2014, the registry contained over 50 reporting organizations, which account for about 68% of Israel's greenhouse gas emissions. The registry respects international guidelines.

TRENDS IN PRIVATE SECTOR R&D

An attractive destination for multinational companies

Israel's high-tech industries are a spin-off of the explosive development of computer science and technology in the 1980s in such places as Silicon Valley and Massachusetts Route 128 in the USA, which ushered in the current high-tech era. Up until that point, Israel's economy had been essentially based on agriculture, mining and secondary sectors such as diamond polishing and manufacturing in textiles, fertilizers and plastics. The key factor which enabled ICT-based high-tech industries to take root and flourish in Israel was the massive investment by the defence and aerospace industries, which spawned new technologies and know-how. This formed the basis for Israel's unique high-tech industries in medical devices, electronics, telecommunications, computer software and hardware etc. (Trajtenberg, 2005). The massive Russian immigration of the 1990s reinforced this phenomenon, doubling the number of engineers and scientists in Israel overnight.

Today, Israel has the world's most R&D-intensive business sector; in 2013, it alone performed 3.49% of GDP. Competitive grants and tax incentives are the two main policy instruments supporting business R&D. Thanks to government incentives and the availability of highly trained human capital, Israel has become an attractive location for the R&D centres of leading multinationals. The country's STI ecosystem relies on both foreign multinationals and large corporate R&D investors, as well as on start-ups (OECD, 2014).

According to the Israel Venture Capital Database, 264 foreign R&D centres are currently active in Israel. Many of these centres are owned by large multinational firms that have acquired Israeli companies, technology and know-how and transformed them through mergers and acquisitions into their own local research facilities. The activity of some R&D centres even spans more than three decades, such as those of Intel, Applied Materials, Motorola and IBM.

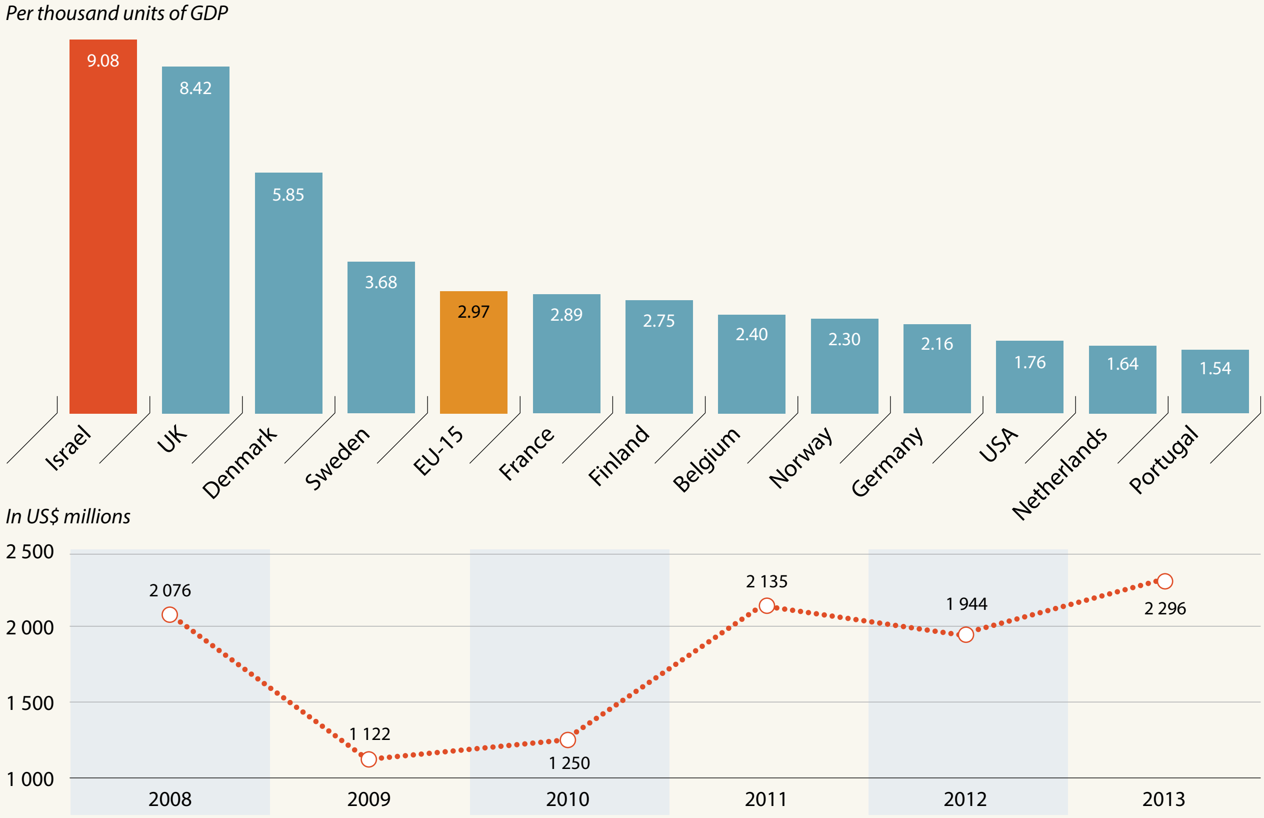
In 2011, foreign R&D centres employed 33 700 workers through local subsidiaries, two-thirds of whom (23 700) worked in R&D (CBS, 2014). The same year, these R&D centres spent a total of NIS 14.17 billion on R&D across the full spectrum of industry, up from 17% over the previous year.

A vibrant venture capital market

Israel's thriving start-up industry is complemented by a vibrant venture capital market, which attracted US$ 2 346 million in 2013 (IVC Research Centre, 2014). Over the past decade, the venture capital industry has played a fundamental role in the development of Israel's high-tech sector. By 2013, Israeli companies had raised more venture capital as a share of GDP than companies in any other country (Figure 16.12). Today, Israel is considered one of the biggest centres for venture capital in the world outside the USA.

Several factors have contributed to this growth. These include tax exemptions on Israeli venture capital, funds established in conjunction with large international banks and financial companies and the involvement of major organizations desirous to capitalize on the strengths of Israeli high-tech companies (BDO Israel, 2014). These organizations include some of the world's largest multinational companies, including Apple, Cisco, Google, IBM, Intel, Microsoft, Oracle Siemens and Samsung (Breznitz and Zehavi, 2007; IVC Research Centre, 2014). In recent years, the share of venture capital invested in the growth stages of enterprises has flourished at the expense of early stage investments.

Figure 16.12: **Venture capital raised by Israeli funds, 2013**



Source: Eurostat, OECD (2014); Israeli Venture Capital Research Centre

Foreigners: nearly 80% of applications to Israel Patent Office

Intellectual property rights in Israel protect copyright and performers' rights, trademarks, geographical indicators, patents, industrial designs, topographies of integrated circuits, plant breeds and undisclosed business secrets. Both contemporary Israeli legislation and case law are influenced by laws and practices in modern countries, particularly Anglo-American law, the emerging body of EU law and proposals by international organizations (OECD, 2011).

Israel has made a concerted effort to improve the economy's ability to benefit from an enhanced system of intellectual property rights. This includes increasing the resources of the Israel Patent Office, upgrading enforcement activities and implementing programmes to bring ideas funded by government research to the market (OECD, 2011).

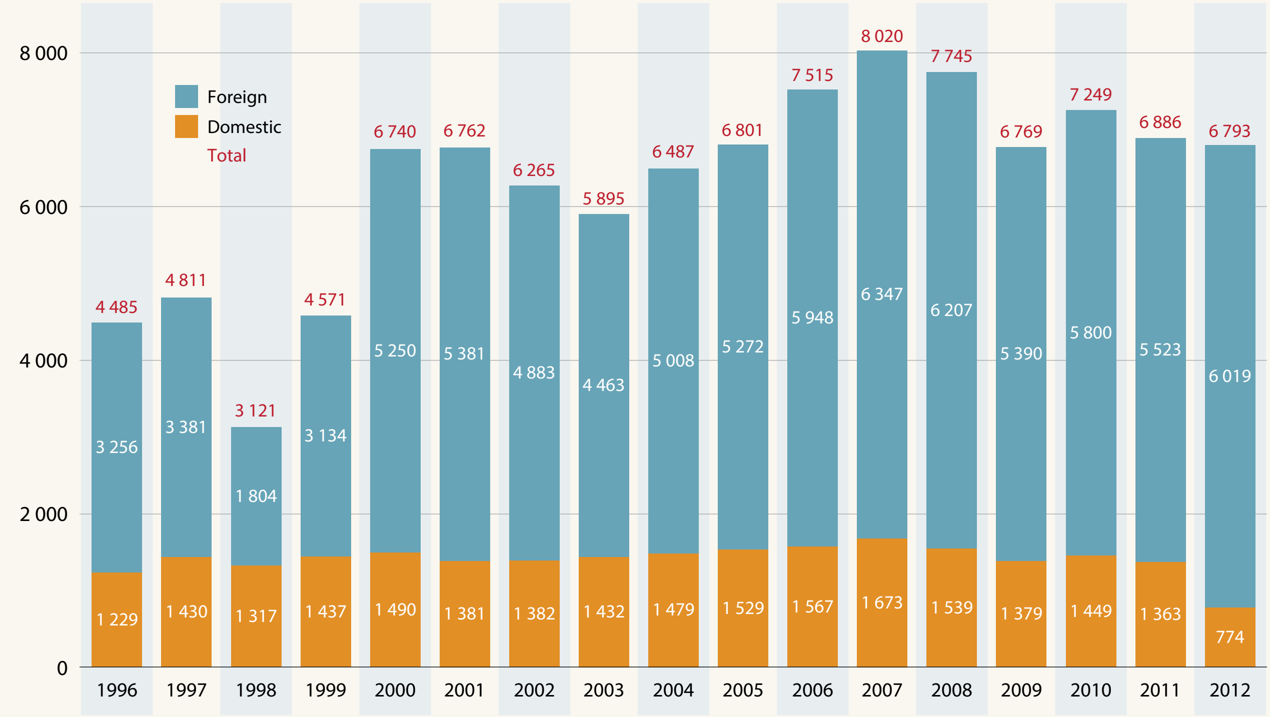
Foreigners account for nearly 80% of the patent applications filed with the Israel Patent Office since 2002 (Figure 16.13). A sizeable share of foreign applicants seeking protection from the Israel Patent Office are pharmaceutical companies such as F. Hoffmann-La Roche, Janssen, Novartis, Merck, Bayer-Schering, Sanofi-Aventis and Pfizer, which happen to be the main business competitors of Israel's own Teva Pharmaceutical Industries.

Israel ranks tenth for the number of patent applications filed with the United States Patent and Trademark Office (USPTO) by country of residence of the first-named inventor (Figure 16.14). Israeli inventors file far more applications with USPTO (5 436 in 2011) than with the European Patent Office (EPO). Moreover, the number of Israeli filings with EPO dropped from 1 400 to 1 063 between 2006 and 2011.

This preference for USPTO is largely due to the fact that foreign R&D centres implanted in Israel are primarily owned by US firms such as IBM, Intel, Sandisk, Microsoft, Applied Materials, Qualcomm, Motorola, Google or Hewlett–Packard. The inventions of these companies are attributed to Israel as the inventor of the patent but not as the owner (applicant or assignee).

The loss of intellectual property into the hands of multinationals occurs mainly through the recruitment of the best Israeli talent by the local R&D centres of multinational firms. Although the Israeli economy benefits from the activity of the multinationals' subsidiaries through job creation and other means, the advantages are relatively small compared to the potential economic gains that might have been achieved, had this intellectual property been utilized to support and foster the expansion of mature Israeli companies of a considerable size (Getz *et al.*, 2014; UNESCO, 2012).

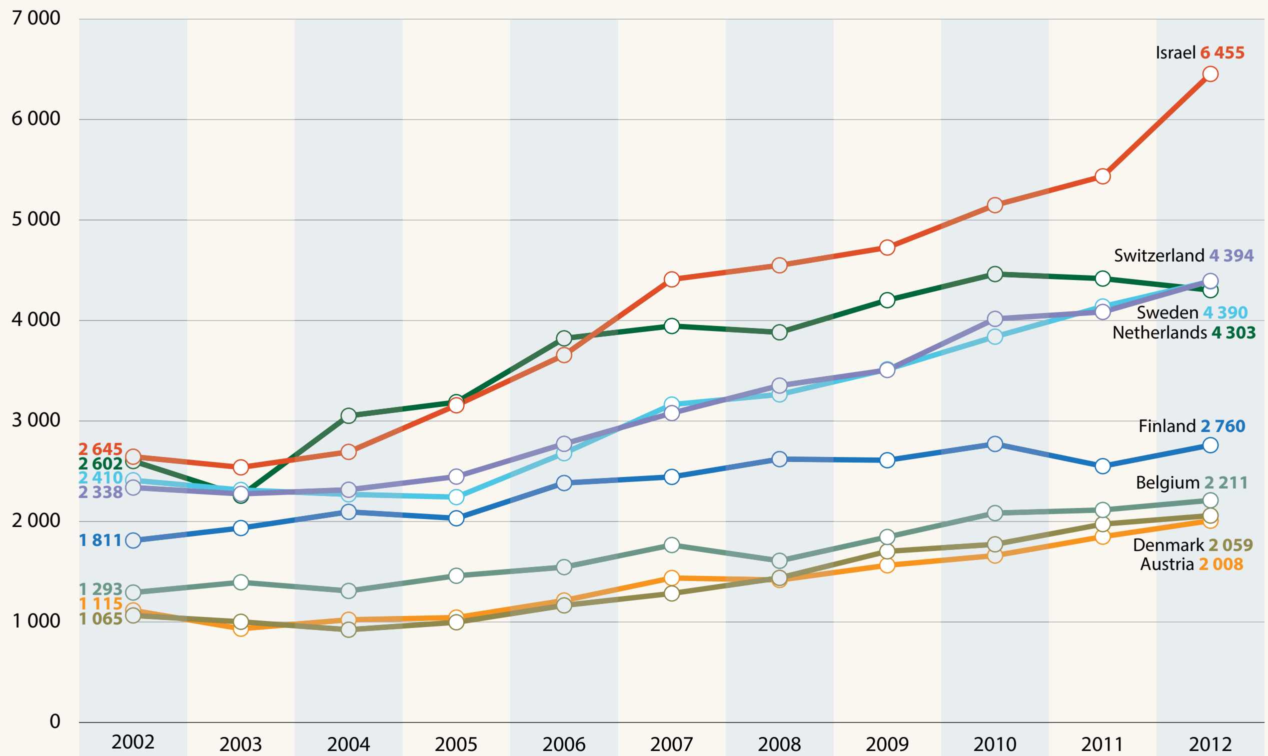
Figure 16.13: **Domestic and foreign patent applications to the Israel Patent Office, 1996–2012**



Source: Israel Patent Office

Figure 16.14: **Israeli patent applications filed with USPTO, 2002–2012**

By inventor's country of residence, other countries with a similar population size are given for comparison



Note: The top two countries registered 268 782 (USA) and 88 686 (Japan) patents respectively in 2012. Israel ranked tenth worldwide.
Source: USPTO

TRENDS IN SCIENTIFIC CO-OPERATION

Broad collaboration around the world

Israel collaborates in STI with a wide range of countries, regions and international organizations. The Israel Academy of Sciences and Humanities has official agreements with 38 institutions (mostly national academies) in 35 European countries, as well as with countries in North and South America, the Indian subcontinent and Southeast Asia.

Israel has been associated with the EU's framework programmes on research and innovation since 1996. Between 2007 and 2013, Israeli public and private institutions contributed their scientific expertise to over 1 500 projects.

Israel also participates in other EU programmes, such as those of the European Research Council or European Biology Laboratory. Israel joined the European Organization for Nuclear Research (CERN) in 2014, after having participated in its activities since 1991 and becoming an associated member in 2011. Israel has been a Scientific Associate of the European Synchrotron Radiation Facility since 1999; the agreement was renewed in 2013 for a fourth term of five years and notably raised Israel's contribution from 0.5% to 1.5% of ESRF's budget. Israel is also one of the ten founding members of the European Molecular Biology Laboratory, which dates from 1974.

In 2012, the Weizmann Institute of Science, together with Tel Aviv University, was chosen as one of the seven core centres of the new Integrated Structural Biology Infrastructure (Instruct), joining prestigious institutions in France and Germany, Italy and the UK. Israel has been selected as one of the seven nodes of the European Strategy Forum of Research Infrastructure, which is establishing about 40 such nodes in total, seven of them in biomedical sciences. The aim of the biomedical Instruct is to provide pan-European users with access to state-of-the-art equipment, technologies and personnel in cellular structural biology, to enable Europe to maintain a competitive edge in this vital research area.

Israel is also one of the nodes of Elixir, which orchestrates the collection, quality control and archiving of large amounts of biological data produced by life science experiments in Europe. Some of these datasets are highly specialized and were previously only available to researchers within the country in which they were generated.

The USA is one of Israel's closest partners in STI. Some collaborative projects are funded through binational funds such as the Binational Industrial Research and Development (BIRD) foundation, which awarded US$ 37 million in grant payments for binational R&D projects from 2010 to 2014, according to its 2014 annual report. Other examples are the Binational Agricultural Research and Development fund, the US–Israel Science and Technology Foundation and the US–Israel Binational Science foundation. The Israeli Industry Centre for R&D, which falls under the Ministry of the Economy, implements bilateral co-operation agreements with various US federated states. The most recent agreements were concluded in 2011 with the State of Massachusetts in life sciences and clean technology and with the State of New York in energy, ICTs and nanotechnology.

Israel's long-lasting collaboration with Germany continues to grow. For example, the annual budget of the German–Israel Foundation for R&D (GIF) increased by € 4.8 million per year between 2010 and 2012 and by € 5 million per year from 2014 to 2016. In the past two years, GIF has distributed about € 12 million per year through the grants it provides to the regular programme and the young scientists programme.

The Israeli Industry Centre for R&D supports co-operative projects through other binational funds, such as the Canada–Israel Industrial Research and Development Foundation, the Korean–Israel Industrial Research and Development Foundation and the Singapore–Israel Industrial Research and Development Foundation.

In 2006, the Israeli and Indian ministers of agriculture signed a long-term agreement for co-operation and training. This was followed two years later by a US$ 50 million shared agricultural fund, focusing on dairy, farming technology and micro-irrigation. In 2011, Israel and India signed a co-operation agreement on urban water systems. In May 2013, the two countries signed an agreement for the establishment of 28 centres of excellence in agriculture. The first 10 centres of excellence specialize in mangoes, pomegranates and citrus fruits. They have been operational since March 2014 and are already offering farmers free training sessions in efficient agricultural techniques such as vertical farming, drip irrigation and soil solarization.

In 2010, the Israeli Industry Centre for R&D established the China–Israel Industrial Research and Development Cooperation Programme. Industrial co-operation agreements have also been signed with the provinces or municipalities of Jiangsu (2008), Shanghai (2011) and Shenzhen (2011). The India–Israel Industrial Research and Development co-operation framework (i4RD) was signed in 2005.

In 2012, the Israel Science foundation and the Natural Science Foundation of China signed an agreement establishing a fund for joint research co-operation. Current schemes involving Israeli academic institutions include the Tel Aviv University–Tsinghua University initiative for the establishment of a joint technological research centre in Beijing and the Technion's planned branch in Guangdong Province for studies in the field of science and engineering. Within trilateral co-operation, Israel, Canada and China established a joint hub in agricultural technologies in China in 2013 (see Box 4.1).

Another example of trilateral co-operation is the Africa Initiative signed by Israel, Germany and Ghana in 2012. The three implementing partners are the Israeli and German agencies for international development co-operation, Mashav and GIZ, and Ghana's Ministry of Food and Agriculture. The aim is to develop a thriving citrus value chain in Ghana, in line with the ministry's policy of enhancing productivity to improve the livelihoods of farmers.

In October 2013, the Israeli Minister of Agriculture signed an agreement establishing a joint Israeli–Vietnamese fund for agricultural R&D, together with a free-trade agreement between the two countries.

Projects in the Middle East

Israel participates in the intergovernmental project for a Synchrotron Light Source for Experimental Science and Applications in the Middle East (SESAME), a 'third-generation' synchrotron light source in Allan (Jordan) which functions under the auspices of UNESCO. The current members of SESAME are Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey. The SESAME facility is expected to be fully operational by 2017 (see Box 17.3).

The Israeli Academic Centre in Cairo was initiated in 1982 by the Israel Academy of Sciences and Humanities. Funded by the Council for higher Education, it is entrusted with the task of strengthening research ties between universities and researchers in Israel and Egypt. The centre operated successfully until 2011 when the political climate in Egypt cooled towards Israel. Since that time, the centre has operated on a smaller scale.

The Israel Academy of Sciences and Humanities and the International Continental Drilling Programme initiated a deep-drilling expedition to the Dead Sea in 2010. Researchers from six countries participated in this scientific project, which was implemented jointly by Israel, Jordan and the Palestinian Authority.

The Israeli–Palestinian Medical and Veterinary Research Collaboration is one recent example of inter-university collaboration between Israel and the Palestinian Authority. This collaborative public health project between the Hebrew University of Jerusalem's School of Veterinary Medicine and the Al Quds Public Health Society was launched in 2014 with funding from the Dutch Ministry of Foreign Affairs.

Also of note is the Israeli–Palestinian Scientific Organization (IPSO), a non-political, non-profit organization founded over a decade ago and based in Jerusalem. Among joint research projects, one in nanotechnology stands out. It involved Israeli chemist Danny Porath at the Hebrew University of Jerusalem and one of his doctoral students, Palestinian chemist Mukhles Sowwan from Al-Quds University. Their joint research project enabled Prof. Sowwan to establish the first nanotechnology laboratory at Al-Quds University. IPSO had planned to issue a call for research proposals in late 2014, having raised about half of the requisite funding, but this call appears to have been delayed.

CONCLUSION

A need to prepare for tomorrow's science-based industries

The Israeli economy is driven by industries based on electronics, computers and communication technologies, the result of over 50 years of investment in the country's defence infrastructure. Israeli defence industries have traditionally focused on electronics, avionics and related systems. The development of these systems has given Israeli high-tech industries a qualitative edge in civilian spin-offs in the software, communications and Internet sectors.

However, the next waves of high technologies are expected to emanate from other disciplines, including molecular biology, biotechnology and pharmaceuticals, nanotechnology, material sciences and chemistry, in intimate synergy with ICTs. These disciplines are rooted in the basic research laboratories of universities rather than the defence industries. This poses a dilemma. In the absence of a national policy for universities, let alone for the higher education system as a whole, it is not clear how these institutions will manage to supply the knowledge, skills and human resources needed for these new science-based industries.

There is no single 'umbrella-type' organization that co-ordinates all of STI and formulates STI policy in Israel. In order to safeguard the long-term relevance of Israeli R&D and the country's innovation capabilities, a holistic R&D framework and strategy should be implemented. This framework should involve the various actors of the STI system: the Office of the Chief Scientist in the Ministry of the Economy and other government ministries, Israel's research universities and research centres of excellence, its hospitals and academic medical centres and its corporate R&D laboratories.

The *Sixth Higher Education Plan* (2011–2015) sets out to improve the quality and competitiveness of the higher education system. It contains important recommendations, such as that of raising the number of academic staff by about 850 over the next six years and encouraging minorities to study at university in anticipation of the looming shortage of professionals in Israel. Enhancing the integration of ultra-orthodox men and Arab women in the labour force and their educational level will be vital to safeguard Israel's growth potential in the years to come.

The *Sixth Higher Education Plan* sidesteps one key issue, however. Israel's universities are neither equipped, nor sufficiently funded to be at the forefront of science and technology in the 21st century. Funding of research infrastructure is particularly worrying because, in decades past, insufficient government funding has been greatly compensated by philanthropic contributions from the American Jewish community. This contribution is expected to diminish significantly.

Long-term economic growth cannot be attained without improving the productivity of the traditional industrial and services sector. The remedy could lie in giving employers incentives to implement innovation, by encouraging them to assimilate advanced technologies, adopt organizational changes and new business models and augment the share of exports in their output.

Globalization presents both tremendous challenges and opportunities for Israel's high-tech industry. An economy centred on delivering innovation and added value could give companies a huge competitive advantage in the global market in the years to come, as multinational companies are continually seeking new ideas and unique products to serve unmet needs.

In recent years, scientific research in interdisciplinary frontier fields such as bioinformatics, synthetic biology, nanobiology, computational biology, tissue biology, biomaterials, system biology and neuroscience, has evolved rapidly in Israeli academia but not shown the same intensity in Israeli industry. These new interdisciplinary and converging fields are likely to constitute the next growth engines for the global economy. Regulatory and targeted policy measures should be formulated by the Israeli authorities to create the necessary infrastructure to absorb the fruits of academic research in these fields and integrate, convert and adapt the fruits of this research to wider economic and practical use.

KEY TARGETS FOR ISRAEL

- Raise industrial-level productivity – the value added by each employee – from PPP$ 63 996 in 2014 to PPP$ 82 247 by 2020;
- Increase the number of university faculty by 15% and the teaching staff of colleges by 25% by 2018;
- Capture a 3–5% share of the US $ 250 billion global space market with a sales volume of US$ 5 billion by 2022;
- Reduce electricity consumption by 20% between 2008 and 2020;
- Generate 10% of electricity from renewable sources by 2020.

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The Arab world needs more champions of science and technology, including in the political arena, to bring about the positive change to which the region aspires.

Moneef R. Zou'bi, Samia Mohamed-Nour,
Jauad El-Kharraz and **Nazar Hassan**

A computer image of office buildings to be constructed in Dubai layer by layer using three-dimensional (3D) printing technology. The furniture will also be 'printed'. See Box 17.7 for details.

Image: courtesy of the Dubai Futures Foundation

17 · The Arab States

Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Sudan, Tunisia, United Arab Emirates, Yemen

Moneef R. Zou'bi, Samia Mohamed-Nour, Jauad El-Kharraz and Nazar Hassan

INTRODUCTION

The global financial crisis has ricocheted on the region

The Arab world[1] is of strategic importance, owing to its location and wealth of oil and natural gas: 57% of the world's proven oil reserves and 28% of those for gas (AFESD *et al*, 2013).

The tremors of the global financial crises of 2008 and 2009 and the subsequent recession in most developed countries affected Arab states in a variety of ways. The oil-exporting countries of the Gulf Cooperation Council felt such tremors, most being characterized by open financial and commercial systems with high exposure to global financial markets and close association with the global commodity markets (AFESD *et al*, 2010). Not so countries such as Algeria, Libya, Sudan and Yemen, where local capital markets are not directly linked to global markets. However, as their economies also rely on oil revenue, the Brent crude price significantly affects their fiscal policy.

In, Egypt, Jordan, Lebanon, Mauritania, Morocco, Syria and Tunisia, where the banking sector is dependent on national borrowing sources, the economy was not directly affected by fluctuations in global capital markets. Such countries nevertheless felt these external economic shocks through their close association with the markets of developed countries and other major trading partners in the European Union (EU) and USA. Needless to say, their exports depend primarily on demand from the developed countries, in addition to income from tourism, remittances from expatriate workers and foreign direct investment (FDI) flows (AFESD *et al*, 2010).

The inability of most Arab countries since 2008 to address socio-economic needs effectively and ensure that their economies have kept pace with population growth has created widespread frustration. Even before the economic crisis of 2008, unemployment in the Arab world was high,[2] at around 12%. Young job seekers constitute over 40% of the region's unemployed. Today, over 30% of the population of Arab states is aged less than 15 years. As of 2013, most Arab states had achieved a gross tertiary enrolment rate of more than 30% and even above 40% for Jordan, Lebanon, Palestine and Saudi Arabia but they have failed to create the appropriate value chain of job openings required to absorb the spreading pool of graduates.

The Arab region: from hope to turmoil

The so-called Arab Spring was triggered by demonstrations in Tunisia in December 2010. Popular unrest quickly spread across the region, revealing a common aspiration towards freedom, dignity and justice (ESCWA, 2014a).

Since December 2010, Arab countries have undergone extraordinary transformations, including regime change in Egypt, Libya, Tunisia and Yemen and the descent of Syria into civil war after what began as peaceful protests in the spring of 2011. Despite having elected parliaments, Jordan and Bahrain also witnessed a series of demonstrations in favour of reform in 2011. In Jordan, the protests were essentially directed against the failure of successive governments to address serious economic issues and combat unemployment. In Bahrain, demonstrations were more political in nature and, to some extent, sectarian.

In part, the upheaval in the Arab world was a reaction by technology-savvy young Arabs to decades of political stagnation and the failure of some Arab governments to afford people adequate levels of socio-economic development. Within a couple of years, however, the failure of the Arab Spring to deliver on its promises had left many disillusioned. One of the great beneficiaries of the Arab Spring was the Muslim Brotherhood movement, which won the election in Egypt in mid-2012; barely a year later, President Mohamed Morsi was deposed, following mass popular protests at the Muslim Brotherhood's failure to build a national consensus to address the country's problems. Since 2015, there have been repeated clashes between the government of President Abdel Fattah al-Sissi and the Muslim Brotherhood, which is now considered a terrorist organization by the governments of several Arab and non-Arab countries, including Bahrain, Egypt, the Russian Federation, Saudi Arabia, Syria and the United Arab Emirates. The Egyptian government has, meanwhile, forged ahead with its ambitious expansion of the Suez Canal (Box 17.1) and, in March 2015, organized a major conference in Sharm El-Sheikh on the theme of economic development (see p. 435).

Military spending is eating up resources for development

Military spending in the Middle East increased by 4% in 2013 to an estimated US$ 150 billion. Saudi Arabia's own budget shot up by 14% to US$ 67 billion, allowing it to leapfrog over the UK, Japan and France to become the world's fourth-largest military spender behind the USA, China and the Russian Federation, according to the Stockholm International

1. Although members of the League of Arab States, Djibouti and Somalia are profiled in Chapter 19 on East and Central Africa.

2. with a few exceptions, such as Kuwait, Qatar and the United Arab Emirates

Box 17.1: Upgrading the Suez Canal

The Suez Canal provides a vital shipping link between Europe and Asia. On 5 August 2014, Egyptian President Abdel Fattah Al-Sissi announced plans for a 'new' Suez Canal that would run in parallel to the current waterway. This was to be the first major expansion of this vital trading route in its 145-year history.

The Egyptian plan to upgrade the Suez Canal could raise its capacity from 49 to 97 passing ships a day by 2023. The current Suez Canal, which connects the Mediterranean with the Red Sea, can mostly only facilitate one-way traffic and is too narrow at some points for vessels to pass one another. The new canal is expected to solve this problem and thereby cut the waiting time for ships from 11 to 3 hours. The area around the canal (76 000 km^2) is being turned into an international industrial and logistics hub. Officials expect the new development to boost annual revenue from the canal, which is operated by the state-owned Suez Canal Authority, from US$ 5 billion at present to US$ 13.5 billion. In October 2014, work began on deepening the Suez Canal.

Some shipping industry executives had expressed doubts as to whether Egypt could obtain sufficient funding to finish the project on schedule. The Egyptian government was adamant that the project would not be dependent on foreign funding. By September 2014, the total amount needed (US$ 8.4 billion) had been raised, according to the Egyptian central bank, through the issuance of 500 million shares reserved for Egyptians. The government inaugurated the new canal on 6 August 2015.

Despite widespread acknowledgment that the project is an economic necessity, some scientists fear that that it could damage the marine ecosystem. A group of 18 scientists from 12 countries published a letter in 2014 in the journal of *Biological Invasions* calling on the Egyptian government to take steps to minimize any ecological damage.

Source: compiled by authors

Peace Research Institute[3] (see also Figure 17.1) However, the largest increase in the region (27%) came from Iraq, which is reconstituting its armed forces.

The escalating pressures on Arab states, particularly those related to security and counterterrorism – including military confrontations with radical groups such as Al Qaida and Da'esh –, have spurred the governments of these countries to increase their own military spending.

Still a long way to go to improve governance

There is little doubt that corruption has played a pivotal role in the outbreak of turmoil since 2010. Available estimates suggest that the smuggling of funds amounted annually to US$ 2 billion in Egypt and US$ 1 billion in Tunisia, according to the institution charged with monitoring the soundness of the global financial sector (Global Financial Integrity, 2013). This amount represented 3.5% of Tunisia's GDP and 2% of Egypt's in 2005.

Government effectiveness has deteriorated in several Arab countries. Kaufmann *et al*. (2013) found that, in the Arab world, only the United Arab Emirates (UAE) and Qatar ranked above the 80th percentile in 2013. Bahrain and Oman ranked between the 60th and 70th percentiles and five countries between the 50th and 60th percentiles, namely, Jordan, Kuwait, Morocco, Saudi Arabia and Tunisia.

The voice and accountability indicator over the past ten years has been disappointing, according to Kaufmann *et al.* (2011; 2013). In 2013, the scores for the top five Arab states (Tunisia, Lebanon, Morocco, Kuwait and Jordan) were low by international standards (between the 45th and 25th percentiles). Algeria, Iraq, Libya and Palestine show some improvement but, overall, 12 Arab states registered a decline in voice and accountability between 2003 and 2013, namely: Algeria, Bahrain, Djibouti, Egypt, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Sudan, Syria and the United Arab Emirates.

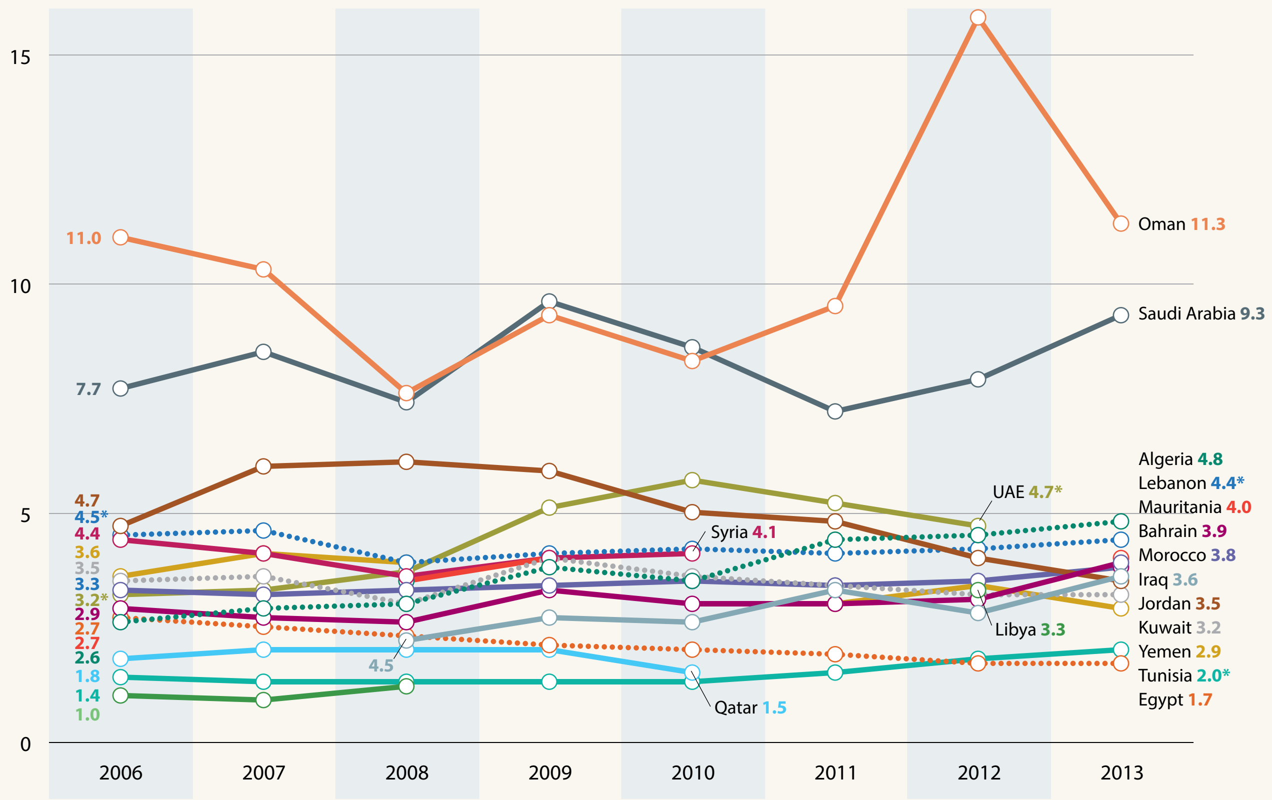
An economic downturn in most Mashreq countries

The countries of the Mashreq have a population of about 196 million, or 53.4% of the Arab population. With the exception of Iraq, they have few oil reserves. Thanks to high commodity prices for oil, Iraq was able to weather the global financial crisis better than its neighbours. The slump in Sudan's economy in 2012, however, was more a consequence of the birth of South Sudan in 2011 and subsequent skirmishes between the two Sudans than the impact of global shocks.

In 2013, GDP per capita in the Mashreq countries, Egypt and Sudan was highest in Lebanon and lowest in Sudan. From 2008 to 2013, annual growth slowed in all the countries of this group, even though it was less noticeable in Palestine in 2013. Over the same period, unemployment rates changed little in all but Egypt, where the slump in tourism and FDI following the revolution in 2011 pushed up unemployment (Table 17.1). With the return to stability, GDP growth recovered to 2.9% in 2014 and is expected to hit 3.6% in 2015. Economic growth

3. See: www.sipri.org/media/pressreleases/2014/Milex_April_2014 (accessed 16 January 2015)

Figure 17.1: **Military expenditure in selected Arab states as a % of GDP, 2006–2013**



*SIPRI estimate

Note: The low figure for Egypt (1.7%) in 2013 only tells half the story, as it excludes the economic activities of the Egyptian armed forces and American aid, which cover 80% of military procurement (Gaub, 2014).

Source: Stockholm International Peace Research Institute database, accessed January 2015

in Jordan and Lebanon, in particular, has been affected by the massive influx of Syrian refugees since 2011.

Together with Egypt and Sudan, the Mashreq countries are considered reservoirs of human talent which supply neighbouring states with teaching faculty, researchers and both skilled and unskilled workers. Egypt, Iraq Jordan, Lebanon, Palestine,[4] Sudan and Syria all boast relatively mature higher education infrastructure that includes some of the oldest universities in the Arab world, including the American University of Beirut (1866) and Cairo University (1908).

The Arab Spring has left a big imprint on the Libyan economy

Since 2008, the Maghreb countries have experienced mixed fortunes. Whereas the economies of Algeria and Mauritania have maintained healthy growth rates, countries directly affected by the Arab Spring have witnessed a more negative trend. Growth slowed to 2.2% in Tunisia and even contracted by 11.6% in Libya (Table 17.1). However, unemployment rates have remained unchanged, with variations from one country to another. Despite average growth of 5.9% between 2011 and 2013, Mauritania's unemployment rate was as high as 31% in 2013, indicating that growth had not been sufficient to provide much-needed jobs.

The Gulf States contribute nearly half of the Arab world's GDP

The six Gulf States, which contribute about 47% of total Arab GDP, are all economically dependent on oil. Some 75 million people (including a sizeable foreign labour force) belong to this group, representing around 20.4% of the Arab world population in 2014 (Table 17.1).

In 2014, the economy slowed in Oman and Qatar, primarily as a consequence of weaker exports and the drop in both private consumption and investment. At the same time, Kuwait and Saudi Arabia emerged from a period of economic contraction, with several sectors showing signs of recovery, including housing in Kuwait and banking in Saudi Arabia.

4. On 29 November 2012, the United Nations General Assembly voted to grant Palestine non-member observer status at the United Nations. Palestine has been a member of UNESCO since 31 October 2011.

Table 17.1: **Socio-economic indicators for the Arab States, 2008 and 2013**

	Population ('000s)		GDP per capita (current PPP$)		GDP average annual growth (%)		Employment rate (% of adult population)		Unemployment rate (% of labour force)	
	2008	2013	2008	2013	2008 – 2010	2011 – 2013*	2008	2013	2008	2013
Gulf States plus Yemen										
Bahrain	1 116	1 332	40 872	43 824	4.4	3.7	63.9	65.0	7.8	7.4
Kuwait	2 702	3 369	95 094	85 660^{-1}	-2.4	6.1	66.0	66.3	1.8	3.1
Oman	2 594	3 632	46 677	44 052	6.4	2.2	52.1	59.9	8.4	7.9
Qatar	1 359	2 169	120 527	131 758	15.4	7.5	85.1	86.2	0.3	0.5
Saudi Arabia	26 366	28 829	41 966	53 780	5.9	6.0	48.6	51.8	5.1	5.7
United Arab Emirates	6 799	9 346	70 785	58 042^{-1}	0.0	2.7	74.0	76.9	4.0	3.8
Yemen	21 704	24 407	4 250	3 958	3.8	-3.2	40.6	40.3	15.0	17.4
Mashreq plus Egypt and Sudan										
Egypt	75 492	82 056	9 596	11 085	5.7	2.0	43.9	42.9	8.7	12.7
Iraq	29 430	33 417	11 405	15 188	6.0	8.2	35.3	35.5	15.3	16.0
Jordan	5 786	6 460	10 478	11 782	5.0	2.7	36.6	36.3	12.7	12.6
Lebanon	4 186	4 467	13 614	17 170	9.1	1.7	43.2	44.4	7.2	6.5
Sudan	34 040	37 964	3 164	3 372	3.2	-6.5	45.3	45.4	14.8	15.2
Syria	20 346	–	–	–	–	–	40.1	–	10.9	–
West Bank & Gaza	3 597	4 170	3 422	4 921^{-1}	4.2	5.6	31.7	31.6	26.0	23.4
Maghreb										
Algeria	35 725	39 208	11 842	13 304	2.4	3.0	37.9	39.6	11.3	9.8
Libya	5 877	6 202	27 900	21 397	3.6	-11.6	43.2	42.6	19.1	19.6
Mauritania	3 423	3 890	2 631	3 042	2.2	5.9	36.3	37.2	31.2	31.0
Morocco	30 955	33 008	5 857	7 200	4.7	4.0	46.2	45.9	9.6	9.2
Tunisia	10 329	10 887	9 497	11 092	3.9	2.2	40.9	41.3	12.4	13.3

+*n*/-*n* = data refer to *n* years before or after reference year.

* For Kuwait, Oman and United Arab Emirates, the years are 2011–2012.

Note: Palestine is designated as the West Bank and Gaza here, owing to data coverage issues.

Source: World Bank's World Development Indicators, May 2015

The slump is hitting oil-rent economies hard

The slump in global oil prices from US$ 115 in June 2014 to US$ 47 in January 2015 has been mending holes in the budgets of Arab oil-importing countries such as Egypt, Jordan, Morocco and Tunisia. By contrast, it has punched holes in the budgets of oil-producing countries, including members of the Organization of Petroleum Exporting Countries (OPEC) [Figure 17.2]. The slump has not affected the export growth of Bahrain and the United Arab Emirates as much as that of other Gulf states, thanks to their diversification of exports. In order to diversify their own sources of income, other Arab governments will need to create a socio-economic environment in which all active stakeholders can thrive, including the private sector.

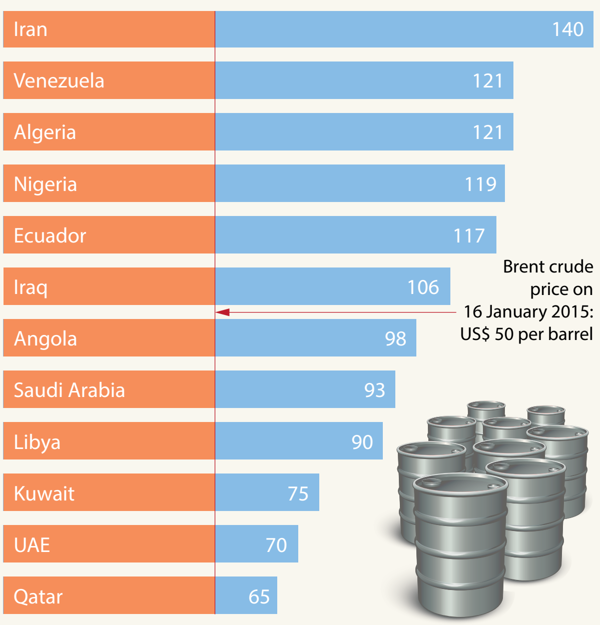
As early as 1986, the Gulf Cooperation Council identified economic diversification as a key strategic goal for its members. Whereas Saudi Arabia, the United Arab Emirates and Qatar have since developed their non-oil sectors, Bahrain and Kuwait are finding it harder to make the transition (Al-Soomi, 2012). Some voices from within the subregion have suggested transforming the Gulf Cooperation Council into a regional socio-economic and political bloc modelled on the European Union (O'Reilly, 2012).

The slump in oil prices comes at a particularly bad time for Iraq, which needs high oil revenue to revive its economy and combat terrorism, and for Libya which is facing internal instability and battling an insurgency by militia groups. Algeria raised its welfare spending in 2011 and now needs oil prices at US$ 121 a barrel to avoid a budget deficit, the International Monetary Fund estimates; it could slip into the red in 2015 for the first time in 15 years (*Wall Street Journal*, 2014). Oil and gas exports still represent two-thirds of national income for Algeria (see Figure 18.1), which has a tiny manufacturing sector (Figure 17.3). This said, Algeria may be less vulnerable the next time Brent crude prices tumble. It is developing solar and wind energy for domestic consumption and export (see p.447). Global investment in renewable energy technologies increased by 16% in 2014, triggered by an 80% decrease in the manufacturing costs of solar energy systems.

FDI flows to the Arab world have slowed

The economic fallout of the current upheaval has negatively affected the flow of FDI into Arab states, not to mention their tourism sector and real estate markets. Interestingly, the drop in FDI appears to have begun before 2011 (Figure 17.4). This can be traced back essentially to the global financial crisis of 2007–2008, thought to have been the worst since the Great Depression of the 1930s. Countries less affected by this turbulence, such as Algeria and Morocco, have seen greater stability in FDI inflows but they also enjoyed modest levels of foreign investment to begin with. There has been a surge in the flow of FDI to Morocco for new projects to expand the railways and deploy renewable energy on a massive scale. In Mauritania, FDI tends to be destined

Figure 17.2: **Estimated oil price needed to balance the government budget in OPEC member states, 2014**



Source: adapted from Wall Street Journal (2014), based on data from the Government of Libya, Angolan Ministry of Finance, International Monetary Fund, Arab Petroleum Investments Corp., Deutsche Bank

primarily for projects related to crude oil and natural gas exploration and drilling.

In Egypt, FDI increased by 7% to US$ 4.1 billion between 2013 and 2014. The Sharm El-Sheikh Economic Development Conference organized by the government in 2015 attracted more than 1 700 investors, as well as former British prime minister Tony Blair, US Secretary of State John Kerry and the International Monetary Fund's managing director Christine Lagarde. By the conference's end, Egypt had attracted US$ 36.2 billion in investment, plus US$ 18.6 billion in infrastructure contracts and US$ 5.2 billion in loans from international financial institutions.

STI GOVERNANCE ISSUES

Bringing the business community in from the cold

In March 2014, the Council of Ministers of Higher Education and Scientific Research in the Arab World endorsed the draft *Arab Strategy for Science, Technology and Innovation* at its 14th congress in Riyadh (Saudi Arabia). The strategy has three main thrusts: academic training in science and engineering, scientific research and regional and international scientific co-operation. One of the strategy's key objectives is to involve the private sector more in regional and interdisciplinary collaboration, in order to add economic and development value to research and make better use of available expertise. Up to now, STI policies in Arab states have failed to catalyse knowledge production effectively or add value to products and services because they focus on developing R&D without taking the business community on board. There has also been a lot of talk about re-orienting the education system towards innovation and entrepreneurship but little action thus far (Box 17.2). Of note are the recent higher education reforms launched by Egypt and Tunisia.

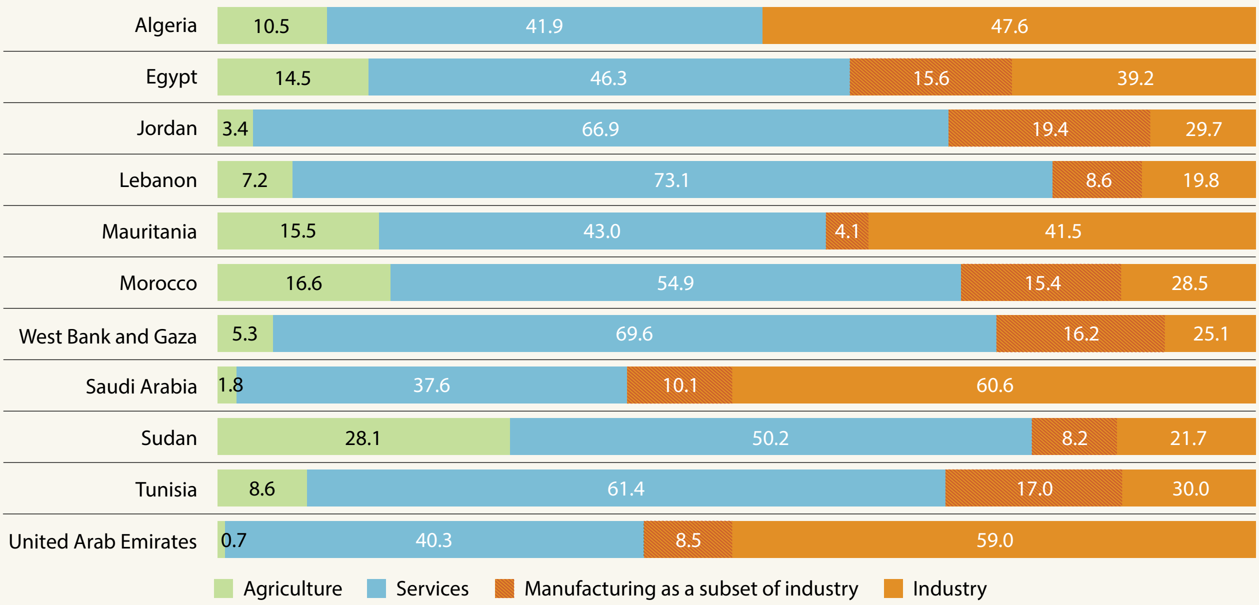
Tunisia and Saudi Arabia currently lead the Arab world in electronics and the United Arab Emirates is investing heavily in space technologies. In the field of renewable energy, Morocco is a leader in hydropower. Algeria, Jordan, Morocco and Tunisia are all developing solar energy. Egypt, Morocco and Tunisia have experience of wind energy that could benefit other countries keen to invest in this area, including Jordan, Libya, Saudi Arabia, Sudan and the United Arab Emirates. Morocco and Sudan are currently the main users of biomass.

The strategy proposes the following areas for co-operation:

- Development and management of water resources;
- Nuclear energy, with applications in the health sector, industry, agriculture, materials science, environment and nuclear energy production;
- Renewable energy: hydropower, solar, wind and biomass;

Figure 17.3: **GDP per economic sector in the Arab world, 2013 or closest year**

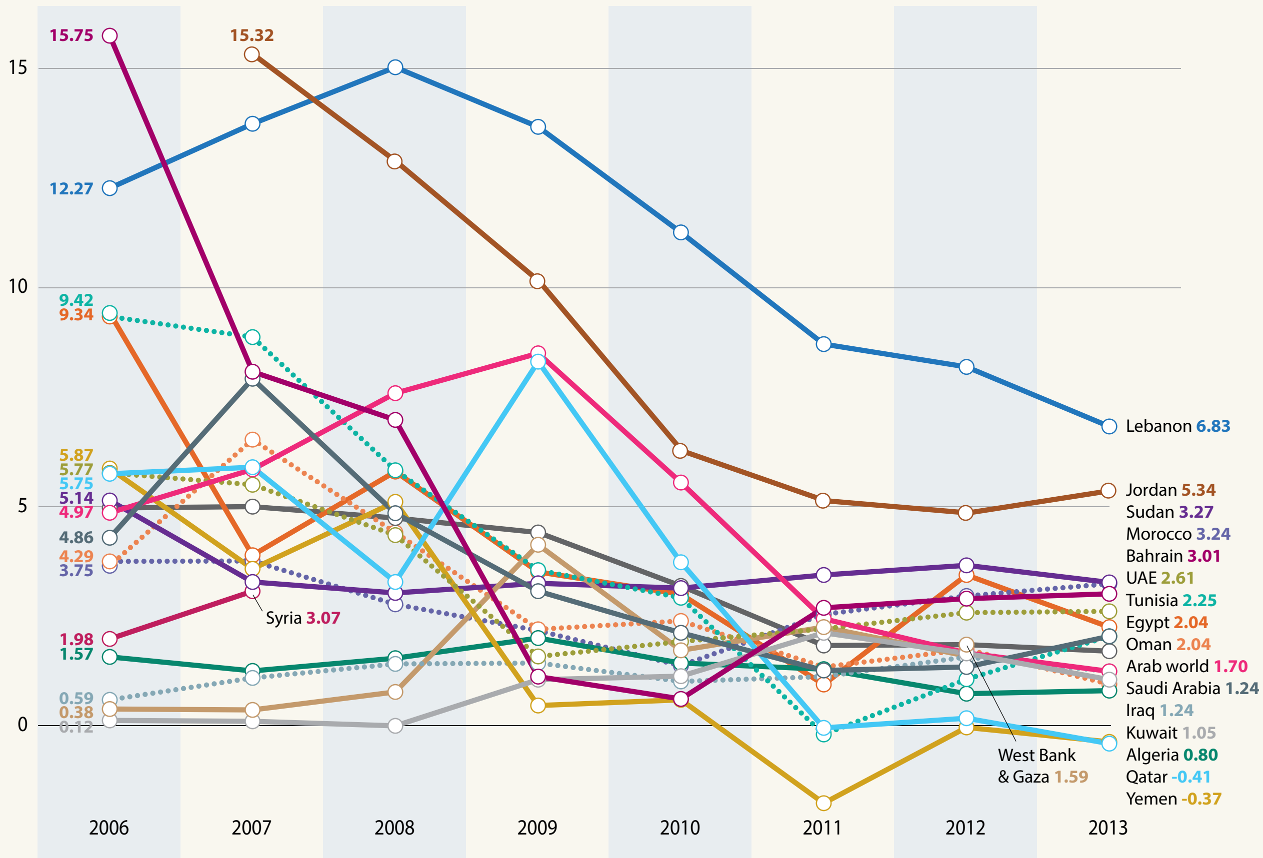
Selected economies



Note: For the West Bank and Gaza, data are for 2012. Palestine is designated as the West Bank and Gaza here, due to data coverage issues.

Source: World Bank's World Development Indicators, January 2015

Figure 17.4: **FDI inflow to selected Arab economies as a share of GDP, 2006–2013 (%)**



Source: World Bank's World Development Indicators, January 2015

- Oil, gas and petrochemicals industries;
- New materials;
- Electronics;
- Information technologies;
- Space sciences: applications in navigation systems, meteorology, irrigation, environmental monitoring, forest management, disaster risk management, urban planning, etc.;
- Nanotechnology: applications in health and pharmaceuticsal fields, food industry, environment, desalination, energy production, etc.;
- Agriculture, livestock and fisheries;
- Industry and production;
- Desertification, climate change and its impact on agriculture;
- Health sciences and biotechnology;
- Future convergent technologies: bioinformatics, nanobiotechnology, etc.

The strategy also emphasizes public outreach by scientists[5] and greater investment in higher education and training to build a critical mass of experts and staunch brain drain. It also advocates involving scientists from the diaspora. It was originally due to be adopted by ministers in 2011 but the timetable was perturbed by the events of 2011.

Priorities: problem-solving research, scientific mobility and education

In September 2013, ministers of research met in Morocco to lay the foundations for a common research policy between the five countries of the Maghreb and five countries of the Western Mediterranean: France, Italy, Malta, Portugal and Spain. These ten countries have met regularly since 1990 to discuss a wide range of issues, from security and economic co-operation to defence, migration, education and renewable energy but this was the first time that the 5+5 Dialogue, as

5. Tunisia's first dinosaur exhibition opened at Tunis Science City in mid-2011, with a focus on Saharan dinosaurs. The exhibition, which had taken two years to prepare, was originally scheduled to run until August 2012. It proved so popular that it was extended to mid-2013.

Box 17.2: **Matching university curricula to market needs**

The Network for the Expansion of Convergent Technologies in the Arab Region (NECTAR) was launched by the UNESCO Cairo Office in June 2011 to help correct the mismatch between the skills companies seek and the programmes provided by most universities.

Biotechnology, nanotechnology, ICTs and cognitive sciences are all convergent technologies which overlap considerably. By developing linkages between academia and industry in these fields, NECTAR plans to reorient academia towards problem-solving and remove the barriers between disciplines that currently hinder innovation in the Arab world.

A top priority for NECTAR has been to modernize the curricula of the Arab region's universities, in collaboration with renowned Arab scientists based at universities in the USA and in Egypt, where the majority of specialists in convergent technologies can be found in the Arab region. NECTAR targets both universities and technical colleges, as technicians are the group which gives convergent technologies their manufacturing edge.

The original plan was for professors from the USA to travel to Cairo to teach intensive courses (3-4 weeks maximum) every year. After the Arab Spring, Cairo and other key cities came to be considered a security risk, so the programme morphed into a virtual education programme. The e-content has been developed by Pennsylvania State University (PSU) and should be ready by August 2015. The courses will be permanently accessible via PSU's portal, with tutoring support on hand from the professors who own the courses. This approach will guarantee continuity and greater equity for Arab universities in terms of access to the coursework.

NECTAR has developed a virtual Higher Industrial Diploma Certificate and a master's degree in Applications of Nano-sciences. Initially, both programmes will be used to train university teaching staff (mainly PhD-holders). These staff members will then serve as the core team for the development of an undergraduate minor programme in nanosciences at each university. The tuition fees have been greatly reduced to encompass only PSU's costs in administering the programme. The diploma certificate will be accredited by PSU, whereas the master's programme will be accredited through participating universities in the Arab world.

There should be strong demand for NECTAR graduates from industries such as pharmaceuticals, chemicals, petrochemicals, oil production, opto-electronics, electronics, information technology, fertilizers, surface coating, building technology, foodstuffs and automotive.

NECTAR organized a regional forum in Cairo in November 2014 on the theme of Galvanizing Science Education and Higher Education towards a Knowledge-based Economy. Since the forum, UNESCO has submitted a proposal to the Egyptian government for a pilot education programme which would stretch from the first year of primary school to postgraduate levels.

Source: Nazar Hassan, UNESCO

the regional forum is known, had focused on research and innovation. In the *Rabat Declaration*, ministers undertake to facilitate training, technology transfer and scientific mobility by creating a specific visa for researchers; in parallel, the Maghreb countries are encouraged to join European research programmes as a first step towards harmonizing national policies and launching joint research projects.

The declaration adopted by ministers meeting in Rabat a year later at the Second[6] Forum on Science, Technology and Innovation in Africa reflects many of the concerns of the *Rabat Declaration:* the need for a greater focus on applied research to solve practical problems related to sanitation, health, agriculture, energy and climate change; the catalytic role of public investment in fostering a strong private sector; the need to improve the teaching of science, technology, engineering and mathematics and to facilitate the mobility of researchers.

Research takes a back seat in most universities

A growing number of Arab governments are setting up observatories to monitor their science systems, including in Egypt, Jordan, Lebanon, Palestine and Tunisia. When studying the data collected, however, analysts often see a direct correlation between the number of graduates or faculty and the number of researchers. This is misleading, as many students and faculty members do not conduct research and only a few actually publish in refereed journals listed by the Web of Science or Scopus and have international contacts. Many Arab universities are simply not research universities. Moreover, until recently, the terms of reference for a university professor in the Arab region did not include research.

The real test comes from counting the time spent effectively by an individual on research, as opposed to teaching or other tasks. It is rare for the actual research activity of teaching staff in government and most private universities to exceed 5–10% of their total academic duties, compared to 35–50% in European and American universities. A recent survey by the American University of Beirut shows that around 40% of academics' time is spent on research; this translates into an average of two publications per year for each full-time equivalent (FTE) researcher (ESCWA, 2014a).

In Jordan and many other Arab states, the bulk of scientific research is carried out within a higher education system that is faced with its own problems, including scarce resources and burgeoning student numbers. With the ranking craze sweeping Jordanian universities, rectors are no longer certain whether their institutions should aim to generate knowledge (i.e. scientific publications) or transmit knowledge (i.e. teach).

Scientists under pressure to target international journals

The pressure to publish in internationally recognized journals discourages publication in local journals. Moreover, Arab scientific journals suffer from fundamental problems, such as irregular periodicity and a lack of objective peer review. Many local periodicals are not regarded as credible vehicles for obtaining an academic promotion – even within the countries where they are published – thus reinforcing the desire of many academics to publish in international peer-reviewed journals whenever possible (ESCWA, 2014b).

In 2010, the Egyptian Academy of Scientific Research and Technology contacted a number of internationally renowned journals to establish a checklist of the criteria an article needed to meet to be accepted for publication. Five years on, there has been a 200% increase in peer-reviewed publications, according to the academy.

In 2014, UNESCO and the Arab League Educational, Cultural and Scientific Organization (ALECSO) decided to establish an online Arab observatory of science and technology. The observatory will host a portal for research projects and an inventory of Arab universities and scientific research centres, as well as patents, publications and master's and PhD theses in digital format; scientists will be able to use the forum to organize virtual conferences. The observatory will also host national observatories for Arab states to facilitate an interactive, semi-automated database of STI indicators.

Lessons can be learned from the Tunisian experience

Arab countries face a host of hurdles, including a lack of focus in research priorities and strategies, insufficient funding to meet research goals, little awareness of the importance of good scientific research, inadequate networking, limited collaborative efforts and brain drain. It is clear from available statistics that countries will need more sustained government support in future, if they are to strengthen university research, overcome weak university–industry linkages and give university graduates the professional and entrepreneurial skills to create viable national innovation systems.

There are lessons to be learned from the experience of Tunisia prior to December 2010 where, despite clear government support for research and higher education, socio-economic progress across the various strata of society had stalled and was failing to create jobs. This situation was at least in part a consequence of the lack of academic freedom and the fact that allegiance to the regime was considered more important than competence.

6. The first took place in Nairobi in March 2012. It focused on STI for youth employment, human capital development and inclusive growth. Both were organized by UNESCO, the Afrian Development Bank, United Nations Economic Commission for Africa and African Union in association with the Association for the Development of Education in Africa.

TRENDS IN R&D

Investment remains low but change is in the air

Gross domestic expenditure on research and development (GERD) as a percentage of GDP remains low in the Arab world. It is, of course, hard for wealthy oil-rent economies like the Gulf States to have a substantial GERD/GDP ratio, as GDP is so high. The countries with the greatest R&D intensity are Libya and Morocco (Figure 17.5). Tunisia used to have the Arab world's highest ratio but, after revising its national data, it published a GERD/GDP ratio of 0.71% in 2009 and 0.68% in 2012. The R&D intensity of Egypt, Jordan and Sudan has been low for decades, despite a growing number of public and private universities. That appears to be changing in Egypt, the only country for which there are recent data for this indicator: GERD reached an all-time high of 0.68% of GDP in 2013. Iraq, meanwhile, has failed to use the windfall of high oil prices in recent years to raise its own GERD/GDP ratio, which stood at about 0.03% in 2011. Most Arab States are still trailing fellow members of the Organization of Islamic Cooperation for this indicator, including Malaysia (1.07% in 2011) and Turkey (0.86% in 2011).

Although data on the type of R&D performed are only available for a handful of countries, they suggest a heavy focus on applied research in the Arab world. In 2011, Kuwait invested the entirety of GERD in applied research, compared to about two-thirds for Iraq and half for Qatar, according to the UNESCO Institute for Statistics. The remainder in Qatar was equally divided between basic research and experimental development. One-quarter of investment (26.6% in 2011) in Qatar went to medical and health sciences.

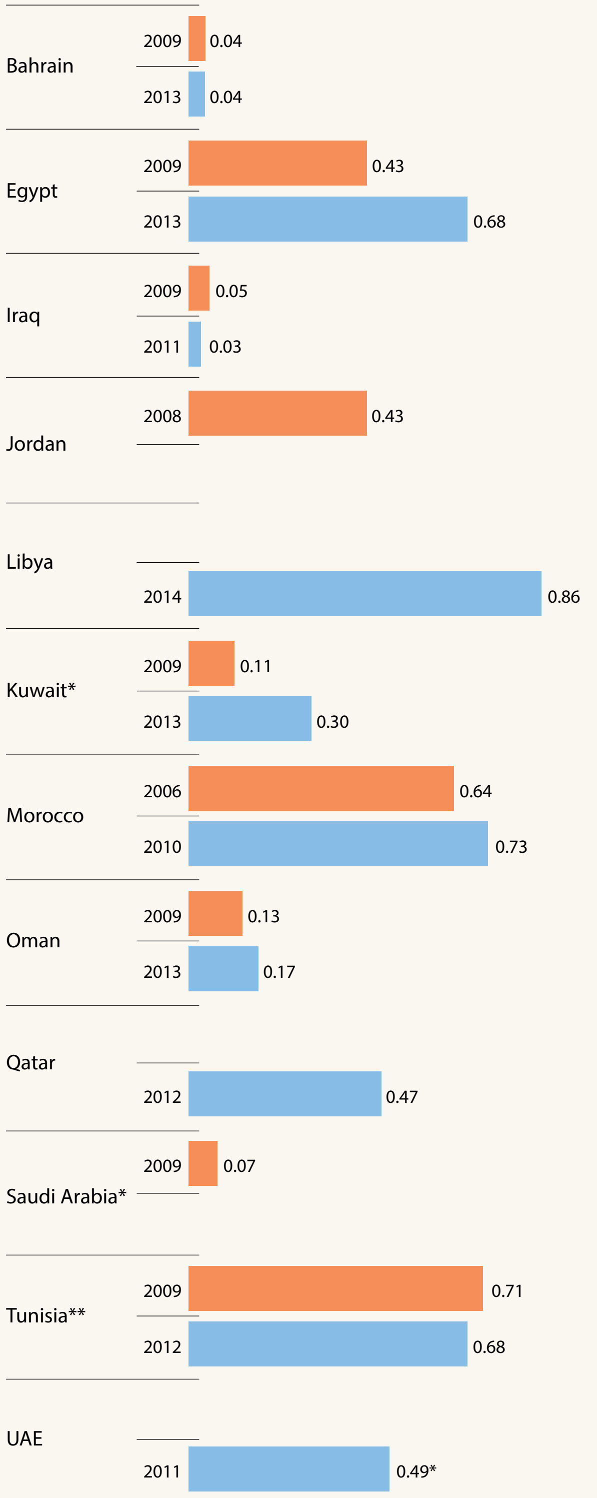
The greatest researcher density: Jordan, Morocco and Tunisia

In a context of rapid population growth, the number of researchers per million population is a more telling indicator of progress than sheer numbers. With 1 394 full-time equivalent (FTE) researchers per million inhabitants in 2012, Tunisia leads the Arab world for this category, followed by Morocco (Figure 17.6). Jordan has a density of researchers similar to that of Tunisia (1 913 in head counts) but this figure dates from 2008.

Egypt and Bahrain close to gender parity

Egypt (43% women) and Bahrain (41%) are relatively close to gender parity (Figure 17.7). In the majority of other countries for which data are available, women make up between one in three and one in five researchers. The notable exception is Saudi Arabia, where just 1.4% of researchers were women in 2009, although only the King Abdulaziz City for Science and Technology was surveyed. A number of countries have been building up their researcher intensity in recent years, albeit from low levels. Palestine is remarkable, in this respect. Thanks to the efforts of Palestinian universities, the government and the Palestine Academy of Science and Technology, 23% of researchers were women by 2013.

Figure 17.5: **GERD/GDP ratio in the Arab world, 2009 and 2013 or closest years (%)**



*estimation **based on national estimation

Note: Data are partial for Bahrain (higher education only), Kuwait (government sector only in 2009) and Saudi Arabia.

Source: UNESCO Institute for Statistics, January 2015; for Sudan: Noor (2012); for Oman: Al-Hiddabi (2014); for Libya: National Planning Council (2014) *National Strategy for Science, Technology and Innovation*

In several countries, women represent more than four out of ten researchers employed in natural sciences (Kuwait, Egypt and Iraq) and medical and health sciences (Kuwait, Egypt, Iraq, Jordan and Morocco). In Egypt, they have attained parity in social sciences and humanities. Most of the small group of Saudi women researchers works in medical and health sciences (Table 17.2).

The share of students graduating in S&T fields ranges from a low of 11% in Jordan to a high of 44% in Tunisia (Table 17.3). Recent data available for ten countries reveal that women represent between 34% and 56.8% of tertiary graduates in science, engineering and agriculture, a relatively high ratio (Table 17.4). In science and agriculture, women have achieved parity and even dominate these fields in most countries. They remain a minority in engineering, with the notable exception of Oman (Table 17.4).

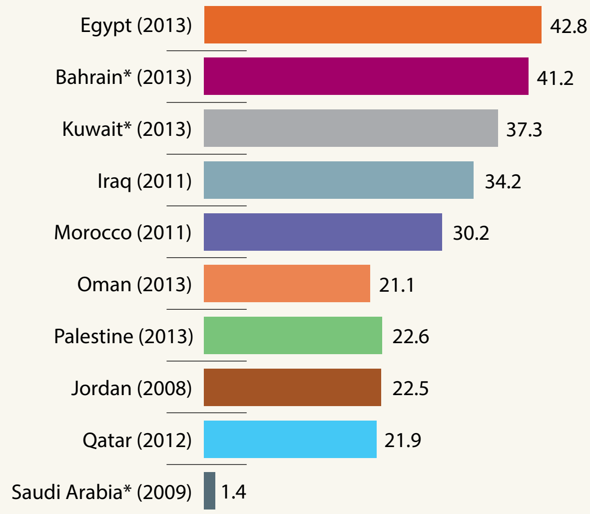
Government expenditure on education represents a sizeable share of GDP in much of the Arab world. Moreover, most of the countries for which data are available devote more than 1% of GDP to higher education (Figure 17.8).

Little business R&D

In many Arab states, the bulk of GERD is performed by the government sector, followed by the higher education sector; the private sector assumes little or even no role in the research enterprise. In Egypt, for instance, the Academy of Scientific Research and Technology estimates that the private sector contributes only around 5% of the country's research expenditure (Bond *et al.,* 2012). Jordan, Morocco, Oman, Qatar, Tunisia and the United Arab Emirates are exceptions to the rule. Erawatch estimates that the private sector performs

Figure 17.7: **Share of women Arab researchers, 2013 (%)**

Selected countries, in head counts



*partial data

Note: For Bahrain, data only cover the higher education sector; for Kuwait and Saudi Arabia, data only cover the government sector.

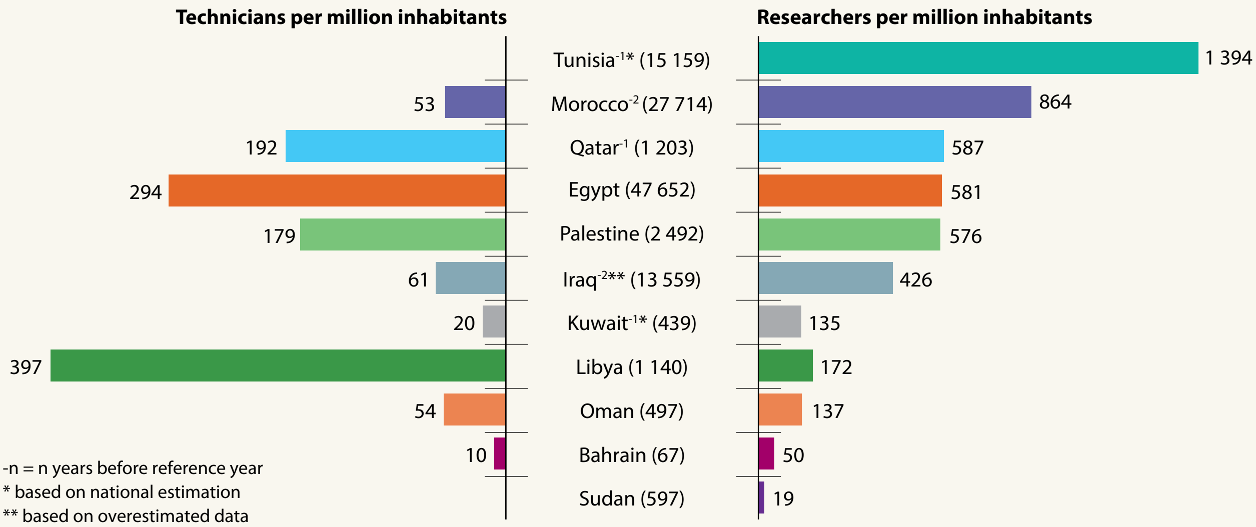
Source: UNESCO Institute for Statistics, January 2015

one-third of GERD in Jordan, 30% in Morocco (2010), 29% in the United Arab Emirates (2011), 26% in Qatar (2012) and 24% in Oman (2011). The figure is closer to 20% in Tunisia, according to the UNESCO Institute for Statistics. Business enterprises also finance about 24% of GERD in Qatar and 20% in Tunisia.

The data for FTE researchers by sector of employment and gender are scant for most Arab states. Available data for Egypt indicate that the majority of researchers were employed by

Figure 17.6: **Arab researchers and technicians (FTE) per million inhabitants, 2013 or closest year**

The total number of researchers is given in brackets



Note: For Bahrain, data only cover the higher education sector; for Kuwait, data only cover the government sector. Data are also partial for Moroccan technicians.

Source: UNESCO Institute for Statistics, January 2015; for Libya: Libyan Authority for Research, Science and Technology; for Sudan: National Research Centre

Table 17.2: **Arab researchers (HC) by field of employment, 2013 or closest year (%)**

Selected economies

	Year	Natural sciences		Engineering and technology		Medical and health sciences		Agricultural sciences		Social sciences		Humanities		Unclassified	
		Total	Women	Total	Women	Total	Women	Total	Female	Total	Women	Total	Women	Total	Women
Gulf States plus Yemen															
Kuwait	2013	14.3	41.8	13.4	29.9	11.9	44.9	5.2	43.8	8.8	33.4	13.3	35.6	33.2	36.5
Oman	2013	15.5	13.0	13.0	6.2	6.5	30.0	25.3	27.6	24.3	23.7	13.2	22.1	2.2	33.3
Qatar	2012	9.3	21.7	42.7	12.5	26.0	27.8	1.6	17.9	14.3	34.6	4.8	33.7	1.3	31.8
Saudi Arabia*	2009	16.8	2.3	43.0	2.0	0.7	22.2	2.6	–	0.0	–	0.5	–	36.4	–
Mashreq and Egypt															
Egypt	2013	8.1	40.7	7.2	17.7	31.8	45.9	4.1	27.9	16.8	51.2	11.4	47.5	20.6	41.0
Iraq	2011	17.7	43.6	18.9	25.7	12.4	41.4	9.4	26.1	32.3	35.7	9.3	26.7	0.0	28.6
Jordan	2008	8.2	25.7	18.8	18.4	12.6	44.1	2.9	18.7	4.0	29.0	18.1	32.3	35.3	10.9
Palestine	2013	16.5	–	10.9	–	5.8	–	4.8	–	27.7	–	34.2	–	0	
Maghreb															
Libya	2013	14.3	15.0	17.0	18	24.4	0.1	11.5	0.1	2.0	20.0	12.4	20.0	32.4	20.0
Morocco	2011	33.7	31.5	7.6	26.3	10.4	44.1	1.8	20.5	26.1	26.6	20.4	27.8	0	0

* government researchers only

Note: For Bahrain, data only cover the higher education sector. For Egypt, the distribution of researchers is only available for the higher education sector; data related to the government sector are 'unclassified.'

Source: UNESCO Institute for Statistics (UIS), June, 2015; for Libya: Libyan Authority for Research, Science and Technology

Table 17.3: **Arab tertiary graduates in science, engineering and agriculture, 2012 or closest year**

	Year	Total (all fields)	Science, engineering and agriculture		Science			Engineering, manufacturing and construction			Agriculture		
			Number	Share of total (%)	Number	Share of science, engineering and agriculture (%)	Share of total (%)	Number	Share of science, engineering and agriculture (%)	Share of total (%)	Number	Share of science, engineering and agriculture (%)	Share of total (%)
Algeria	2013	255 435	62 356	24.4	25 581	41.0	10.0	32 861	52.7	12.9	3 914	6.3	1.5
Egypt	2013	510 363	71 753	14.1	21 446	29.9	4.2	38 730	54.0	7.6	11 577	16.1	2.3
Jordan	2011	60 686	7 225	11.9	3 258	45.1	5.4	2 145	29.7	3.5	1 822	25.2	3.0
Lebanon	2011	34 007	8 108	23.8	3 739	46.1	11.0	4 201	51.8	12.4	168	2.1	0.5
Morocco	2010	75 744	27 524	36.3	17 046	61.9	22.5	9 393	34.1	12.4	1 085	3.9	1.4
Palestine	2013	35 279	5 568	15.8	2 832	50.9	8.0	2 566	46.1	7.3	170	3.1	0.5
Qatar	2013	2 284	671	29.4	119	17.7	5.2	552	82.3	24.2	0	0.0	0.0
Saudi Arabia	2013	141 196	39 312	27.8	25 672	65.3	18.2	13 187	33.5	9.3	453	1.2	0.3
Sudan	2013	124 494	23 287	18.7	12 353	53.0	9.9	7 891	33.9	6.3	3 043	13.1	2.4
Syria	2013	58 694	12 239	20.9	4 430	36.2	7.5	6 064	49.5	10.3	1 745	14.3	3.0
Tunisia	2013	65 421	29 272	44.7	17 225	58.8	26.3	11 141	38.1	17.0	906	3.1	1.4
UAE	2013	25 682	5 866	22.8	2 087	35.6	8.1	3 742	63.8	14.6	37	0.6	0.1

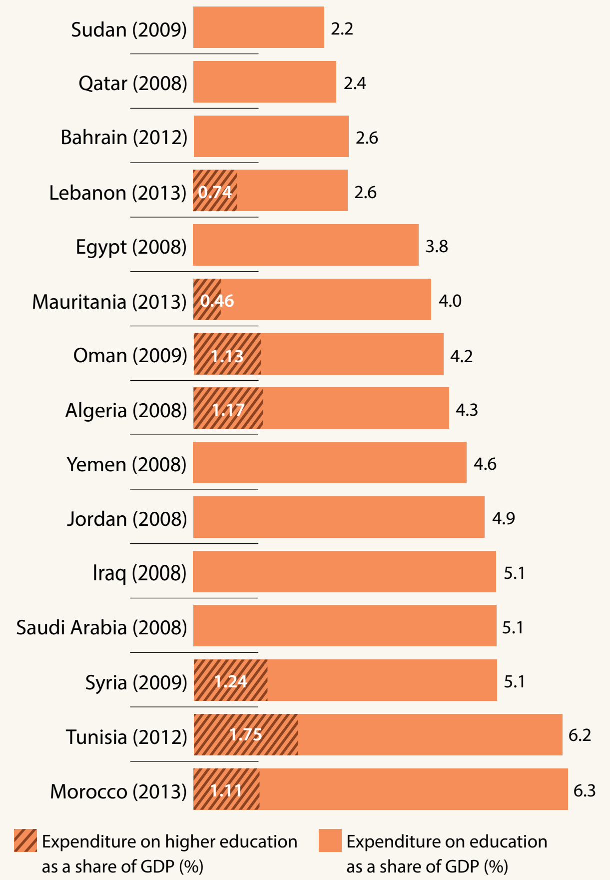
Source: UNESCO Institute for Statistics, July 2015

Table 17.4: **Share of Arab female graduates in science, engineering and agriculture, 2014 or closest year (%)**

Country	Year	Science	Engineering	Agriculture	Science, engineering and agriculture
Bahrain	2014	66.3	27.6	0.0	42.6
Jordan	2011	65.2	13.4	73.4	51.9
Lebanon	2011	61.5	26.9	58.9	43.5
Oman	2013	75.1	52.7	6.0	56.8
Palestine	2013	58.5	31.3	37.1	45.3
Qatar	2013	64.7	27.4	0.0	34.0
Saudi Arabia	2013	57.2	3.4	29.6	38.8
Sudan	2013	41.8	31.8	64.3	41.4
Tunisia	2013	63.8	41.1	69.9	55.4
UAE	2013	60.2	31.1	54.1	41.6

Source: UNESCO Institute for Statistics, July 2015

Figure 17.8: **Arab government expenditure on education as a share of GDP (%)**



Source: UNESCO Institute for Statistics, July 2015; for Iraq and Jordan: UNDP (2009) *Arab Knowledge Report,* Table 5-4, p. 193.

the higher education sector (54%) in 2013 and the remainder by government (46%), although the business sector was not surveyed (ASRT, 2014). In Iraq, as many as eight out of ten (83%) researchers are working in academia.

In Egypt, medical and health sciences occupy the greatest number of researchers, a reflection of the country's priorities. In Kuwait and Morocco, the majority of researchers are working in the natural sciences (Table 17.2). In Oman in 2011, the majority of researchers were social scientists, whereas Qatari researchers tend to be most numerous in engineering and technology. Interestingly, one-third of Palestinian researchers worked in the humanities in 2011, the highest ratio among Arab states.

Morocco leads for high-tech exports, Qatar and Saudi Arabia for publications

Given the modest role played by the private sector in the Arab world, it is hardly surprising that the share of high-tech products in manufactured exports is low, particularly for Gulf states (Figure 17.9). Morocco tops the region for high-tech exports and comes second only to Egypt for patents (Table 17.5).

Interestingly, two oil-rent economies published the most scientific articles per million inhabitants in 2014. Along with Egypt, their output has also grown faster than that of any other country in recent years. Qatar and Saudi Arabia also have the region's highest citation rate (Figure 17.10).

Two-thirds of articles produced by scientists in the Arab world between 2008 and 2014 were co-authored with international partners. Egypt, Saudi Arabia and the USA tend to be the closest collaborators but Chinese scientists have also become a key partner for Iraq, Qatar and Saudi Arabia (Figure 17.10). It is worth noting that the Thomson Reuters selection of Highly Cited Researchers of 2014[7] lists only three Arab scientists whose 'first' affiliation is with a university in the Arab world. They are Prof. Ali H. Nayfeh (University of Jordan and Virginia Tech), Prof. Shaher El-Momani (University of Jordan and King Abdulaziz University in Saudi Arabia) and Prof. Salim Messaoudi (Algeria), a faculty member of King Fahd University of Petroleum and Minerals in Saudi Arabia.

7. http://highlycited.com/archive_june.htm

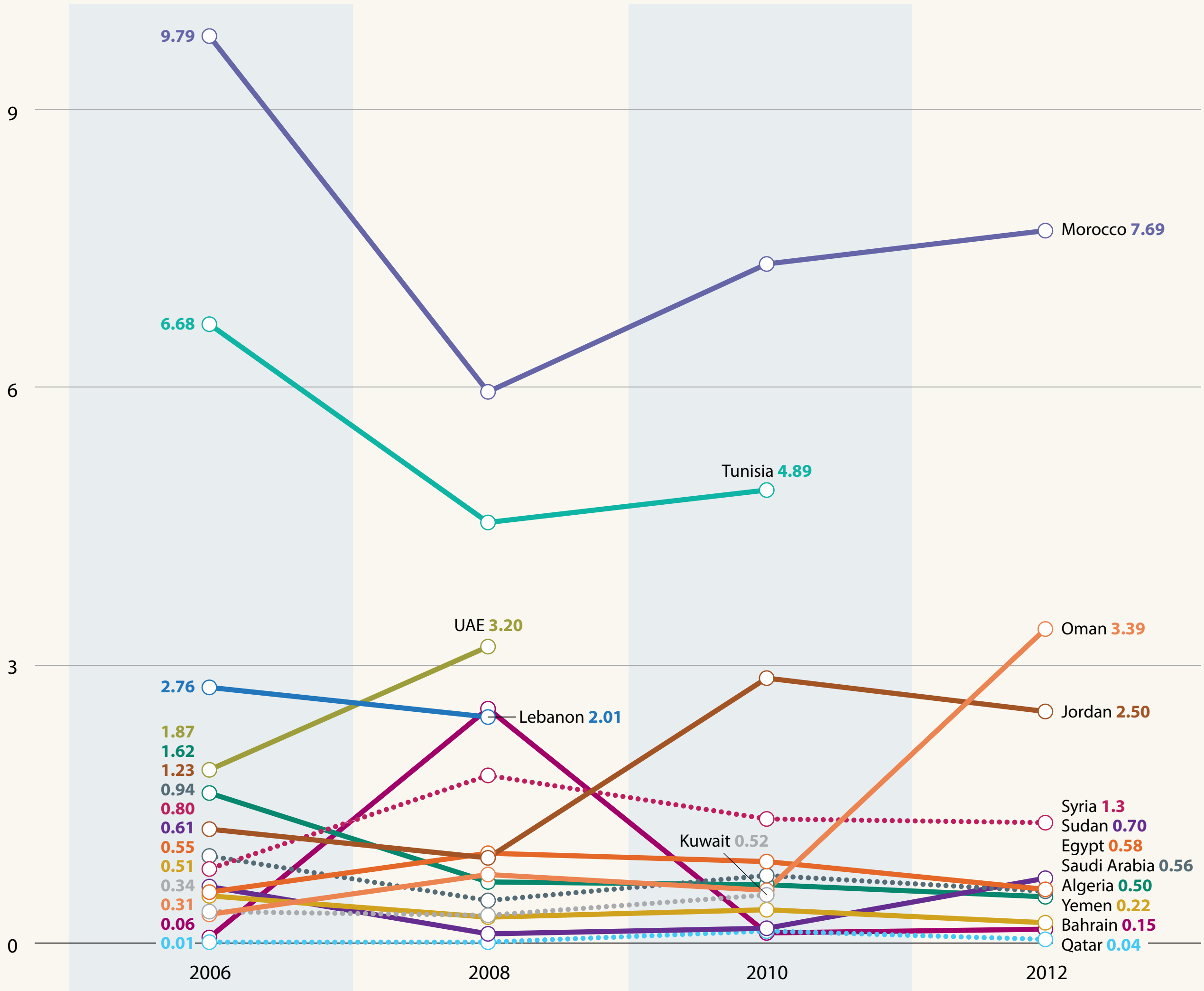
Table 17.5: **Patent applications in Arab states, 2010–2012**

	Patent applications residents			Patent applications non-residents			Total patent applications		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Egypt	605	618	683	1 625	1 591	1 528	2 230	2 209	2 211
Morocco	152	169	197	882	880	843	1034	1 049	1 040
Saudi Arabia	288	347		643	643		931	990	
Algeria	76	94	119	730	803	781	806	897	900
Tunisia	113	137	150	508	543	476	621	680	626
Jordan	45	40	48	429	360	346	474	400	394
Yemen	20	7	36	55	37	49	75	44	85
Lebanon	0	0	0	13	2	2	13	2	2
Sudan	0	0	0	0	1	0	0	0	0
Syria	0	0	0	1	0	0	1	0	0

Source: WIPO statistics database, December 2014; Thomson Reuters' Web of Science, data treatment by Science-Metrix

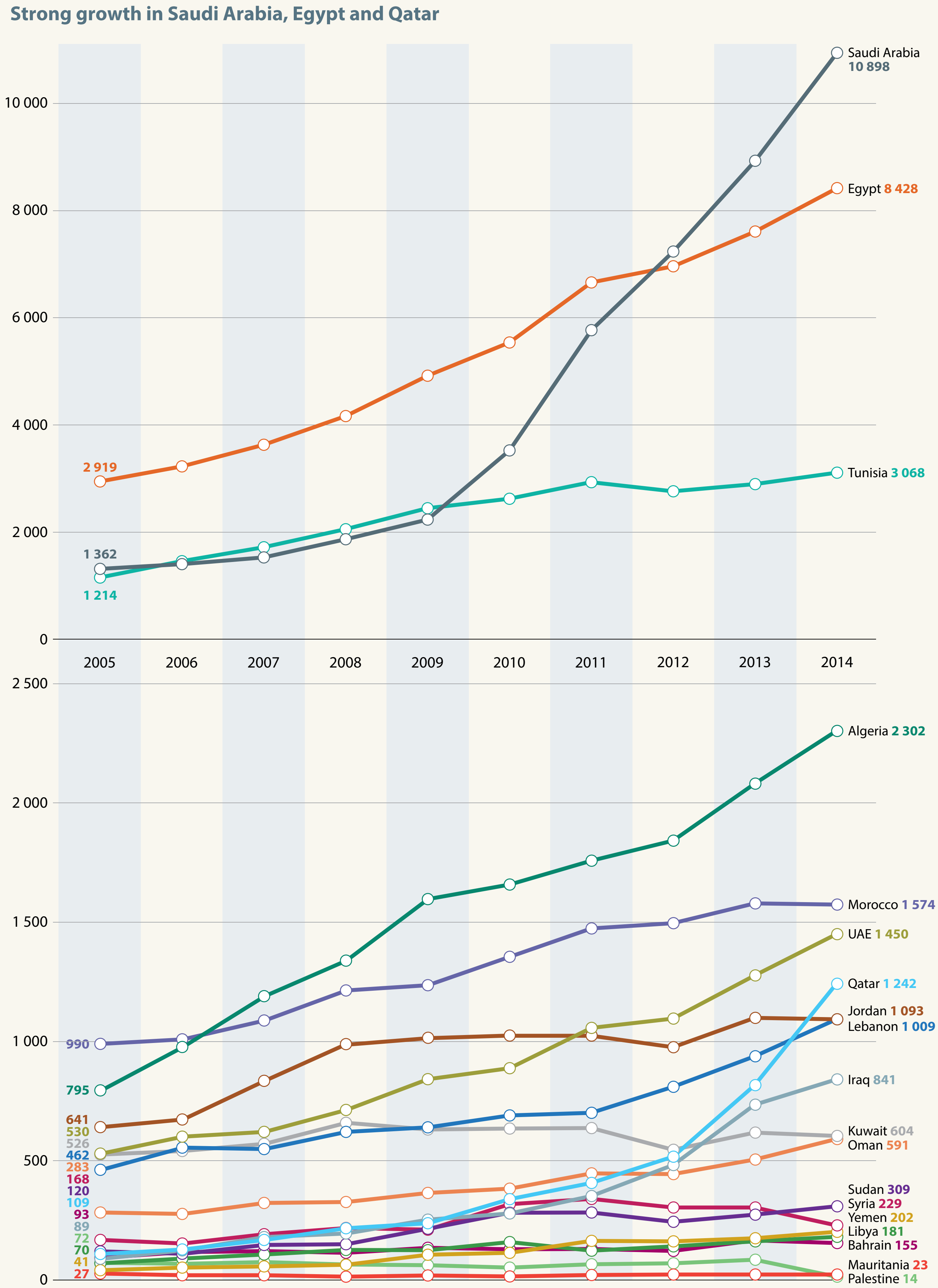
Figure 17.9: **High-tech exports from the Arab world, 2006, 2008, 2010 and 2012**

As a share of manufactured exports (%)



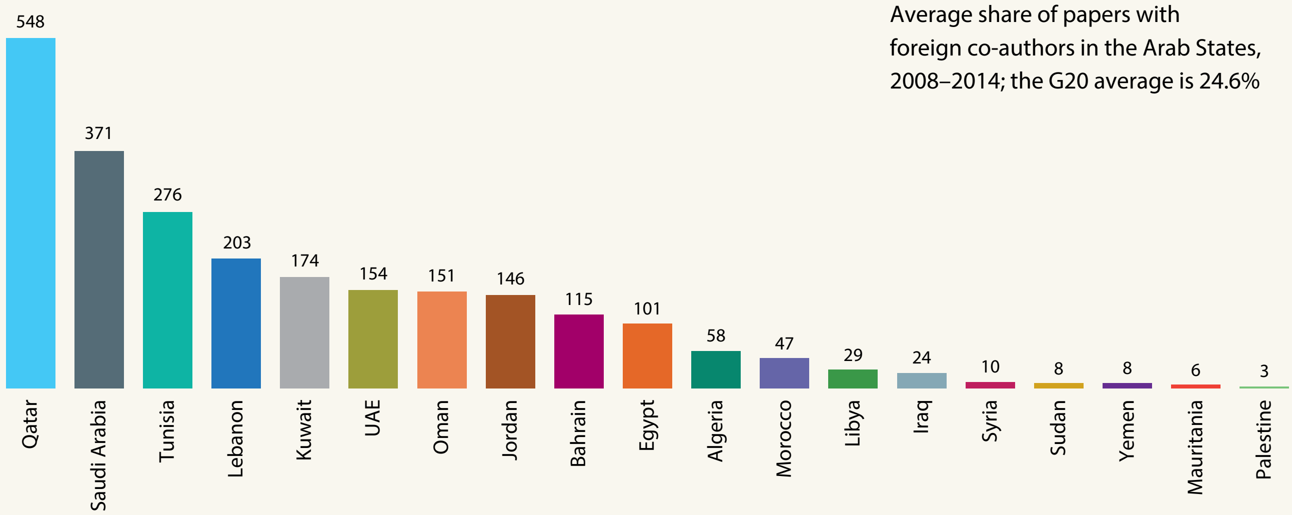
Source: United Nations Statistics Division, July 2014

Figure 17.10: **Scientific publication trends in the Arab States, 2005–2014**



Qatar, Saudi Arabia and Tunisia have the highest publication intensity

Publications per million inhabitants in 2014

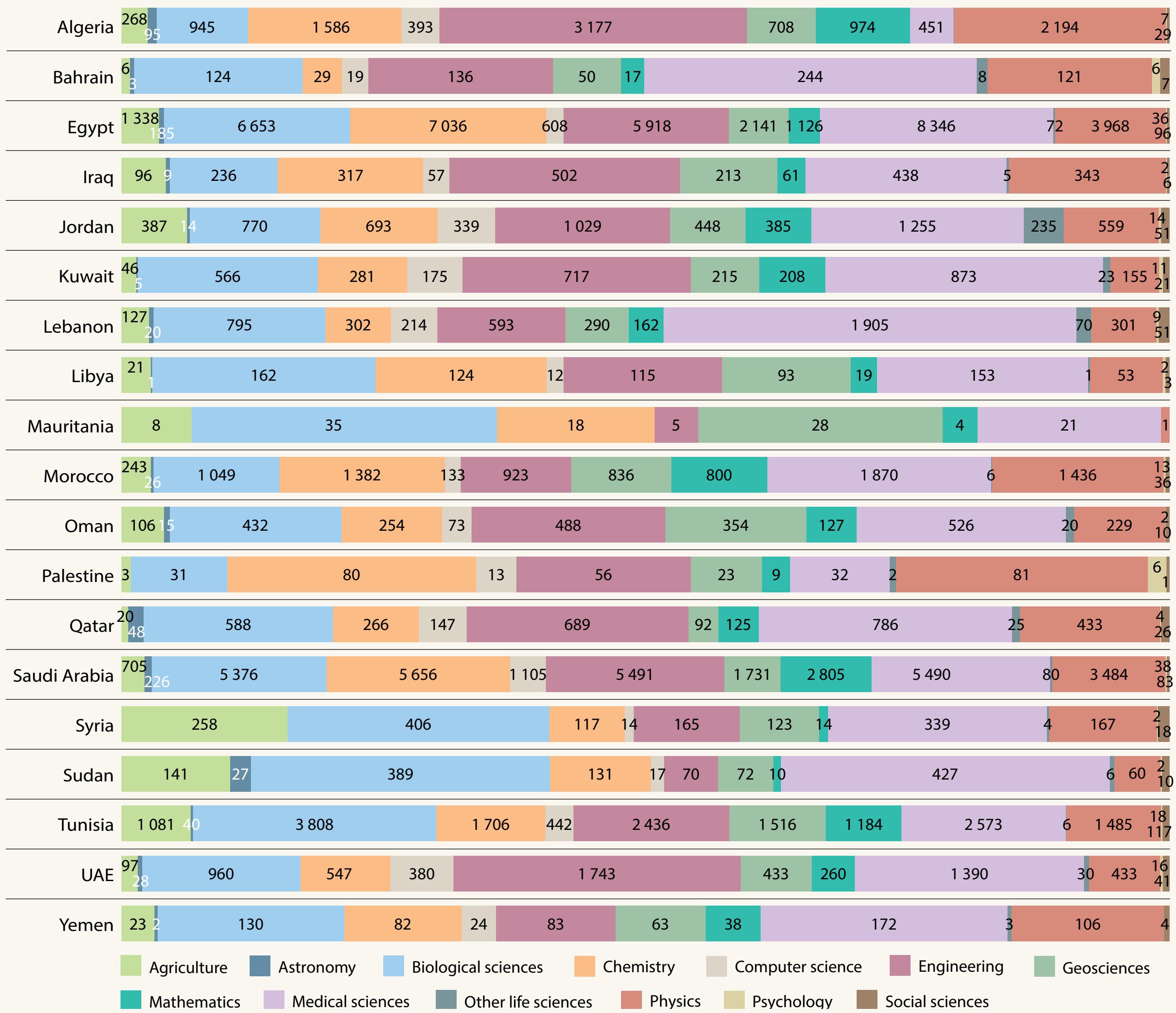


67.2%

Average share of papers with foreign co-authors in the Arab States, 2008–2014; the G20 average is 24.6%

The Arab States publish most in life sciences, followed by engineering and chemistry

Cumulative totals by field, 2008–2014



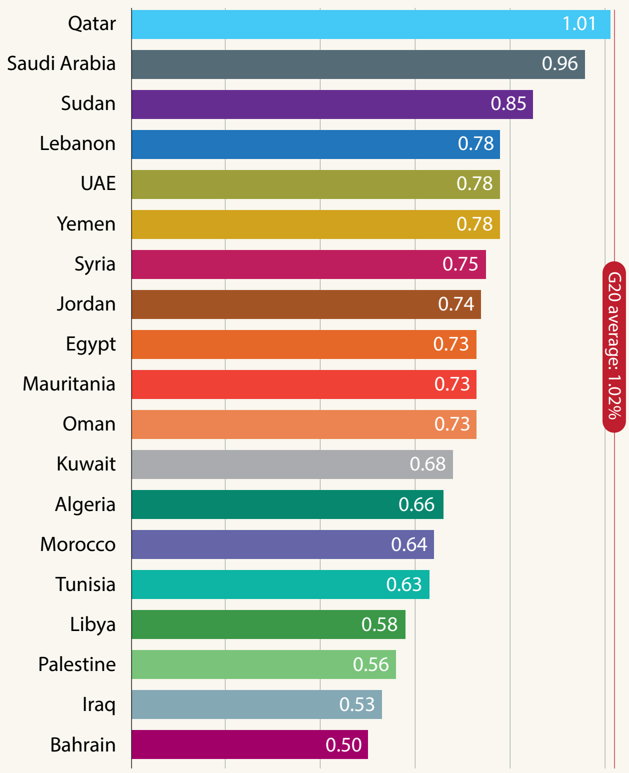
Note: The totals do not include unclassified publications, which make up a sizeable share in some cases: Saudi Arabia (8 264), Egypt (6 716), Tunisia (2 275), Algeria (1 747), Jordan (1 047), Kuwait (1 034) and Palestine (77).

Chapter 17

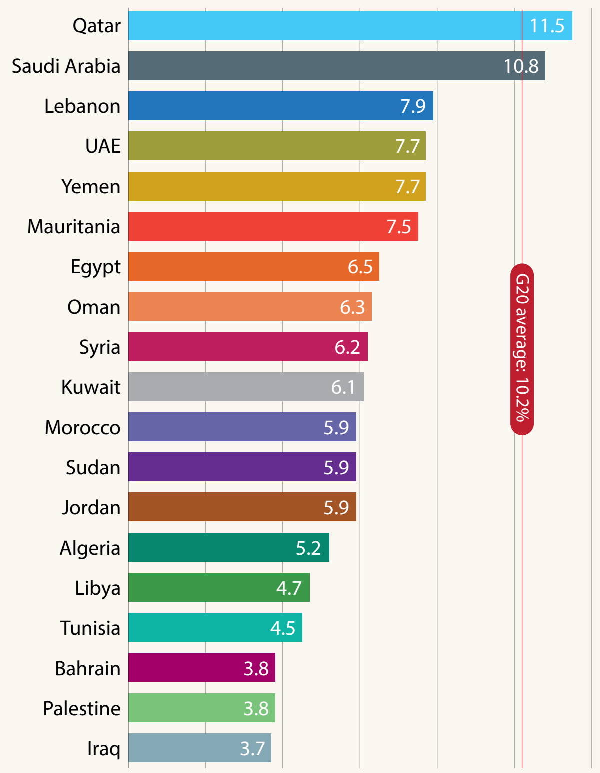
Figure 17.10 *(continued)*

Qatar and Saudi Arabia have the highest citation rate

Average citation rate for publications, 2008–2012



Share of papers among 10% most-cited, 2008–2012 (%)



China has become a key collaborator for Iraq, Qatar and Saudi Arabia

Main foreign partners, 2008–2014

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Algeria	France (4 883)	Saudi Arabia (524)	Spain (440)	USA (383)	Italy (347)
Bahrain	Saudi Arabia (137)	Egypt (101)	UK (93)	USA (89)	Tunisia (75)
Egypt	Saudi Arabia (7 803)	USA (4 725)	Germany (2 762)	UK (2 162)	Japan (1 755)
Iraq	Malaysia (595)	UK (281)	USA (279)	China (133)	Germany (128)
Jordan	USA (1 153)	Germany (586)	Saudi Arabia (490)	UK (450)	Canada (259)
Kuwait	USA (566)	Egypt (332)	UK (271)	Canada (198)	Saudi Arabia (185)
Lebanon	USA (1 307)	France (1277)	Italy (412)	UK (337)	Canada (336)
Libya	UK (184)	Egypt (166)	India (99)	Malaysia (79)	France (78)
Mauritania	France (62)	Senegal (40)	USA (18)	Spain (16)	Tunisia (15)
Morocco	France (3 465)	Spain (1 338)	USA (833)	Italy (777)	Germany (752)
Oman	USA (333)	UK (326)	India (309)	Germany (212)	Malaysia (200)
Palestine	Egypt (50)	Germany (48)	USA (35)	Malaysia (26)	UK (23)
Qatar	USA (1 168)	UK (586)	China (457)	France (397)	Germany (373)
Saudi Arabia	Egypt (7 803)	USA (5 794)	UK (2 568)	China (2 469)	India (2 455)
Sudan	Saudi Arabia (213)	Germany (193)	UK (191)	USA (185)	Malaysia (146)
Syria	France (193)	UK (179)	Germany (175)	USA (170)	Italy (92)
Tunisia	France (5 951)	Spain (833)	Italy (727)	Saudi Arabia (600)	USA (544)
United Arab Emirates	USA (1 505)	UK (697)	Canada (641)	Germany (389)	Egypt (370)
Yemen	Malaysia (255)	Egypt (183)	Saudi Arabia (158)	USA (106)	Germany (72)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

ALGERIA

Diversifying the national energy mix

In 2008, Algeria adopted a plan to optimize its national innovation system. Piloted by the Ministry of Higher Education and Scientific Research (MoHESR), the plan proposed a reorganization of science, coupled with the development of infrastructure, human resources and research, as well as greater scientific co-operation and funding. Algeria devoted just 0.07% of GDP to GERD in 2005; although these data are partial, they suggest an extremely low R&D intensity in the years prior to the plan's adoption.

The National Commission for the Evaluation of Permanent Researchers was launched in 2000 to give scientists a boost by allocating more financial resources to research and introducing incentives for them to make better use of the results of their research. The aim was also to enhance collaboration with the Algerian diaspora. The commission met for the 12th time in February 2012. More recently, MoHESR has announced plans to establish a national academy of sciences in 2015.

Algerian scientists published most in engineering and physics between 2008 and 2014. Their output has progressed steadily, doubling between 2005 and 2009 then again between 2010 and 2014 (Figure 17.10). Over the seven years to 2014, 59% of Algerian scientific papers had foreign co-authors.

Although Algeria is Africa's third-biggest oil producer (see Figure 19.1) and the world's tenth-biggest producer of natural gas, the country's known gas reserves could be exhausted within half a century, according to British Petroleum's *Statistical Review of World Energy* in 2009 (Salacanin, 2015). Like its neighbours Morocco and Tunisia, Algeria is diversifying its energy mix. Sixty solar and wind projects have been approved within the country's Renewable Energy and Energy Efficiency Programme, which was adopted in March 2011 and revised in 2015. The aim is for 40% of electricity for national consumption to be produced using renewable energy sources by 2030. Up to 22 000 MW of power-generating capacity from renewable sources will be installed between 2011 and 2030, 12 000 MW to meet domestic demand and 10 000 MW destined for export. In July 2013, Algeria signed a memorandum of understanding with the EU in the field of energy which includes provisions for the transfer of technology to Algeria for both fossil fuels and renewable energy.

BAHRAIN

A need to reduce dependency on oil

Bahrain has the smallest hydrocarbon reserves of any Gulf state, producing just 48 000 barrels per day from its one onshore field (Salacanin, 2015). The bulk of the country's revenue comes from its share of the offshore field administered by Saudi Arabia. The gas reserve in Bahrain is expected to last for less than 27 years, leaving the country with few sources of capital to pursue the development of new industries.

The *Bahraini Economic Vision 2030* does not indicate how the stated goal of shifting from an economy built on oil wealth to a productive, globally competitive economy will be attained.

Apart from the Ministry of Education and the Higher Education Council, the two main hives of activity in STI are the University of Bahrain and the Bahrain Centre for Strategic, International and Energy Studies. The latter was founded in 2009 to undertake research with a focus on strategic security and energy issues to encourage new thinking and influence policy-making.

The University of Bahrain was established in 1986. It has over 20 000 students, 65% of whom are women, and around 900 faculty members, 40% of whom are women. From 1986 to 2014, university staff published 5 500 papers and books. The university spends about US$ 11 million per year on research, which is conducted by a contingent of 172 men and 128 women.

New infrastructure for science and education

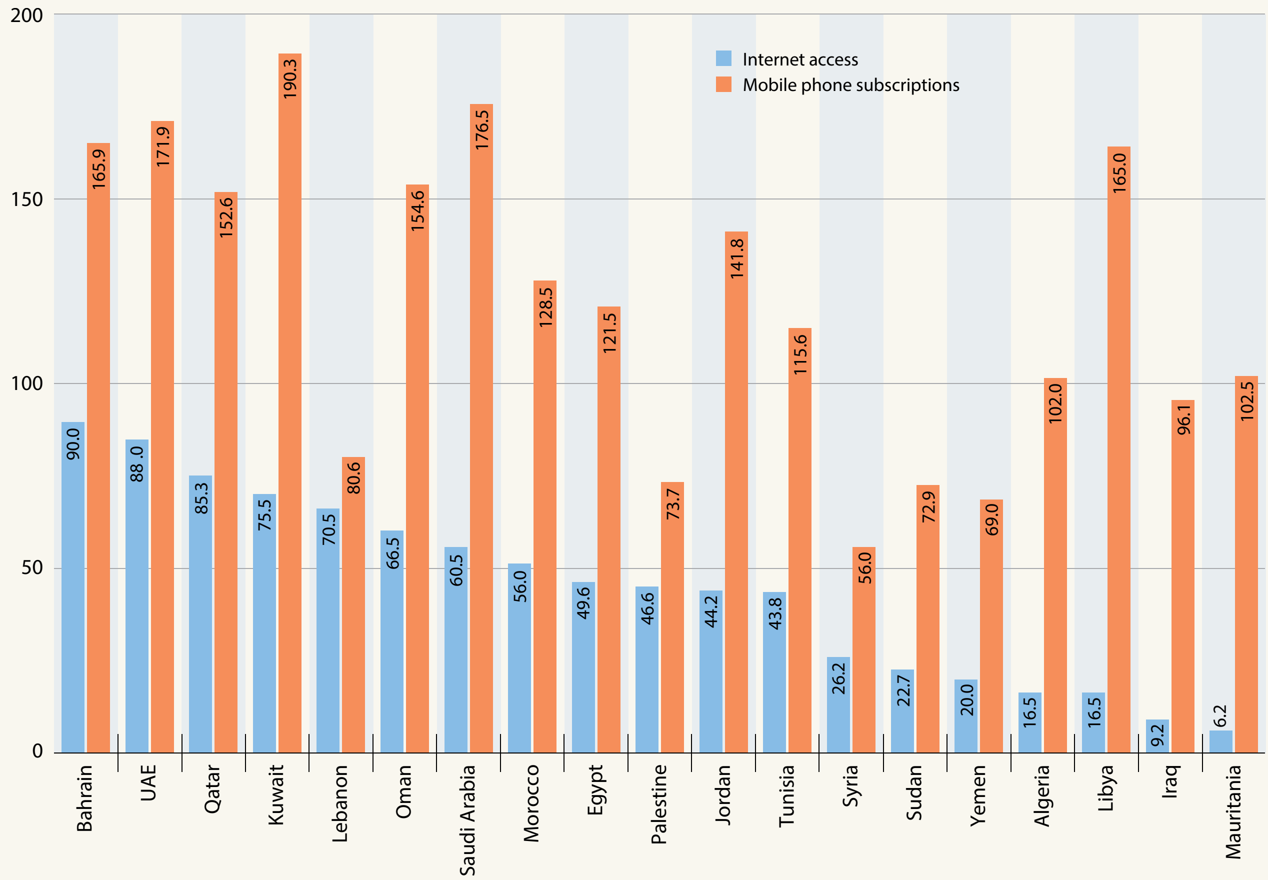
In November 2008, an agreement was signed by the Bahraini government and UNESCO to establish a Regional Centre for Information and Communication Technology in Manama under the auspices of UNESCO. The aim is to establish a knowledge hub for the six member states of the Gulf Cooperation Council. In March 2012, the centre hosted two high-level workshops on ICTs and education.

In 2013, the Bahrain Science Centre was launched as an interactive educational facility targeting 6–18-year olds. The topics covered by current exhibitions include junior engineering, human health, the five senses, Earth sciences and biodiversity.

In April 2014, Bahrain launched its National Space Science Agency. The agency is working to ratify international space-related agreements such as the Outer Space Treaty, the Rescue Agreement, the Space Liability Convention, the Registration Convention and the Moon Agreement. The agency will be establishing sound infrastructure for the observation of outer space and the Earth. It also hopes to

Figure 17.11: **Internet access and mobile phone subscriptions in Arab states, 2013**

Per 100 inhabitants



Source: International Telecommunications Union, February 2015

build a science culture within the kingdom and encourage technological innovation, among other goals.

Bahrain tops the Arab world for internet penetration, trailed by the United Arab Emirates and Qatar (Figure 17.11). Internet access has gone up tremendously in all Gulf States. Just half of Bahrainis and Qataris (53%) and two-thirds of those in the United Arab Emirates (64%) had access in 2009, compared to more than 85% in 2013. At the other end of the scale, fewer than one person in ten had internet access in Iraq and Mauritania in 2013.

EGYPT

Revolutionary fervour has spilled over into science

Current national policy documents in Egypt all consider science and technology to be vital for the country's future. The Constitution adopted in 2014 mandates the state to allocate 1% of GDP to R&D and stipulates that the 'state guarantees the freedom of scientific research and encourages its institutions as a means towards achieving national sovereignty and building a knowledge economy that supports researchers and inventors (Article 23).[8]

For decades, science and technology in Egypt were highly centralized and dominated by the public sector. R&D was carried out mostly by state-run universities and research centres supervised by the Ministry of Higher Education and Scientific Research, which split into the Ministry of Higher Education and the Ministry of Scientific Research (MoSR) in 2014. Egypt's research centres used to be scattered across different ministries but they are currently being reorganized under the umbrella of the Supreme Council of Scientific Research Centres and Institutes, in order to improve co-ordination.

The *UNESCO Science Report 2010* had recommended that Arab states establish national STI observatories. The Egyptian Science, Technology and Innovation Observatory was launched in February 2014 to provide advice on policy-making strategies and resource allocation through data collection and reporting on the development of national S&T capacities. The observatory is hosted by Egypt's Academy

8. See: http://stiiraqdev.wordpress.com/2014/03/15/sti-constitutions-arab-countries/

of Scientific Research and Technology. It published its first data collection in 2014 (ASRT, 2014). The observatory did not collect data for the business enterprise sector but nevertheless reported a rise in GERD from 0.43% to 0.68% of GDP between 2009 and 2013. The observatory also reports 22 000 FTE researchers in government research institutes and 26 000 at public universities. Just over half of Egypt's 42 universities (24) are public institutions but these also account for three-quarters of university enrolment.

A reform to produce market-ready graduates

Public expenditure on higher education stands at the acceptable level of 1% of GDP, compared to an average of 1.4% for OECD countries. This corresponds to 26% of the total public spending on education, close to the OECD average of 24%. Nonetheless, most of these resources cover administrative costs, in particular the salaries of academic and non-academic staff, rather than going on educational programmes. This practice has created a legacy of outdated equipment, infrastructure and learning materials. The amount spent on each student averages just US$ 902 (23% of GDP per capita), just one-tenth of the US$ 9 984 (37% of GDP per capita) spent on each student in OECD countries.

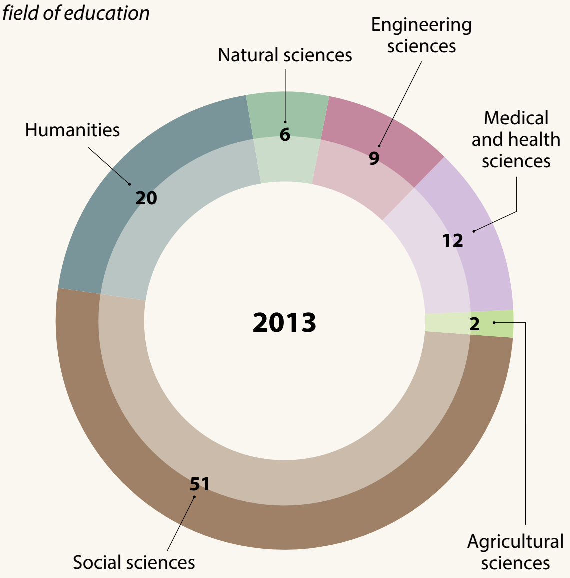
Universities offer a minimum degree course of four years and there tends to be a high ratio of students to staff, especially in humanities and social sciences which attract seven out of ten Egyptian students (Figure 17.12). The proportion of female university graduates in tertiary education has inched closer to gender parity in recent years but only in urban areas. The urban–rural gender divide is still alive and well.

Technical colleges offer a two-year programme of study in a number of specializations, including manufacturing, agriculture, commerce and tourism. A few technical colleges provide five-year courses leading to advanced diplomas but these technical diplomas lack the social status of university degrees. Whereas 60% of secondary school pupils are channelled towards technical and vocational secondary schools, almost 95% of enrolment in post-secondary technical colleges comes from general secondary schools; this leaves many pupils from technical and vocational secondary schools with no prospects for further education.

The government has announced a US$ 5.87 billion reform plan for higher education to produce market-ready graduates able to contribute to a knowledge economy. The plan runs from 2014 to 2022 and will be implemented in two phases. The plan is financed by the new constitutional entitlements that require the state to allocate at least 4% of the budget to education, 2% to higher education and 1% to scientific research (Articles 19–21 of the 2014 Constitution); it will also entail legislative reform to improve governance mechanisms.

Figure 17.12: **Egyptian student enrolment in public universities, 2013 (%)**

By field of education



Source: ASRT (2014)

A stronger focus on technical and vocational education

The plan aims to improve access to technical education within universities, ensure quality assurance, raise the level of educational services, link the output of the higher education system with labour market requirements and make universities more international. Recently, the government has begun preparing for the introduction of preferential admission criteria for promising students. This should improve the flexibility of their academic pathways.

Zewail City of Science and Technology revived

The Nile University is Egypt's first research university. Founded in 2006 by the non-profit Egyptian Foundation for Technology Education, this private institution was built on the outskirts of Cairo on land gifted by the government. In May 2011, the caretaker government reassigned the land and buildings to the Zewail City of Science and Technology and declared the complex a National Project of Scientific Renaissance (Sanderson, 2012).

The Zewail City of Science and Technology project had been lying dormant ever since its mentor, Nobel Prize laureate Ahmed Zewail, presented the concept to President Mubarak in 1999. The project was later revived, in recognition of the fact that Egypt would only be able to develop a knowledge economy if it could foster a technopreneurship culture led by projects such as Zewail's. In April 2014, President Al-Sissi decided to allot 200 acres to the Zewail City of Science and Technology for its permanent campus in the Sixth of October city, situated about 32 km from central Cairo. Once completed, Zewail City for Science and Technology[9] will have five constituents: a university, research institutes, a technology park, an academy and a centre for strategic studies.

The Academy of Scientific Research and Technology (ASRT) was founded in 1972. This non-profit organization is affiliated with the Ministry of Higher Education and Scientific Research (MoHSR), born of the merger with the Ministry of Higher Education in September 2015. It is not an academy of sciences in the conventional sense of the word as, until 2007, it controlled the budget for R&D in universities and research centres. Today, it acts as a think-tank and policy advisor to the ministry and co-ordinates the country's research programmes.

In early 2015, the Ministry of Scientific Research (MoSR) began putting the final touches to Egypt's *Strategy for Science, Technology and Innovation*. In February 2015, UNESCO provided the ministry with technical assistance in organizing a Policy Dialogue on STI in the presence of international experts. A report commissioned subsequently by UNESCO proposed a series of recommendations for nurturing scientific research in Egypt (Tindemans, 2015). These include:

- A platform should be established at cabinet level with stakeholders from the economy and society to devise a vision and strategy for enhancing the role played by STI in socio-economic development;
- In order to improve the monitoring and co-ordination of policy implementation and facilitate evaluation, MoSR should play a decisive role in the budgetary cycle for the institutes under its supervision and should publish each year a comprehensive overview of public and private sector expenditure on R&D; the ministry should also head a high-level permanent committee of civil servants from ministries entrusted with responsibility for collecting and validating basic information on the national innovation system;
- The Ministry of Scientific Research should develop close ties to the Ministry of Industry of Trade;
- Parliament should adopt a legal framework for scientific research comprised of both generic and more specialized laws;
- Patent law should be less rigid to favour innovation;
- Government departments need to be much more knowledgeable about the needs and aspirations of the private sector; they need to engage in much closer collaboration with the Industrial Modernization Centre, the Federation of Egyptian Industries;
- ASRT and MoSR should set up a framework to promote industrial innovation and co-operation by firms with universities and government research institutes;
- A national innovation funding agency should be set up to support private sector research and public–private co-operation, with the provision of competitive funding being its core task;
- The Egyptian Science, Technology and Innovation Observatory should consider it a priority to obtain information on both public and private sector investment in R&D; current data on GERD and researchers need to be subjected to critical analysis to ensure their reliability; the establishment of a panel of independent international experts could help with this critical analysis; and
- The Ministry of Scientific Research should develop close ties to the Ministry of Higher Education. The shortfall in scientific research is also reflected in the non-contextualization of learning materials in tertiary curricula.

IRAQ

Scientific research inscribed in the Constitution

Once a regional powerhouse of R&D, Iraq has lost its institutional and human capital to successive wars since 1980 and the subsequent exodus of its scientists. Since 2005, the Iraqi government has been seeking to restore the country's proud heritage. Iraq's Constitution of 2005 stipulates that 'the State shall encourage scientific research for peaceful purposes that serve humanity and shall support excellence, creativity, innovation and different aspects of ingenuity' (Article 34).

In 2005, UNESCO began helping Iraq to develop a Master *Plan for Science, Technology and Innovation* that would ultimately cover the period 2011–2015, in order to revive the economy in the aftermath of the US-led invasion in 2003 and to address pressing social needs such as poverty and environmental degradation. Following an analysis of the strengths and weaknesses of different sectors, UNESCO accompanied Iraq in preparing a *Framework and Agenda for Action* (2013) to complement the country's *National Development Plan* for the years 2013–2017 and to set the stage for a more comprehensive STI policy.

In 2010, the Universities of Baghdad, Basra and Salahaddin province joined the Avicenna Virtual Campus for Science and Technology. This gives them access to the teaching materials produced by other members of the UNESCO network,[10] which the Iraqi universities can then enrich with their own content. Further expansion of the Avicenna network within Iraq has been perturbed by the occupation of swaths of Iraqi territory by the Da'esh terrorist group.

9. see: www.zewailcity.edu.eg

10. Avicenna also involves universities from Algeria, Cyprus, Egypt, France, Italy, Jordan, Lebanon, Malta, Morocco, Palestine, Spain, Syria, Tunisia, Turkey and the UK.

On 20 June 2014, Iraq launched its first satellite for environmental monitoring. TigrisSat was launched from a base in the Russian Federation. The satellite is being used to monitor sand and dust storms in Iraq, as well as potential precipitation, vegetative land cover and surface evaporation.

JORDAN

Plans for an observatory of STI

Jordan's Higher Council for Science and Technology (est. 1987) is an independent public body that acts as a national umbrella organization for scientific research. It is the Higher Council for Science and Technology which drew up the first national policy for science and technology in 1995. In 2013, it completed the national *Science, Technology and Innovation Policy and Strategy* (2013–2017), which has seven broad objectives. These are to:

- incite the government and the scientific community to adopt the R&D priorities for developing a knowledge economy identified by the council and the Scientific Research Support Fund in 2010 in *Defining Scientific Research Priorities in Jordan for the Years 2011–2020*;
- generalize a science culture in the education system;
- harness R&D to development;
- build knowledge networks in science, technology and research;
- adopt innovation as a key stimulus for investment opportunities;
- translate the results of R&D into commercial ventures; and
- contribute to excellence in training and skills acquisition.

The Higher Council for Science and Technology has identified five domains in which projects are to be implemented to operationalize the policy: the institutional framework; policies and legislation; STI infrastructure; human resources; and the STI environment. An analysis of the national innovation system revealed that research was making an insufficient contribution to economic growth and to solving chronic problems, such as those related to water, energy and food. For the 2013–2017 period, some 24 projects have been proposed at a projected cost of around US$ 14 million that is still to be allocated by the government. These include a review of the national STI policy, institutionalizing innovation, developing incentive schemes for researchers and innovators, founding technology incubators and setting up a research database. A unit is to be created within the Higher Council for Science and Technology specifically for expatriate Jordanian scientists. The council is responsible for implementing, following up and evaluating all 24 projects, along with relevant ministries.

For over six years, the Higher Council for Science and Technology has been involved in a project that is setting up an Observatory of Science, Technology and Innovation, in collaboration with the United Nations' Economic and Social Commission for Western Asia (ESCWA). The observatory will maintain the country's first comprehensive database of domestic R&D and is to be hosted by the council.

In 2013, the Higher Council for Science and Technology published the *National Innovation Strategy*, 2013–2017, which had been prepared[11] in collaboration with the Ministry of Planning and International Co-operation with the support of the World Bank. Targeted fields include energy, environment, health, ICTs, nanotechnology, education, engineering services, banking and clean technologies.

Revival of two research funds

Jordan's Scientific Research Support Fund[12] was revived in 2010 after being instituted in 2006. Administered by the Ministry of Higher Education and Scientific Research, it finances investment in human resources and infrastructure through competitive research grants related to ecological water management and technological applications. The fund backs entrepreneurial ventures and helps Jordanian companies to solve technical problems; it also encourages private bodies to allocate resources for R&D and provides university students with scholarships based on merit. So far, the fund has provided 13 million Jordanian dinars (*circa* US$ 18.3 million) to finance R&D projects in Jordan, 70% of which has been used to fund projects in energy, water and health care.

The revamped Scientific Research Support Fund is also intended to streamline the activities supported by the Fund for Scientific Research and Vocational Training (est. 1997). This fund was launched partly to ensure that all public shareholding Jordanian companies either spent 1% of their net profits on research or vocational training within their own structure or paid an equivalent amount into the fund for redistribution for the same purpose. The problem was that the definition of what constituted research and vocational training was too broad. As a result, new regulations were adopted in 2010 to clarify the terms and provide for the collection of the 1% to be spent on R&D.

Jordan is home to the King Abdullah II Design and Development Bureau (KADDB), an independent government entity within the Jordanian Armed Forces that develops defence products and security solutions for the region. KADDB works with Jordanian universities to help students tailor their research projects to KADDB's needs.

11. Despite the similarity in name, this document differs from the *Science, Technology and Innovation Policy and Strategy* (2013–2017).

12. See: www.srf.gov.jo

Box 17.3: **SESAME project soon to light up the region**

Jordan is home to the region's first major interdisciplinary science centre, the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), which houses the highest energy accelerator in the Middle East.

Synchrotrons work by accelerating electrons around a circular tube at high speed, during which time excess energy is given off in the form of light. By focusing this intense light, the tiniest structures can be mapped in great detail. The light source acts like a super X-ray machine and can be used by researchers to study everything from viruses and new drugs to novel materials and archaeological artefacts.

Synchrotrons have become an indispensable tool for modern science. There are some 50 such storage-ring-based synchrotron light sources in use around the world. The majority are found in high-income countries but Brazil (see Box 8.2) and China also have them.

By early 2017, construction of the storage ring will have been completed and the SESAME laboratory and its two beamlines will be fully operational, making it the first synchrotron light source in the region. Already, scientists are visiting SESAME for their work, thanks to the Fourier Transform Infrared microscope that has been in operation there since August 2014.

Construction of the centre began in 2003. SESAME has been established under the aegis of UNESCO as a co-operative intergovernmental venture by the scientists and governments of the region in which it is located. Its governance is assured by the SESAME Council.

The SESAME members are Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey. There are also observers: Brazil, China, the European Union, France, Germany, Greece, Italy, Japan, Kuwait, Portugal, the Russian Federation, Spain, Sweden, Switzerland, the UK and USA.

Alongside its scientific aims, SESAME promotes solidarity and peace in the region through scientific co-operation.

Source: Susan Schneegans, UNESCO
See: www.sesame.org.jo/sesame

Jordan has hosted the ESCWA Technology Centre since its inception in 2011. The centre's mission is 'to assist member countries and their public and private organizations to acquire the necessary tools and capabilities to accelerate socio-economic development.'

Jordan also hosts the the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), which should be fully operational by 2017 (Box 17.3).

KUWAIT

A difficult transition

The contribution of most non-oil economic sectors in Kuwait declined after the Iraqi invasion in 1990, especially after hundreds of companies and foreign institutions, including banking and investment brokers, moved their operations elsewhere in the region. The economic slowdown was mainly due to the flight of capital and the cancellation of important development projects like the petrochemical project with the Dow Chemical Company, which filed a lawsuit against Kuwait demanding compensation of US$ 2.1 billion. In May 2012, Dow Chemical won the case, thus increasing Kuwait's financial losses (Al-Soomi, 2012).

In the past few years, there have been some missed opportunities to implement development projects of significant economic value; in parallel, Kuwait's dependence on oil revenue has grown. Kuwait was a regional leader in science and technology and higher education in the 1980s but has been losing ground ever since. The World Economic Forum's 2014 *Global Competitiveness Report* reveals a significant deterioration in many STI-related indicators.

Besides the Ministry of Education and the Ministry of Higher Education, the three major players in science in Kuwait are the Kuwait Foundation for the Advancement of Sciences, Kuwait Institute of Scientific Research and Kuwait University. The Kuwait Foundation for the Advancement of Sciences developed a new plan in 2010–2011 to mobilize financial and human resources, in order to reinvigorate both the government and private sectors, with a concomitant desire to improve public understanding of science.

The Kuwait Institute of Scientific Research (est. 1967) carries out applied research in three broad fields: oil, water, energy and construction; environment and life sciences; and techno-economics. It also advises the government on research policy. In recent years, the institute has emphasized scientific excellence, a client focus, achieving international technological leadership, the commercialization of research results and the establishment of new centres. The current eighth strategic plan covering 2015–2020 focuses on technology roadmapping to develop system solutions for selected technologies in oil, energy, water and life sciences.

The Kuwait University Research Sector supports faculty initiatives in basic and applied research and in humanities. It offers research grants within a number of funding schemes and finances a joint research programme in the area of natural resources development with the Massachusetts Institute of Technology in the USA. For its part, the Kuwait University Research Park has a more commercial focus. It aims to lay the foundations for innovation and spin-off technologies with scope for industry–research linkages and potential for patenting and marketing. Faculty researchers have made headway; they announced the acquisition of six US patents during the 2010/2011 academic year, two new patent awardees the following year and four in 2012/2013.

LEBANON

Three instituitions dominate research

Despite the existence of over 50 private universities and one public one, most research[13] in Lebanon is carried out by just three institutions: the Lebanese University, Saint-Joseph University and the American University of Beirut. On occasion, these three institutions collaborate with one of the four research centres managed by the National Council for Scientific Research (CNRS, est. 1962) and/or the Lebanese Agricultural Research Institute.

Lebanon counts several NGOs active in science, including the Arab Academy of Sciences (est. 2002) and the Lebanese Association for the Advancement of Science (est. 1968). The Lebanese Academy of Sciences was created by government decree in 2007.

As there is no ministry in charge of national policy-making in science and technology, the CNRS is considered as the main umbrella organization for science and the government advisor in this field, under the authority of the prime minister. The CNRS fulfils an advisory function, drawing up the general outline of Lebanon's national science policy. It also initiates, encourages and co-ordinates research projects. It is also responsible for managing the Centre for Geophysics, the Centre for Marine Sciences, the Centre for Remote Sensing and the Lebanese Atomic Energy Commission.

In 2006, the CNRS finished drafting the national *Science, Technology and Innovation Policy* with support from UNESCO and ESCWA.[14] The policy introduced new funding mechanisms for research and encouraged researchers from various institutions to work together under the umbrella of an associated research unit on major multidisciplinary themes. It also introduced new programmes to boost innovation and capacity-building, joint PhD programmes and established the basis for Lebanese participation in key Euro-Mediterranean projects.

The policy also identified a series of national priority research programmes inspired by the work of specialized task forces:

- Information technology (IT) deployment in the enterprise sector;
- Web and Arabized software technologies;
- Mathematical modelling, including financial/economic applications;
- Renewable energy sources: hydro-electric, solar, wind;
- Material/Basic sciences for innovative applications;
- Sustainable management of coastal areas;
- Integrated water management;
- Technologies for new agricultural opportunities, including the medicinal, agricultural and industrial use of local plant biodiversity;
- Nutritional food quality;
- Research in subfields of molecular and cellular biology;
- Research in clinical sciences;
- Forging links between practitioners of medical and health sciences, social sciences and paramedical professions.

An observatory of STI

The CNRS has incorporated these R&D priorities into its own research grant programme (Figure 7.13). Moreover, as follow-up to the *Science, Technology and Innovation Policy,* it embarked on establishing the Lebanese Observatory for Research, Development and Innovation (LORDI) in 2014 with support from ESCWA, in order to monitor key indicators of R&D input and output. Lebanon participates in a platform linking Mediterranean observatories of STI. This co-operative platform was set up by the Mediterranean Science, Policy, Research and Innovation Gateway (Med-Spring project) within the EU's Seventh Framework Programme for Research and Innovation (2007–2013).

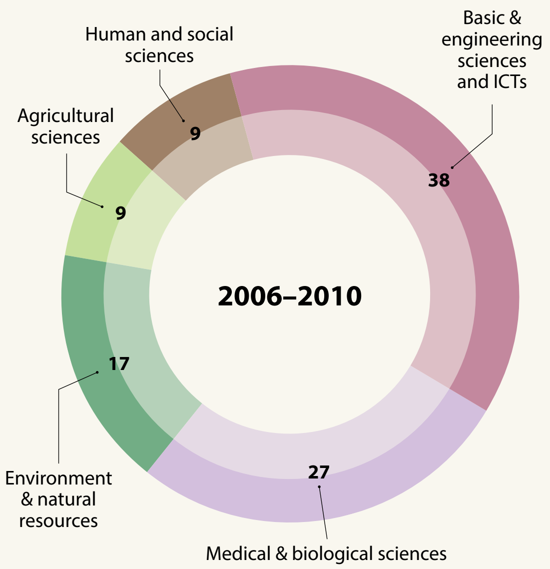
Lebanon's first comprehensive energy strategy

In November 2011, the Lebanese Council of Ministers officially adopted the *National Energy Efficiency Action Plan* for the years 2011–2015. This plan had been developed by the Lebanese Centre for Energy Conservation, the technical arm of the Ministry of Energy and Water in the areas of energy efficiency, renewable energy and 'green' buildings. This is the first comprehensive strategy in energy efficiency and renewable energy for a country

13. http://portal.unesco.org/education/en/files/55535/11998897175Lebanon.pdf/Lebanon.pdf

14. UNESCO has an office in Beirut and ESCWA is hosted by Lebanon.

Figure 17.13: **Distribution of research grants by the Lebanese National Council for Scientific Research, 2006–2010 (%)**



Source: presentation by the Lebanese National Council for Scientific Research (CNRS) to a meeting of the Mediterranean network of observatories of STI, December 2013

that depends on imports for 95% of its energy requirements. The plan is a Lebanese version of the *Arab Energy Efficiency Guidelines* developed by the League of Arab States and comprises 14 national initiatives designed to help Lebanon reach its target of 12% renewable energy by 2020.

LIBYA

The legacy of extreme state control still visible

During the four decades preceding the 2011 uprising, the Libyan economy had drifted towards near-complete state control. Private property ownership and private enterprise in sectors such as retail and wholesale trading were severely curtailed by law, while uncertainty over tax and regulatory regimes prevented the development of economic activity beyond the oil sector; today, this sector is still officially controlled by the National Oil Corporation, which mimics a ministry, in addition to being a regulatory agency and state-owned company. Mining and quarrying represented 66% of GDP in 2012 and 94% of government revenue a year later (AfDB, 2014).

This economic and intellectual suffocation led to large-scale brain drain, making Libya dependent on a sizeable immigrant population to drive highly skilled sectors, among others. There are currently an estimated 2 million foreign workers in Libya, most of whom are illegal (ETF, 2014).

Despite immigrant labour, the Libyan economy was also characterized by a relatively low economic participation rate of around 43% of the adult population between 2008 and 2013 (Table 17.1). Moreover, in its *Rapid Assessment of the Libyan Labour Market* in 2012, the World Bank estimated that 83% of employees were working in government or government-owned enterprises.

The extreme degree of state control was also reflected in Libya's STI environment. Between 2009 and 2013, every single researcher in Libya was employed by the government sector, according to the Libyan Authority for Research, Science and Technology, although it does not survey the business enterprise sector. According to the same source, the number of FTE researchers rose over this period from 764 to 1 140, representing a leap from 128 to 172 FTE researchers per million inhabitants, even if this remains a low ratio for a high-income country like Libya. Despite the turmoil, Libyan researchers managed to increase their annual output from 125 to 181 papers between 2009 and 2014, according to the Web of Science. There are no available data but the Libyan oil industry is known to conduct research on its own behalf.

Political fragmentation delaying recovery

Libya's first post-revolution national elections in July 2012 formally transferred power from the National Transitional Council to the General National Congress in August 2012. Soon afterwards, the country descended into armed conflict. The Council of Deputies (parliament) was formed after the June 2014 elections and is recognized as the legitimate government of Libya by the international community. Currently, it meets in virtual exile in Tobruk, near the Egyptian border. Meanwhile, the country's constitutional capital, Tripoli, is held by supporters of a New General National Congress composed of Islamists who fared poorly in the low-turnout elections. In Benghazi and elsewhere, the climate of insecurity has delayed the start of the school and academic years.

Initially, disruptions to oil production caused a 60% contraction in GDP in 2011 but the economy recovered remarkably quickly, rebounding by 104% in 2012. The deteriorating security situation since, coupled with protests at oil terminal cities since the second half of 2013, have augmented macro-economic instability, causing GDP to contract by 12% in 2013 and the fiscal balance to plummet from a surplus of 13.8% in 2012 to a deficit of 9.3% in 2013 (AfDB, 2014). Private sector activity remains subdued, given the current political uncertainty, exacerbating weak regulatory and institutional conditions and restrictive regulations that limit job creation. Libya's development potential has been further weakened by new laws passed in 2013 limiting foreign ownership of companies to 49% (down from 65% under earlier legislation).

Returning Libyans could help to rebuild higher education

Once security returns, Libya can hope to tap into its large oil wealth to begin building its national innovation system. Priority areas should include strengthening the higher education system and wooing talented Libyans living abroad.

According to the Libyan Authority for Research, Science and Technology, there were an estimated 340 000 tertiary students in 2013/2014 (54% female), down from 375 000 in 2003. This compares with an 18–25-year cohort in excess of 600 000, according to the UNESCO Institute for Statistics. A development plan for 2008–2012 with a budget of US$ 2 billion had envisaged the creation of 13 new universities, on top of the existing 12. While much of the physical infrastructure has since been built, the upheavals since 2011 have prevented these new universities from opening their doors.

Returning Libyan brains could potentially play a major role in rebuilding the Libyan higher education system, with the right incentives. Currently, an estimated 17 500 Libyans are pursuing postgraduate studies abroad, compared to 22 000 within the country. According to the Libyan higher education authorities, there were approximately 3 000 Libyan students enrolled in postgraduate studies at British universities alone and almost 1 500 in North America in 2009. Anecdotal evidence suggests that the security situation has since triggered a fresh exodus of talent: the number of Libyan students enrolled in Malaysian universities, for instance, grew by 87% between 2007 and 2012 from 621 to 1 163 (see Figure 26.9).

A national strategy for STI

In October 2009, the Libyan Ministry of Higher Education and Scientific Research launched the first programme to provide Libyan researchers with direct funding. The aim of this ongoing programme is to disseminate a research culture in Libyan society, including both the government and business enterprise sectors. The programme disbursed more than US$ 46 million between 2009 and 2014.

In December 2012, the ministry established a national committee to lay the foundations of a national innovation system, under the stewardship of the Libyan Authority for Research, Science and Technology and in collaboration with all economic sectors. The committee prepared a draft National Strategy for Science, Technology and Innovation and instigated several prizes: students from the country's main universities competed in the first round of the entrepreneurship prize – supported by the British Council – in the 2012/2013 academic year and in the first round of the innovation prize in the 2013/2014 academic year.

The *National Strategy for Science, Technology and Innovation* was approved by the Libyan National Planning Council in June 2014. The strategy fixes some long-term targets, such as that of raising GERD to 2.5% of GDP by 2040 (Table 17.6). It also foresees the establishment of centres of excellence, smart cities, business incubators, special economic zones and technology parks, as well as the creation of an STI information database. Science and technology are to be harnessed to ensure sustainable development and security.

Table 17.6: **Libyan targets for STI to 2040**

	2014	2020	2025	2030	2040
FTE researchers per million inhabitants	172^{-1}	5 000	6 000	7 500	10 000
GERD/GDP ratio (%)	0.86	1.0	1.5	2.0	2.5
Number of patents	0	20	50	100	200
Number of published journals	25	100	200	500	1 000
Number of research proposals	188	350	650	1 250	2 250
Number of SMEs specializing in STI	0	10	50	100	200
Share of private sector expenditure on R&D in GERD (%)	0	10	15	20	30
Private sector income from R&D (% of GDP)	0	1	5	10	30
Share of technological products in exports (%)	0	5	10	15	40
Number of PhD students	6 000	8 000	10 000	8 000	8 000
Innovation score (Global Innovation Index)	135	90	70	50	30
Global Competitiveness Index (World Economic Forum)	3.5	3.7	3.9	4.0	4.5

-*n* = *n* years before reference year

Source: Libyan National Planning Council (2014) *National strategy for Science, Technology and Innovation*

R&D priorities have yet to be identified but, according to the strategy, should focus on problem-solving research, Libya's contribution to international knowledge production and on diversifying Libya's technological capabilities through investment in such areas as solar energy and organic agriculture.

MAURITANIA

Towards a national strategy for STI

The main finding of the *Science Technology and Innovation Policy Review of Mauritania*[15] undertaken by the United Nations Conference on Trade and Development and UNESCO in 2010 was that current capabilities were inadequate to address the challenges faced by the country. Most public and private enterprises lack the capacity to innovate that would make them internationally competitive. The skills base needs developing, particularly in scientific and technical disciplines, as well as in entrepreneurship and management. Also needed are more rapid technology diffusion and a greater absorptive capacity of technology. Some of the main shortcomings identified were:

- Limited and uncertain public financing for public R&D and lack of private sector investment in R&D or training;
- No active promotion of domestic quality standards as a means of improving the quality of domestic production and encouraging private investment in training and improved technologies;
- An excessively theoretical (as opposed to applied) focus of research at the University of Nouakchott and a lack of co-ordination between the university, public research institutes and ministries for training and R&D;
- A need to reduce bureaucratic obstacles to starting and operating a business;
- A weak entrepreneurial base sustained by the lack of business development services and by a culture of trading rather than investment in production;
- Lack of access by domestic enterprises to information on available technologies and the transfer and absorption of foreign technologies; and
- A lack of policies to leverage the significant reserve represented by the diaspora for domestic benefit.

With the technical assistance of UNESCO, Mauritania is currently drafting the national STI strategy recommended by the review. The focus is on developing skills and physical infrastructure, as well as on improving the co-ordination of private sector development policies, education reform and trade and foreign investment policies. Reforms will also need to build strong productive capacities in agriculture and fisheries, the mining industry and services sector, in order to take advantage of any improvement in macro-economic conditions.

New institutions and a plan for higher education

Mauritania's first tertiary institution, the National School of Administration, dates back to 1966; it was followed by the National School of Higher Studies (École nationale supérieure) in 1974 and the University of Nouakchott in 1981. Between 2008 and 2014, the government licensed three private tertiary colleges and founded the Institute of Higher Technological Studies (Institut supérieur des études technologiques, 2009) in Rosso and the University of Science, Technology and Medicine (2012). The new university has about 3 500 students and 227 teaching staff, including researchers. It is comprised of a Faculty of Science and Technology, a Faculty of Medicine and a professional training institute.

These developments reflect the government's will to improve access to higher education for the growing population. In accordance with the ten-year *Strategy for Science, Technology and Innovation* adopted by the African Union in 2014 (see Chapter 19), the government intends to use higher education as a lever for economic growth.

In April 2015, the Ministry of Higher Education and Scientific Research adopted an ambitious *Three-Year Plan for Higher Education* covering 2014–2017. This plan has four main objectives:

- Strengthen institutional management and governance of tertiary institutions;
- Improve the relevance of the curricula, the quality of training and the employability of graduates;
- Broaden access to tertiary study programmes; and
- Promote scientific research on major national development issues.

For the first time, the current administration has managed to collect relatively comprehensive data on higher education and scientific research data across the country. These data should enable the Ministry of Higher Education and Scientific Research and line ministries to identify the main obstacles to research.

15. See: http://unctad.org/en/Docs/dtlstict20096_en.pdf

MOROCCO

Added value a must to maintain competitiveness

Morocco has managed to navigate the fallout from the global financial crisis relatively well, with average growth of over 4% between 2008 and 2013. As Europe is the main destination for Moroccan exports, these have nevertheless been affected by the slowdown in the European economy since 2008. The economy is diversifying but remains focused on low value-added products; the latter still represent about 70% of manufactured goods and 80% of exports. Unemployment remains high, at over 9% (Table 17.1), and about 41% of the labour force lacks any qualification. There are also signs of waning competitiveness in some areas: in recent years, Morocco has conceded market shares for clothing and shoes in the face of tough international competition from Asia, in particular, but managed to expand its market share for fertilizers, passenger vehicles and equipment for the distribution of electricity (Agénor and El-Aynaoaui, 2015).

Morocco's S&T system is essentially centred around the Ministry of Higher Education and Scientific Research (MoHESR) and the Inter-Ministerial Permanent Committee on Scientific Research and Technological Development (est. 2002), together with the Hassan II Academy of Science and Technology (est. 2006). The National Centre for Scientific and Technical Research (CNRST) is another key player; it runs the National Support Programme for Sectorial Research, for instance, which issues calls for research proposals to public institutions.

Less than a year after its inception, the Higher Council for Education, Training and Scientific Research[16] presented a report to the king on 20 May 2015 offering a *Vision for Education in Morocco 2015–2030*. The report advocates making education egalitarian and, thus, accessible to the greatest[17] number. Since improving the quality of education goes hand in hand with promoting R&D, the report recommends developing an integrated national innovation system which would be financed by gradually increasing the share of GDP devoted to R&D 'to 1% in the short term, 1.5% by 2025 and 2% by 2030'.

The *Moroccan Innovation Strategy* was launched at the country's first National Innovation Summit in June 2009 by the Ministry of Industry, Commerce, Investment and the Digital Economy. It has three main thrusts: to develop domestic demand for innovation; foster public–private linkages; and introduce innovative funding mechanisms. Today, the latter include Intilak for innovative start-ups and Tatwir for industrial enterprises or consortia. The ministry is supporting research in advanced technologies and the development of innovative cities in Fez, Rabat and Marrakesh.

The *Moroccan Innovation Strategy* fixed the target of producing 1 000 Moroccan patents and creating 200 innovative start-ups by 2014. In parallel, the Ministry of Industry, Commerce and New Technologies (as it had since become) created a Moroccan Club of Innovation in 2011, in partnership with the Moroccan Office of Industrial and Commercial Property. The idea is to create a network of players in innovation, including researchers, entrepreneurs, students and academics, to help them develop innovative projects.

Morocco's third technopark is scheduled to welcome its first start-ups and SMEs in September 2015. Like its two predecessors in Casablanca and Rabat, the new technopark in Tangers will be hosting companies specializing in ICTs, green technologies and cultural industries. Through a public–private partnership, offices in an existing building have been converted for an estimated cost of 20 million dirhams (MAD, *circa* US$ 2 million). They should be able to accommodate up to 100 enterprises, which will be sharing the premises with some of the project's key partners, such as the Moroccan Entrepreneurial Network and the Association of Women CEOs of Morocco (Faissal, 2015).

The National Fund for Scientific Research and Technological Development was adopted by law in 2001. At the time, domestic enterprises funded just 22% of GERD. The government encouraged companies to contribute to the fund to support research in their sector. Moroccan telecom operators were persuaded to cede 0.25% of their turnover; today, they finance about 80% of all public research projects in telecommunications supported through this fund. The financial contribution of the business enterprise sector to GERD has meanwhile risen to 30% (2010).

The government is also encouraging citizen engagement in innovation on the part of public institutions. For instance, the Moroccan Phosphate Office (Office chérifien des phosphates) is investing in a project to develop a smart city, King Mohammed VI Green City, around Mohammed VI University located between Casablanca and Marrakesh, at a cost of MAD 4.7 billion (*circa* US$ 479 million).

University–business partnerships remain very limited in Morocco. Nevertheless, a number of competitive funds fostering this type of collaboration have been renewed in recent years. These include the following:

16. The council was founded in accordance with the provisions of Article 168 of the Moroccan Constitution of 2011.

17. The *National Strategy for the Development of Scientific Research to 2025* (2009) recommended raising the secondary enrolment rate from 44% to at least 80% and the tertiary enrolment rate for 19–23 year-olds from 12% to over 50% by 2025.

- The third InnovAct programme was launched by the Moroccan Research Association in 2011, according to Erawatch. Whereas the programme's two predecessors (launched in 1998 and 2005) had targeted SMEs, the new programme has extended the beneficiary groups to include consortia of enterprises. SMEs are expected to pay 50–60% and consortia 80% of the project costs. The scheme encourages university–industry collaboration; companies receive logistical support and the financial means to recruit university graduates to work on their research project. The programme aims to support up to 30 enterprises each year operating mainly in the following industries: metallurgical, mechanical, electronic and electrical; chemical and parachemical; agro-food; textiles; technologies for water and environment; aeronautics; biotechnology; nanotechnology; off-shoring; and automotive;
- The Hassan II Academy of Science and Technology funded 15 research projects in 2008 and 2009. Calls for research proposals encourage private–public collaboration and take into consideration the project's potential socio-economic impact or spillovers;
- MoHESR places a number of poles of competence under contract for four years to bring together public and private research establishments together on a joint project through its accredited laboratories. There were 18 poles of competence up until 2010 but these have since been whittled down to 11 after several did not meet the ministry's new criteria for funding. The networks include one on medicinal and aromatic plants, another on higher energy physics, a third on condensed matter and systems modelling and a fourth on neurogenetics;
- The Moroccan Spin-off and Incubation Network *(Réseau Maroc incubation et essaimage)*[18] supports business incubation, in general, and technology transfer through university spin-offs, in particular. It provides start-ups with pre-seed capital to help them develop a solid business plan. The network is co-ordinated by the CNRST and currently groups 14 incubators at some of the top Moroccan universities.

18. See: www.rmie.ma

One in five graduates moves abroad

Each year, 18% of Moroccan graduates head mainly for Europe and North America; this trend has led to calls for foreign universities to be established in Morocco and for the development of prestigious campuses.

The Hassan II Academy of Science and Technology has international scientific outreach. In addition to recommending research priorities and evaluating research programmes, it helps Moroccan scientists to network with their national and international peers. The academy has identified a number of sectors where Morocco has a comparative advantage and skilled human capital, including mining, fisheries, food chemistry and new technologies. It has also identified a number of strategic sectors, such as energy, with an emphasis on renewable energies such as photovoltaic, thermal solar energy, wind and biomass; as well as the water, nutrition and health sectors, the environment and geosciences (HAST, 2012).

A growing investment in renewable energy

Morocco is expanding its investment in renewable energies (Box 17.4). A total of MAD 19 million (*circa* US$ 2 million) has been earmarked for six R&D projects in the field of solar thermal energy, under agreements signed by the Institute for Research in Solar and New Energy (IRESEN) with scientific and industrial partners. Moreover, IRESEN is currently financing research in the field of renewable energy that is being conducted by more than 200 engineers and PhD students and some 47 university teachers-cum-researchers.

Box 17.4: **Morocco plans to lead Africa in renewables by 2020**

Morocco has decided to compensate for its lack of hydrocarbons by becoming the leader in Africa for renewable energy by 2020. In 2014, it inaugurated the continent's biggest wind farm at Tarfaya in the southwest of the country.

The government's latest project is to create the world's biggest solar farm at Ouarzazate. The first phase, known as Noor I, should be completed by October 2015.

A consortium led by the Saudi Arabian company Acwa Power and its Spanish partner Sener won the call for tenders for the first phase and Acwa Power has just won the same for the second phase. It is estimated that it will cost the consortium nearly € 2 billion to build and run Noor II (200 MW) and Noor III (150 MW).

The project is also being funded by donors such as the German public bank Kreditanstalt für Wiederaufbau (€ 650 million) and the World Bank (€ 400 million).

Ultimately, the Ouarzazate solar farm will have a capacity of 560 MW but the government doesn't intend to stop there. It plans to produce 2 000 MW of solar power by 2020.

Source: Le Monde (2015)

OMAN

An incentive scheme to bolster research

According to the country report by the US Energy Information Administration, hydrocarbons accounted for about 86% of government revenue and half of GDP in 2013. Oman has an ambitious plan to reduce the oil sector's contribution to GDP to 9% by 2020. The aim is to diversify the economy, such as by developing the tourism sector, as part of the government's *Economic Vision 2020*. There is little latitude for expanding agricultural production but Oman hopes to exploit its long coastline's potential for the development of fisheries and gas-based industries to achieve the goals of *Economic Vision 2020* (Salacanin, 2015).

Oman's S&T system is centred around the Ministries of Education and Higher Education and Sultan Qaboos University. The Research Council is Oman's sole research funding body and thus spearheads R&D in the country. Established in 2005, it has an extensive mandate. The Research Council has identified the hurdles facing Oman, such as complex administrative processes, little funding, research of poor quality and the lack of relevance of R&D to socio-economic needs (Al-Hiddabi, 2014).

To address these difficulties, the Research Council developed a *National Research Plan for Oman* in 2010 which is linked to Oman's overall development plans. The plan outlines three stages: the first priority is to improve the status of research and boost productivity; at the second stage, the priority will be to build national research capacity in priority areas determined by the availability of appropriately qualified personnel and the establishment of the requisite infrastructure; at the last stage, the focus will be on strengthening the country's niche areas.

The Research Council has also developed an incentive scheme to foster research excellence. The programme rewards researchers through an open research grant scheme tied to their output. Besides stimulating productivity, the idea is to increase the number of active researchers, motivate them to mentor postgraduate students and encourage them to publish in international, refereed journals and to apply for patents.

In October 2014, Oman hosted the General Meeting of the World Academy of Sciences (TWAS). Two months later, the Research Council co-organized the second Arab–American Frontiers Symposium with the US National Academy of Sciences to facilitate research collaboration between outstanding young scientists, engineers and medical professionals from the USA and a number of Arab states.

PALESTINE

More research links needed with the market

Although Palestine does not have a national STI policy, a recent innovation survey by Khatib *et al.* (2012) of the two industrial sectors of stone quarrying and food and beverages yielded encouraging findings. The survey found that both sectors were innovative and having a positive impact on employment and exports. The survey recommended directing academic programmes towards local economic development to help establish the necessary co-operative links between the public and private sectors.

The Palestine Academy of Sciences and Technology (PALAST) acts as an advisory board to the government, parliament, universities and research institutes, as well as to private donors and international organizations. One of PALAST's special features is the presence of a powerful standing committee made up of a number of government ministers; the standing committee operates alongside a scientific council of elected members from PALAST (PALAST 2014).

An observatory of STI

In 2014, PALAST launched its Science, Technology and Innovation Observatory, which had been developed with the support of ESCWA. The observatory's main purpose is to collect data on STI on a regular basis and promote networking.

Hundreds of entrepreneurial web sites have been created by young Palestinians in the past few years to showcase new digital products that include games and software for specific professions. Although internet connection costs have fallen by almost 30% in recent years, the lack of connectivity to a 3G network in the West Bank and Gaza Strip hinders the use of mobile applications for education, health and entertainment.

QATAR

Incentives for entrepreneurship

Besides its oil and gas industry, Qatar relies on the petrochemical, steel and fertilizer industries to drive the economy. In 2010, Qatar showed the world's fastest growth rate for industrial production: 27.1% over the previous year. Qataris enjoy the world's highest GDP per capita (PPP$ 131 758) and one of the world's lowest unemployment rates: 0.5% (Table 17.1).

The *Qatar National Vision 2030* (2008) advocates finding an optimum balance between the current oil-based economy and a knowledge economy characterized by innovation and entrepreneurship, excellence in education and the efficient delivery of public services. To support this shift towards a knowledge economy, the government budget for education to 2019 has been raised by about 15%.

The government has also begun offering investors tax breaks and other incentives to support entrepreneurship and promote SMEs. Its efforts to diversify the economy appear to be paying off. Industries and services derived from hydrocarbons have been expanding, fuelling private-sector growth. Although the manufacturing sector is still in its infancy, there has been a boom in the construction sector, thanks largely to heavy investment in infrastructure; this in turn has boosted the finance and real estate sectors (Bq, 2014). Much of construction is occurring in the non-hydrocarbon sector: in transportation, health, education, tourism and sport – Qatar is hosting the World Football Cup in 2022. The government is also promoting Qatar as a tourist destination among its neighbours, in particular. Consequently, non-hydrocarbon sectors grew by 14.5% in 2013.

Qatar's new park is country's primary technology incubator

The *Qatar National Research Strategy* (2012) identified four priority areas: energy, environment, health sciences and ICTs. When the Qatar Foundation subsequently established the Qatar Science and Technology Park, it focused on these four areas. The park has become Qatar's primary incubator for technological development, the commercialization of research and support for entrepreneurship. Located within the Qatar Foundation's Education City, the park has access to the resources of a cluster of leading research universities with antennae in the park, including five US institutions: Virginia Commonwealth University School of the Arts, Weill Cornell Medical College, Texas A&M University at Qatar, Carnegie Mellon University and Georgetown University.

SAUDI ARABIA

Policies to reduce dependence on foreign labour

As part of its agenda for embracing the knowledge economy, the government has launched a multibillion dollar development scheme to build six greenfield cities and industrial zones. By 2020, these industrial cities are expected to generate US$ 150 billion in GDP and create 1.3 million jobs. This strategy has been endorsed by the record number of non-oil exports in 2013. However, Saudi Arabia remains overdependent on foreign labour: there are only 1.4 million Saudis employed in the private sector, compared with 8.2 million foreigners, according to the Ministry of Labour (Rasooldeen, 2014). The government is trying to recruit citizens through a drive dubbed 'Saudization'.

In parallel, the government is investing in professional training and education as a way of reducing the number of foreign workers in technical and vocational jobs. In November 2014, it signed an agreement with Finland to utilize Finnish excellence to strengthen its own education sector (Rasooldeen, 2014). By 2017, the Technical and Vocational Training Corporation of Saudi Arabia is to have constructed 50 technical colleges, 50 girls' higher technical institutes and 180 industrial secondary institutes. The plan is the first step in creating training placements for about 500 000 students, half of them girls. Boys and girls will be trained in vocational professions such as IT, medical equipment handling, plumbing, electricity, mechanics, beauty care and hairdressing.

Two universities among the top 500

Saudi Arabia has now entered the third phase of implementation of its first national S&T policy (2003). The policy called for the establishment of centres of excellence and for upgrading the skills and qualifications of human resources. The country is keen to co-operate with the outside world, invest more in information technologies and harness S&T to preserving its natural resources and protecting the environment.

The *Five-Year Development Plan* adopted in 2010 proposed allocating US$ 240 million in research grants each year, together with the creation of a number of research centres and technology incubators at different universities.

According to the 2014 Academic Ranking of World Universities, both King Abdulaziz University and King Saud University rank among the world's top 500. The former has succeeded in attracting over 150 highly cited[19] researchers from around the world as adjunct professors and the latter 15. Internationally recruited faculty are expected to undertake research in Saudi Arabia and collaborate with Saudi faculty members. This policy has allowed both universities to move up the field in international rankings, while boosting overall research output and building endogenous capacity in R&D.

King Abdulaziz City for Science and Technology (KACST) serves as both the national science agency and as a hub for national laboratories. It is involved in policy-making, data collection and funding of external research. It also acts as the national patent office. KACST's planning directorate is responsible for developing national databases with STI indicators. KACST conducts applied research in a wide range of areas, including petrochemicals, nanotechnologies, space and aeronautics, advanced materials, mathematics, health, agriculture and construction technologies. It also acts as a technology incubator by fostering ties between research universities and between the public and private sectors to

19. http://highlycited.com/archive_june.htm

Box 17.5: Fellowships for budding inventors from the Gulf

The Institute for Imagination and Ingenuity (i2 Institute) is the brainchild of Hayat Sindi, co-founder of Diagnostics for All, a non-profit company designated one of the world's ten most innovative biotech companies in 2012 by *FastCompany* magazine in the USA. Originally from Saudi Arabia, Dr Sindi was the first woman from the Gulf to obtain a PhD in biotechnology, while she was studying at Cambridge University (UK).

For Dr Sindi, 'the Middle East has to overcome huge barriers to entrepreneurship'. Chief among these are a lack of formal business skills among scientists and engineers; a culturally intrinsic fear of failure; a lack of potential investors willing to provide the necessary venture capital; and the fact that investors in the region do not focus on science-based ventures.

Dr Sindi founded the Institute for Imagination and Ingenuity in 2011 to accompany budding young inventors from the region at the incubation stage of their project. Her NGO helps them package their idea and attract venture capital through a three-stage fellowship programme, the only one of its kind in the Arab world.

The first call for applications took place in November 2012. Master's and PhD students were invited to apply for a grant in one of four areas: water, energy, health or environment. Some 50 candidates who already held a local and international patent for their idea were selected. They were then invited to pitch their idea to an international jury made up of scientists and business leaders in February 2013. Ultimately, just 12 fellows were singled out to share a grant of US$ 3–4 million; each was then assigned a regional and global mentor to help him or her develop a business plan.

The fellows were able to develop their business plan during the first stage of their eight-month fellowship, through the entrepreneur programme run jointly with Harvard Business School and the Massachusetts Institute of Technology (MIT) in the USA for a period of six weeks.

The second stage of their induction was the social science programme. Here, they met other fellows who had specialized in social innovation, such in as the provision of clean energy or water. All 12 fellows were asked to come up with a solution to a specific social problem. The aim of this exercise was to give them confidence in their ability to take on new challenges.

The third programme developed the i2 fellows' communication skills at MIT's Media Lab, teaching them how to sell their project to different audiences and how to speak in public.

In 2014, potential investors were invited to a conference hosted by King Abdullah Economic City in Riyadh (Saudi Arabia) to hear the fellows present their projects. The deadline for the second round of applications was end April 2014.

Source: www.i2institute.org; UNESCO (2013)

encourage innovation and the transfer and adaptation of technology with commercial potential.

One interesting initiative is the Institute for Imagination and Ingenuity founded by Makkah-born Dr Hayat Sindi in 2011; it is striving to develop an entrepreneurial culture in the Arab world through mentorship (Box 17.5).

Research to curb energy consumption

Saudi Arabia needs to engage in a serious deliberation about its domestic energy consumption, which is expected to increase by 250% by 2028. One-third of oil production was being used domestically in 2012 and demand is growing by about 7% per year, driven by increasing wealth, rapid population growth and low domestic energy prices. The OECD's International Energy Agency recorded about US$ 40 billion in domestic energy subsidies in 2011.The government is cognizant of the problem. In 2010, it upgraded the National Energy Efficiency Programme (launched in 2003) to a permanent faciliity, the Saudi Energy Efficiency Centre. In May 2015, the government announced a programme to develop solar energy which should allow the country to export gigawatts of electric power instead of fossil fuels.

The late King Abdullah was a keen proponent of education and research. In 2007, he called for the establishment of an independent centre to conduct objective research in the field of energy. This gave rise to the King Abdullah Petroleum Studies and Research Centre, which opened in Riyadh in 2013; a Board of Trustees ensures the centre's independence and oversees its endowment. In 2009, Saudi Arabia launched the King Abdullah University of Science and Technology.

SUDAN

Conflict and brain drain undermining development

Sudan has been plagued by armed conflict in the past decade: the conflict in Darfur, which lasted from 2003 until the signing of a ceasefire agreement with rebel groups in 2010; and a long-standing conflict in the south of the country, which resulted in the establishment of South Sudan as an independent state in 2011.

Sudan has had its own academy of sciences since 2006 but otherwise has struggled to consolidate its science system over the past decade. One impediment is the loss of young talent to brain drain: between 2002 and 2014, Sudan lost more than 3 000 junior and senior researchers to migration, according to the National Research Centre and Jalal (2014). Researchers are drawn to neighbouring countries such as Eritrea and Ethiopia by the better pay, which is more than double that offered to university staff in Sudan. More recently, Sudan has become a refuge for students from the Arab world, particularly since the turmoil of the Arab Spring. Sudan is also attracting a growing number of students from Africa.

In 2010, the privately run Future University in Khartoum was upgraded from a college to a university. Established in 1991, it was the first college in the region to introduce an IT programme, offering degrees in a wide range of fields, including computer science, artificial intelligence, bio-informatics, electronics engineering, geo-informatics and remote sensing, telecommunication and satellite engineering, biomedical engineering, laser and mechatronics engineering and architecture. The Future University is participating in NECTAR (Box 17.2).

A fresh policy impetus

In 2013, the Ministry of Science and Communication embarked on a revision of its *Science and Technology Policy* (2003) with the technical assistance of UNESCO. A number of consultation meetings were organized with high-level experts from around the world; these produced a series of recommendations, including those advocating:

- the re-establishment of a higher council for science and technology, to be headed by the First Deputy President of the Republic, which would co-ordinate and oversee relevant institutions and research centres attached to various ministries, with the Ministry of Science and Communication acting as rapporteur of the council.;
- the establishment of a fund to finance government research, with a focus on employing the proceeds of Awqaf and Zakat;[20] this should be combined with the adoption of legislation increasing financial allocations to scientific research, such as exemptions from some or all of customs duties on imported goods and equipment that support research; these measures should enable GERD to rise to 1% of GDP by 2021; and
- the establishment of an observatory of STI indicators, with the technical support of UNESCO.

Sudan has a fairly diverse institutional framework. The following research centres, among others, fall under the umbrella of the Ministry of Science and Communication:

- Agricultural Research Corporation;
- Animal Resources Research Corporation;
- National Research Centre;
- Industrial Research and Consultancy Centre;
- Sudan Atomic Energy Corporation;
- Sudanese Metrology Authority;
- Central Laboratories; and the
- Social and Economic Research Bureau.

Unfortunately, Sudan does not yet possess the human or financial resources necessary to promote science and technology effectively. Were it to encourage more private sector involvement and regional co-operation, restructure its essentially agriculture-based economic system and pool its resources, it would be in a position to develop its S&T capacity (Nour, 2012). The bilateral co-operation agreement signed by the Ministry of Science and Communication with the South African Department of Science and Technology in November 2014 is a step in the right direction. During the minister's visit to South Africa in March 2015, the Sudanese government identified space science and agriculture as priority areas for collaboration (see Table 20.6).

SYRIA

An exodus of scientific talent

Despite hosting prestigious international research institutes such as the International Centre for Agricultural Research in Dry Areas and the Arab Centre for the Study of Arid Zones and Dry Lands, Syria's S&T system was in a dire state even before the outbreak of civil war in 2011. Syrian parliamentarian Imad Ghalioun estimated in 2012 that, even before the uprising, the government had allocated just 0.1% (US$ 57 million) of GDP to R&D and, afterwards, as little as 0.04% of GDP (Al-Droubi, 2012). The civil war has led to an exodus of scientific talent. In 2015, the United Nations estimated that four million Syrians had sought refuge in neighbouring countries since 2011, mainly Jordan, Lebanon and Turkey.

TUNISIA

Greater academic freedom

During the difficult transition to democracy over the past four years, science and technology have often taken a back seat to more pressing problems. This has led to frustration in the scientific community at the speed of reform. The situation has improved for scientists in terms of academic freedom but other concerns persist.

20. Within Islam, Awqaf is a voluntary donation of money or assets which are held in trust for charitable purposes. Zakat is an obligatory religious tax paid by every Muslim that is considered one of the five pillars of Islam. There are established categories of beneficiary of this tax, which is used to maintain a socio-economic equilibrium by helping the poor.

The first reform was introduced within weeks of the revolution. During her brief stint as Secretary of State for Higher Education from January to March 2011 in the caretaker government, Faouzia Charfi changed the procedure for filling top university posts. For the first time in Tunisia, elections were held in June 2011 for faculty directors and university presidents (Yahia, 2012). This is a step forward, even if corruption continues to plague the Tunisian university system, according to a study published in June 2014[21] by the Tunisian University Forum, an NGO formed after 14 January 2011.

That this NGO could even publish such a study without fear of retribution is a sign, in itself, of greater academic freedom in Tunisia since President Zine El-Abidine Ben Ali fled the country on 14 January 2011. According to Faouzia Charfi, under the former president, 'universities and researchers had little freedom to develop their own strategies or even to choose who they worked with'. Other scientists have said that regime bureaucrats thwarted their attempts to establish independent links with industry (Butler, 2011). Scientists were also discouraged from maintaining international ties. Organizers of scientific meetings, for instance, were obliged to submit the topics and research on the agenda to regime bureaucrats, in order to obtain prior authorization. Ten months after the revolution, a group of PhD holders and students formed the Tunisian Association of Doctors and PhD Students in Science to help Tunisian scientists network with one another other and with scientists abroad (Yahia, 2012).

Despite restrictions, 48% of scientific articles published by Tunisian researchers had foreign co-authors in 2009. This share had risen to 58% by 2014. In 2009, the government began negotiating an agreement for a joint research programme with the European Union (EU). The three-year programme was ultimately launched on 12 October 2011, with € 12 million in EU funding. The Tunisian Agency for the Promotion of Scientific Research was given responsibility for distributing the programme funds in accordance with the country's priority research areas: renewable energy, biotechnology, water, the environment, desertification, micro-electronics, nanotechnology, health and ICTs.
The programme also sought to forge links between academic research and the Tunisian industrial sector. The German Society for International Cooperation, for instance, conducted a study of market needs to help simplify co-ordination between the academic and industrial sectors. At the launch of the programme, the Tunisian Minister for Industry and Technology, Abd El-Aziz Rasaa, announced plans to raise Tunisia's technological exports from 30% of the total in 2011 to 50% by 2016 (Boumedjout, 2011).

21. See: www.businessflood.com/forum-universitaire-tunisien-etude-sur-le-diagnostic-et-la-prevention-de-la-corruption-dans-le-milieu-universitaire-tunisien

The economy has proved relatively resilient over the past four years, thanks partly to its broad base, with well-developed agricultural, mining, petroleum and manufacturing sectors. This helped to cushion the drop in tourism, which accounted for 18% of GDP in 2009 but only 14% four years later. Tourism was beginning to recover when terrorist acts against a museum and hotel complex in March and June 2015 once more destabilized the industry. Tunisia's relative stability and reputed health clinics have also made it a beacon for medical tourism.

High-level support for science

Compared to most African and Arab states, the STI system in Tunisia is fairly advanced and enjoys strong government support. The Higher Council of Scientific Research and Technology is chaired by none other than the prime minister himself. The body responsible for formulating policy and implementation strategies, the Ministry of Higher Education, Scientific Research and Information and Communication Technologies, can count upon the expertise of both the National Consultative Council of Scientific Research and Technology and the National Evaluation Committee of Scientific Research Activities. The latter is an independent body in charge of evaluating both public scientific research and private sector research programmes benefiting from the public purse. The National Observatory of Science and Technology is another vital component of the Tunisian STI system. It was established in 2006, two years before being placed under the Ministry of Higher Education and Scientific Research.

A strategy to build bridges between universities and industry

The University Council is presided by the Minister of Higher Education, Scientific Research and Information and Communication Technologies. In January 2015, the University Council approved a broad reform of scientific research and higher education that is to be implemented over the period 2015–2025. The reform will focus on modernizing university curricula, in order to give graduates the skills employers need, and on giving universities greater administrative and financial autonomy. In 2012, the ministry had already taken a step in this direction by placing its relations with universities on a contractual basis[22] for the first time.

The reform will also strengthen university–industry ties and revise the university map to ensure greater equity between regions. Central to this strategy is the ongoing development of technoparks, as they foster research and job creation in the regions.

Tunisia is investing heavily in technoparks. Elgazala Technopark in the Tunis region was the first, both for Tunisia and the

22. The two parties concluded a framework contract which authorizes universities and institutions to devise their own teaching and research strategies for a period of four years within the framework of specific projects and programmes; these strategies are accompanied by implementation plans.

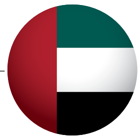
Maghreb. Established in 1997, it specializes in communication technologies and now hosts about 80 companies, including 13 multinationals (Microsoft, Ericsson, Alcatel Lucent, etc). Several other technoparks have been established since, including those in Sidi Thabet (2002, for biotechnology and pharmaceuticals), Borj Cedria (2005, for environment, renewable energy, biotechnology and materials science), Monastir (2006, for textiles) and Bizerte (2006, for the agro-industry). In 2012, the government announced the creation of a new technopark in Remada specializing in ICTs. Meanwhile, the Ecosolar Village of Zarzis–Jerba should soon be operational. It will create jobs in renewable energy production, seawater desalination and organic farming; this technopark also plans to position itself as a training platform for the entire African region. Tunisia intends to raise the share of renewables in the energy mix to 16% (1 000 MW) by 2016 and to 40% (4 700 MW) by 2030, within its *Solar Plan*[23] adopted in 2009.

The longer term goal is to develop an internationally competitive research system. In November 2013, the government signed an agreement with France Clusters, which groups French technoparks, for the provision of training and advice on the creation of new technoparks in Tunisia. Elgazala and Sidi Thabet Technoparks are both members of the International Association of Science Parks. Gafsa Technopark, which specializes in useful chemical substances, has been designed in partnership with the Korean International Cooperation Agency; it is being funded by the government, the park management companies and the tandem formed by the Chemical Group and the Compagnie des phosphates de Gafsa.

The adoption of a new Constitution by parliament in June 2014, followed by the smooth handover of power, first in the October parliamentary elections then by the incumbent president to his successor, Beji Caid Essebsi, in late 2014, suggest that the country is well on the way to political stability. Moreover, science has not been forgotten in the new Constitution. Article 33 expressly states that 'the state provides the means necessary to the development of technological and scientific research'.

23. See: www.senat.fr/rap/r13-108/r13-108.pdf

UNITED ARAB EMIRATES



A good business climate

The United Arab Emirates has been reducing its dependence on oil exports by developing other economic sectors, including the business, tourism, transportation and construction sectors and, more recently, space technologies. Abu Dhabi has become the world's seventh-biggest port. The global financial crisis of 2008–2009 affected Dubai's real estate market, in particular. Companies like Dubai World, which supervised a government investment portfolio in urban development, ran up substantial external debt.

With the slump in oil prices since mid-2014, current economic growth is being buoyed mainly by the sustained recovery of Dubai's construction and real estate sectors, together with significant investments in transportation, trade and tourism. Dubai has launched a megaproject for the construction of the world's biggest shopping centre and no fewer than 100 hotels. It is also erecting a 'greenprint' for sustainable cities (Box 17.6) and investing in a fully functional 3D building (Box 17.7). A project to develop a national railway is also 'back on track' after being brought to a halt by the global financial crisis.

The United Arab Emirates has a reputation for having one of the best business climates in the region. In mid-2013, the United Arab Emirates Federation adopted a new Companies Law that comes closer to respecting international standards.

Box 17.6: **Masdar City: a 'greenprint' for the city of the future**

Masdar City is located about half an hour from Abu Dhabi. This artificial city is being constructed between 2008 and 2020 as a 'greenprint' for the city of the future. The aim is to build the world's most sustainable city, one capable of combining rapid urbanization with low consumption of energy, water and waste.

The city blends traditional Arabic architectural techniques with modern technology to cope with high summer temperatures and capture prevailing winds. Masdar City has one of the largest installations of photovoltaic panels on rooftops in the Middle East.

The city is sprouting around the Masdar Institute of Science and Technology, an independent research-driven, graduate-level university set up in 2007 with a focus on advanced energy and sustainable technologies. Companies are being encouraged to foster close ties with the university to accelerate the commercialization of breakthrough technologies.

By 2020, it is estimated that Masdar City will be home to 40 000 people, plus businesses, schools, restaurants and other infrastructure.

There are some who argue that the money might have been better spent on greening the country's existing cities rather than on creating an artificial one.

Source: adapted from: www.masdar.ac.ae

Box 17.7: Dubai to 'print' its first 3D building

Dubai is planning to erect the world's first fully functional three-dimensional (3D) printed building. The building will temporarily house the staff of the Museum of the Future, pending completion of permanent facilities in 2018.

Experts estimate that 3D printing technology could reduce construction time of buildings by 50–70%, labour costs by 50–80% and construction waste by 30–60%.

The office building will be printed layer by layer using a 3D printer then assembled on site in Dubai. All the furniture and structural components will also be built using 3D printing technology, combining a mixture of special reinforced concrete, glass fibre reinforced gypsum and fibre-reinforced plastic.

The scheme is backed by the National Innovation Committee. Its chairman, Mohammad Al Gergawi, considers that 'this building will be a testimony to the efficiency and creativity of 3D printing technology, which we believe will play a major role in reshaping the construction and design sectors'.

Dubai is partnering with the Chinese firm WinSun Global on this project, along with leading architecture firms Gensler, Thornton Thomasetti and Syska Hennessy, the China State Construction Company and the firms eConstruct and Killa Design.

Source: Gulf News (2015)

It does not soften the rule, however, that prevents a majority foreign participation in local companies. It also introduces an 'Emirization' jobs programme advocating recruitment based on nationality, a measure which could curtail foreign investment, according to the Coface credit insurance[24] group.

No knowledge economy without science

The *Government Strategy* (2011–2013) lays the foundations for realizing *Vision 2021*, adopted in 2010. One of the strategy's seven priorities is to develop a competitive knowledge economy. Under this priority figures the objective of promoting and enhancing innovation and R&D, among others.

In May 2015, the Ministry of the Economy announced the launch of the Mohammed Bin Rashid Al Maktoum Business Innovation Award, in partnership with the Dubai Chamber of Commerce and Industry. This initiative crowns the United Arab Emirates' Year of Innovation and is coherent with the country's strategy of developing the pillars of a knowledge economy.

The Dubai Private Sector Innovation Index

The Dubai Chamber of Commerce and Industry is also launching two novel initiatives to nurture innovation. The first is the Dubai Private Sector Innovation Index, the first of its kind, to measure Dubai's progress towards becoming the world's most innovative city. The second initiative is the Dubai Chamber Innovation Strategy Framework, the first outside the USA; it will provide a benchmarking tool against other countries and a road map for future implementation.

Two satellites in place for Earth monitoring

The Emirates Institution for Advanced Science and Technology (EIAST, est. 2006) placed its first Earth-observation satellite in orbit in 2009, Dubai Sat 1, followed by Dubai Sat 2 in 2013. These satellites were designed and developed by the Korean company Satrec Initiative, along with a team of EIAST engineers; they are intended for urban planning and environmental monitoring, among other applications. EIAST engineers are now working with their partner on a third satellite, Khalifa Sat, due to be launched in 2017. In 2014, the government announced plans to send the first Arab spaceship to Mars in 2021. The United Arab Emirates has been advocating the creation of a pan-Arab space agency for years.

A National Research Foundation

The National Research Foundation was launched in March 2008 by the Ministry of Higher Education and Scientific Research. Individuals or teams of researchers from public and private universities, research institutes and firms may apply for competitive grants. To be approved, research proposals must survive international peer review and prove that they offer socio-economic benefits.[25]

The United Arab Emirates University is the country's premier source of scientific research. Through its research centres,[26] it has contributed significantly to the country's development of water and petroleum resources, solar and other renewable energies and medical sciences. Since 2010, the university has filed at least 55 invention patents. As of June 2014, about 20 patents had been granted to the university.[27]

The United Arab Emirates University has established strong research partnerships in areas such as oil and gas, water, health care, agricultural productivity, environmental protection, traffic

24. See: www.coface.com/Economic-Studies-and-Country-Risks/United-Arab-Emirates

25. See www.nrf.ae/aboutus.aspx

26. These include the Zayed bin Sultan Al Nahyan Centre for Health Sciences; National Water Centre; Roadway Transportation and Traffic Safety Research Centre; Centre for Public Policy and Leadership; Khalifa Center for Genetic Engineering and Biotechnology and the Centre for Energy and Environmental Research

27. See: www.uaeu.ac.ae/en/dvcrgs/research safety and the rehabilitation of concrete structures. It has established an active research network of partners in countries that include Australia, France, Germany, Japan, Republic of Korea, Oman, Qatar, Singapore, Sudan, the UK and USA.

YEMEN

No scope for science in current political quagmire

Yemen boasts several universities of repute, including the University of Sana'a (est. 1970). Yemen has never adopted a national S&T policy, though, nor allocated adequate resources to R&D.

Over the past decade, the Ministry of Higher Education and Scientific Research has organized a number of conferences to assess the reality of scientific research in the country and identify barriers to public-sector research. The ministry also launched a task force in 2007 to establish a science museum and instituted a presidential science prize in 2008. In 2014, ESCWA received a request from the ministry for assistance in establishing an STI observatory in Yemen; this endeavour has since come to a standstill in the face of the escalating conflict.

Yemen has not held parliamentary elections since 2003. The tremors of the Arab Spring led to President Saleh ceding power to his deputy, Abd Rabbuh Mansur Hadi, in February 2012, and to the establishment of a National Dialogue Conference at the initiative of the Gulf Cooperation Council. In 2015, tensions deteriorated into war between forces of the former regime and those of President Abd Rabbuh Mansur Hadi, who is backed by several Arab countries.

CONCLUSION

A need for a coherent agenda and sustainable funding

The draft *Arab Strategy for Science, Technology and Innovation* endorsed by the Council of Ministers of Higher Education and Scientific Research in the Arab World in 2014 proposes an ambitious agenda. Countries are urged to engage in greater international co-operation in 14 scientific disciplines and strategic economic sectors, including nuclear energy, space sciences and convergent technologies such as bio-informatics and nanobiotechnology. The *Strategy* advocates involving scientists from the diaspora and urges scientists to engage in public outreach; it also calls for greater investment in higher education and training to build a critical mass of experts and staunch brain drain.

The *Strategy* nevertheless eludes some core issues, including the delicate question of who will foot the hefty bill of implementing the strategy. How can heavily indebted countries contribute to the platform? What mechanisms should be put in place to combat poverty and offer greater equity of access to knowledge and wealth at national levels? Without pondered answers to these questions, coupled with innovative out-of-the-box solutions, no strategy will be able to exploit the region's capabilities effectively.

For the *Strategy* to fly, the region's scientific community needs a coherent agenda containing a portfolio of solution-oriented scientific projects and programmes that expressly serve the region's needs, along with clearly identified sources of funding.

The events of the past few years may have stirred the cooking pot but real progress will only be measured against collective structural change at the economic, social and political levels. From the preceding country profiles, we can see that some countries are losing their winning ticket to development and progress; the motives may be economic or political but the result is the same: an exodus of experts and researchers from countries which have spent millions of dollars educating them. In many of these countries, there is a lack of a well-functioning innovation system with a clear governance and policy framework, compounded by poor ICT infrastructure that hampers access to information and opportunities to create knowledge and wealth. Governments can leverage social innovation to tackle some of these problems.

The poor state of Arab innovation systems can be attributed to many factors. The present report has highlighted, for instance, the region's low spending levels on R&D, the relatively small pool of qualified experts and research scientists and engineers, the small number of tertiary students enrolling in scientific disciplines, poor institutional support and the effects of the inimical political and social perspectives on the promotion of science.

Despite Heads of State having committed to raising GERD to 1% of GDP more than 25 years ago, not a single Arab country has yet reached that target. In most countries, the education system is still not turning out graduates who are motivated to contribute to a healthier economy. Why not? Governments should ask themselves whether the fault lies solely with the education system, or whether other impediments are stifling innovation and an entrepreneurial culture, such as a poor business climate.

How will countries of the Gulf embrace economic diversification without building a critical mass of experts, technicians and entrepreneurs? Higher education curricula are mostly fact-heavy and lecture-based, with a limited use of ICT tools and hands-on learning and little contextualization. This environment favours passive learning and examination-based assessments that measure students' ability to memorize knowledge and curriculum content rather than their ability to develop the necessary analytical skills and creativity to innovate. Teachers need to adopt novel approaches that transform them from a teleprompter into a facilitator.

There is a clear mismatch between the skills graduates are being given and labour market demand. The oversupply of university graduates and the channelling of students who perform poorly into vocational education – rather than acknowledging the key role qualified technicians play in the knowledge economy – is fuelling unemployment among tertiary graduates and leaving the market without skilled labour. The Saudi experiment since 2010 in technical and vocational education is worth noting, in this regard.

Morocco has announced its intention of making education more egalitarian. Other Arab countries could do likewise. Governments should institute scholarship schemes to give rural and poor tertiary students the same opportunities as their peers from wealthier and urban backgrounds. Recent statistics show that a fresh university graduate remains unemployed for 2–3 years on average before landing his or her first job. This situation could be turned to advantage. A national programme could be launched to recruit and train young university graduates from all academic disciplines to teach for one or two years after graduation in rural areas where there is a chronic lack of primary and secondary school teachers.

Several Arab governments are setting up observatories to improve the monitoring of their science systems through data collection and analysis. Others should follow suit, in order to monitor the effectiveness of national policies and form a network of observatories to ensure information-sharing and the development of common indicators. Some are already taking this course of action; Lebanon, for instance, is participating in a platform linking Mediterranean observatories of STI.

There is more to developing a national innovation system than putting in place material institutions. Intangible considerations and values are vital, too. These include transparency, rule of law, intolerance of corruption, reward for initiative and drive, a healthy climate for business, respect for the environment and the dissemination of the benefits of modern science and technology to the general population, including the underprivileged. Employability and placement in public insitutions should depend solely on the expertise and seniority of the individual, rather than on political considerations.

Lingering political conflicts in the Arab region have created a tendency to define national security in military terms. As a result, resources are allocated to defence and military budgets rather than to R&D that could help address the poverty, unemployment and erosion of human welfare that continue to plague the region. The countries with the highest share of military spending in GDP come from the Middle East. The resolution of political problems and the creation of collective security arrangements for the region would free up public resources that could be devoted to finding solutions to pressing problems through scientific research. Such a re-orientation would accelerate the process of economic diversification and socio-economic development.

The private sector could be encouraged to contribute to the R&D effort. We have seen how Moroccan telecom operators support public research projects in telecommunications by ceding 0.25% of their turnover to a dedicated fund. One could imagine a token amount being collected from large companies to finance R&D in their own sectors, especially in water, agriculture and energy. For the Arab States, it is imperative to accelerate the transfer of innovative technologies by developing educational large-scale pilot projects in priority areas, including renewable energy systems. This will also help to build up a critical mass of technicians in the region.

A 'value chain' is comprised of a series of interdependent components, each of which influences and is influenced by the other. Top-down approaches cannot bring about the required change. Rather, decision-makers need to create an environment that liberates the nation's dynamic forces, be they academic or economic – forces like Hayat Sindi, who is using mentors to develop an entrepreneurial culture in the region. The Arab world needs more champions of science and technology, including in the political arena, to bring about the positive change to which it aspires.

KEY TARGETS FOR ARAB COUNTRIES

- Raise GERD to at least 1% of GDP in all Arab countries;
- Raise GERD in Libya to 1% of GDP by 2020;
- Raise GERD in Morocco to 1.5% of GDP by 2025;
- RaiseTunisia's technological exports from 30% (2011) to 50% of the total by 2016;
- Produce 1 000 patents and create 200 innovative start-ups in Morocco by 2014;
- Ensure that renewable energy accounts for 12% of Lebanon's energy mix by 2020

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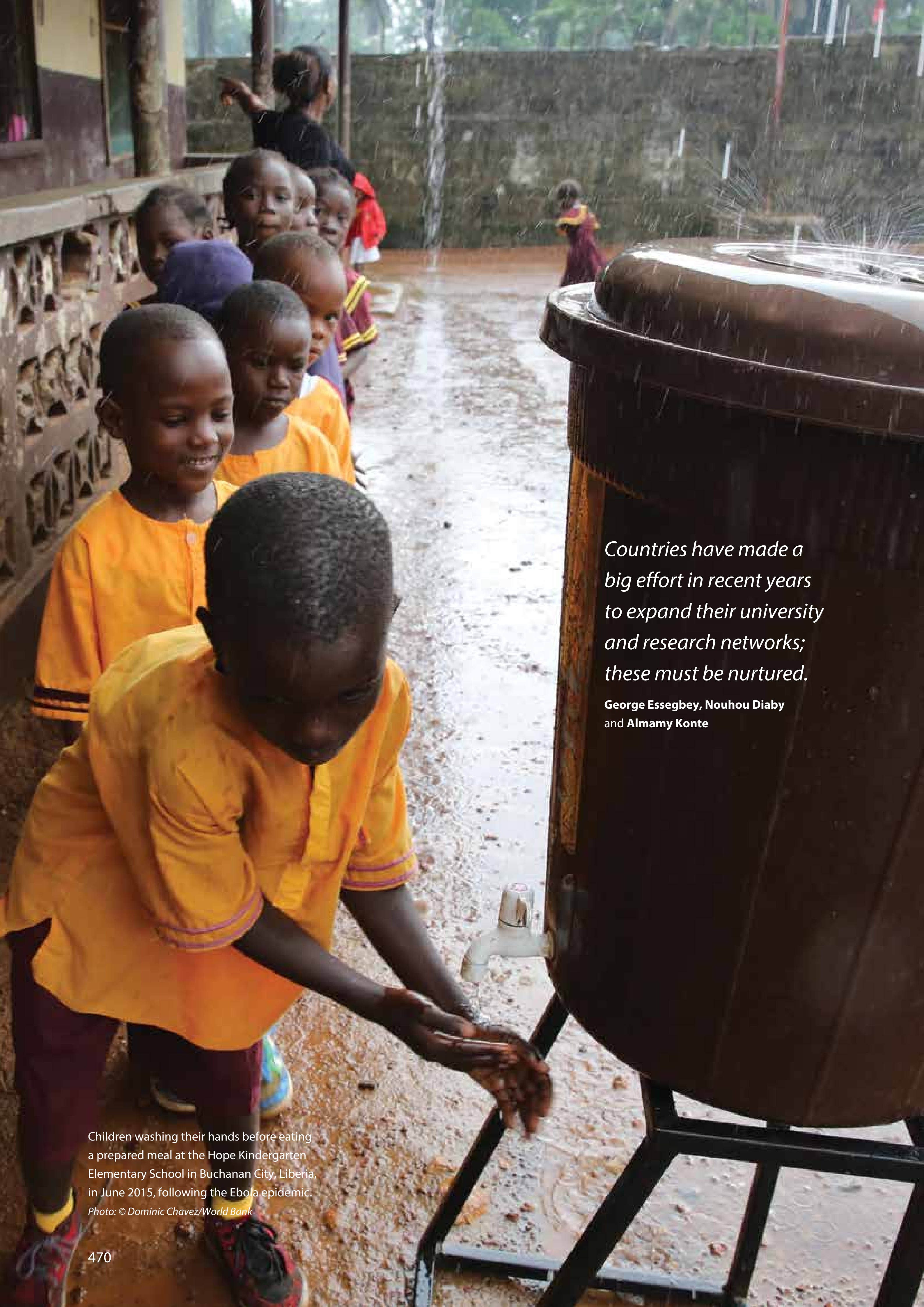
ACKNOWLEDGMENTS

The authors wish to thank Professor Mohamed Alwasad from the Libyan Authority for Research, Science and Technology for supplying background information and data on Libya.



Countries have made a big effort in recent years to expand their university and research networks; these must be nurtured.

George Essegbey, Nouhou Diaby and **Almamy Konte**

Children washing their hands before eating a prepared meal at the Hope Kindergarten Elementary School in Buchanan City, Liberia, in June 2015, following the Ebola epidemic.
Photo: © Dominic Chavez/World Bank

18 · West Africa

Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo

George Essegbey, Nouhou Diaby and Almamy Konte

INTRODUCTION

A drive to achieve middle-income status by 2030

Most West African countries are striving to achieve lower or upper middle-income status[1] within the next 15 years. This goal is enshrined in the current development plans and economic policies of Côte d'Ivoire, Gambia, Ghana, Liberia, Mali, Senegal and Togo, for instance. Nigeria even plans to join the world's top 20 economies by 2020. Yet, for two-thirds of West African countries, middle-income status remains an elusive goal: annual GDP per capita remains below US$ 1 045 in all of Benin, Burkina Faso, Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Sierra Leone and Togo.

Countries' development plans tend to have three main thrusts: wealth creation, greater social equity and more sustainable development. In their quest for middle-income status, they are giving priority to improving governance practices, creating a more business-friendly climate, stronger health and agricultural systems, modern infrastructure and a skilled labour force. These plans reflect a desire to exploit the resources which form the backbone of their economies in a more sustainable manner and a determination to diversify and modernize the economy. None of this will be possible without a skilled labour force and recourse to science, technology and innovation (STI).

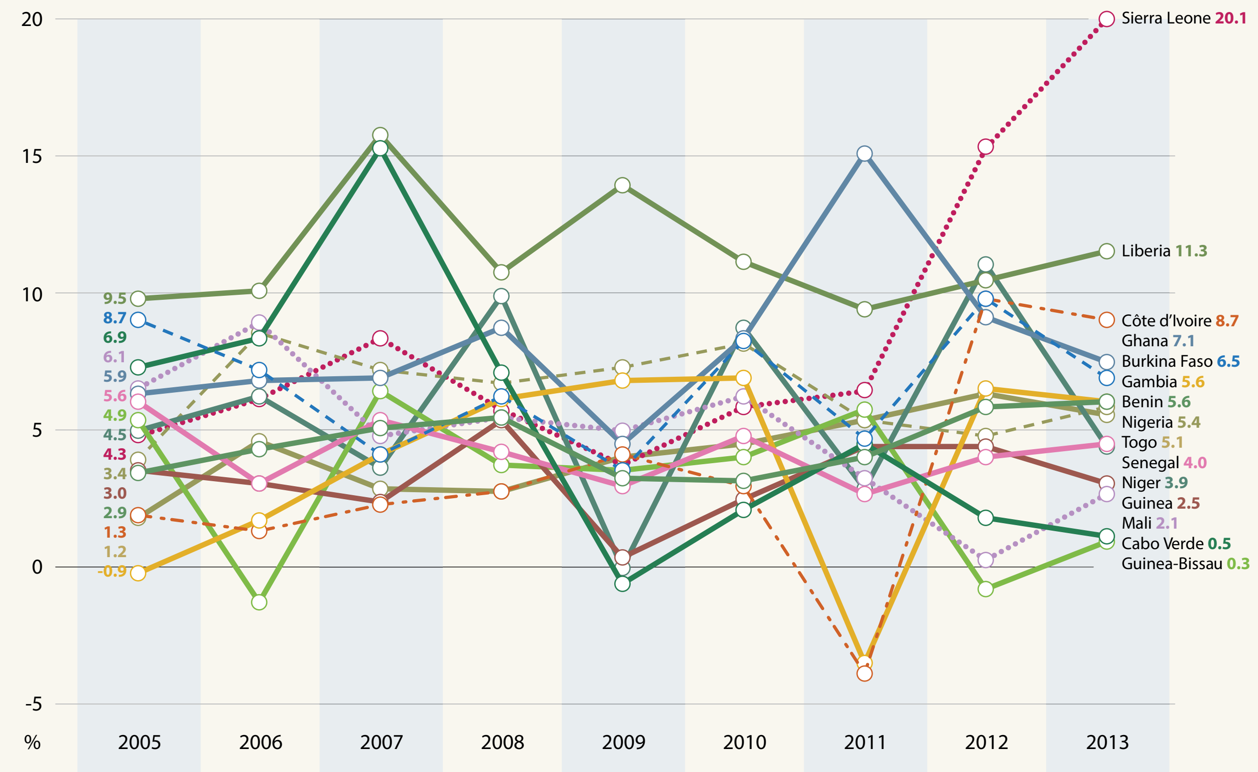
Strong growth in recent years, despite a series of crises

The Economic Community of West African States (ECOWAS) has experienced strong economic growth in recent years, despite a series of crises.

In Mali, a Tuareg rebellion in January 2012 attempted to establish an independent homeland in the north through an alliance with jihadist groups. The situation has stabilized since the government appealed for French intervention in January 2013 but remains fragile. The conflict caused Mali's economy to shrink by 0.4% in 2012, after six years of sustained growth of 5% on average (Figure 18.1).

1. Five countries have already achieved lower middle-income status, namely: Cabo Verde, Côte d'Ivoire, Ghana, Nigeria and Senegal. The next step will be upper middle-income status.

Figure 18.1: **Economic growth in West Africa, 2005–2013** (%)



Source: World Bank's World Development Indicators, September 2014.

Guinea-Bissau suffered a military coup d'état in April 2012, prompting the African Union to impose sanctions which were lifted two years later following the election of President José Mario Vaz.

Côte d'Ivoire is still picking up the pieces after its civil war ended with the arrest of the ex-president for war crimes in April 2011. After stagnating for years, Côte d'Ivoire's economy rebounded by 9% in 2013.

Meanwhile, in the north of Africa's most populous country, the Boko Haram sect (literally 'books are forbidden') pursues its reign of terror against the Nigerian population, with growing incursions across the border into Cameroon and Niger. Nigerians can at least rejoice at the smooth handover of power from incumbent president Goodluck Jonathan to his successor Muhammadu Buhari after the election results were announced on 31 March 2015.

Farther north, in Burkina Faso, a popular revolt put an end to the 27-year rule of President Blaise Compaoré on 30 October 2014, after he tried to modify the Constitution in order to run for a fifth term. Former diplomat Michel Kafando has been designated interim president by consensus and charged with organizing a general election in November 2015.

In Guinea, Liberia and Sierra Leone, the Ebola epidemic has been a tragic reminder of the chronic underinvestment in West African health systems. Between March and December 2014, 8 000 people died, a mortality rate of about 40%. There has been a growing tide of solidarity. In September, Cuba dispatched hundreds of doctors and nurses to the afflicted countries. A month later, the East African Community sent its own contingent of 600 health professionals, including 41 doctors, to combat the epidemic. They were joined in early December by 150 volunteer health professionals from Benin, Côte d'Ivoire, Ghana, Mali, Niger and Nigeria, as part of a joint initiative by ECOWAS and its specialized agency, the West African Health Organisation. The European Union, African Union, USA and others have also pitched in with funding and other forms of support. The year before Ebola struck, Liberia and Sierra Leone had experienced remarkable growth of 11% and 20% respectively. Ebola could set these fragile economies back years (Figure 18.1).

Structural weaknesses masked by strong growth

Despite these crises, the ECOWAS Commission is optimistic about the subregion's prospects for growth. It projects an even better performance in 2014 (7.1% growth) than in 2013 (6.3%). This high growth rate nevertheless conceals serious structural weaknesses. For decades, West African economies have relied almost entirely on revenue from raw commodities: about 95% of Nigeria's export revenue is derived from crude oil and natural gas; gold and cocoa alone account for about 53% of Ghana's exports and nearly three-quarters of Mali's export earnings come from cotton (Figure 18.2). When raw materials are extracted or grown in West Africa but processed on other continents, this deprives the subregion of industries and jobs. Despite this axiom, West African countries have so far failed to diversify their economies and to tap export earnings from value-added and manufactured products.

It is true that some countries have made a start. Côte d'Ivoire, Ghana, Guinea, Nigeria and Senegal, for instance, have industries producing value-added goods. To enhance value addition and strengthen the raw material base of industries, these countries have all set up research institutes to transform raw products into semi-processed or processed goods. Both Ghana and Nigeria have also set up institutes specializing in aeronautics, nuclear energy, chemistry and metallurgy. The first technology parks and cybervillages are emerging in these countries (ECOWAS, 2011a).

Could Ghana fall prey to the 'oil curse?' A recent study by the Institute of Statistical, Social and Economic Research at the University of Ghana ponders whether 'the increased importance of oil in GDP [since petroleum exports began in 2011] signals the risk of Ghana becoming oil-dependent. [...] The advent of oil production seems to be changing the pattern of the country's exports,' the study observes (see Figure 19.1). 'Is Ghana teetering toward an oil-dominant country, or might the proceeds be employed wisely to diversify the economy?' (ISSER, 2014)

Economic diversification hampered by a skills shortage

One handicap to diversifying the economy is the shortage of skilled personnel, including technicians, in fast-growing sectors such as mining, energy, water, manufacturing, infrastructure and telecommunications. The lack of skilled personnel also impinges on the efficiency of national health systems and agriculture.

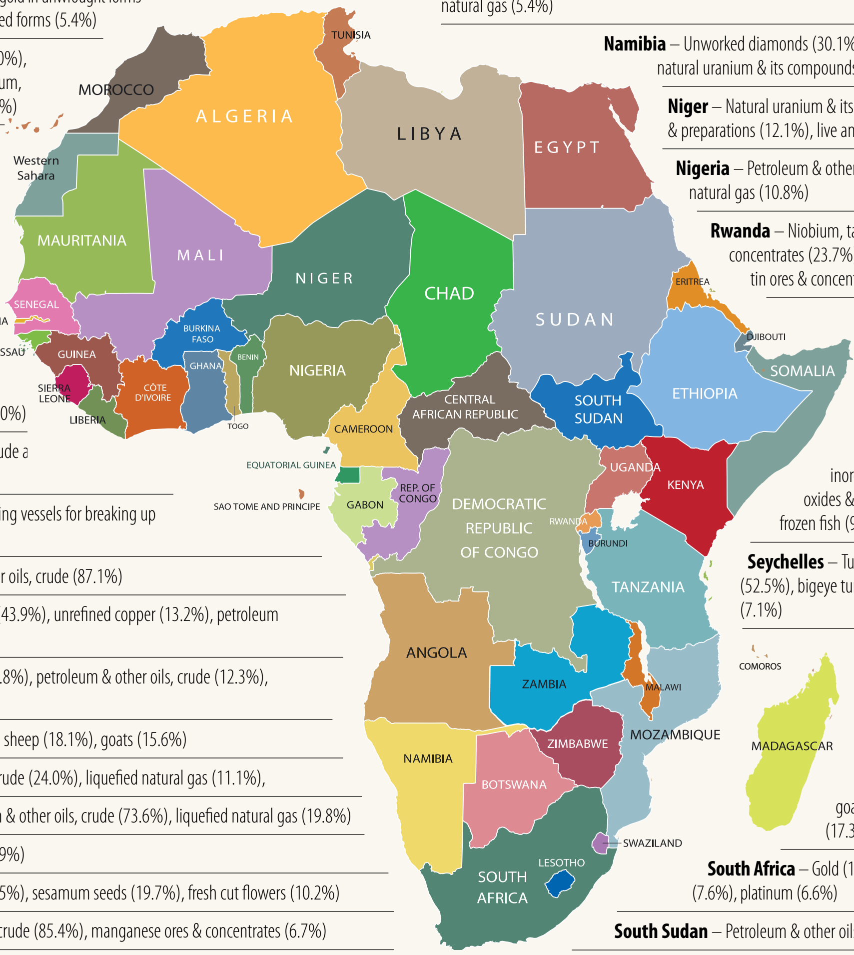
In this context, the launch of the African Centres of Excellence project in April 2014 by the World Bank comes as a welcome addition to the education matrix. Eight governments[2] are to receive almost US$ 150 million in loans to fund research and training at 19 of the subregion's best universities (Table 18.1). The Association of African Universities will be responsible for co-ordination and knowledge-sharing among all 19 universities and has received World Bank funding for the purpose.

For all its virtues, the African Centres of Excellence project cannot be a substitute for national investment. Currently, just three[3] West African countries devote more than 1% of

2. Nigeria (US$ 70 million), Ghana (US$ 24 million), Senegal (US$ 16 million), Benin, Burkina Faso, Cameroon and Togo (US$ 8 million each). Gambia will also receive a US$ 2 million loan and a US$ 1 million grant for short-term training.

3. Data are unavailable for Nigeria.

Figure 18.2: **Top three export products in Africa, 2012**



Algeria – Petroleum & other oils, crude (45.0%), natural gas in gaseous state (20.0%), light oils and preparations (8.7%)

Angola – Petroleum & other oils, crude (96.8%)

Benin – Cotton (19.0%), petroleum oils or bituminous minerals (13.7%), gold (13.4%)

Botswana – Unworked diamonds (74.3%), other non-industrial diamonds (7.2%), gold in semi-manufactured forms (5.4%)

Burkina Faso – Cotton (44.9%), gold in unwrought forms (29.4%), gold in semi-manufactured forms (5.4%)

Burundi – Unroasted coffee (58.0%), black tea (12.2%), niobium, tantalum, vanadium ores & concentrates (9.0%)

Cabo Verde – Mackerel (16.5%), skipjack or stripe-bellied bonito (15.4%), yellowfin tunas (14.2%)

Cameroon – Petroleum & other oils, crude (48.1%), cocoa beans (9.0%), tropical woods (7.7%)

Central African Rep. – Unsorted diamonds (32.3%), tropical wood (26.6%), cotton (14.0%)

Chad – Petroleum & other oils, crude & preparations (97.0%)

Comoros – Cloves (56.1%), floating vessels for breaking up (21.2%), essential oils (9.8%)

Congo. Rep. – Petroleum & other oils, crude (87.1%)

Congo. Dem. Rep. – Cathodes (43.9%), unrefined copper (13.2%), petroleum & other oils, crude (13.2%)

Côte d'Ivoire – Cocoa beans (31.8%), petroleum & other oils, crude (12.3%), natural rubber (7.2%)

Djibouti – Live animals (23.0%), sheep (18.1%), goats (15.6%)

Egypt – Petroleum & other oils, crude (24.0%), liquefied natural gas (11.1%),

Equatorial Guinea – Petroleum & other oils, crude (73.6%), liquefied natural gas (19.8%)

Eritrea – Gold (88.0%), silver (4.9%)

Ethiopia – Unroasted coffee (39.5%), sesamum seeds (19.7%), fresh cut flowers (10.2%)

Gabon – Petroleum & other oils, crude (85.4%), manganese ores & concentrates (6.7%)

Gambia – Wood (48.6%), cashew nuts (16.2%), petroleum & other oils (6.5%)

Ghana – Gold (36.0%), cocoa beans and paste (16.5%), petroleum & other oils, crude (22.0%)

Guinea – Gold (40.5%), bauxite (34.0%), alumine (9.0%)

Guinea-Bissau – Cashew nuts (83.9%)

Kenya – Black tea (20.0%), fresh cut flowers (12.1%), unroasted coffee (5.9%)

Lesotho – Diamonds (45.5%), men's/boys' cotton trousers & shorts (13.4%), women's/girls' synthetic trousers & shorts (6.1%)

Liberia – Iron ores & concentrates (21.1%), natural rubber (19.3%), tankers (12.3%)

Libya – Petroleum & other oils, crude (88.4%), natural gas in gaseous state (5.6%)

Madagascar – Cloves (15.8%), shrimps & prawns (7.2%), titanium ores & concentrates (5.5%)

Malawi – Tobacco (50.1%), natural uranium & its compounds (10.4%), raw sugar cane (8.0%)

Mali – Cotton (72.7%), sesamum seeds (8.8%)

Mauritania – Iron ores and concentrates (46.7%), copper ores and concentrates (15.6%), octopus (10.5%)

Mauritius – Tunas, skipjack & bonito (15.3%), solid cane or beef sugar (10.5%), cotton t-shirts & the like (7.4%)

Morocco – Phosphoric acid and polyphosphoric (8.2%), ignition wiring sets and other wiring sets of a type used for vehicles, aircrafts, ships (6.1%), diammonium hydrogenorthosphosphate (4.5%)

Mozambique – Aluminium, not alloyed (28.8%), light oils & preparations (12.1%), liquefied natural gas (5.4%)

Namibia – Unworked diamonds (30.1%), unrefined copper (13.4%), natural uranium & its compounds (13.2%)

Niger – Natural uranium & its compounds (62.2%), light oils & preparations (12.1%), live animals (6.0%)

Nigeria – Petroleum & other oils, crude (84.0%), liquefied natural gas (10.8%)

Rwanda – Niobium, tantalum, vanadium ores & concentrates (23.7%), unroasted coffee (23.5%), tin ores & concentrates (19.2%)

Sao Tome & Principe – Cocoa beans (47.6%), wristwatches (9.2%), jewellery (6.4%)

Senegal – Petroleum & other oils (20.8%), inorganic chemical elements, oxides & halogen salts (12.0%), fresh & frozen fish (9.0%)

Seychelles – Tunas, skipjack & bonito (52.5%), bigeye tunas (13.2%), yellowfin tunas (7.1%)

Sierra Leone – Iron ores & concentrates (45.2%), titanium ores & concentrates (16.4%), unworked diamonds (12.1%)

Somalia – Sheep (29.4%), goats (28.2%), live bovine animals (17.3%)

South Africa – Gold (11.6%), iron ores & concentrates (7.6%), platinum (6.6%)

South Sudan – Petroleum & other oils, crude (99.6%)

Sudan – Petroleum & other oils, crude (65.6%), Sheep (10.6%), sesamum seeds (4.2%)

Swaziland – Raw sugar cane (17.4%), odoriferous substances used in food & beverages (14.8%), iron ores & concentrates (10.9%)

Tanzania – Precious metal ores & concentrates (11.7%), tobacco (11.5%), unroasted, not decaffeinated coffee (6.6)

Togo – Gold (12.1%), natural calcium phosphates, phosphatic chalk (11.7%), light oils & preparations (10.3%)

Tunisia – Petroleum & other oils, crude (11.2%), ignition wiring sets and other wiring sets of a type used for vehicles, aircrafts, ships (6.2%); men's/boys' cotton trousers and shorts (4.3%)

Uganda – Unroasted, not decaffeinated coffee (30.6%), cotton (5.6%), tobacco (5.5%)

Zambia – Cathodes (47.6%), unrefined copper (26.1%), maize, excl. seed (5.0%)

Zimbabwe – Tobacco (30.8%), ferro-chromium (11.6%), cotton (9.6%)

Note: Data for Ghana are for 2013.
Source: ADB *et al.* (2014), Table 18.7; for Ghana: calculated for 2013 from ISSER (2014)

GDP to higher education: Ghana and Senegal (1.4%) and Mali (1.0%). In Liberia, the proportion is even lower than 0.3% (see Table 19.2). Up to now, the priority has been to achieve the Millennium Development Goal of universal primary education by 2015. Low investment in higher education has led to a surge in private universities over the past decade, which now represent more than half of all universities in some countries (ECOWAS, 2011a).

Table 18.1: **The African Centres of Excellence Project, 2014**

	Centre of excellence	Lead institution
Benin	Applied Mathematics	University of Abomey-Calavi
Burkina Faso	Water, Energy, Environmental Sciences and Technologies	International Institute of Water and Environmental Engineering (2iE)
Cameroon	Information and Communication Technologies	University of Yaoundé
Ghana	Training Plant Breeders, Seed Scientists and Technologists	University of Ghana
	Cell Biology of Infectious Pathogens	University of Ghana
	Water and Environmental Sanitation	Kwame Nkrumah University of Science and Technology
Nigeria	Agricultural Development and Sustainable Environment	Federal University of Agriculture
	Dryland Agriculture	Bayero University
	Oil Field Chemicals	University of Port Harcourt
	Science, Technology and Knowledge	Obafemi Awolowo University
	Food Technology and Research	Benue State University
	Genomics of Infectious Diseases	Redeemers University
	Neglected Tropical Diseases and Forensic Biotechnology	Ahmadu Bello University
	Phytomedicine Research and Development	University of Jos
	Reproductive Health and Innovation	University of Benin, Nigeria
	Materials	African University of Science and Technology
Senegal	Maternal and Infant Health	Cheikh Anta Diop University
	Mathematics, Informatics and Information and Communication Technologies	University of Gaston Berger, St Louis
Togo	Poultry Sciences	University of Lomé

Source: World Bank

Centres of excellence: a problem shared is a problem halved

Most West African scientists currently work in isolation from their peers even within the same country. The World Bank scheme is coherent with *Africa's Science and Technology Consolidated Plan of Action, 2005–2014*, which called for the establishment of regional networks of centres of excellence and for a greater mobility of scientists across the continent.

West Africa is participating in several of these networks. Ouagadougou (Burkina Faso) hosts the African Biosafety Network of Expertise (Box 18.1) and the Senegalese Institute for Agricultural Research in Dakar is one of the four nodes of the pan-African biosciences network (see Box 19.1). In addition, Senegal and Ghana host two of the five African Institutes of Mathematical Sciences (see Box 20.4).

In 2012, the West African Economic and Monetary Union (WAEMU) designated 14 centres of excellence in the region (Table 18.2). This label entitles these institutions to financial support from WAEMU for a two-year period. Within the framework of its *Policy on Science and Technology* (see p. 476), ECOWAS intends to establish several centres of excellence of its own on a competitive basis.

Table 18.2: **The WAEMU Centres of Excellence, 2012**

	Centre of excellence	City
Burkina Faso	Centre for Research in Biological and Food Science and Nutrition	Ouagadougou
	Higher Institute of Population Sciences	Ouagadougou
	International Centre for Research and Development into Animal Husbandry in Subtropical Zones	Bobo-Dioulasso
	International Institute of Water and Environmental Engineering	Ouagadougou
Côte d'Ivoire	National School of Statistics and Applied Economics	Abidjan
Mali	West African Network of Education Research	Bamako
Niger	Regional Centre for Training and Applications in Agro-meteorology and Operational Hydrology	Niamey
	Regional Specialized Teaching Centre in Agriculture	Niamey
Senegal	African Centre for Higher Management Studies	Dakar
	Multinational Higher School of Telecommunications	Dakar
	School of Veterinary Science and Medicine	Dakar
	Africa Rice Centre	Saint-Louis
	Higher Institute of Management	Dakar
Togo	African School of Architecture and Urban Planning	Lomé

Source: WAEMU

Box 18.1: **The African Biosafety Network of Expertise**

The African Biosafety Network of Expertise was established in Ouagadougou on 23 February 2010 with the signing of a host agreement between NEPAD and the Government of Burkina Faso. The network serves as a resource for regulators dealing with safety issues related to the introduction and development of genetically modified organisms. In addition to providing regulators with access to policy briefs and other relevant information online in English and French, the network organizes national and subregional workshops on specific topics.

For instance, one-week biosafety courses for African regulators were run by the network in Burkina Faso in November 2013 and in Uganda in July 2014, in partnership with the University of Michigan (USA). Twenty-two regulators from Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda and Zimbabwe took part in the latter course.

In April 2014, the network ran a training workshop in Nigeria at the request of the Federal Ministry of Environment for 44 participants drawn from government ministries, regulatory agencies, universities and research institutions. The aim was to strengthen the regulatory capacity of institutional biosafety committees. This training was considered important to ensure continued regulatory compliance for ongoing confined field trials and multilocation trials for Maruca-resistant cowpea and biofortified sorghum. The workshop was run in partnership with the International Food Policy Research Institute's Program for Biosafety Systems.

From 28 April to 2 May 2014, Togo's Ministry of Environment and Forest Resources organized a stakeholders' consultative workshop to validate Togo's revised biosafety law. Around 60 participants took part, including government officials, researchers, lawyers, biosafety regulators and civil society representatives; the workshop was chaired by a member of the National Biosafety Committee. The aim of the draft bill was to align Togo's biosafety law signed in January 2009 with international biosafety regulations and best practices, especially the *Nagoya Kuala Lumpur Supplementary Protocol on Liability and Redress* that Togo had signed in September 2011. The validation workshop was a critical step before the new bill could be tabled at the National Assembly for adoption later that year.

In June 2014, the network organized a four-day study tour to South Africa for ten regulators and policy-makers from Burkina Faso, Ethiopia, Kenya, Malawi, Mozambique and Zimbabwe. The main objective was to allow them to interact directly with their peers and industrial practitioners in South Africa. The study tour was organized under the auspices of the NEPAD Planning and Coordinating Agency, in partnership with the Southern Africa Network for Biosciences (SANBio), see Box 19.1).

The African Biosafety Network of Expertise was conceptualized in *Africa's Science and Technology Consolidated Plan of Action* (2005) and fulfils the recommendation of the High-Level African Panel on Modern Biotechnology, entitled *Freedom to Innovate* (Juma and Serageldin, 2007). The network is funded by the Bill and Melinda Gates Foundation.

Source: www. nepadbiosafety.net

Source of map: 2013 African Biosafety Network of Expertise

A REGIONAL VISION FOR SCIENCE AND TECHNOLOGY

A roadmap for more effective development

Regional integration can help accelerate development in West Africa. The *Vision 2020* document[4] adopted by ECOWAS member states in 2011 is consistent with the continent's long-term objective of creating an African Economic Community (Box 18.2). *Vision 2020* aspires to 'create a borderless, prosperous and cohesive region built on good governance and where people have the capacity to access and harness its enormous resources through the creation of opportunities for sustainable development and environmental preservation… We envision, by 2020, an environment in which the private sector will be the primary engine of growth and development' (ECOWAS, 2011b).

Vision 2020 proposes a road map for improving governance, accelerating economic and monetary integration and fostering public–private partnerships. It endorses the planned harmonization of investment laws in West Africa and suggests pursuing 'with vigour' the creation of a regional investment promotion agency. Countries are urged to promote efficient, viable small and medium-sized enterprises (SMEs) and to expose traditional agriculture to modern technology, entrepreneurship and innovation, in order to improve productivity.

The agriculture sector suffers from chronic underinvestment in West Africa. Only Burkina Faso, Mali, Niger and Senegal have so far raised public expenditure to 10% of GDP, the target fixed by the *Maputo Declaration* (2003). Gambia, Ghana and Togo are on the threshold of reaching this target. Nigeria devotes 6% of GDP to agriculture and the remaining West African countries less than 5% (see Table 19.2).

Other underdeveloped areas are the water, sanitation and electricity sectors, which hold potential for public–private partnerships. The situation is most urgent in Benin, Ghana, Guinea and Niger, where less than 10% of the population enjoys improved sanitation. Although people have greater access to clean water than to sanitation, this basic commodity still eludes more than half of the population in most countries. Access to electricity varies widely, from 13% in Burkina Faso to 72% in Ghana (see Table 19.1).

Internet penetration has been excruciatingly slow in West Africa, contrary to mobile phone subscriptions. As of 2013, 5% of the population or less had access to internet in Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Liberia, Mali, Niger, Sierra Leone and Togo. Only Cabo Verde and Nigeria could provide one in three citizens with internet connections (see Table 19.1).

4. See the ECOWAS Community Development Programme: www.cdp-pcd.ecowas.int

A framework for co-ordinating the region's STI policies

Why has the research sector had so little impact on technological progress in West Africa? Apart from obvious factors like underinvestment, this situation has resulted from the relatively low political commitment to STI on the part of individual countries. There is a lack of:

- national research and innovation strategies or policies with a clear definition of measurable targets and the role to be played by each stakeholder;
- involvement by private companies in the process of defining national research needs, priorities and programmes; and
- institutions devoted to innovation that can make the link between research and development (R&D).

The low impact of science and technology (S&T) in West Africa has also resulted from the differences in education systems, the lack of convergence among research programmes and the low level of exchanges and collaboration between universities and research institutions. The centres of excellence cited earlier should help to foster collaboration and the dissemination of research results, as well as a greater convergence among research programmes. In education, the three-tiered degree system (bachelor's –master's–PhD) has now been generalized to most West African countries. In the case of WAEMU countries, this is largely thanks to the Support to Higher Education, Science and Technology Project, funded by a grant from the African Development Bank. Between 2008 and 2014, WAEMU invested US$ 36 million in this reform.

The *ECOWAS Policy on Science and Technology* (ECOPOST) is the logical next step. Adopted in 2011, it is an integral part of *Vision 2020*. ECOPOST provides a framework for member states wishing to improve – or elaborate for the first time – their own national policies and action plans for STI. Importantly, ECOPOST includes a mechanism for monitoring and evaluating the policy's implementation, an aspect often overlooked. Nor does it neglect funding. It proposes creating a solidarity fund which would be managed by a directorate within ECOWAS to help countries fund investment in key institutions and improve education and training; the fund would also be used to attract foreign direct investment (FDI). As of early 2015, the fund had not yet been established.

The regional policy advocates the development of a science culture in all sectors of society, including through science popularization, the dissemination of research results in local and international journals, the commercialization of research results, greater technology transfer, intellectual property protection, stronger university–industry ties and the enhancement of traditional knowledge.

Box 18.2: An African Economic Community by 2028

The Abuja Treaty (1991) established a calendar for creating an African Economic Community by 2028. The first step was to establish regional economic communities in parts of Africa where these were still lacking. The next target is to establish a free trade area and customs union in each regional economic community by 2017 then across the entire continent by 2019. A continent-wide African Common Market is to become operational in 2023. The last stage will consist in establishing a continent-wide economic and monetary union and parliament by 2028, with a single currency to be managed by the African Central Bank.

The six regional pillars of the future African Economic Community are the following regional communities:

- Economic Community of West African States (ECOWAS): 15 states, population of *circa* 300 million;
- Economic Community of Central African States (ECCAS), 11 states, population of *circa* 121 million;
- Southern African Development Community (SADC), 15 states, population of *circa* 233 million;
- East African Community (EAC), 5 states, population of *circa* 125 million;
- Common Market for Eastern and Southern Africa (COMESA), 20 states, population of *circa* 406 million;
- Intergovernmental Authority on Development (IGAD), 8 states, population of *circa* 188 million.

Some countries belong to more than one economic community, creating overlap (see Annex 1 for the membership of these regional blocs). Kenya, for instance, is a member of COMESA, EAC and IGAD. There are also smaller regional blocs. One example is the West African Economic and Monetary Union grouping Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal and Togo.

ECOWAS has launched a common passport to facilitate travel and finance ministers agreed in 2013 to launch a Common External Tariff in 2015 to discourage wide price differentials and smuggling across the region.

In 2000, nine COMESA members formed a free trade area: Djibouti, Egypt, Kenya, Madagascar, Malawi, Mauritius, Sudan, Zambia and Zimbabwe. They were later joined by Burundi and Rwanda (2004), Comoros and Libya (2006) and by the Seychelles in 2009. In 2008, COMESA agreed to expand its free-trade zone to include EAC and SADC members. The COMESA–EAC–SADC Tripartite Free Trade Agreement was signed on 10 June 2015 in Sharm-El-Sheikh (Egypt).

On 1 July 2010, the five EAC members formed a common market grouping Burundi, Kenya, Rwanda, Tanzania and Uganda. In 2014, Rwanda, Uganda and Kenya agreed to adopt a single tourist visa. Kenya, Tanzania and Uganda have also launched the East African Payment System. The region is also investing in a standard gauge regional rail, roads, energy and port infrastructure to strengthen links to Mombasa and Dar es Salaam. Intra-EAC trade grew by 22% in 2012 over the previous year. On 30 November 2013, the EAC countries signed a Monetary Union Protocol with the aim of establishing a common currency within 10 years.

Pending the single African currency, 14 countries currently use the West African CFA and Central African CFA currency (in place since 1945), which is indexed on the euro managed by the European Central Bank. The indexation of the CFA on a strong currency favours imports over exports. Five countries currently use the South African Rand: Lesotho, Namibia, South Africa, Swaziland and Zimbabwe.

Source: AfDB *et al.* (2014); other information compiled by authors

ECOPOST encourages countries *inter alia* to:

- raise gross domestic expenditure on R&D (GERD) to 1% of GDP, as recommended by the African Union a decade ago; currently, it averages 0.3% in West Africa;
- define their own research priorities, so that researchers are working on topics of national interest rather than those proposed by donors;
- create a national S&T fund which would allocate funds to research projects on a competitive basis;
- establish science and innovation prizes;
- define a harmonized regional status for researchers;
- put in place a national fund for local innovators which would also help them protect their intellectual property rights;
- adapt university curricula to local industrial needs;
- develop small research and training units in key industrial fields, such as lasers, fibre optics, biotechnology, composite materials and pharmaceuticals;
- equip research laboratories, including with ICTs;

- establish science and technology parks and business incubators;
- help companies specializing in electronics to set up business in their country and develop the use of satellites and remote sensing for telecommunications, environmental monitoring, climatology, meteorology, etc.;
- develop a national capacity to manufacture computer hardware and design software;
- facilitate the spread of modern IT infrastructure to foster teaching, training and research;
- incite the private sector to finance research and technology through tax incentives and related measures;
- create networks between universities, research institutions and industry to promote collaboration;
- foster clean, sustainable sources of energy and the development of local construction materials;
- establish national and regional databases on R&D activities.

Countries are also encouraged to work with the ECOWAS Commission to improve data collection. Of the 13 countries which participated in the first phase[5] of the African Science, Technology and Innovation Indicators Initiative (ASTII), just four from ECOWAS contributed to ASTII's first collection of R&D data for publication in the *African Innovation Outlook* (2011): Ghana, Mali, Nigeria and Senegal (NPCA, 2011).

ECOWAS was barely more visible in the second *African Innovation Outlook*, with just six countries contributing R&D data, out of 19 across the continent: Burkina Faso, Cabo Verde, Ghana, Mali, Senegal and Togo (NPCA, 2014). Nigeria was totally absent and only Ghana and Senegal provided a full set of data for all four performance sectors, which is why they alone feature in Figure 18.5.

Subregional training workshops were organized for countries by ECOWAS in 2013 and 2014 on STI indicators and how to draft research proposals.

ECOWAS has taken other steps recently to tackle the lack of technological impact of the research sector:

- In 2012, the ministers in charge of research adopted the *ECOWAS Research Policy* (ECORP) while meeting in Cotonou;
- In 2011, ECOWAS created the West Africa Institute within a public–private partnership (Box 18.3).

TRENDS IN EDUCATION

Efforts to generalize primary education are paying off

One of West Africa's toughest challenges will be to educate and train young people and develop a highly skilled labour force, particularly in science and engineering. Illiteracy remains a major hurdle to expanding science education: only two out of three young people (62.7%) between the ages of 15 and 24 are literate, with the notable exception of Cabo Verde (98.1%). The proportion of literates is as low as one person in four in Niger (23.5%).

5. ASTII was launched in 2007 by the African Union's New Partnership for Africa's Development (NEPAD), in order to improve data collection and analysis on R&D.

Box 18.3: The West Africa Institute

The West Africa Institute was established in Praia (Cabo Verde) in 2010 to provide the missing link between policy and research in the regional integration process. The institute is a service provider, conducting research for regional and national public institutions, the private sector, civil society and the media. The think tank also organizes political and scientific dialogues between policy-makers, regional institutions and members of civil society.

There are ten research themes: the historical and cultural bases of regional integration; citizenship; governance; regional security; economic challenges to market integration in West Africa; new ICTs; education; the problem of shared resources (land, water, minerals, coastal and maritime security); funding of NGOs in West Africa; and migration.

The idea for the West Africa Institute emerged from 15 research workshops on the theme of regional integration organized in the ECOWAS member states by UNESCO's Management of Social Transformations programme.

In 2008, the Summit of Heads of State and Government of ECOWAS in Ouagadougou (Burkina Faso) unanimously endorsed the idea to create the West Africa Institute.

In 2009, UNESCO's General Conference established the West Africa Institute as one of its category 2 institutes, which means that it functions under the auspices of UNESCO. A year later, the Government of Cabo Verde passed a law establishing the institute in the capital.

The institute is the fruit of a public–private partnership involving ECOWAS, WAEMU, UNESCO, the pan-African Ecobank and the Government of Cabo Verde.

Source: westafricainstitute.org

The considerable efforts made at the primary level are paying off, with the average enrolment rate having risen from 87.6% to 92.9% between 2004 and 2012 (Table 18.3). According to the *ECOWAS Annual Report* (2012), enrolment has increased by as much as 20% since 2004 in four countries: Benin, Burkina Faso, Côte d'Ivoire and Niger.

However, in most West African countries, one in three children do not complete the primary cycle. The share is even higher than 50% in Burkina Faso and Niger. In 2012, there were an estimated 17 million children out of school in ECOWAS countries. Although this represents a 3% improvement over the previous decade, this figure pales in comparison to that for sub-Saharan Africa as a whole, where the drop-out rate has fallen by 13%. Cabo Verde and Ghana are the exceptions to the rule, both having a high completion rate (over 90%). Ghana has achieved almost 100% enrolment at primary level, largely thanks to the government's free school meals programme. Five out of six ECOWAS countries reported a higher percentage of qualified primary teachers in 2012 than eight years earlier; especially notable are improvements in Senegal (+15%) and Cabo Verde (+13%).

Table 18.3: **Gross enrolment in ECOWAS countries, 2009 and 2012 (%)**

Share of population at all levels of education

	Primary (%)		Secondary (%)		Tertiary (%)	
	2009	2012	2009	2012	2009	2012
Benin	114.87	122.77	–	54.16^{+1}	9.87	12.37^{-1}
Burkina Faso	77.68	84.96	20.30	25.92	3.53	4.56
Cabo Verde	111.06	111.95	85.27	92.74	15.11	20.61
Côte d'Ivoire	79.57	94.22	–	39.08^{+1}	9.03	4.46
Gambia	85.15^{+1}	85.21	58.84	–	–	–
Ghana	105.53	109.92	58.29	58.19	8.79	12.20
Guinea	84.60	90.83	34.29^{-1}	38.13	9.04	9.93
Guinea-Bissau	116.22^{+1}	–	–	–	–	–
Liberia	99.64	102.38^{-1}	–	45.16^{-1}	9.30^{+1}	11.64
Mali	89.25	88.48	39.61	44.95^{+1}	6.30	7.47
Niger	60.94	71.13	12.12	15.92	1.45	1.75
Nigeria	85.04*	–	38.90*	–	–	–
Senegal	84.56	83.79	36.41^{+1}	41.00^{-1}	8.04	–
Togo	128.23	132.80	43.99^{-1}	54.94^{-1}	9.12^{+1}	10.31

*estimation by UNESCO Institute for Statistics

-n/+n = data refer to n years before or after reference year

Source: UNESCO Institute for Statistics, May 2015

The challenge now will be to raise the enrolment rate at secondary level from 45.7% in 2011, albeit with marked differences from one country to another: just one in four children from Niger and Burkina Faso attend secondary school, whereas, in Cabo Verde, enrolment has shot up to 92.7% (2012).

To promote girls' education, ECOWAS established the ECOWAS Gender Development Centre in Dakar in 2003. Moreover, ECOWAS provides scholarships for girls from disadvantaged families to enable them to pursue their technical or vocational education. The *ECOWAS Annual Report* for 2012 states that the number of girls receiving scholarships in each country had doubled from five to ten or more by 2012 in some countries.

Growing student rolls but universities remain elitist

On average, the gross enrolment rate for tertiary education in West Africa was 9.2% in 2012. Some countries have made impressive progress, such as Cabo Verde between 2009 (15.1%) and 2012 (20.6%). In others, a university education remains elusive: the figures for Niger and Burkina Faso have stagnated at 1.7% and 4.6% of school leavers respectively.

University rolls are rising but this needs placing in a context of strong population[6] growth. The notable exception is Côte d'Ivoire, where student numbers have been a casualty of the violence and political uncertainty arising from the disputed 2010 election, which prompted the closure of universities and eventually unseated President Gbagbo.

It is difficult to draw conclusions for West Africa as a whole, given the patchy data. The available data nevertheless reveal some interesting trends. For instance, student rolls have surged in recent years in Burkina Faso and Ghana (Table 18.4). Burkina Faso shows the particularity, moreover, of having one of the subregion's highest ratios of PhD students: one in 20 graduates goes on to enroll in a PhD. The number of PhDs in engineering fields remains low: 58 in Burkina Faso and 57 in Ghana in 2012, compared to 36 in Mali and just one in Niger in 2011. Of note is that Ghana is the only country with a critical mass of PhD students in agriculture (132 in 2012), a situation which bodes ill for agricultural development in the subregion. Likewise, Burkina Faso trains a much greater number of PhDs in the field of health than its neighbours; women tend to be most attracted to health sciences: they represent one in three of these PhD candidates in Burkina Faso and Ghana, compared to about one in five in science and engineering (Figure 18.3).

6. The population is growing by more than 3% each year in the Sahelian countries of Mali and Niger and by more than 2.3% in all but Sierra Leone (1.8%) and Cabo Verde (0.95%). See Table 19.1

Table 18.4: **Tertiary enrolment in West Africa, 2007 and 2012 or nearest available year**

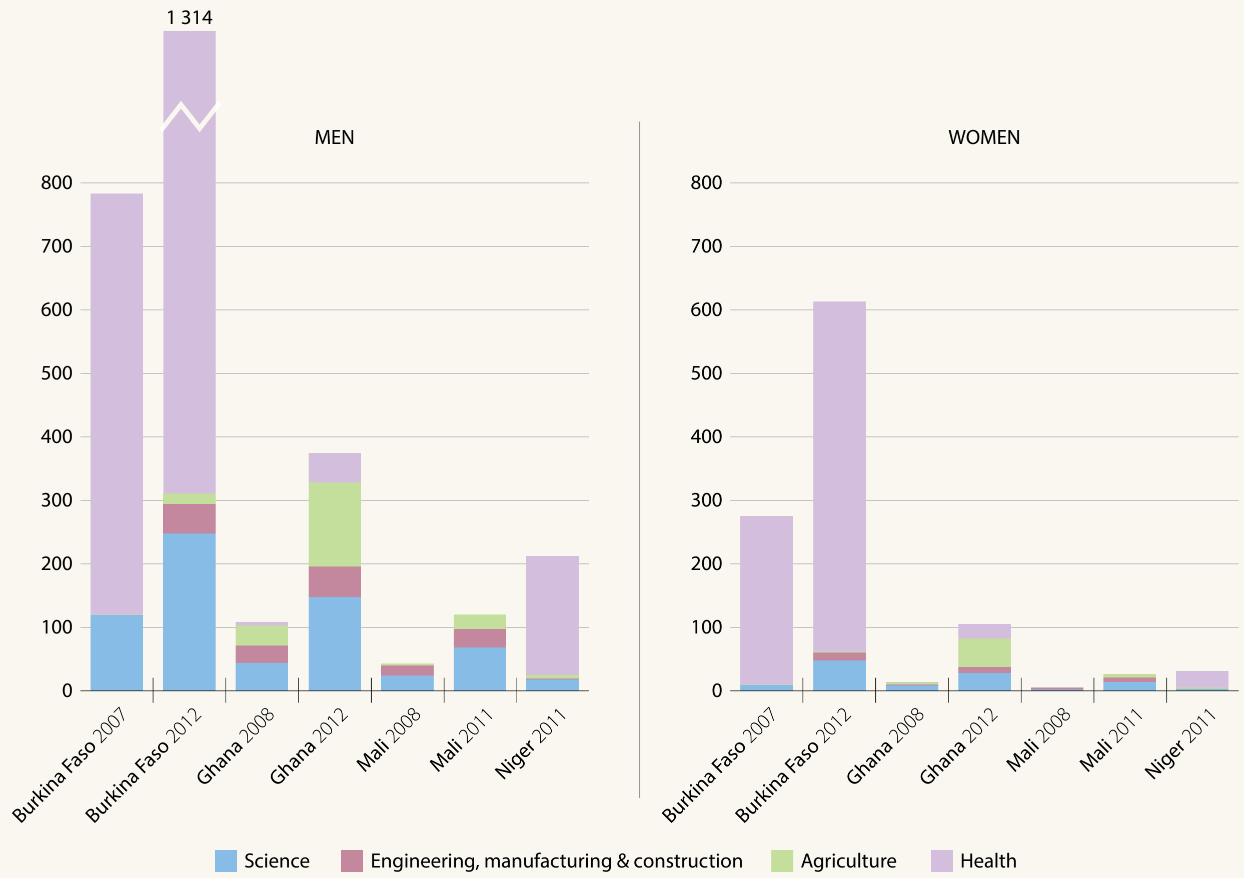
By level and field of study, selected countries

	Total			Science			Engineering, manufacturing and construction			Agriculture			Health		
	Post-secondary	1st & 2nd degree	PhD	Post-secondary	1st & 2nd degree	PhD	Post-secondary	1st & 2nd degree	PhD	Post-secondary	1st & 2nd degree	PhD	Post-secondary	1st & 2nd degree	PhD
Burkina Faso, 2007	7 964	24 259	1 236	735	3 693	128	284	–	0	100	219	2	203	1 892	928
Burkina Faso, 2012	16 801	49 688	2 405	1 307	8 730	296	2 119	303	58	50	67	17	0	2 147	1 554
Côte d'Ivoire, 2012	57 541	23 008	269		12 946			7 817			1 039			1724	
Ghana, 2008	64 993	124 999	281	6 534	18 356	52	7 290	9 091	29	263	6 794	32	946	4 744	6
Ghana, 2012	89 734	204 743	867	3 281	24 072	176	8 306	14 183	57	1 001	7 424	132	3 830	10 144	69
Mali, 2009	10 937	65 603	127	88	6 512	69	0	950	9	602	408	2	1 214	5 202	4
Mali, 2011	10 541	76 769	343	25	1 458	82	137	1 550	36	662	0	23	2 024	3 956	0
Niger, 2009	3 252	12 429	311	258	1 327	30	–	–	–	–	315	4	871	1 814	–
Niger, 2011	3 365	14 678	285	139	1 825	21	240	56	1	0	479	6	1 330	2 072	213

Source: UNESCO Institute for Statistics, January 2015

Figure 18.3: **West African PhD students enrolled in S&T fields by gender, 2007 and 2012 or closest year**

Selected countries



Source: UNESCO Institute for Statistics, January 2015

TRENDS IN R&D

Most countries still far from 1% target

ECOWAS countries still have a long way to go to reach the AU's target of devoting 1% of GDP to GERD. Mali comes closest (0.66%), followed by Senegal (Figure 18.4). The strong economic growth experienced by the subregion in recent years does, of course, make it harder to improve the GERD/GDP ratio, since GDP keeps rising. Although the government is the main source of GERD, foreign sources contribute a sizeable chunk in Ghana (31%), Senegal (41%) and Burkina Faso (60%). Gambia receives nearly half of its GERD from private non-profit sources (see Table 19.5).

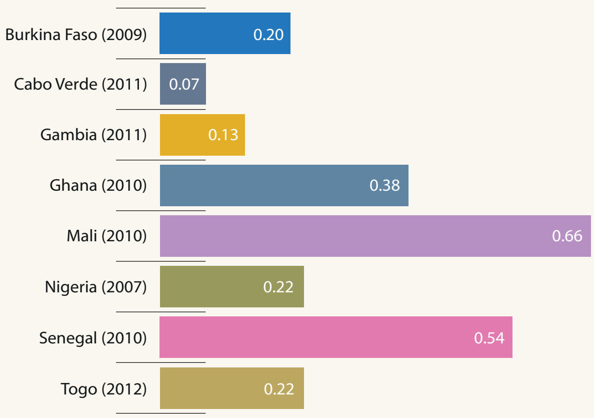
GERD tends to be spent mainly in either the government or university sectors, depending on the country, although only Ghana and Senegal have provided data for all four performing sectors. These data reveal that the share of GERD performed by the business enterprise sector in these two countries is negligible (Figure 18.5). This will need to change if the region is to raise its investment in R&D.

A lack of researchers, in general, and women, in particular

It would be hazardous to extrapolate to the entire subregion without recent data for more than seven countries but the available data do suggest a shortage of qualified personnel. Only Senegal stands out, with 361 full-time equivalent (FTE) researchers per million population in 2010 (Table 18.5). Despite policies promoting gender equality, women's participation in R&D remains low. Cabo Verde, Senegal and Nigeria have some of the best ratios: around one in three (Cabo Verde) and one in four researchers. Concerning the sector of employment, the surprise comes from Mali, where half (49%) of researchers were working in the business enterprise sector in 2010 (Table 18.5).

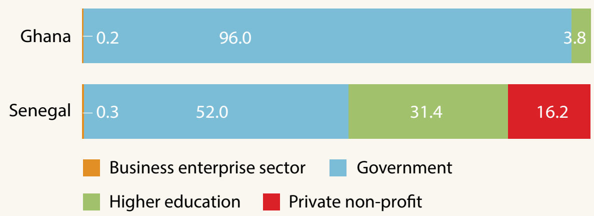
Figure 18.4: **GERD/GDP ratio in West Africa, 2011 or closest year (%)**

Selected countries



Source: UNESCO Institute for Statistics, January 2015

Figure 18.5: **GERD in Ghana and Senegal by sector of performance, 2010**



Note: Complete data for each sector are unavailable for other West African countries.

Source: UNESCO Institute for Statistics, January 2015

Table 18.5: **Researchers (FTE) in West Africa, 2012 or closest year**

	Total			By sector of employment (% of total)			By field of science and share of women											
	Numbers	Per million population	Women (%)	Business sector (%)	Government (%)	Higher education (%)	Natural Sciences	Women (%)	Engineering	Women (%)	Med. & Health Sciences	Women (%)	Agricultural Sciences	Women (%)	Social Sciences	Women (%)	Humanities	Women (%)
Burkina Faso, 2010	742	48	21.6	–	–	–	98	12.2	121	12.8	344	27.4	64	13.7	26	15.5	49	30.4
Cabo Verde, 2011	25	51	36.0	0.0	100.0	0.0	5	60.0	8	12.5	0.0	–	0.0	–	6	50.0	6	33.3
Ghana, 2010	941	39	17.3	1.0	38.3	59.9	164	17.5	120	7.7	135	19.3	183	14.1	197	18.6	118	26.8
Mali, 2010	443	32	14.1	49.0	34.0	16.9	–	–	–	–	–	–	–	–	–	–	–	–
Nigeria, 2007	5 677	39	23.4	0.0	19.6	80.4	–	–	–	–	–	–	–	–	–	–	–	–
Senegal, 2010	4 679	361	24.8	0.1	4.1	95.0	841	16.9	99	14.1	898	31.7	110	27.9	2 326	27.2	296	17.1
Togo, 2012	242	36	9.4	–	22.1	77.9	32	7.1	13	7.8	40	8.3	63	3.8	5	14.1	88	14.1

Note: The sum of the breakdown by field of science may not correspond to the total because of fields not elsewhere classified.

Source: UNESCO Institute for Statistics, January 2015

A modest publication record, little intraregional collaboration

When it comes to scientific publications, West Africa has not progressed as quickly as the rest of the continent since 2005 (Figure 18.6). Output remains low, with only Gambia and Cabo Verde publishing more than 30 articles per million population. In the coming years, the country to watch may be Ghana, where the number of articles almost tripled to 579 between 2005 and 2014.

From 2008 to 2014, the top three partners for ECOWAS authors came from the USA, France and the UK, in that order. South Africa, Burkina Faso and Senegal are the main African partners of ECOWAS countries. South Africa has established bilateral agreements with Ghana, Mali and Nigeria to boost co-operation in science and technology (see Table 20.6).

A report by the African Observatory of Science, Technology and Innovation on scientific production in the African Union between 2005 and 2010 indicates that only 4.1% of scientific papers published by Africans involved co-authors from the same continent in 2005–2007 and 4.3% in 2008–2010 (AOSTI, 2014).

Judging from the publication record, ECOWAS research focuses on medical and biological sciences, even if Nigeria did publish 1 250 research articles on agriculture between 2008 and 2014. Agricultural research takes a back seat in most ECOWAS countries, despite being a priority. This is hardly surprising, given the small number of PhDs in agriculture emerging from the universities of most West African countries and the generally low level of investment in agriculture. Research in mathematics, astronomy and computer science is negligible, even among the subregion's leaders, Nigeria and Ghana (Figure 18.6).

In the great majority of ECOWAS countries, more than eight out of ten scientific articles catalogued in the Web of Science between 2008 and 2014 had foreign partners. In the case of Cabo Verde, Guinea-Bissau and Liberia, this was even the case for the totality of articles, although it must be said that these three countries have a low output. There are two exceptions to the rule: in Côte d'Ivoire, three-quarters of articles (73%) had foreign co-authors between 2008 and 2014 and, in Nigeria, just over one-third (37%). In comparison, the average for members of the Organisation for Economic Co-operation and Development (OECD) is 29%. As for G20 countries, they publish just under 25% of articles with foreign partners on average. The average for sub-Saharan Africa is 63%.

COUNTRY PROFILES

BENIN

A need to match R&D with development needs

In Benin, the Ministry of Higher Education and Scientific Research is responsible for implementing science policy. The National Directorate of Scientific and Technological Research handles planning and co-ordination, whereas the National Council for Scientific and Technical Research and National Academy of Sciences, Arts and Letters each play an advisory role.

Financial support comes from Benin's National Fund for Scientific Research and Technological Innovation. The Benin Agency for the Promotion of Research Results and Technological Innovation carries out technology transfer through the development and dissemination of research results.

The regulatory framework has evolved since 2006 when the country's first science policy was prepared. This has since been updated and complemented by new texts on science and innovation (the year of adoption is between brackets):

- A manual for monitoring and evaluating research structures and organizations (2013);
- A manual on how to select research programmes and projects and apply to the National Fund for Scientific Research and Technological Innovation (2013) for competitive grants;
- A draft act for funding scientific research and innovation and a draft code of ethics for scientific research and innovation were both submitted to the Supreme Court in 2014;
- A strategic plan for scientific research and innovation (under development in 2015).

Equally important are Benin's efforts to integrate science into existing policy documents:

- *Benin Development Strategies 2025: Benin 2025 Alafia* (2000);
- *Growth Strategies for Poverty Reduction 2011–2016* (2011);
- Phase 3 of the *Ten-year Development Plan for the Education Sector*, covering 2013–2015;
- *Development Plan for Higher Education and Scientific Research 2013–2017* (2014).

The priority areas for scientific research are health, education, construction and building materials, transportation and trade, culture, tourism and handicrafts, cotton/textiles, food, energy and climate change.

The main research structures are the Centre for Scientific and Technical Research, National Institute of Agricultural Research, National Institute for Training and Research in Education, Office of Geological and Mining Research and the Centre for Entomological Research. The University of Abomey-Calavi also deserves mention for having been selected by the World Bank as a centre of excellence in applied mathematics (Table 18.1).

The main challenges facing R&D in Benin are the:

- unfavourable organizational framework for R&D: weak governance, a lack of co-operation between research structures and the absence of an official document on the status of researchers;
- inadequate use of human resources and the lack of any motivational policy for researchers; and the
- mismatch between R&D and development needs.

BURKINA FASO

S&T have become a development priority

Since 2011, Burkina Faso has clearly made S&T a development priority. The first sign was the creation of the Ministry of Scientific Research and Innovation in January 2011. Up until then, management of STI had fallen under the Department of Secondary and Higher Education and Scientific Research. Within this ministry, the Directorate General for Research and Sector Statistics is responsible for planning. A separate body, the Directorate General of Scientific Research, Technology and Innovation, co-ordinates research. This is a departure from the pattern in many other West African countries where a single body fulfils both functions.

In 2012, Burkina Faso adopted a *National Policy for Scientific and Technical Research*, the strategic objectives of which are to develop R&D and the application and commercialization of research results. The policy also makes provisions for strengthening the ministry's strategic and operational capacities.

One of the key priorities is to improve food security and self-sufficiency by boosting capacity in agricultural and environmental sciences. The creation of a centre of excellence at the International Institute of Water and Environmental Engineering (2iE) in Ouagadougou within a World Bank project (Table 18.1) provides essential funding for capacity-building in these priority areas. Burkina Faso also hosts the African Biosafety Network of Expertise (Box 18.1).

A dual priority is to promote innovative, effective and accessible health systems; the growing number of doctoral candidates in medicine and related fields is a step in the right direction (Figure 18.3). The government wishes to develop, in parallel, applied sciences and technology and social and human sciences. To complement the national research policy, the government has prepared a *National Strategy to Popularize Technologies, Inventions and Innovations* (2012) and a *National Innovation Strategy* (2014).

Other policies also incorporate science and technology, such as that on *Secondary and Higher Education and Scientific Research* (2010), the *National Policy on Food and Nutrition Security* (2014) and the National Programme for the Rural Sector (2011).

In 2013, Burkina Faso passed the Science, Technology and Innovation Act establishing three mechanisms for financing research and innovation, a clear indication of high-level commitment. These mechanisms are the National Fund for Education and Research, the National Fund for Research and Innovation for Development and the Forum of Scientific Research and Technological Innovation[7]. The creation of national funds for R&D is one of the recommendations of ECOPOST.

The other most important actors are the National Centre for Scientific and Technological Research, Institute for Environment and Agricultural Research, National Agency for Biodiversity, National Council for Phytogenetic Resources Management and the Technical Secretariat for Atomic Energy. Responsibility for technology transfer and the popularization of research results falls to the National Agency for the Promotion of Research Results and the National Centre for Scientific and Technological Research.

Burkina Faso faces a number of challenges in developing R&D:

- a small pool of researchers: 48 per million population in 2010;
- a lack of research funding,
- outdated research facilities,
- poor access to information and internet: 4.4% of the population in 2013;
- an insufficient utilization of research results; and
- brain drain.

Before he passed away in December 2013, Nelson Mandela, a champion of education, lent his name to two graduate universities entrusted with the mission of producing a new generation of Africa-focused researchers, the African Institutes of Science and Technology in Tanzania and Nigeria. A third is planned for Burkina Faso.

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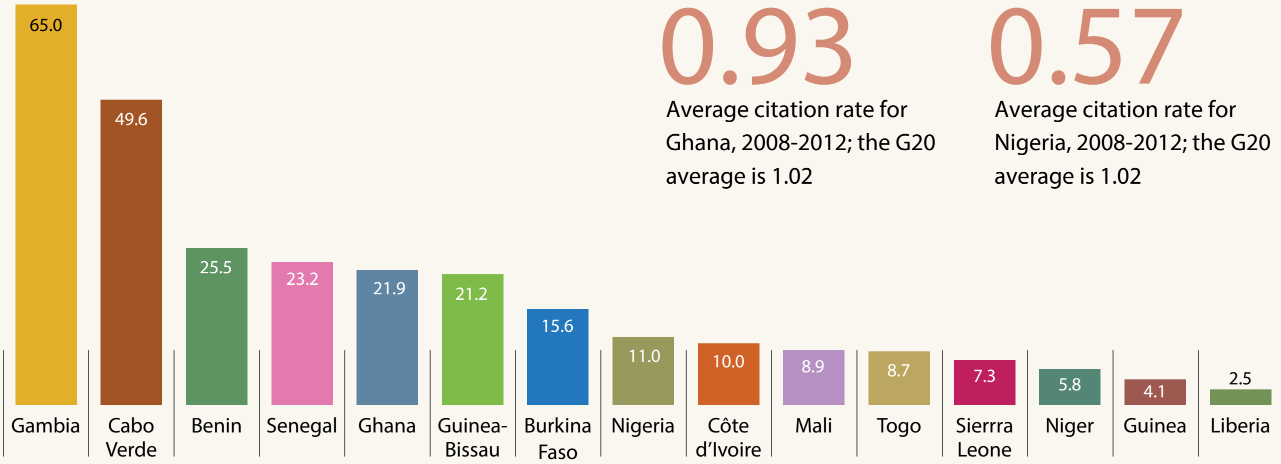
7. Funding comes from the national budget and various annual subsidies: 0.2% of tax revenue, 1% of mining revenue and 1% of the revenue from operating mobile phone licenses. The funds also benefit from royalties on sales from the results of research and the patent license agreement concerning inventions funded by the public purse.

Figure 18.6: **Scientific publication trends in West Africa, 2005–2014**

Scientists from Gambia and Cabo Verde publish most in international journals

Per million inhabitants, 2014



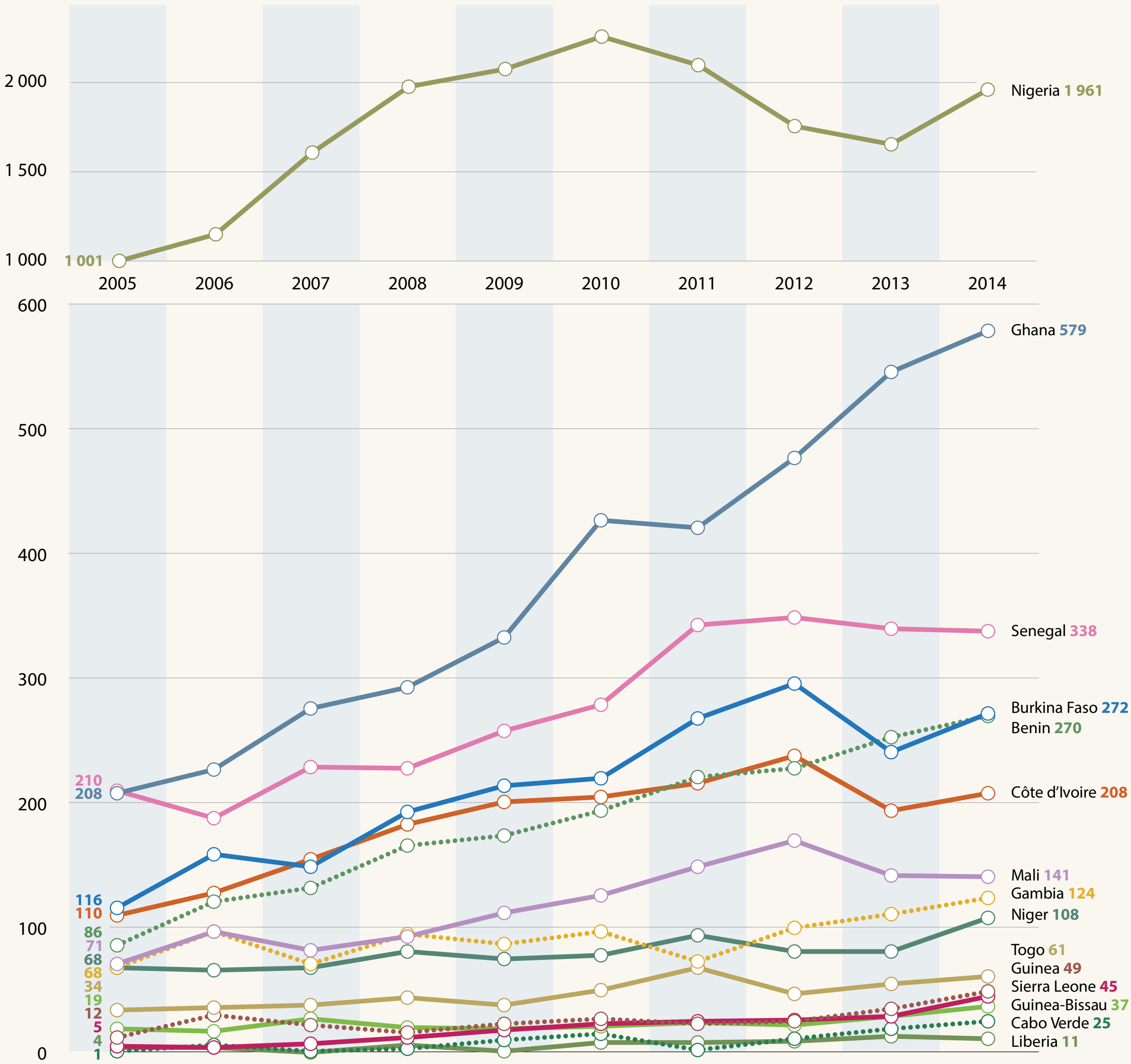
0.93

Average citation rate for Ghana, 2008-2012; the G20 average is 1.02

0.57

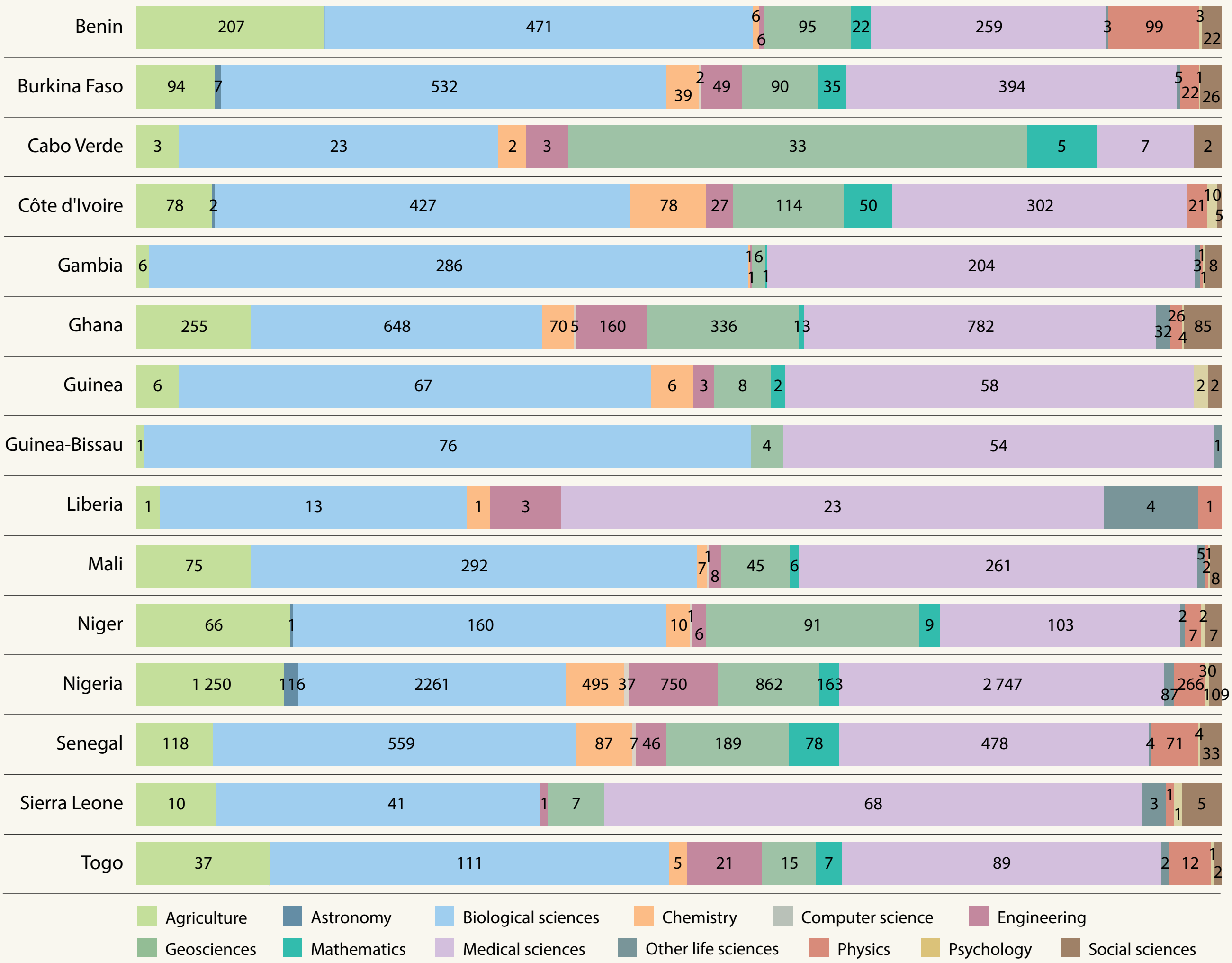
Average citation rate for Nigeria, 2008-2012; the G20 average is 1.02

Ghana now has the second-biggest volume of output after Nigeria



West African scientists publish much more in health than in agriculture

Cumulative totals by field, 2008–2014



Note: Totals exclude unclassified articles.

A wide range of scientific partners, including in Africa

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Benin	France (529)	Belgium (206)	USA (155)	UK (133)	Netherlands (125)
Burkina Faso	France (676)	USA (261)	UK (254)	Belgium (198)	Germany (156)
Cabo Verde	Portugal (42)	Spain (23)	UK (15)	USA (11)	Germany (8)
Côte d'Ivoire	France (610)	USA (183)	Switzerland (162)	UK (109)	Burkina Faso (93)
Gambia	UK (473)	USA (216)	Belgium (92)	Netherlands (69)	Kenya (67)
Ghana	USA (830)	UK (636)	Germany (291)	South Africa (260)	Netherlands (256)
Guinea	France (71)	UK (38)	USA (31)	China (27)	Senegal (26)
Guinea-Bissau	Denmark (112)	Sweden (50)	Gambia /UK (40)	–	USA (24)
Liberia	USA (36)	UK (12)	France (11)	Ghana (6)	Canada (5)
Mali	USA (358)	France (281)	UK (155)	Burkina Faso (120)	Senegal (97)
Niger	France (238)	USA (145)	Nigeria (82)	UK (77)	Senegal (71)
Nigeria	USA (1309)	South Africa (953)	UK (914)	Germany (434)	China (329)
Senegal	France (1009)	USA (403)	UK (186)	Burkina Faso (154)	Belgium (139)
Sierra Leone	USA (87)	UK (41)	Nigeria (20)	China/Germany (16)	–
Togo	France (146)	Benin (57)	USA (50)	Burkina Faso (47)	Côte d'Ivoire (31)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix, November 2014

CABO VERDE

A model for civil rights and development

Cabo Verde remains a model for political rights and civil liberties in Africa, according to a country study by the African Development Bank in 2014. Thanks to its sustained economic performance, this isolated and fragmented territory with a dry Sahelian climate and scarce natural resources acceded to the World Bank's middle-income category in 2011. In order to maintain the momentum, the government has devised its third *Growth and Poverty Strategy Paper* covering the period 2012–2016. Expanding the coverage of health service delivery and human capital development have been designated priority areas, in order to ensure inclusive growth, with an emphasis on technical and vocational training. In recent years, Cabo Verde has invested more than 5% of GDP in education. This strategy has paid off. The literacy rate is now the highest in West Africa (98%), with 93% of young people being enrolled in secondary school and one in five in tertiary education (Table 18.3).

Plans to strengthen research

Research spending, on the other hand, remains among the lowest in West Africa, at 0.07% of GDP in 2011. The Ministry of Higher Education, Science and Culture plans to strengthen the research and academic sectors by placing emphasis on greater mobility, through exchange programmes and international co-operation agreements. As part of this strategy, Cabo Verde is participating in the Ibero-American academic mobility programme that expects to mobilize 200 000 academics between 2015 and 2020.

ICTs at the heart of development plans

Cabo Verde Telecom linked all the islands by fibre optic cable in 2000. In December 2010, it joined the West African Cable System project[8] to provide residents with an alternative access route to high-speed internet. Thanks to this, internet penetration more than doubled between 2008 and 2013 to 37.5% of the population. As the cost remains high, the government provides centres where people can surf the internet free of charge.

The government now plans to build a 'cyber-island' which would develop and offer ICT services, including software development, computer maintenance and back office operations. Approved in 2013, the Praia Technology Park is a step in this direction; financed by the African Development Bank, it is expected to be operational by 2018.

The government launched the Mundu Novu project in 2009 to modernize education. The project is introducing the concept of interactive education into teaching and mainstreaming informatics into curricula at different levels. Some 150 000 computers are being distributed[9] to public schools. By early 2015, the Mundu Novu education plan had equipped 18 schools and training centres with internet access, installed the Wimax antenna network across the country, produced teaching kits on ICTs for 433 classrooms in 29 pilot schools (94% of all classrooms), given university students access to digital libraries and introduced courses in information technology, in addition to implementing an Integrated Management and Monitoring System for university students.

CÔTE D'IVOIRE

A plan to consolidate peace and promote inclusive growth

With the political crisis now over, the incoming government of President Alassane Ouattara has vowed to restore the country to its former leading role in sub-Saharan Africa. The *National Development Plan for 2012–2015* has two primary objectives: to achieve double-digit growth by 2014 and to turn Côte d'Ivoire into an upper middle-income country by 2020. A second national development plan is under preparation for 2016–2020.

The budget for the *National Development Plan* is broken down into five strategic areas: greater wealth creation and social equity (63.8%, see Figure 18.7), provision of quality social services for vulnerable populations, particularly women and children (14.6%), good governance and the restoration of peace and security (9.6%), a healthy environment (9.4%) and the repositioning of Côte d'Ivoire on the regional and international scenes (1.8%).

Key targets of the *Plan* requiring recourse to S&T include:

- rehabilitation of the railway linking Abidjan to Burkina Faso's border, rehabilitation and extension of the ports of Abidjan and San Pédro, creation of a new airline company (infrastructure and transport);
- increasing the productivity of yam, banana plantain and manioc by at least 15% (agriculture);
- creation of two transformation units for iron and manganese and one for gold refining (mining);
- construction of the Soubré dam, electrification of 200 rural communities each year (energy);
- establishment and equipping of three technopoles to promote innovation, transformation of 50% of raw materials into value-added goods (industry and SMEs);

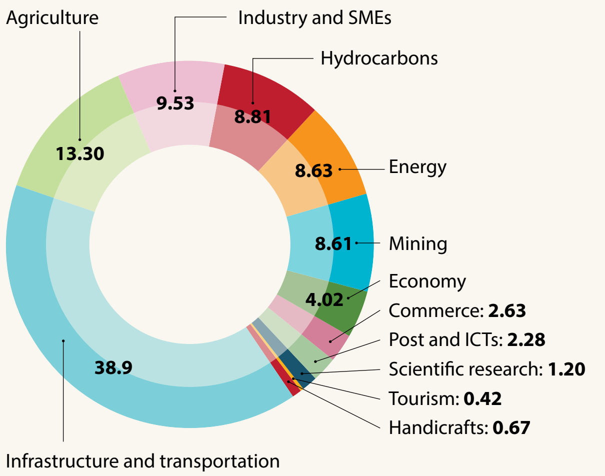
8. See: www.fosigrid.org/africa/cape-verde

9. Microsoft has given the official government agency working on Mundu Novu, Operational Information Society Nucleus, a 90% discount on the operating systems being installed in schools, through an agreement signed in August 2010.

- expansion of the country's fibre optic[10] network, introduction of an e-education programme, establishment of cybercentres in every municipality (post and ICTs);
- construction and equipping of 25 000 classrooms, construction of four universities and a university village, rehabilitation of several existing universities (education);
- rehabilitation of hospitals and clinics, free health care for children under the age of five, free childbirth care and free emergency care (health);
- construction of latrines in rural areas, rehabilitation of sewage systems in Abidjan and Yamoussoukro (sanitation);
- connection of 30 000 low-income families each year to subsidized piped water (drinking water);
- rehabilitation of the lagoon and Cocody Bay in Abidjan and construction of a technopole to treat and recycle industrial and dangerous waste (environment).

Figure 18.7: **Priority sectors of Côte d'Ivoire's *National Development Plan* to 2015**

Within budget devoted to greater wealth creation and social equity (%)



Source: Ministry of Planning and Development (2012) *National Development Plan, 2012–2015*

Infrastructure is a top priority

The share of the *Plan* devoted to scientific research remains modest (Figure 18.7). Twenty-four national research programmes group public and private research and training institutions around a common research theme. These programmes correspond to eight priority sectors for 2012–2015, namely: health, raw materials, agriculture, culture, environment, governance, mining and energy; and technology.

According to the Ministry of Higher Education and Research, Côte d'Ivoire devotes about 0.13% of GDP to GERD.

Apart from low investment, other challenges include inadequate scientific equipment, the fragmentation of research organizations and a failure to exploit and protect research results.

Côte d'Ivoire does not yet have a dedicated STI policy. Related policies are implemented by the Ministry of Higher Education and Scientific Research. The main planning body is the Directorate General of Scientific Research and Technological Innovation and its technical directorate. For its part, the Higher Council for Scientific Research and Technological Development serves as a forum for consultation and dialogue with stakeholders and research partners.

Research and innovation are promoted and funded by the National Agricultural Investment Programme (est. 2010), the Policy Support Programme for Scientific Research (est. 2007), the Interprofessional Fund for Agricultural Research and Advice (est. 2002), the National Fund for Scientific and Technological Research (yet to be established) and the Ivorian Fund for the Development of National Enterprises (est. 1999).

The following structures foster innovation and technology transfer: the Department for the Promotion of Research and Technological Innovation, the Ivorian Organization for Intellectual Property and Promotion and the Centre for the Demonstration of Technologies. To this list should be added the Ivorian Society of Tropical Technology. Set up in 1979, this government centre promotes agro-industrial innovation and provides training in the preservation and transformation of crops (manioc, banana plantain, cashew nut, coconut, etc.) into value-added goods such as soap and cocoa butter.

Other key structures include the Pasteur Institute, Centre for Oceanological Research, National Centre for Agronomic Research, National Institute of Public Health, Centre for Ecological Research and the Centre for Economic and Social Research.

GAMBIA

A desire to link training with STI development

Gambia's *Programme for Accelerated Growth and Employment,* covering the period 2012–2015, drives its own vision of attaining middle-income status. One of the smallest countries in West Africa, with a per capita GDP of PPP$ 1 666, Gambia is conscious of the need for a robust STI capacity to address its pressing development challenges. Just 14% of the population has access to internet, for instance, and only three in four Gambians have access to a clean water supply.

10. Just 2.4% of Ivoirians had internet access in 2012.

The establishment of the Ministry of Higher Education, Research, Science and Technology in 2007 signals the country's desire to link the training of skilled personnel with STI development. Other encouraging signs are the president's decision to make 2012 the Year of Science, Technology and Innovation, the efforts to establish the first-ever national academy of sciences in Gambia and the adoption of the *National Science, Technology and Innovation Policy 2013–2022,* prepared with UNESCO's assistance.

This policy aims specifically to foster entrepreneurship among youth and women, in order to enhance their employability. It also aims to modernize both agriculture (peanuts and derivatives, fish, cotton lint, palm kernels) and national industries (tourism, beverages, agricultural machinery assembly, woodworking, metalworking, clothing) to create quality products and services.

A number of institutions provide research and training, the main ones being the University of Gambia, the National Agricultural Research Institute, the Centre for Innovation against Malaria, the Public Health Research and Development Centre, the Medical Research Council and the International Trypanotolerance Centre.

Low tertiary enrolment, little R&D

Development indicators for Gambia are fairly encouraging for a small country with limited resources. Public expenditure on education has quadrupled since 2004 to 4.1% of GDP. Of this, just 7% (0.3% of GDP) is invested in tertiary education. Although nine out of ten children attend primary school, enrolment rates have not progressed at either the primary or secondary levels since 2009, suggesting that the government may be focusing on improving the quality of primary and secondary education (Table 18.3). Tertiary enrolment remains extremely low, at just 3% of the 18–25 age cohort, even though it has risen in recent years.

Just 0.13% of GDP is spent on R&D (2011). Gambia does have the particularity, though, of having an active private non-profit sector, which performs nearly half of R&D[11] according to available data – although it should be noted that the business enterprise sector has not been surveyed. On the whole, however, STI in Gambia is characterized by inadequate infrastructure and insufficient skills and institutional capacity to realize its science and innovation goals, combined with a lack of funding. The *National Science, Technology and Innovation Policy* is intended to address these constraints.

11. This may be at least partly due to the fact that the Medical Research Council in Gambia, a unit of the UK's council of the same name, is classified as a private non-profit institution.

GHANA

A desire to create a science culture

The *Ghana Shared Growth and Development Agenda 2014–2017* contextualizes the sector-specific policies for agriculture, industry, health and education defined by the *National Science, Technology and Innovation Policy*[12] (2010). The main objectives of this policy are to use STI to reduce poverty, increase the international competitiveness of enterprises and promote sustainable environmental management and industrial growth. The long-term goals of the policy are to create a science and technology culture oriented towards problem-solving.

Ghana has one of West Africa's most developed national innovation systems. There is a Council for Scientific and Industrial Research, established in 1958, with 13 specialized institutes for research on crops, animals, food, water and industry. The export of cocoa contributed over 40% of the country's foreign exchange earnings up until the 1980s and still contributes about 20%. The Cocoa Research Institute of Ghana plays an important role in developing the cocoa industry, through research into crop breeding, agronomy, pest management and extension services, among others. Other scientific institutions include the Ghana Atomic Energy Commission, the Centre for Scientific Research into Plant Medicine and the Noguchi Memorial Institute for Medical Research at the University of Ghana.

Ghana has only a small pool of researchers (39 per million population in 2010) but they are increasingly publishing in international journals. Ghana's scientific publication record almost tripled between 2005 and 2014 (Figure 18.6). This performance is all the more noteworthy in that Ghana devoted just 0.38% of GDP to GERD in 2010 (see Table 19.5).

Greater investment needed to stimulate R&D

Between 2004 and 2011, Ghana invested 6.3% of GDP in education, on average, and between one-fifth and one-quarter of this in higher education. The number of students enrolled in degree courses shot up from 82 000 to 205 000 (12% of the age cohort) between 2006 and 2012 and the number of PhD candidates from 123 to 867 (see Table 19.4).

The investment in education has not lived up to expectations, as it has not acted as a stimulus for R&D. This is because science and engineering are accorded insufficient status in Ghana. Government scientists and academics (who perform 96% of GERD) receive an inadequate budget and private sector opportunities are rare. In the 2000s, successive governments made efforts to enhance the infrastructure for modern business

12. This policy followed a review of Ghana's national innovation system by UNCTAD, the World Bank and Ghana's Science and Technology Policy Research Institute.

development. They fostered business incubators for ICTs, industrial parks for textiles and garments and smaller experimental incubators within research institutes like the Food Research Institute. These are all located in the Accra-Tema metropolis where they are too inaccessible for the thousands of entrepreneurs living outside the capital who need these facilities to develop their businesses.

Despite insufficient investment, some universities maintain high standards, such as the University of Ghana (1948), the country's oldest, and Kwame Nkrumah University of Science and Technology (KNUST, 1951). Both have been selected for the World Bank's African Centres of Excellence project (Table 18.1). KNUST has developed a reputation for excellence in engineering, medicine, pharmacy, basic sciences and applied sciences. In 2014, the government established a centre of excellence in petroleum engineering at KNUST with the World Bank which will serve as a hub for developing Africa's capacity in the oil and gas value chain. In all, seven public universities conduct extensive R&D.[13]

Within the World Bank project, the West Africa Centre for Crop Improvement at the University of Ghana is receiving US$ 8 million for research and the training of crop breeders at PhD and MSc levels over 2014–2019, as well as for the provision of other services. The West Africa Centre on the Cell Biology of Infectious Pathogens within the University of Ghana and KNUST's Regional Water and Environmental Sanitation Centre are receiving similar support (Table 18.1).

GUINEA

Middle-income status by 2035

Following the death of President Lansana Conte in 2008, Guinea experienced a severe political crisis until the election of the current President Alpha Conde in November 2010. This challenging political transition plunged the country into an economic recession in 2009 (-0.3% growth), prompting the government to extend its *Poverty Reduction Strategy* to 2012.

The ambition of the new authorities is to transform Guinea into a middle-income economy within 25 years. This ambition will be articulated in *Guinea 2035*, which was under preparation in 2015. The government intends to promote:

- the collection of economic intelligence, in order to anticipate changes in the national and international economic environments and to identify opportunities for access to new markets through innovation and creativity. Over the period 2013–2015, economic intelligence poles are being established for the administration (public services) and private sector (employers);
- clean industries;
- security of intellectual and economic property;
- management and exploitation of knowledge and information, in the priority areas of science and industrial, technological and medical production processes.

Key reforms in higher education and research

The government has made it a priority to achieve universal primary education by 2015, in line with the Millennium Development Goals. The roadmap for achieving this ambition is the government's *Programme for the Education Sector 2008–2015*, adopted in 2007. By 2009, 85% of children were attending primary school but this share had barely progressed by 2012, no doubt owing to the political unrest in 2008 and 2009. The share of secondary pupils rose from 34% to 38% between 2008 and 2012 (Table 18.3). Guinea's education effort accounted for 2.5% of GDP in 2012, one of the lowest proportions in West Africa.

One-third of education expenditure goes on higher education. One in 10 Guineans aged between 18 and 25 years is enrolled at university, one of the highest rates in West Africa. Important reforms are under way in Guinea to improve university governance and the financing of institutions of higher learning and scientific research, to create an advanced (doctoral) graduate school, implement a system of quality assurance and develop relevant professional networks in higher education.

The government is also promoting access to ICTs and their use in teaching, scientific research and administration. Guinea currently has one of the lowest rates of internet penetration in Africa, at just 1.5% (2012).

A need to review the legal framework for R&D

The development of R&D is governed by the Guidance Law for Scientific and Technical Research. This law has not been updated since its adoption on 4 July 2005, nor implemented or reviewed.

The Ministry of Higher Education and Scientific Research is the main body responsible for policies related to higher education and scientific research. Within the ministry, the National Directorate for Scientific and Technical Research (DNRST) is responsible for the implementation of the policy and research institutions that constitute the executive component. The DNRST is also responsible for designing, developing and co-ordinating the monitoring and evaluation of national policy.

13. In addition, there are ten polytechnics, one in each of Ghana's ten administrative regions and 23 institutes for vocational and technical training. The evolving policy on polytechnics is to transform these into technical universities.

In addition to the Ministry of Higher Education and Scientific Research, there is a Higher Council of Scientific and Technical Research. This consultative body related to on matters has national S&T policy; it consists of representatives of ministries, the scientific community and users of the products of research.

R&D funding comes from two sources: the state, through the national development budget, allocates grants to research institutions, documentation centres and universities; and international co-operation. In recent years, R&D in Guinea has received financial assistance from France, via its Aid Fund for Co-operation and the Priority Solidarity Fund, as well as from Japan, Belgium, Canada, the World Bank, UNDP, UNESCO, the Islamic Educational, Scientific and Cultural Organization and others.

GUINEA-BISSAU

Political troubles have undermined the economy

Once hailed as a model for African development, Guinea-Bissau has suffered a civil war (1998–1999), followed by several coups d'état, the latest in April 2012. Political instability has undermined the economy, making it one of the poorest countries in the world.

Guinea-Bissau is dependent on primary crops – mainly cashew nuts for its foreign exchange – and subsistence agriculture. There are other resources that could be exploited and processed, such as fish, timber, phosphates, bauxite, clay, granite, limestone and petroleum deposits.

Guinea-Bissau's long-term vision is encapsulated in *Guinea-Bissau 2025 Djitu ten* (1996). The government's vision is articulated in the first *National Strategy for Poverty Reduction* covering the period 2008–2010 and its successor covering 2011–2015. The title of the latter reflects the strategy's overarching goals, *Reducing Poverty by Strengthening the State, Accelerating Growth and Achieving the Millennium Development Goals*.

Higher education policy currently under review

Like most WAEMU countries which share a common currency (the CFA), Guinea-Bissau has made considerable efforts in the past five years to improve its higher education system. These efforts have been supported by Guinea-Bissau's partners and especially by WAEMU through its Support to Higher Education, Science and Technology Project and its assistance in developing Guinea-Bissau's higher education policy in 2011. This policy is currently under review, in consultation with key stakeholders, particularly private-sector employers, socio-professional organizations, policy-makers and civil society.

Thus, like other WAEMU countries, Guinea-Bissau has held national consultations on the future of higher education and scientific research. In March 2014, the Ministry of Education organized a national dialogue on this topic on the theme of What Future for Higher Education and Scientific Research in Guinea-Bissau in the Short, Medium and Long Term? The consultation brought together a wide range of national and foreign stakeholders. The recommendations emanating from this consultation, combined with the election of President José Mario Vaz in May 2014 and the consequential removal of the sanctions imposed by the African Union after the coup d'état in 2012, should enable Guinea-Bissau to take this reform agenda forward.

LIBERIA

Strong economic growth has not spilled over into the STI sector

Liberia is a country recovering from a quarter of a century of civil war. Although it has turned the page of strife since the election of President Ellen Johnson Sirleaf in 2005, the economy remains in ruins and, since early 2014, has been struggling with the crippling effects of the Ebola epidemic. With GDP per capita of just PPP$ 878 in 2013, Liberia remains one of the poorest countries in Africa.

The country does have considerable natural assets, including the largest rainforest in West Africa. Its economy is based on rubber, timber, cocoa, coffee, iron ore, gold, diamonds, oil and gas. Between 2007 and 2013, the economy grew by 11% on average. Even though this economic recovery is commendable, it has not spilled over into the STI sector.

Low public spending on agriculture and education

Nor has public spending risen in such key sectors as agriculture (less than 5% of GDP) and education (2.38% of GDP), where just 0.10% of GDP goes to higher education. Although Liberia has achieved universal primary education, less than half of pupils attend secondary school. In addition, university enrolment has stagnated: almost the exact same number of students (33 000) were enrolled in degree courses in both 2000 and 2012. At the other extreme, Liberia shares the distinction with Sierra Leone of devoting more of GDP to health (15%) than any other country in sub-Saharan Africa.

An emphasis on better governance

Liberia has set its sights on becoming a middle-income country by 2030, in its *National Vision: Liberia Rising 2030*[14] (Republic of Liberia, 2012). The first priority will be to create the conditions for socio-economic growth, through better governance

14. *Liberia Rising* 2030 follows on the heels of *Lifting Liberia*, the country's poverty reduction strategy for 2008–2011.

practices such as respect for the rule of law, infrastructure development, a more business-friendly environment, free basic education and more trained teachers, investment in technical and vocational education and higher education. *Liberia Rising* cites a World Bank Doing Business survey (2012) in which 59% of Liberian firms identified lack of electricity and 39% lack of transportation as a major constraint.

With the entire infrastructure for energy generation and distribution having been destroyed by the war, it is planned to make greater use of renewable energy and to install affordable power services, with 'more access to fuel that does not contribute to deforestation.' Being able to supply electricity to most of the economy is considered 'essential' for achieving middle-income status. Emphasis is being placed on ensuring greater inclusiveness, as 'instability and conflict remain the primary risk to long-term wealth creation in Liberia…The challenge will be to turn away from the traditional practice of concentrating wealth and power in the elite and in Monrovia (the capital).'

It is expected that financing for the *National Vision* will come essentially from large mining companies – including those currently prospecting offshore for oil and gas – and from development partners. In 2012, FDI contributed 78% of GDP, by far the largest share in sub-Saharan Africa (Republic of Liberia, 2012).

Liberia has not yet published an STI policy but it does have a national industrial policy, *Industry for Liberia's Future* (2011), a *National Environmental Protection Policy* (2003), a *National Biosafety Framework* (2004) and a *National Health Policy* (2007).

An S&T college for the University of Liberia

In higher education, the main development has been the commissioning of the T.J.R. Faulkner College of Science and Technology in 2012 at the University of Liberia. The latter was founded in 1862 and already had two colleges, the College of Agriculture and Forestry and the College of Medicine. Other universities also have science and engineering faculties. Liberia also has specialized institutions such as the Liberia Institute for Biomedical Research and the Central Agriculture Research Institute.

The National Commission on Higher Education is responsible for developing STI. There is also a Renewable Energy Agency, a Forestry Development Authority and an Environmental Protection Agency. Currently, the Ministry of Education holds responsibility for science education and research, through its Division for Science and Technology Education. There are calls, however, for the establishment of a Ministry of Research, Science and Technology.

MALI

A policy but no long-term plan for research

In 2009, the Ministry of Secondary and Higher Education and Scientific Research developed a *National Policy for Higher Education and Scientific Research* (MoSHESR, 2009). It has three main objectives:

- to strengthen the social and economic utility of higher education and research;
- to regulate the flow of students enrolled in higher education, in order to establish the best possible compromise between the needs of the labour market, social demand and the available means; and
- to optimize available resources by directing the lion's share towards teaching and research, while making better use of the private sector's potential role, in order to limit social spending.

Despite the guidance offered by this science policy, no strategic plan for developing long-term scientific research has yet been formally adopted, nor any document defining the human, material and financial resources needed to mobilize and implement such a policy. The United Nations' Economic Commission for Africa did support a study in 2009–2011 on developing a national STI policy and an accompanying implementation plan but this process was perturbed by the military coup in 2011 which preceded the Touareg rebellion in the north. In the absence of these elements, departments or individuals within education and research structures continue to initiate research projects themselves or, in some cases, the initiative is taken by donors, an only too familiar pattern in Africa.

From one university to five

Until 2011, Mali had a single university, established in 1996. Nearly 80 000 students enrolled in the 2010–2011 academic year, 343 of whom were PhD candidates (Table 18.4). In order to accommodate the burgeoning student numbers, the government decided to divide the University of Bamako into four separate entities in 2011, each with its own institute of technology: the University of Science, Techniques and Technologies in Bamako; University of Arts and Humanities in Bamako; University of Social Sciences and Management in Bamako; and the University of Law and Political Sciences in Bamako.

In parallel, the University of Segou was approved by decree in 2009 and welcomed its first cohort of 368 students in January 2012, according to the Malian journal *L'Essor*. The Faculty of Agriculture and Veterinary Medicine was the first to open, followed by the Faculty of Social Sciences, the Faculty of Health Sciences and the Faculty of Science and Engineering. It is planned to set up a vocational training centre on campus.

Since 2009, the UNESCO Office in Bamako has been implementing a project to help university professors adopt the three-tier degree cycle (bachelor's– master's –PhD). UNESCO collaborated with the University of Bamako and the National Directorate of Higher Education in organizing a mission to Dakar in April 2013 for about 20 university professors, so that they could study doctoral schools and quality assurance mechanisms in Senegal with a view to emulating these in Mali. UNESCO also ran a number of national and international workshops, including one on the use of ICTs to improve education and research. The University of Bamako has since joined the African Network of Scientific and Technological Institutions, hosted by the UNESCO Nairobi office.

NIGER

The country's first STI policy

In Niger, several ministries are involved in designing S&T policy but the Ministry of Higher Education, Scientific Research and Innovation is the principal player. The *National Policy on Science, Technology and Innovation* was approved in 2013 and was awaiting adoption by parliament in 2015. In parallel, UNESCO is helping Niger develop a strategic implementation plan.

In March 2013, Niger participated in a subregional workshop[15] in Dakar co-organized by UNESCO's Global Observatory of STI Policy Instruments (GO→SPIN) programme and AOSTI. The workshop was the first step in mapping research and innovation in Niger.

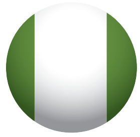
In 2010, Niger created a Support Fund for Scientific Research and Technological Innovation (FARSIT). With an annual budget of CFA 360 million (€ 548 000), FARSIT aims to support research projects of socio-economic relevance; strengthen the capacity of institutions, teams and laboratories to conduct R&D; encourage creativity and technological innovation; and improve research training.

A first long-term plan for all levels of education

University enrolment rates in Niger are among the lowest in Africa, at just 175 students per 10 000 population (Table 18.3). Developing a viable higher education system of quality thus remains a major challenge for a country where half the population is less than 15 years of age. In 2010, three new universities were founded: the University of Maradi, the University of Zinder and the University of Tahoua.

In 2014, the government adopted a *Programme for the Education and Training Sector, 2014–2024*.This is Niger's first long-term planning document for education as a whole, from the pre-primary to tertiary levels. The previous plan in 2001 focused solely on basic education, encompassing pre-school, primary school, adult literacy and non-formal education.

NIGERIA



The National Fund for STI approved

Nigeria plans to use its *Vision 20:2020: Economic Transformation Blueprint* (2009) to place it among the top 20 economies[16] in the world by 2020, with annual per capita income of at least US$ 4 000. *Vision 20:2020* integrates STI into the development of key economic sectors and is built on three pillars, namely: optimizing the nation's key sources of economic growth; guaranteeing the productivity and well-being of Nigerians; and fostering sustainable development.

One of the nine strategic targets of *Vision 20:2020* was initially to set up a US$ 5 billion endowment fund to finance the establishment of a National Science Foundation. This fund was pledged by former President Olusegun Obasanjo (1999–2007) towards the end of his mandate and has not materialized. Progress towards other targets is hard to evaluate for lack of data, examples being the target of investing a share of GDP in R&D comparable to that of the 20 leading economies or that of increasing numbers of R&D personnel.

In 2011, the Federal Executive Council approved the allocation of 1% of GDP to set up a National Science, Technology and Innovation Fund. This strategy features in the *Science, Technology and Innovation Policy* approved by the Federal Executive Council in 2011, which recommends putting in place reliable funding arrangements to ensure that R&D focuses on national priorities. Four years later, this fund has not yet materialized.

A policy shift towards innovation

The policy also recommended a shift in research focus from basic research to innovation. In his foreword, the Federal Minister of Science and Technology[17] observed that 'one notable feature of this policy is the emphasis on innovation, which has become a tool for fast-tracking sustainable development.' President Goodluck Jonathan put it this way: 'we are going to run our economy based on S&T because nowhere in this world can you move the economy without S&T…for the next four years, we will emphasize S&T so much

15. The workshop was attended by high-level experts, government officials, researchers, statisticians and parliamentary commission staff from Burkina Faso, Burundi, Côte d'Ivoire, Gabon, Niger and Senegal.

16. For details of Nigeria *20:2020*, see the *UNESCO Science Report 2010: the Current Status of Science around the World*, p. 309.

17. The Federal Ministry of Science and Technology is supported by the National Council on Science and Technology, the National Assembly Committees on Science and Technology and the National Centre for Technology Management. Nigeria being a federal republic, there are also relays in the state ministries and assemblies.

Box 18.4: **Taxing business to upgrade tertiary education in Nigeria**

One of the strategies outlined in Nigeria's *Science, Technology and Innovation Policy* (2011) is for funding frameworks to be set up with various partners.

One such framework is the TETFund. It was established under the Tertiary Education Trust Fund Act of 2011 to serve as the agency responsible for managing and disbursing tax funds to public tertiary institutions. It is also responsible for monitoring the utilization of funds.

Under the fund, a 2% education tax is imposed on the assessable profits of all registered companies in Nigeria. TETFund then disburses 50% of the money to universities, 25% to polytechnics and 25% to teachers' colleges. Grants are provided for the purchase of essential physical infrastructure for teaching and learning, research and publication and academic staff training and development.

Source: www.tetfund.gov.ng

because we have no choice.' The aim is to transform Nigerians into 'science and technology thinking entities.'

The policy also recommended founding a National Research and Innovation Council. This was effectively established in February 2014. Membership includes the federal ministers of science and technology; education; information and communications technology; and environment.

The emphasis in STI is on space science and technology, biotechnology and renewable energy technologies. Although Nigeria has had a National Biotechnology Development Agency since 2001, the National Biosafety Management Agency Bill lingered in parliament for years; the bill was finally passed in 2011 but was still awaiting presidential consent in early 2015.

In 2012, an International Centre for Biotechnology was established under the auspices of UNESCO at the University of Nigeria in Nsukka. The institute provides high-level training (including at subregional level), education and research, particularly in areas related to food security, conservation of harvested crops, gene banking and tropical diseases.

Some key goals of the *Science, Technology and Innovation Policy* are to:

- develop an endogenous capability in launching and exploiting Nigeria's own satellites (it already has three) for telecommunications and research;
- run advanced field trials of genetically modified crops designed to increase agricultural productivity and food security (see also Box 18.1);
- promote solar technology systems as dependable back-ups to the national grid and to address energy needs in marginalized communities;
- promote the design and use of local construction materials and a 'green construction culture' through the development of 'green homes' and 'green cement;'
- establish or develop technology transfer offices to improve intellectual property protection and thereby encourage industrial R&D;
- build the Sheda Science and Technology Complex (SHESTCO) in Abuja within the Silicon Valley Project, which is developing a high-tech capability in ICTs, materials science, solar and new technologies, along with skills in engineering and maintenance. In a visit to the complex in October 2014, the Federal Minister of Science and Technology, Dr Abdu Bulama, pledged to 'do everything under our mandate to ensure Silicon Valley becomes a reality. Hence, we are partnering with UNESCO, Poland and other international bodies to fast-track the process.'

The success of Nigeria's ambitious programme will rest on its strategy for developing human resources (Box 18.4). Nigeria currently has 40 federal universities, 39 state universities and 50 private universities, according to the Nigeria Universities Commission. There are also 66 polytechnics, 52 monotechnics and about 75 research institutes.

Despite this, federal spending on R&D in 2007 represented only about 0.22% of GDP, according to the UNESCO Institute for Statistics, and over 96% of this was provided by the government. These statistics should improve as implementation of the *Science, Technology and Innovation Policy* progresses.

Economic diversification an urgent necessity

The president has implemented two schemes to support the economy since 2010:

- With power outages costing the Nigerian economy billions of dollars each year, the president launched a *Roadmap for Power Sector Reform* in 2010. Central to this scheme has been the privatization of the state electricity provider, the Power Holding Company of Nigeria, which has been broken up into 15 different companies.

- In October 2011, the president launched the Youth Enterprise with Innovation in Nigeria (You Win)[18] grant scheme to generate jobs. By 2015, some 3 600 aspiring entrepreneurs between 18 and 45 years had received up to 10 million naira each (US$ 56 000) to help them launch or expand their business, mitigate start-up risks or set up spin-offs from existing businesses. A fledgling ICT business and dental clinic figure among the recipients.

One of the goals of Vision *20:2020* is to diversify the economy, yet, by 2015, oil and gas still accounted for 35% of Nigeria's economic output and 90% of its exports, according to OPEC. With the Brent crude price having more than halved to about US$ 50 since mid-2014, Nigeria has devalued the naira and announced plans to cut public spending by 6% in 2015. More than ever, economic diversification is an urgent necessity.

SENEGAL

A focus on higher education reform

In 2012, Senegal adopted a *National Strategy for Economic and Social Development for 2013–2017*, based on the vision of its *Senegal Emerging Plan*, Senegal's development plan for becoming an upper middle-income country by 2035. Both documents consider higher education and research as a springboard to socio-economic development and thus a priority for reform.

In early 2013, a national dialogue was held on the future of higher education. It produced 78 recommendations that the Ministry of Higher Education and Research has since translated into an action plan entitled *Priority Programme Reform and the Development Plan for Higher Education and Research, 2013–2017* (PDESR). This action plan was adopted in stages by the Presidential Council on Higher Education and Research through 11 presidential decisions taken by the Head of State, including a funding commitment of US$ 600 million over five years.

In its first year of implementation, PDESR created three new public universities: the University of Sine Saloum of Kaolack in central Senegal, specializing in agriculture, the Second University of Dakar, situated 30 km from Dakar and specializing in basic sciences, and the Virtual University of Senegal. Within the plan, a network of vocational training institutes and upgraded laboratories has been developed with the introduction of high bandwidth to connect public universities with one another.

A lot remains to be done, however. There is little synergy in R&D, which suffers from a low budget and inadequate equipment, a low status for researchers and a lack of university–industry linkages. Research results are also insufficiently applied, owing to weak oversight and relatively low scientific output (Figure 18.6).

New governing bodies and an astronomical observatory

The creation of a National Council of Higher Education, Research, Innovation, Science and Technology in 2015 should allow Senegal to meet some of these challenges. It will act as a consultative committee to the Minister of Higher Education and Research and as a monitoring body. The ongoing construction of Senegal's first planetarium and mini-astronomical observatory could also be a sign of a growing science culture.

A law passed in December 2014 should also help to galvanize research. The law creates a governing board for universities. Half of board members must be external to the university, such as from the private sector.

Another new development has been the creation of the Directorate-General for Research in 2014. Placed under the Ministry of Higher Education and Research, it is responsible for planning and co-ordinating research at the national level, especially that conducted by universities and academic research institutes. The ministry relies on the National Agency for Applied Scientific Research, the National Academy of Science and Technology of Senegal and the Senegalese Agency for Intellectual Property and Technological Innovation to promote Senegalese research.

Some national research institutions fall under the authority of other ministries, such as the Institute for Food Technology (Ministry of Mines and Industry), the Senegalese Institute for Agricultural Research and the National Institute for Soil Science (Ministry of Agriculture).

The Ministry of Higher Education and Research runs an extension programme called Centres for Research and Experimentation to promote technology transfer. These centres popularize innovative research that improves social welfare.

Several research funds, including one targeting women

The public sector uses a variety of instruments to fund research:

- the Impulse Fund for Scientific and Technical Research, set up in 1973 and transformed in 2015 into the National Fund for Research and Innovation;
- the Project for Supporting and Promoting Female Teachers and Researchers in Senegal (2013), which only funds women applicants;

18. *See:* www.youwin.org.ng

- the National Fund for Agricultural and Food Research, set up in 1999, which funds research and the commercialization of results for users; and
- the Fund for Scientific and Technical Publications, set up in the 1980s.

SIERRA LEONE

Inclusive, green and middle-income by 2035

Sierra Leone also aspires to become 'an inclusive, green middle-income country by 2035', in the words of the country's *Agenda for Prosperity: the Road to Middle Income Status, 2013–2018*.[19] Current GDP per capita may be only US$ 809 per year but the fact that GDP progressed by 20.1% in 2013 gives cause for hope of realizing this goal. Sierra Leone has, of course, been struggling with the Ebola epidemic. Some 95 health workers have died, a sad reminder of the country's inadequate health facilities: there is just one doctor for 50 000 people.

Among the *Agenda for Prosperity's* objectives to 2035, those which will depend upon science and technology include:

- a health care and delivery system within a 10-km radius of every village;
- modern infrastructure with reliable energy supplies;
- world-standard ICTs (just 1.7% of the population had internet access in 2013);
- private-sector led growth creating value-added products;
- an effective environmental management system in place that protects biodiversity and is capable of pre-empting environmental disasters;
- becoming a model in responsible and efficient natural resource exploitation.

In 2006, the Ministry of Education, Science and Technology engaged a participatory process for the drafting of the *Sierra Leone Education Sector Plan: a Road to a Better Future* (2007–2015). The *Plan* emphasizes human resource development, starting with the bottom of the pyramid. Despite this laudable intention, public expenditure on education only increased from 2.6% to 2.9% of GDP between 2007 and 2012. The share devoted to tertiary education likewise rose little: from 19% to 22% of total expenditure on education (0.7% of GDP in 2012). In the *Plan*, the ministry projected that student enrolment in public universities would rise to about 15 000 by 2015 and to 9 750 in private and distance institutions offering vocational training, including for teachers (MoEdST, 2007).

Fourah Bay College, founded in 1827, is the oldest Western-type university in West Africa. Currently, it is part of the University of Sierra Leone, the country's only university boasting a Faculty of Engineering and a Faculty of Pure and Applied Sciences.

TOGO

A first STI policy

In July 2014, Togo took a major step by developing its first *National Policy for Science, Technology and Innovation* and the action plan for its implementation. In addition, a Presidential Council on the Future of Higher Education and Research was established, following a national consultation. Togo has identified such a wide range of priority research areas that they encompass almost all scientific fields: agriculture, medicine, natural sciences, humanities, social sciences and engineering and technology.

The Ministry of Higher Education and Research is responsible for implementing science policy, in tandem with the Directorate for Scientific and Technical Research, which is in charge of co-ordination and planning.

Togo does not have a biotechnology policy but it does have a framework for biosafety. In April 2014, the Ministry of Environment and Forest Resources organized a consultative workshop to align Togo's revised biosafety law with international biosafety regulations and best practices (Box 18.1).

Togo's main research centres are the Universities of Lomé and Kara, together with the Institute for Agronomic Research, which manages an extension service. To date, though, the country has neither a structure for promoting research and technology transfer, nor any funding to drive it.

The country faces a host of other challenges, including poorly equipped – or even totally unequipped – laboratories, an unattractive working environment for scientists and a lack of information.

CONCLUSION

Research networks need sustainable funding

The overall development goal for ECOWAS countries is to attain lower or upper middle-income status. This ambition permeates their respective development plans and policies. Even for those countries which have moved into the middle-income bracket, there is the fundamental challenge of diversifying the economy and ensuring that wealth creation impacts positively on the lives of all citizens. Development entails building roads and hospitals, expanding railways, installing telecommunications,

19. This document follows on from *Agenda for Change, 2007–2012*.

developing a reliable, responsible energy network, improving agricultural productivity, producing value-added goods, improving sanitation systems and so on. Any one of these areas needs science or engineering, or both.

Countries have made a big effort in recent years to expand their university and research networks. These institutions must not remain empty shells. They must be nurtured, staffed with competent people who have the means to dispense quality education and conduct creative research that is responsive to socio-economic problems and market needs. That necessitates sustainable investment. In this regard, Nigeria's tax on businesses for use in upgrading universities serves as an interesting funding model that could be replicated in other West African countries which host multinationals.

ECOWAS countries are formulating beautifully crafted policies and programmes but these must also be implemented, funded and monitored, so that progress can be measured and future plans adapted to the shifting reality. New scientific programmes are emerging that are well-designed and well-funded, like the African Centres of Excellence (Table 18.1). Hopefully, these programmes will create a momentum that will have a lasting impact on these countries and the wider subregion.

In our view, there are five main challenges for the years to come. West African governments need to:

- invest more in science and engineering education, in order to develop the skilled labour force necessary to become a middle-income country within 20 years; the number of engineers and agricultural researchers is particularly low in most countries;
- establish viable national S&T policies, in other words, policies that are accompanied by an implementation plan that foresees an evaluation of implementation and a relevant funding mechanism for research and the commercialization of results;
- make a greater effort to reach the national target of devoting 1% of GDP to R&D, if they are serious about becoming middle-income countries within 20 years; greater government investment would have the advantage of allowing researchers to work on topics of national interest rather than those proposed by donors;
- encourage the business sector to participate more actively in R&D , in order to stimulate demand for knowledge production and technological development, while reducing budgetary pressure on governments, which tend to bear the greatest funding burden for R&D, along with donors; in this context, governments which have not yet done so should put in place national funds to help local innovators protect their intellectual property rights, as recommended by ECOPOST; other measures could include making provision for representatives of the private sector to sit on the governing boards of universities and research institutes, as Senegal has done (see p. 494), tax incentives to support business innovation, the creation of science and technology parks and business incubators to encourage start-ups and public–private partnerships and research grants to support collaborative research between the government, industry and academia in priority areas;
- foster exchanges and intraregional collaboration among West African researchers, while maintaining partnerships beyond the subregion, in order to ensure the quality and impact of scientific production; the African Centres of Excellence project and the WAEMU centres of excellence offer a golden opportunity for researchers across the region to 'put their heads together' to solve common development problems and respond to market needs.

KEY TARGETS FOR SUB-SAHARAN AFRICA

- Raise GERD to 1% of GDP in all ECOWAS countries;
- Raise the share of public expenditure on agriculture to 10% of GDP in all ECOWAS countries;
- Establish a national fund in each ECOWAS country to help local innovators protect their intellectual property;
- Establish a free trade area and customs union in each regional economic community by 2017 and across the entire continent by 2019;
- A continent-wide African Common Market to be operational by 2023;
- Put in place a continent-wide economic and monetary union by 2028, with a parliament and single currency to be managed by the African Central Bank.

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Most countries have based their long-term planning ('vision') documents on harnessing science, technology and innovation to development.

Kevin Urama, Mammo Muchie and **Remy Twingiyimana**

A schoolboy studies at home using a book illuminated by a single electric LED lightbulb in July 2015. Customers pay for the solar panel that powers their LED lighting through regular instalments to M-Kopa, a Nairobi-based provider of solar-lighting systems. Payment is made using a mobile-phone money-transfer service.
Photo: © Waldo Swiegers/Bloomberg via Getty Images

19 · East and Central Africa

Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo (Republic of), Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Kenya, Rwanda, Somalia, South Sudan, Uganda

Kevin Urama, Mammo Muchie and Remy Twiringiyimana

INTRODUCTION

Mixed economic fortunes

Most of the 16 East and Central African countries covered in the present chapter are classified by the World Bank as being low-income economies. The exceptions are Cameroon, the Republic of Congo, Djibouti and the newest member, South Sudan, which joined its three neighbours in the lower middle-income category after being promoted from low-income status in 2014. Equatorial Guinea is the region's only high-income country but this classification masks great variations in income levels; poverty is widespread and life expectancy at birth is among the region's lowest, at 53 years (Table 19.1).

All but four nations are classified as heavily indebted poor countries, the exceptions being Djibouti, Equatorial Guinea, Kenya and South Sudan. Poverty and high unemployment are endemic in the region. Life expectancy varies between 50 and 64 years, a strong indicator of the developmental challenges facing the region.

The region's economic fortunes have been a mixed bag since 2010. Several countries have managed to raise their GDP growth rates, or at least maintain them at 2004–2009 levels: Burundi, Chad, Comoros, Eritrea and Kenya. Two have sustained some of the highest growth rates in Africa – Cameroon and Ethiopia – and one recorded 24% growth in its first year of existence: South Sudan. Of note is that only two of these countries are oil-exporters: Chad and South Sudan.

Five of the continent's top 12 oil-producing countries are found in East and Central Africa (Figure 19.1). Economic growth is expected to slow down in Africa's oil-exporting countries, following a slump in Brent crude prices since mid-2014, as African exporters have fewer reserves than the Gulf States to tide them over until prices recover. Analysts suggest several explanations for the current drop in value of conventional sources of oil. On the one hand, clean energy policies have fostered the development of more fuel-efficient technology, including in the automotive industry. In parallel, technological developments in hydraulic fracturing (fracking) and horizontal drilling have made it profitable to extract oil from unconventional sources, such as tight rock formations [shale oil in the USA and oil (tar) sands in Canada], deep-sea oil (most countries are now finding deposits) and biofuels (Brazil and others); high global oil prices until recently have allowed countries which invest in these technologies to take a growing share of the global oil market. This highlights the need for oil-producing African countries to invest in science and technology (S&T) to maintain their own competitiveness in the global market.

Half the region is 'fragile and conflict-affected'

Other development challenges for the region include civil strife, religious militancy and the persistence of killer diseases such as malaria and HIV, which sorely tax national health systems and economic productivity. Poor governance and corruption undermine economic activity and foreign investment in several countries. Those which score poorly in Transparency International's Corruption Perceptions Index also tend to rank poorly in the Ibrahim Index of African Governance (Table 19.1): Burundi, Central African Republic, Chad, Republic of Congo, Eritrea, Somalia and South Sudan. Interestingly, both indices consider Rwanda as having the best governance record in East and Central Africa.

Seven countries are classified as 'fragile and conflict-affected' by the World Bank, namely Burundi, Central African Republic, Chad, Comoros, Eritrea, Somalia and South Sudan. In particular, the Central African Republic and South Sudan have experienced civil war in recent years. These conflicts tend to affect their neighbours as well, such as by disrupting trade flows, creating streams of cross-border refugees, or giving rise to cross-border attacks. For instance, South Sudanese have been seeking asylum in Uganda and the Boko Haram (literally, 'books are forbidden') sect in Nigeria has made violent incursions into neighbouring Cameroon and Niger and could threaten the trade route between Cameroon and Chad.

Meanwhile, Kenya's economy has suffered from terrorist attacks by the Somalian Al-Shabaab group which have undermined the country's important tourist industry, in particular. In April 2015, Al-Shabaab massacred 148 students and staff at Garissa University, the only such institution in the north of the country, which had only opened in 2011. Across the border, Somalia is engaged in a fragile process of state- and peacebuilding, its economy in ruins after two decades of political instability and insecurity.

In the Central African Republic, the economy has suffered considerably since late 2012 when rebel groups took control of towns in the centre and north of the country. Despite the deployment of peacekeepers from the African Union, United Nations and France and the signing of a ceasefire in July 2014, the situation remains volatile. For the first decade of the century, the country had experienced positive, albeit erratic, growth.

Table 19.1: **Socio-economic indicators for sub-Saharan Africa, 2014 or closest year**

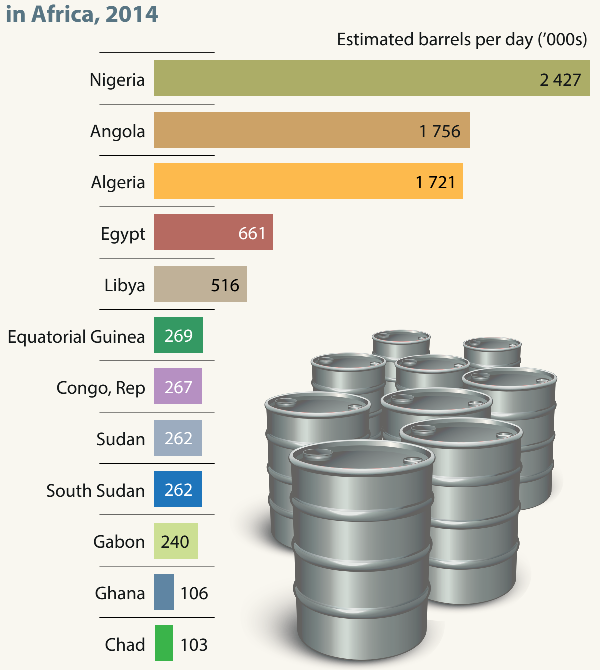
	Population ('000s), 2014	Annual population growth rate (%), 2014	Life expectancy at birth (years), 2013	GDP per capita (current PPP$), 2013	GDP growth rate (%), 2013	No of products accounting for more than 75% of exports, 2012	Ibrahim African governance Index, 2014	Access to improve d sanitation (%), 2011	Access to improved water, (%), 2011	Access to electricity (%), 2011	Internet access per 100 population, 2013	Mobile phone subscriptions per 100 population, 2013
Angola	22 137	3.05	51.9	7 736	6.80	1	44	88.6	93.9	99.4	19.10	61.87
Benin	10 600	2.64	59.3	1 791	5.64	9	18	5.0	57.1	28.2	4.90	93.26
Botswana	2 039	0.86	47.4	15 752	5.83	2	3	38.6	91.9	45.7	15.00	160.64
Burkina Faso	17 420	2.82	56.3	1 684	6.65	3	21	7.7	43.6	13.1	4.40	66.38
Burundi	10 483	3.10	54.1	772	4.59	3	38	41.7	68.8	–	1.30	24.96
Cabo Verde	504	0.95	74.9	6 416	0.54	8	2	–	–	–	37.50	100.11
Cameroon	22 819	2.51	55.0	2 830	5.56	6	34	39.9	51.3	53.7	6.40	70.39
Central African Republic	4 709	1.99	50.1	604	-36.00	4	51	14.6	58.8	–	3.50	29.47
Chad	13 211	2.96	51.2	2 089	3.97	1	49	7.8	39.8	–	2.30	35.56
Comoros	752	2.36	60.9	1 446	3.50	2	30	17.7	87.0	–	6.50	47.28
Congo, Rep.	4 559	2.46	58.8	5 868	3.44	1	41	–	–	37.8	6.60	104.77
Congo, Dem. Rep.	69 360	2.70	49.9	809	8.48	4	40	17.0	43.2	9.0	2.20	41.82
Côte d'Ivoire	20 805	2.38	50.8	3 210	8.70	10	47	14.9	76.0	59.3	2.60	95.45
Djibouti	886	1.52	61.8	2 999	5.00	7	35	61.4^{+1}	92.1^{+1}	–	9.50	27.97
Equatorial Guinea	778	2.74	53.1	33 768	-4.84	2	45	–	–	–	16.40	67.47
Eritrea	6 536	3.16	62.8	1 196	1.33	1	50	9.2	42.6	31.9	0.90	5.60
Ethiopia	96 506	2.52	63.6	1 380	10.49	6	32	2.4	13.2	23.2	1.90	27.25
Gabon	1 711	2.34	63.4	19 264	5.89	1	27	–	–	60.0	9.20	214.75
Gambia	1 909	3.18	58.8	1 661	4.80	4	23	–	75.8	–	14.00	99.98
Ghana	26 442	2.05	61.1	3 992	7.59	6	7	7.0	54.4	72.0	12.30	108.19
Guinea	12 044	2.51	56.1	1 253	2.30	2	42	8.3	52.4	–	1.60	63.32
Guinea-Bissau	1 746	2.41	54.3	1 407	0.33	1	48	–	35.8	–	3.10	74.09
Kenya	45 546	2.65	61.7	2 795	5.74	56	17	24.6	42.7	19.2	39.00	71.76
Lesotho	2 098	1.10	49.3	2 576	5.49	6	10	–	–	19.0	5.00	86.30
Liberia	4 397	2.37	60.5	878	11.31	8	31	–	–	–	4.60	59.40
Madagascar	23 572	2.78	64.7	1 414	2.41	30	33	7.9	28.6	14.3	2.20	36.91
Malawi	16 829	2.81	55.2	780	4.97	5	16	9.6	42.1	7.0	5.40	32.33
Mali	15 768	3.00	55.0	1 642	2.15	2	28	15.3	28.1	–	2.30	129.07
Mauritius	1 249	0.38	74.5	17 714	3.20	35	1	88.9	99.2	99.4	39.00	123.24
Mozambique	26 473	2.44	50.2	1 105	7.44	9	22	8.5	33.6	20.2	5.40	48.00
Namibia	2 348	1.92	64.3	9 583	5.12	8	6	23.6	67.2	60.0	13.90	118.43
Niger	18 535	3.87	58.4	916	4.10	3	29	4.8	34.3	–	1.70	39.29
Nigeria	178 517	2.78	52.5	5 602	5.39	1	37	36.9	45.6	48.0	38.00	73.29
Rwanda	12 100	2.71	64.0	1 474	4.68	5	11	30.2	60.3	–	8.70	56.80
Sao Tome & Principe	198	2.50	66.3	2 971	4.00	6	12	–	–	–	23.00	64.94
Senegal	14 548	2.89	63.4	2 242	2.80	25	9	35.1	59.9	56.5	20.90	92.93
Seychelles	93	0.50	74.2	24 587	5.28	4	5	97.1	96.3	–	50.40	147.34
Sierra Leone	6 205	1.84	45.6	1 544	5.52	4	25	10.9	36.7	–	1.70	65.66
Somalia	10 806	2.91	55.0	–	–	4	52	–	–	–	1.50	49.38
South Africa	53 140	0.69	56.7	12 867	2.21	83	4	58.0	81.3	84.7	48.90	145.64
South Sudan	11 739	3.84	55.2	2 030	13.13	1	–	–	–	–	–	25.26
Swaziland	1 268	1.45	48.9	6 685	2.78	21	24	48.5	38.9	–	24.70	71.47
Tanzania	50 757	3.01	61.5	2 443	7.28	27	19	6.6	55.0	15.0	4.40	55.72
Togo	6 993	2.55	56.5	1 391	5.12	11	15	13.2	48.4	26.5	4.50	62.53
Uganda	38 845	3.31	59.2	1 674	3.27	17	36	26.2	41.6	14.6	16.20	44.09
Zambia	15 021	3.26	58.1	3 925	6.71	3	13	41.3	49.1	22.0	15.40	71.50
Zimbabwe	14 599	3.13	59.8	1 832	4.48	9	46	40.6	79.2	37.2	18.50	96.35

+n = n years after reference year

Note: Not included in the African Governance column of this table are Algeria (20th), Egypt (26th), Libya (43rd), Mauritania (39th), Morocco (14th) or Tunisia (8th).

Source: World Bank's World Development Indicators, April 2015; for exports: AfDB, OECD & UNDP (2014) *African Economic Outlook 2014*; for African Governance Index: Mo Ibrahim Foundation (2014) *Ibrahim Index of African Governance – Country Profiles*: www.moibrahimfoundation.org; for water, sanitation and electricity: WHO, World Bank's World Development Indicators; UNICEF, UNDP and International Energy Agency, compiled by UNESCO

Figure 19.1: **Top 12 crude oil-producing countries in Africa, 2014**



Source: www.eia.gov

South Sudan's economic fortunes have been largely tied to its oil exports, which in turn have fluctuated wildly due to internal unrest and according to the state of political relations with neighbouring Sudan, through which its export pipeline runs. Over the past year, Equatorial Guinea has had to contend with stagnant world oil prices which have held its own GDP in check.

Ethiopia has been the shining star in the region, maintaining its double-digit growth rate over the past few years. Uganda has been another strong performer, although its growth seems to have been somewhat stunted by the slow global recovery from the 2008–2009 financial crisis. Eritrea has made some of the biggest gains, having managed to turn negative growth prior to 2010 into a 4.8% average ever since. On the whole, it does not appear as if the global crisis has had a major lasting impact on economies in the region, although the slowing-down of the Chinese economy since 2014 is a potential cause for concern for resource-exporting countries.

Regional integration can favour development

Most countries in East and Central Africa are still in the early stages of transition from traditional agrarian to modern industrial economies, as evidenced by the generally large contribution of agriculture to GDP (Figure 19.2). Agriculture even contributes more than half of GDP in Central African Republic, Chad and Sierra Leone. Notable exceptions to the rule are the Republic of Congo and Gabon, where the oil industry dwarfs all other economic activities.

Public spending on agriculture tends to be fairly low, at less than 5% of GDP for most countries (Table 19.2). This has obvious implications for expenditure on agricultural R&D as a subset of the total. So far, only three countries have reached the target in the *Maputo Declaration* (2003) of devoting 10% of GDP to agriculture: Burundi (10%), Niger (13%) and Ethiopia (21%). The large proportion of the working population employed in agriculture is another indicator of these countries' levels of development. The lack of economic diversification handicaps both agrarian and fossil-fuel based economies, as they tend to be heavily dependent on natural resources for foreign exchange, in particular.

Public expenditure on health is low in most countries, the exceptions being Burundi (4.4% of GDP), Djibouti (5.3%) and Rwanda (6.5%) in 2013. These same three countries also accord a high priority to education (more than 5% of GDP), as do Comoros (7.6% in 2008), the Republic of Congo (6.2% in 2010) and Kenya (6.7% in 2010).

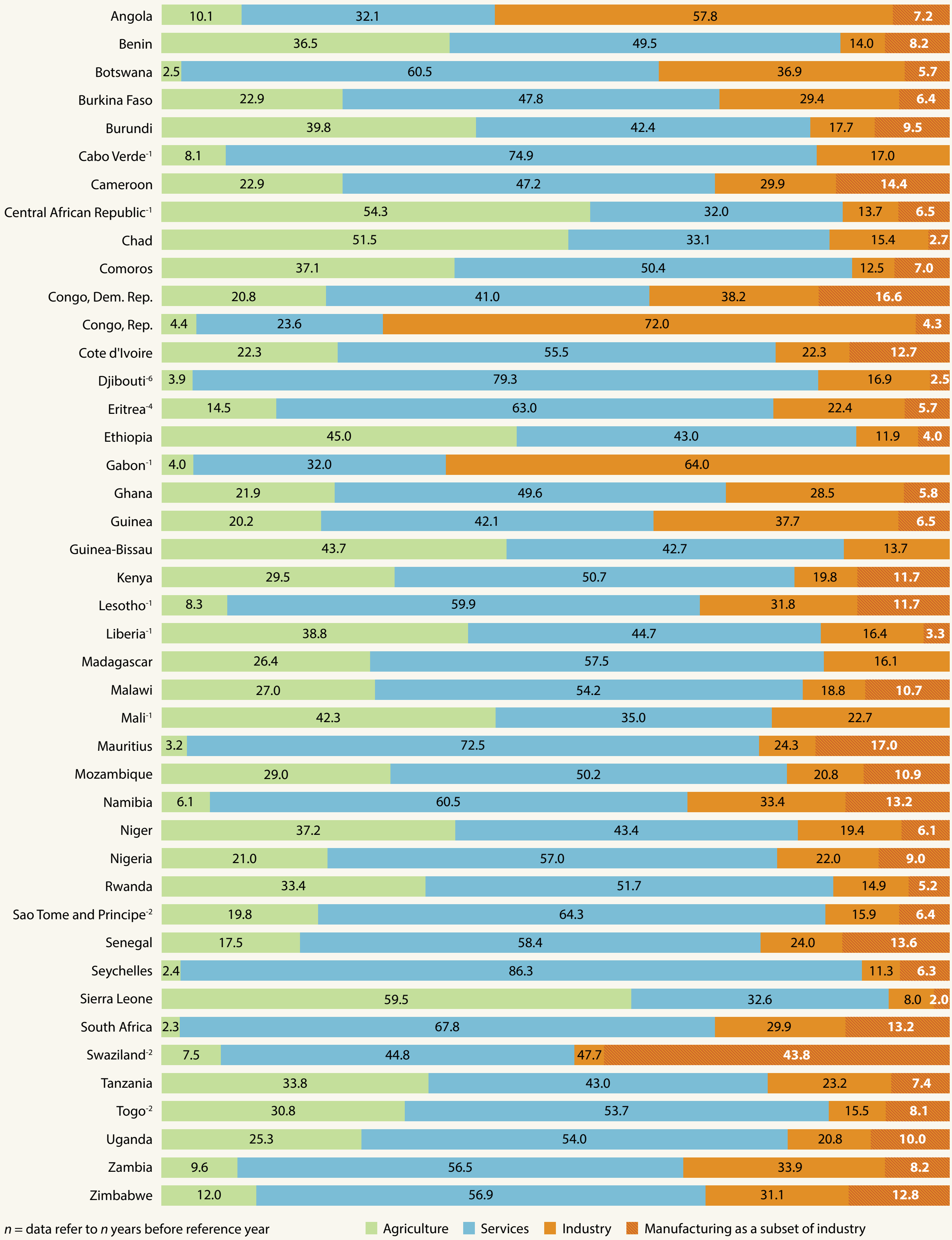
Military expenditure tends to account for less than 2% of GDP in the region, with the notable exception of Chad (2.0% in 2011), Burundi (2.2% in 2013), Central African Republic (2.6% in 2010), Djibouti (3.6% in 2008), Equatorial Guinea (4.0% in 2009) and, above all, South Sudan (9.3% in 2012) [Table 19.2].

The credibility of political institutions and election outcomes remains a major challenge. Owing to instability and governance challenges in East Africa, the region was the continent's lowest recipient of foreign direct investment (FDI) in 2008 and 2009. In 2013, FDI flowed most abundantly into the economies of Djibouti (19.6% of GDP), the Republic of Congo (14.5%) and Equatorial Guinea (12.3%). Whereas the oil industry was the main pole of attraction in the latter two countries, FDI flowed mostly into Djibouti's port area, which is strategically located on trade routes to the Middle East. The region's resource potential is expected to attract greater FDI flows in future. Potential areas for investment include oil and mineral exploration in Chad, Ethiopia, Sudan and Uganda, intensified economic and business reforms led by Rwanda and large infrastructure projects, such as the ongoing construction of the Ethiopian Grand Renaissance Dam and the development of geothermal energy in Kenya (see p. 524).

Intraregional trade is important for many small or landlocked East and Central African economies but it is severely hindered by the poor state of transport infrastructure. A major challenge will be to develop railway and road linkages to ports, so as to better connect countries with one another and the global economy.

Regional integration offers one means of addressing the challenges outlined above. Political co-operation is just as essential as economic co-operation, however, in order to

Figure 19.2: **Composition of GDP in sub-Saharan Africa by economic sector, 2013 (%)**



-*n* = data refer to *n* years before reference year

Note: Data are unavailable for Equatorial Guinea, Gambia, Somalia and South Sudan.

Source: World Bank's World Development Indicators, April 2015

deal with civil, ethnic and cross-border conflicts, as well as to manage access to, and possible disputes over, natural resources that straddle national boundaries, including river catchments. The construction of the Ethiopian Grand Renaissance Dam on the Blue Nile illustrates the importance of intraregional dialogue. Once completed, it will be the largest hydroelectric power plant in Africa (6 000 MW) and the eighth-largest in the world. After Egypt expressed reservations, a Tripartite National Committee was set up with Sudan which met for the first time in September 2014. This led to the signing of a tripartite co-operation agreement in the Sudanese capital on 23 March 2015 which established the principle of energy-sharing by both upstream and downstream countries once the dam is completed. The ten points of the agreement were being debated in Egypt and Ethiopia in mid-2015.

Regional integration also offers an opportunity for greater solidarity in an emergency situation. One illustration of this new paradigm is the decision by the East African Community in October 2014 to send a contingent of 600 health professionals to West Africa, including 41 doctors, to combat the Ebola epidemic (see p. 472).

A step closer to regional integration

There are three main regional economic communities in East Africa: the Common Market for Eastern and Southern Africa (COMESA[1]), the East African Community (EAC) and the Intergovernmental Authority on Development (IGAD). There is quite a lot of overlap, with many member states belonging to more than one regional trade bloc. Djibouti, Eritrea, Ethiopia and Sudan belong to both COMESA and IGAD, for instance, Burundi and Rwanda to both COMESA and EAC and Kenya and Uganda to all three. Some countries also belong to the Southern African Development Community (SADC), such as Tanzania, which is a member of the EAC. This overlap can potentially strengthen regional co-operation, as long as the various blocs co-ordinate their policies. The ultimate goal for the African Union is to develop an African Economic Community by 2023 (see Box 18.2).

The EAC was established in 1967 but collapsed in 1977 before being resuscitated in 2000. COMESA was founded in 1993 as the successor to the Preferential Trade Area for Eastern and Southern Africa. Both founding treaties make provisions for co-operation to develop STI. A number of East and Central African countries have also entered into bilateral co-operation agreements with South Africa in science and technology, most recently Ethiopia and Sudan in 2014 (see Table 20.6).

The Inter-University Council for East Africa (IUCEA) was formally integrated into the operational framework of the EAC by the East African Legislative Assembly in 2009 through the IUCEA Act. IUCEA has been entrusted with the mission of developing a Common Higher Education Area by 2015. In order to harmonize higher education systems in EAC countries, IUCEA established the East African Quality Assurance Network in 2011, which is in the process of developing a regional policy and an East African qualifications framework for higher education. IUCEA also established a partnership with the East African Business Council in 2011 to foster joint research and innovation by the private sector and universities and identify areas for curricular reform. The two partners organized the region's first forum for academia and private firms under the auspices of the EAC in Arusha in 2012 and a second with the East African Development Bank in Nairobi in 2013.

On 1 July 2010, the five EAC members – Burundi, Kenya, Rwanda, Tanzania and Uganda – formed a common market; the agreement provides for the free movement of goods, labour, services and capital. In 2014, Rwanda, Uganda and Kenya agreed to adopt a single tourist visa. Kenya, Tanzania and Uganda have also launched the East African Payment System. On 30 November 2013, the EAC countries signed a Monetary Union Protocol with the aim of establishing a common currency within 10 years.

The EAC *Common Market Protocol* (2010) makes provisions for market-led research, technological development and the adaptation of technologies in the community, in order to support the sustainable production of goods and services and enhance international competitiveness. States are to collaborate with the East African Science and Technology Commission and other institutions to develop mechanisms for commercializing indigenous knowledge and ensuring intellectual property protection. Member states also undertake to establish a research and technological development fund for the purpose of implementing the provisions in the protocol. Other clauses include:

- promoting linkages among industries and other economic sectors within the EAC community;
- promoting industrial R&D and the transfer, acquisition, adaptation and development of modern technology;
- promoting sustainable and balanced industrialization to cater for the least industrialized members;
- facilitating the development of micro-, small and medium-sized (SME) enterprises and promoting indigenous entrepreneurs; and
- promoting knowledge-based industries.

1. For the members of these regional communities, see Annex 1. Tanzania is profiled in Chapter 20 on the SADC countries, see p. 559

Table 19.2: **Investment priorities in sub-Saharan Africa, 2013 or closest year**

	Military expenditure (% of GDP), 2013	Public health expenditure (% of GDP), 2013	Public expenditure on agriculture (% of GDP), 2010	Public expenditure on education (% of GDP), 2012	Government expenditure on tertiary education (% of GDP), 2012	Expenditure on tertiary education (% total public expenditure on education), 2012	FDI inflows (% of GDP), 2013
Angola	4.9	2.5	<5	3.5^{-2}	0.2^{-6}	8.7^{-6}	-5.7
Benin	1.0	2.5	<5	5.3^{-2}	0.8^{-2}	15.6^{-2}	3.9
Botswana	2.0	3.1	<5	9.5^{-3}	3.9^{-3}	41.5^{-3}	1.3
Burkina Faso	1.3	3.7	11	3.4^{-1}	0.8	20.2^{-1}	2.9
Burundi	2.2	4.4	10	5.8	1.2	20.6	0.3
Cabo Verde	0.5	3.2	<5	5.0^{-1}	0.8^{-1}	16.6^{-1}	2.2
Cameroon	1.3	1.8	<5	3.0	0.2	7.8	1.1
Central African Republic	2.6^{-3}	2.0	<5	1.2^{-1}	0.3^{-1}	27.3^{-1}	0.1
Chad	2.0^{-2}	1.3	6	2.3^{-1}	0.4^{-1}	16.3^{-1}	4.0
Comoros	–	1.9	–	7.6^{-4}	1.1^{-4}	14.6^{-4}	2.3
Congo, Rep.	1.1^{-3}	3.2	–	6.2^{-2}	0.7^{+1}	10.9^{-2}	14.5
Congo, Dem. Rep.	1.3	1.9	–	1.6^{-2}	0.4^{-2}	24.0^{-2}	5.2
Côte d'Ivoire	1.5^{-1}	1.9	<5	4.6^{-4}	0.9^{-5}	21.0^{-5}	1.2
Djibouti	3.6^{-5}	5.3	–	4.5^{-2}	0.7^{-2}	16.5^{-2}	19.6
Equatorial Guinea	4.0^{-4}	2.7	<5	–	–	–	12.3
Eritrea	–	1.4	–	2.1^{-6}	–	–	1.3
Ethiopia	0.8	3.1	21	4.7^{-2}	0.2^{-2}	3.5^{-2}	2.0
Gabon	1.3	2.1	–	–	–	–	4.4
Gambia	0.6^{-6}	3.6	8	4.1	0.3	7.4	2.8
Ghana	0.5	3.3	9	8.1^{-1}	1.1^{-1}	13.1^{-1}	6.7
Guinea	–	1.7	–	2.5	0.8	33.4	2.2
Guinea-Bissau	1.7^{-1}	1.1	<5	–	–	–	1.5
Kenya	1.6	1.9	<5	6.6^{-2}	1.1^{-6}	15.4^{-6}	0.9
Lesotho	2.1	9.1	<5	13.0^{-4}	4.7^{-4}	36.4^{-4}	1.9
Liberia	0.7	3.6	<5	2.8	0.1	3.6	35.9
Madagascar	0.5	2.6	8	2.7	0.4	15.2	7.9
Malawi	1.4	4.2	28	5.4^{-1}	1.4^{-1}	26.6^{-1}	3.2
Mali	1.4	2.8	11	4.8^{-1}	1.0^{-1}	21.3^{-1}	3.7
Mauritius	0.2	2.4	<5	3.5	0.3	7.9	2.2
Mozambique	0.8^{-3}	3.1	6	5.0^{-6}	0.6^{-6}	12.1^{-6}	42.8
Namibia	3.0	4.7	<5	8.5^{-2}	2.0^{-2}	23.1^{-2}	6.9
Niger	1.1^{-1}	2.4	13	4.4	0.8	17.6	8.5
Nigeria	0.5	1.1	6	–	–	–	1.1
Rwanda	1.1	6.5	7	4.8	0.6	13.3	1.5
Sao Tome & Principe	–	2.0	7	9.5^{-2}	–	–	3.4
Senegal	0.002	2.2	14	5.6^{-2}	1.4^{-2}	24.6^{-2}	2.0
Seychelles	0.9	3.7	<5	3.6^{-1}	1.2^{-1}	32.5^{-1}	12.3
Sierra Leone	0.001	1.7	<5	2.9	0.7	23.2	3.5
South Africa	1.1	4.3	<5	6.6	0.8	11.9	2.2
South Sudan	9.3^{-1}	0.8	–	0.7^{-1}	0.2^{-1}	25.3^{-1}	–
Swaziland	3.0	6.3	5	7.8^{-1}	1.0^{-1}	12.8^{-1}	0.6
Tanzania	0.9	2.7	7	6.2^{-2}	1.7^{-2}	28.3^{-2}	4.3
Togo	1.6^{-2}	4.5	9	4.0	1.0	26.1	1.9
Uganda	1.9	4.3	<5	3.3	0.4	11.5	4.8
Zambia	1.4	2.9	10	1.3^{-4}	0.5^{-7}	25.8^{-7}	6.8
Zimbabwe	2.6	–	–	2.0^{-2}	0.4^{-2}	22.8^{-2}	3.0

-n/+n: data refer to n years before or after reference year

Source: for education: UNESCO Institute for Statistics; for agriculture: ONE.org (2013) *The Maputo Commitments and the 2014 African Union Year of Agriculture*; for all other variables: World Bank's World Development Indicators, April 2015

Fourteen out of 20 COMESA members have formed a free-trade zone since 2000 (see Box 18.2). This agreement has facilitated trade in the tea, sugar and tobacco sectors, in particular. Intra-industry linkages have also evolved considerably, with trade in semi-manufactured goods among member states having overtaken trade in similar products with the rest of the world. In 2008, COMESA agreed to expand its free-trade zone to include EAC and SADC members. Negotiations are currently under way for a COMESA–EAC–SADC Tripartite Free Trade Agreement by 2016.

The Intergovernmental Authority on Development (IGAD) was created in 1996 to supersede the Intergovernmental Authority on Drought and Development, which had been founded by Djibouti, Ethiopia, Kenya, Somalia, Sudan and Uganda in 1986, after a severe famine. Eritrea and South Sudan joined IGAD after gaining independence in 1993 and 2011 respectively. The IGAD Climate Prediction and Applications Centre, based in Nairobi, Kenya, began life as the Drought Monitoring Centre in 1989, before being fully integrated into IGAD through a related protocol in 2007. In addition to the eight IGAD countries, the centre counts Burundi, Rwanda and Tanzania among its members. More recently, the Regional Centre on Groundwater Resources Education, Training and Research in East Africa was set up at the Kenya Water Institute in Nairobi in 2011, under the auspices of UNESCO.

IGAD's current flagship programme (2013–2027) sets out to develop drought-resilient communities, institutions and ecosystems in the IGAD region by 2027. The seven thrusts of IGAD's Drought Resilience programme are:

- Natural resources and environment;
- Market access, trade and financial services;
- Livelihoods support and basic social services;
- Research, knowledge management and technology transfer;
- Conflict prevention, resolution and peace-building; and
- Co-ordination, institutional development and partnership.

TRENDS IN STI POLICY AND GOVERNANCE

An alignment with the continent's long-term vision

The programmes of COMESA, EAC and IGAD have been aligned with those of *Africa's Science and Technology Consolidated Plan of Action* (CPA, 2005–2014). When implementation of the CPA was reviewed in 2012, on the recommendation of the Fourth African Ministerial Conference on Science and Technology in Egypt (AMCOST, 2013)[2], the reviewers noted that 'the COMESA region has developed an innovation strategy which calls for a strong collaboration between COMESA and the NEPAD Agency and the African Union Commission in implementing the strategy.' They went on to say that 'the CPA has also been used as a template for formulating the science and technology policy for IGAD. In the East African Community, a programme from the CPA has been embedded into the health sector, leading to the launch of the African Medicines Regulatory Harmonization programme in March 2012.'

The SADC and the Economic Community of West Africa (ECOWAS) have also 'domesticated the Plan of Action:' the SADC adopted a *Protocol on Science, Technology and Innovation* in 2008 (see p. 537) and the CPA has informed the formulation of the *ECOWAS Policy on Science and Technology* (see p. 476).

The review of the CPA revealed significant achievements in the following areas:

- Establishment of four networks of centres of excellence within the African Biosciences Initiative (Box 19.1), as well as two complementary networks, Bio-Innovate (Box 19. 1) and the African Biosafety Network of Expertise (see Box 18.1);
- Establishment of a virtual African Laser Centre, which counted 31 member institutions in 2012;
- Establishment of the African Institutes of Mathematical Sciences (see Box 20.4);
- Establishment of the Southern Africa and West Africa Networks of Water Centres of Excellence;
- Launch of the African Science, Technology and Innovation Indicators Initiative;
- Establishment of the African Observatory for Science, Technology and Innovation in Equatorial Guinea;
- Launch of the African Medicines Regulatory Harmonization programme in the EAC in 2012;
- Introduction of African Union Competitive Research Grants administered by the African Union Commission – the first and second calls for research proposals took place in December 2010 and January 2012 for projects in post-harvest technologies and agriculture; renewable and sustainable energy; water and sanitation; fisheries and climate change;

2. This review was conducted by a high-level panel of eminent scientists supported by a group of experts from the African Academy of Sciences, AUC, NEPAD Agency, AfDB, UNECA, UNESCO and the International Council for Science, among others.

Box 19.1: Networks of centres of excellence in biosciences

In 2002, the Biosciences Eastern and Central Africa Network (BecA) became the first of four subregional hubs to be established by NEPAD, with support from the Canadian government. The hubs were set up within the African Biosciences Initiative, a cluster of three programmes for biodiversity science and technology, biotechnology and indigenous knowledge systems.

BecA manages the African Biosciences Challenge Fund, established in 2010. The fund has the dual function of capacity-building and R&D project-funding on a competitive basis. BecA runs training workshops and provides fellowships to scientists and graduate students from African national agricultural research organizations and universities.*

BecA regularly launches calls for researchers interested in implementing their projects over a maximum 12-month period at the network's hub, the International Livestock Research Institute in Nairobi. Priority research areas include improving control of priority livestock diseases; harnessing genetic diversity for conservation, resistance to disease and improved productivity; molecular breeding of important food security crops; plant–microbe interactions; orphan crops; the biological control of crop pests, pathogens and weeds; genomics and metagenomics; climate-smart forage grasses; mixed livestock–crop systems; and soil health.

A number of institutes have offered their facilities to the hub for regional use. These nodes are the University of Buea (Cameroon), Ethiopian Institute of Agricultural Research, National Agricultural Research Organization (Uganda); Kigali Institute of Science and Technology (Rwanda) and the University of Nairobi (Kenya).

BecA has established a wide range of partnerships, including with African Women in Agricultural Research and Development and the Association for Agricultural Research in Eastern and Central Africa. In 2012 and 2013, UNESCO funded the participation of 20 women scientists in the hub's Advanced Genomics and Bioinformatics workshops.

The Bio-Innovate network was set up in 2010 under BecA as a successor of BioEARN. It promotes the use of biosciences to improve crop productivity, smallholder farmers' resilience to climate change and to add value to local bio-resources by increasing the efficiency of the agro-processing industry. Funded by Sweden, the network covers Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda.

An encouraging evaluation

An evaluation of the fund by Dalbert Global Development Advisors published in April 2014 observed that the fund had 'achieved considerable growth and impact, reaching *circa* 500 individual scientists and researchers across the region over the past three years'. Some 30 FTE scientists were due to receive fellowships in 2014, the same number as the previous year. Among the 250 respondents to the evaluators' survey, 90% gave the hub a high score of 4.2 out of five for the quality of the facilities and training. One in three researchers (33%) and 43% of workshop participants between 2010 and 2013 were women, noted the report, a proportion the hub wished to raise to 50%. This offers the hub a 'unique opportunity to provide mentoring opportunities' for women, the report states, recalling that 'the majority of those who produce, process and market Africa's food are women'.

Of some concern was that one in four research staff indicated spending more than 50% of their time on administrative tasks. The report also noted that the hub remained financially vulnerable, with a small number of primary donors and no evidence to suggest that alumni would return in large numbers as fee-paying users of the hub's modern facilities. Up until now, the programme has been supported primarily by the Australian and Swedish governments, the Syngenta Foundation for Sustainable Agriculture and the Bill and Melinda Gates Foundation.

One of four African bioscience networks

From 2005 onwards, NEPAD established three other networks within the African Biosciences Initiative. These are the Southern African Network for Biosciences (SANbio), with its hub at the Council for Scientific and Industrial Research in Pretoria (South Africa); the West African Biosciences Network (WABNet), with its hub at the Institut sénégalais de recherches agricoles in Dakar (Senegal), and; the Northern Africa Biosciences Network (NABNet), based at the National Research Centre in Cairo (Egypt).

Each network has several nodes which co-ordinate R&D in a particular area. Those for SANBio, for instance, are Northwest University in South Africa (indigenous knowledge), the University of Mauritius (bioinformatics), Mauritius National Livestock Research Centre (livestock production), University of Namibia (mushroom production and commercialization for rural communities), University of Malawi–Bunda College (fisheries and aquaculture); and the SADC Plant Genetics Resources Centre in Zambia (gene banking). Research programmes have also been strengthened at other partner institutions within each network.

Source: http://hub.africabiosciences.org; www.nepad.org/humancapitaldevelopment/abi

*from Burundi, Cameroon, Central Africa Republic, Democratic Republic of Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Kenya, Madagascar, Rwanda, São Tomé & Príncipe, Somalia, South Sudan, Sudan, Tanzania and Uganda

- institutionalization of a biennial ministerial forum on STI, in partnership with UNESCO, the African Development Bank (AfDB) African Union Commission and United Nations Economic Commission for Africa (UNECA). The first forum took place in in Nairobi in April 2012, the second in Rabat in October 2014.

The review also identified the following shortfalls in CPA implementation, among others:

- The failure to set up the 'African Science and Technology Fund was one of the landmark and visible weaknesses in implementation of the CPA; the modest achievements recorded should be viewed in this context.' With hardly any governments having raised GERD to the target level of 1% of GDP, more than 90% of funding mobilized for implementation of the CPA came from bilateral and multilateral donors.
- STI priorities ought to have been linked to priorities of other development sectors to enhance impact.
- There should have been a differentiated approach to enable countries with limited human and infrastructural capacity (such as in post-conflict countries) to participate fully in CPA programmes.
- The lack of targets and a robust monitoring and evaluation strategy to track progress in implementation has led to minimal demonstration of the CPA's achievements. There should have been a strong, operational accountability framework for implementing partners.
- There was a limited focus on assessing how research efforts are contributing to solving needs in agriculture, food security, infrastructure, health, human capacity development and poverty reduction.
- Recent research on indigenous knowledge has mainly focused on documentation rather than sustainable exploitation.
- There has been inadequate linkage of the CPA to other continental frameworks and strategies.

Adopted by the African Union in 2014, the *Science, Technology and Innovation Strategy for Africa* (STISA-2024) is the first of five ten-year plans which intend to accelerate Africa's transition to an innovation-led, knowledge-driven economy by the year 2063 (*Agenda 2063*). STISA-2024 focuses on the following six priority areas:

- Eradication of hunger and achieving food security;
- Prevention and control of diseases;
- Communication (physical and intellectual mobility);
- Protecting our space;
- Living together – building society; and
- Wealth creation.

In order to achieve the objectives within these six priority areas, the following four pillars have been defined:

- Upgrading and/or building research infrastructure;
- Enhancing technical and professional competences;
- Innovation and entrepreneurship; and
- Providing an enabling environment for STI development in Africa.

STISA-2024 can learn from the review of the CPA. For instance, the reviewers considered a pan-African fund as being vital to sustain the networks of centres of excellence, encourage creative individuals and institutions to generate and apply science and technology and to promote technology-based entrepreneurship. Although STISA-2024 states that 'it is urgent to set up' an African Science and Technology Innovation Fund, it identifies no specific funding mechanism. Notwithstanding this, the African Union Commission has already heeded another of the review's recommendations by encouraging member countries to align their national and regional strategies on STISA-2024.

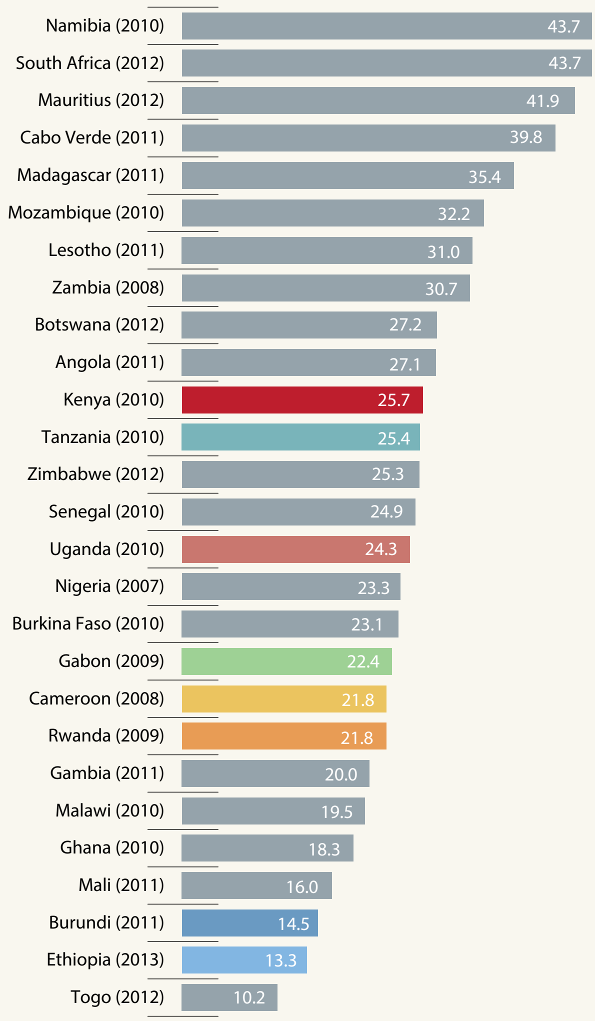
Gender equality on the development agenda

The 2012 review observed that, although the CPA did not have specific programmes in this area, implementing institutions had put initiatives in place to promote the role of women in STI. One initiative they cited were the regional scientific awards for women (US$ 20 000), which recompensed 21 recipients between 2009 and 2012. The EAC, ECOWAS, SADC and the Economic Community of Central African States have all participated in these awards.

A number of governments in East and Central Africa are also promoting gender equality in their policies and development plans. Examples are:

- Burundi's *Vision 2025* promises an energetic policy to promote gender equality and greater participation by women in education, politics and economic development. In 2011, 14.5% of researchers were women (Figure 19.3).
- Chad adopted a *National Policy on Gender* in 2011 which is being implemented by the Ministry of Social Action, Family and National Solidarity.
- In the Republic of Congo, a Ministry for the Promotion of Women and Integration of Women in National Development was established in September 2012.
- Ethiopia's *Growth and Transformation Plan 2011–2015* plans to raise the proportion of women university students to 40%. In 2013, 13.3% of researchers were women (Figure 19.3). The Ethiopian Minister of Science and Technology happens to be a woman, Demitu Hambisa.

Figure 19.3: **Women researchers in sub-Saharan Africa, 2013 or closest year (%)**



Note: Recent data are unavailable for some countries.

Source: UNESCO Institute for Statistics, April 2015

- Gabon adopted a *National Gender Equality and Equity Policy* in 2010. In 2009, 22.4% of researchers were women (Figure 19.3) and, in 2013, 16% of parliamentary seats were held by women (World Bank, 2013).
- In Rwanda, the Ministry of Gender and Family Promotion is situated in the Office of the Prime Minister. Rwanda's 2003 Constitution made provisions for a Gender Monitoring Office, which was established in 2007. The Constitution stipulates that both sexes should occupy no less than 30% of all decision-making bodies, thereby encouraging Rwandan women to compete for senior positions. Women won 51 out of the 80 seats (64%) in Rwanda's 2013 parliamentary elections, confirming Rwanda as world leader for this indicator. In research, however, women remain a minority (21.8% in 2009, Figure 19.3).
- The Government of Kenya produced a policy brief in 2014 on *Mainstreaming Gender in the National STI Policy of Kenya*, in partnership with UNESCO and the African Technology Policy Studies network; the policy brief served as an addendum to the draft National Science, Technology and Innovation Policy of 2012.

The emergence of technology and innovation hubs

In his blog for the World Bank, Tim Kelly observed in April 2014 that 'one of the key features of the African digital renaissance is that it is increasingly home-grown. In other sectors of the African economy, such as mining or agribusiness, much of the know-how is imported and the wealth extracted but Africa's 700 million or so mobile subscribers use services that are provided locally and they are also downloading more applications that are developed locally'.[3]

One of the main sources of locally developed applications are the technology hubs springing up across Africa (Figure 19.4). There are now over 90 such hubs across the continent, which vary in size and composition. Some have served as models, such as iHub in Kenya, BongoHive in Zambia, MEST in Ghana, the Co-creation hub in Nigeria and SmartXchange in South Africa. One of the more recent additions is the Botswana Innovation Hub (see p. 547).

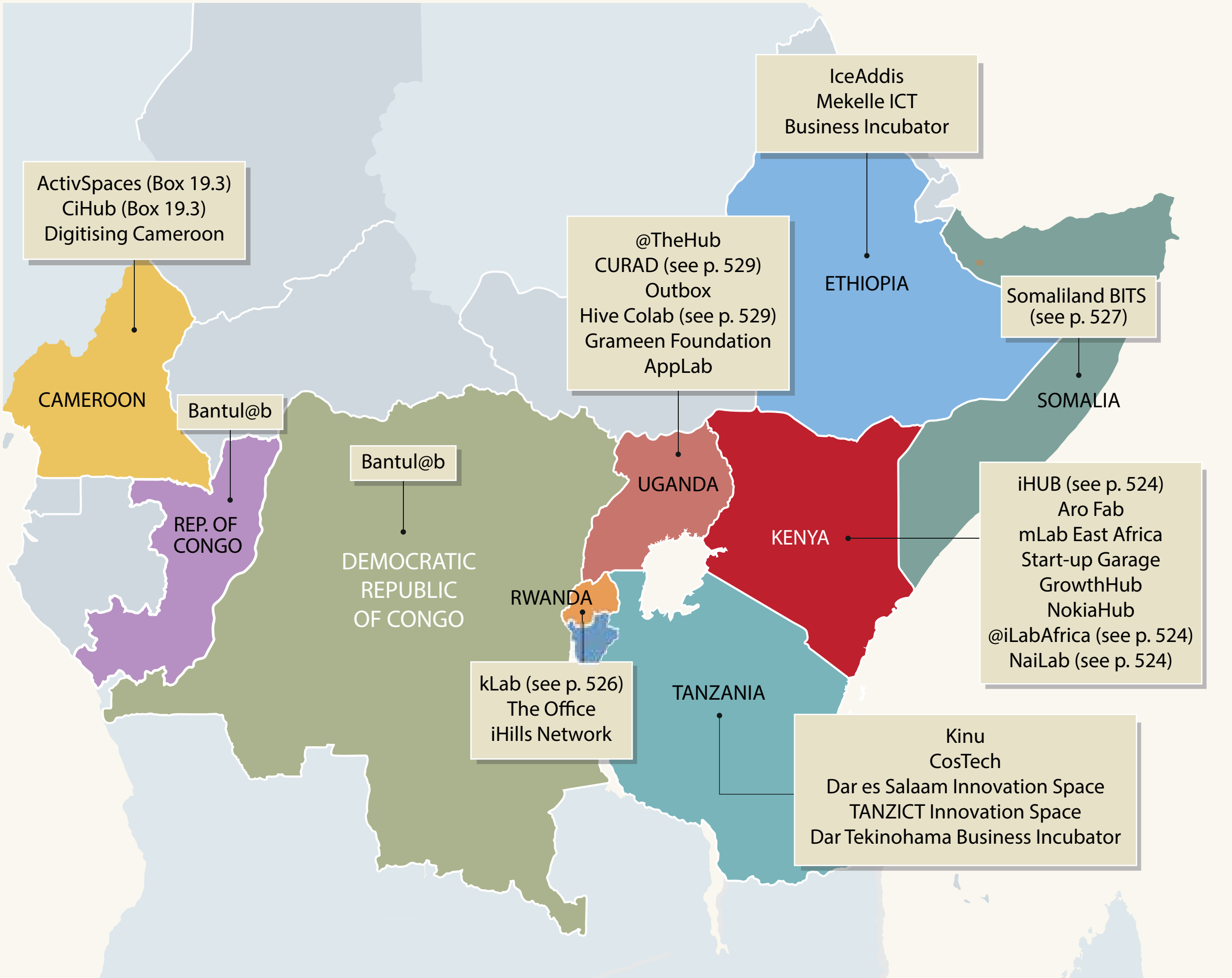
Spiralling from the MPesa, Kenya's money transfer service via a mobile phone, many applications have now been developed for different sectors ranging from agriculture and health to crowd-sourcing weather information for disaster risk reduction. While the impact of these technology hubs is yet to be systematically documented, an early prognosis is that this type of social innovation is already creating more prosperous societies in Africa (Urama and Acheampong, 2013).

Some of the start-ups graduating from incubators are tapping into the mobile phone app and banking revolution that is sweeping across East Africa. One example is MyOrder, an app which effectively enables street vendors to launch mobile web shops, with clients placing orders and making payments by mobile phone. Another app is Tusqee, which makes it possible for school administrators to send pupils' grades to their parents' phones (Nsehe, 2013).

If the start-ups cannot do it alone, neither can the technology incubators. Conscious of the economic impact of innovation, some governments are investing in the development of technology hubs. Kenya even plans to establish hubs in all 47 of its counties (see p.523). This is coherent with the adoption of policies in recent years which encompass innovation by Burundi in 2011, Ethiopia in 2010, Uganda in 2009 and Rwanda in 2005, among others.

3. See: http://blogs.worldbank.org/ic4d/tech-hubs-across-africa-which-will-be-legacy-makers

Figure 19.4: **Technology hubs in East and Central Africa, 2014**



Source: Adapted from iHB Research, World Bank and Bongohive

Persistently low internet penetration

Low internet penetration nevertheless prevents many East and Central African countries from seizing fully the opportunities offered by ICTs for socio-economic development. Penetration rates of less than 7% are found in Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo, Eritrea, Ethiopia and Somalia (Table 19.1). Kenya leads the region for this indicator, having realized the feat of raising internet penetration from 14% to 39% of the population between 2010 and 2013, a compound annual growth rate of 41%.

Mobile phone subscriptions are far more widespread, reaching from one-quarter (Burundi) to more than 200% (Gabon) of the population. Their ubiquity has inspired countless applications for mobile phones.

Prizes for science and innovation

A growing number of national and regional prizes have been introduced recently to encourage research and innovation.

One example is the Olusegun Obasanjo Prize for Science and Innovation, named after the former president of Nigeria and implemented by the African Academy of Sciences. Also of note are the Annual Innovation Awards run by COMESA since February 2014 to celebrate individuals and institutions that have used STI to further the regional integration agenda.

Other actors are establishing prizes. In November 2014, the Moroccan Bank of Trade and Industry announced the creation of the African Entrepreneurship Award, with an endowment of US $1 million. This private bank operates in 18 African countries and around the world. In 2009, the annual Innovation Prize for Africa was established by the African Innovation Foundation, a Zurich-based, non-profit organization; the Innovation Prize is open to all Africans, with prize money valued at US$ 150 000. Now in its fourth year, the prize has been held in Ethiopia, South Africa and Nigeria. So far, it has attracted around 2 000 applications from 48 African countries.

TRENDS IN EDUCATION AND R&D

Generally low public spending on higher education

Public spending on education as a share of GDP varies considerably across the region (Table 19.2). The share of public education spending earmarked for tertiary education ranges from over 25% in some countries to just 3.5% in Ethiopia.

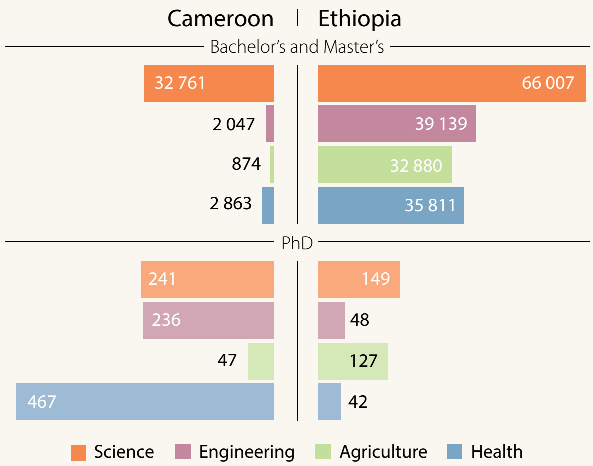
Primary school enrolment rates have grown in recent years in all countries for which data are available (Table 19.3). There is much greater variability in enrolment rates at secondary and tertiary levels; more than half of countries record secondary enrolment rates of less than 30% and, in the others, the enrolment of girls trails that of boys. Female secondary school enrolment rates remain below those of males in all but Rwanda and Comoros. At tertiary level, Cameroon, Comoros and Congo have recorded enrolment rates of over 10% in recent years, whereas Kenya's rate was a disappointing 4% at last count in 2009; Cameroon has recorded particularly rapid progress, raising its enrolment rate from 5.8% in 2005 to 11.9% in 2011. The gender disparity is also evident at tertiary level and is particularly pronounced in the Central African Republic, Chad, Eritrea and Ethiopia, where the male participation rate is more than 2.5 times higher than that for females (Table 19.3).

Data are only available by field of study for Cameroon and Ethiopia but these offer an interesting contrast. In both countries, most of those studying S&T at university were enrolled in scientific disciplines in 2010. The ratio of engineering to science students was much higher in Ethiopia (59%) than in Cameroon (6%). In Ethiopia, enrolment in agriculture was almost as high as in engineering or health sciences, whereas it was by far the least popular field of study in S&T in Cameroon (Figure 19.5), a state of affairs also observed in West and Southern Africa (see Chapters 18 and 20). The CPA review lamented the fact that young African researchers were reluctant to train in fields such as agricultural science which lacked popular appeal and was of the view that 'the shortage of qualified personnel in such fields was a big challenge for the continent.'

A greater R&D effort by some countries

In Kenya, gross domestic expenditure on research and development (GERD) is approaching the CPA target of 1% of GDP; it has also risen in recent years in Ethiopia (0.61%), Gabon (0.58%) and Uganda (0.48%) [Figure 19.6 and Table 19.5].

Figure 19.5: **Science and engineering students in Cameroon and Ethiopia, 2010**



Source: UNESCO Institute for Statistics, May 2015

Table 19.3: **Gross enrolment ratio for education in East and Central Africa, 2012 or closest year**

	Primary			Secondary			Tertiary		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Burundi	138.0	136.9	137.4	33.0	24.2	28.5	4.2^{-2}	2.2^{-2}	3.2^{-2}
Cameroon	117.9	103.2	110.6	54.3	46.4	50.4	13.7^{-1}	10.1^{-1}	11.9^{-1}
Central African R.	109.3	81.3	95.2	3.6	12.1	17.8	4.2	1.5	2.8
Chad	108.2	82.4	95.4	31.2	14.3	22.8	3.6^{-1}	0.9^{-1}	2.3^{-1}
Comoros	105.9^{+1}	99.9^{+1}	103.0^{+1}	62.8^{+1}	65.0^{+1}	63.9^{+1}	10.6	9.1	9.9
Congo, Rep.	105.5	113.4	109.4	57.5	49.8	53.7	12.7	8.0	10.4
Djibouti	73.1	65.9	69.5	49.4	38.1	43.8	5.9^{-1}	4.0^{-1}	4.9^{-1}
Equatorial Guinea	91.8	89.6	90.7	32.8^{-7}	23.6^{-7}	28.2^{-7}	–	–	–
Eritrea	–	–	–	–	–	–	3.0^{-2}	1.1^{-2}	2.0^{-2}
Ethiopia	93.4^{-6}	80.5^{-6}	87.0^{-6}	35.5^{-6}	22.3^{-6}	28.9^{-6}	4.2^{-7}	1.3^{-7}	2.8^{-7}
Kenya	114.1	114.6	114.4	69.5	64.5	67.0	4.8^{-3}	3.3^{-3}	4.0^{-3}
Rwanda	132.3	135.1	133.7	30.8	32.8	31.8	7.8	6.0	6.9
Somalia	37.6^{-5}	20.8^{-5}	29.2^{-5}	10.1^{-5}	4.6^{-5}	7.4^{-5}	–	–	–
South Sudan	102.9^{-1}	68.1^{-1}	85.7^{-1}	–	–	–	–	–	–
Uganda	106.5^{+1}	108.2^{+1}	107.3^{+1}	28.7^{+1}	25.0^{+1}	26.9^{+1}	4.9^{-1}	3.8^{-1}	4.4^{-1}

-n/+n: data refer to *n* years before or after reference year

Note: Gross enrolment includes pupils of all ages, including those below or above the official age for the given level of education. See also glossary, p. 738.

Source: UNESCO Institute for Statistics, May 2015

Table 19.4: **Tertiary enrolment by level of programme in sub-Saharan Africa, 2006 and 2012 or closest years**

	Year	Post-secondary non-degree	Bachelor's and master's	PhD or equivalent	Total tertiary	Year	Post-secondary non-degree	Bachelor's and master's	PhD or equivalent	Total tertiary
Angola	2006	0	48 694	0	48 694	2011	–	–	–	142 798
Benin	2006	–	–	–	50 225	2011	–	–	–	110 181
Botswana	2006	–	–	–	22 257	2011	–	–	–	39 894
Burkina Faso	2006	9 270	21 202	0	30 472	2012	16 801	49 688	2 405	68 894
Burundi	2006	–	–	–	17 953	2010	–	–	–	29 269
Cabo Verde	2006	–	–	–	4 567	2012	580	11 210	10	11 800
Cameroon	2006	14 044	104 085	2 169	120 298	2011	–	–	–	244 233
Central African Rep.	2006	1 047	3 415	0	4 462	2012	3 390	9 132	0	12 522
Chad	2005	–	–	–	12 373	2011	–	–	0	24 349
Comoros	2007	–	–	–	2 598	2012	–	–	0	6 087
Congo, Dem. Rep.	2006	–	–	–	229 443	2012	–	–	–	511 251
Congo, Rep.	–	–	–	–	–	2012	18 116	20 974	213	39 303
Côte d'Ivoire	2007	60 808	–	–	156 772	2012	57 541	23 008	269	80 818
Eritrea	–	–	–	–	–	2010	4 679	7 360	0	12 039
Ethiopia	2005	0	191 165	47	191 212	2012	173 517	517 921	1 849	693 287
Ghana	2006	27 707	82 354	123	110 184	2012	89 734	204 743	867	295 344
Guinea	2006	–	–	–	42 711	2012	11 614	89 559	0	101 173
Guinea-Bissau	2006	–	–	–	3 689	–	–	–	–	–
Kenya	2005	36 326	69 635	7 571	113 532	–	–	–	–	–
Lesotho	2006	1 809	6 691	0	8 500	2012	15 697	9 805	5	25 507
Liberia	–	–	–	–	–	2012	10 794	33 089	0	43 883
Madagascar	2006	9 368	37 961	2 351	49 680	2012	33 782	54 428	2 025	90 235
Malawi	2006	0	6 298	0	6 298	2011	–	–	–	12 203
Mali	–	–	–	–	–	2012	8 504	88 514	260	97 278
Mauritius	2006	9 464	12 497	260	22 221	2012	8 052	32 035	78	40 165
Mozambique	2005	0	28 298	0	28 298	2012	0	123 771	8	123 779
Namibia	2006	5 151	8 012	22	13 185	–	–	–	–	–
Niger	2006	2 283	8 925	0	11 208	2012	6 222	15 278	264	21 764
Nigeria	2005	658 543	724 599	8 385	1 391 527	–	–	–	–	–
Rwanda	2006	–	–	–	37 149	2012	–	–	0	71 638
Sao Tome & Principe	2006	0	0	0	0	2012	0	1 421	0	1 421
Senegal	2006	–	–	–	62 539	2010	–	–	–	92 106
Seychelles	2006	0	0	0	0	2012	–	–	–	100
South Africa	–	–	–	–	–	2012	336 514	655 187	14 020	1 005 721
Swaziland	2006	0	5 692	0	5 692	2013	0	7 823	234	8 057
Tanzania	2005	8 610	39 626	3 318	51 554	2012	–	142 920	386	166 014
Togo	2006	3 379	24 697	0	28 076	2012	10 002	55 158	457	65 617
Uganda	2006	–	–	–	92 605	2011	–	–	–	140 087
Zimbabwe	–	–	–	–	–	2012	26 175	–	–	94 012

Note: Data are unavailable for Equatorial Guinea, Gabon, Gambia, Sierra Leone, Somalia, South Sudan and Zambia.
Source: UNESCO Institute for Statistics, May 2015

The government tends to be the main source of R&D spending but the business enterprise sector contributes more than 10% of GERD in Gabon and Uganda (Table 19.5). Foreign sources contribute a sizeable share of GERD in Burundi (40%), Kenya (47%), Tanzania (42%) and Uganda (57%).

Although two R&D surveys have been published[4] since 2011 within Africa's Science, Technology and Innovation Indicators Initiative, there is a paucity of data on researchers in most of East and Central Africa. According to available data, Gabon and Kenya have the highest density of researchers by head count (Figure 19.7).

Distinct progress for the six most prolific countries

Four countries dominate scientific publishing (Cameroon, Ethiopia, Kenya and Uganda) but productivity is also rising in Gabon, the Republic of Congo and Rwanda, albeit from low levels (Figure 19.8). Gabon, Cameroon and Kenya count the most articles per million inhabitants but it is Ethiopia which has shown the most rapid progress, more than doubling its production since 2005 to take second place behind Kenya in terms of volume; Ethiopia's output remains modest, however, at just nine publications per million inhabitants.

The lion's share of articles focus on life sciences but research is growing in geosciences in Cameroon, Ethiopia, Kenya and Uganda. Of note is that Cameroon has a diverse research portfolio, leading the region for the number of Web of Science articles in chemistry, engineering, mathematics and physics in 2014. Overall, the growth in scientific publications in most countries reflects greater political support for S&T.

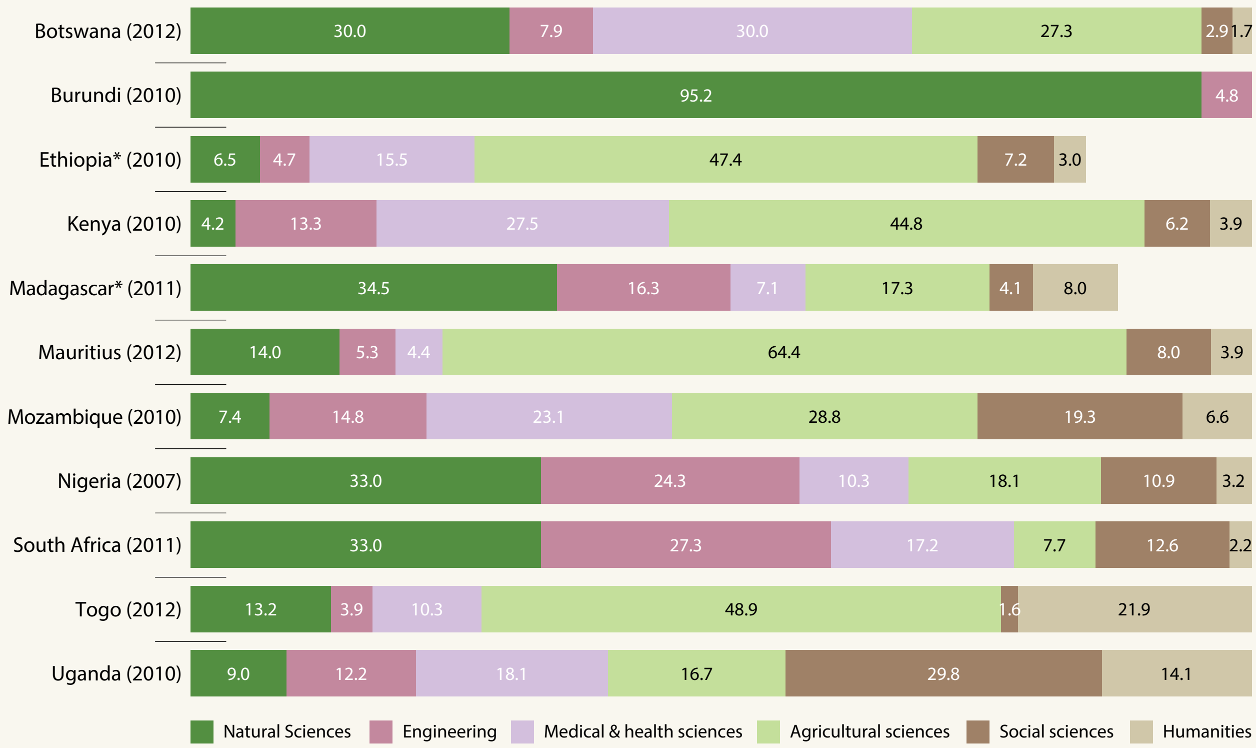
Very few patents since 2010

Only two ECA countries have obtained patents from the United States Patent and Trademark Office in the past five years. Cameroon registered four utility patents (for new inventions) in 2010, followed by three in 2012 and four in 2013. This is a dramatic improvement on the two patents generated by Cameroon in the period 2005–2009. The other country is Kenya; it registered seven utility patents between 2010 and 2013, which is nevertheless a marked decline from the 25 patents it received in the previous five-year period. No other types of patent (design, plant or reissue) have been granted since 2010, indicating that ECA countries continue to struggle to generate and register new inventions.

4. The first surveys were published in the *African Innovation Outlook* in 2011 and 2014. Funds have been secured from Sweden to 2017 for the third edition of the *Outlook*.

Figure 19.6: **GERD in sub-Saharan Africa by field of science, 2012 or closest year (%)**

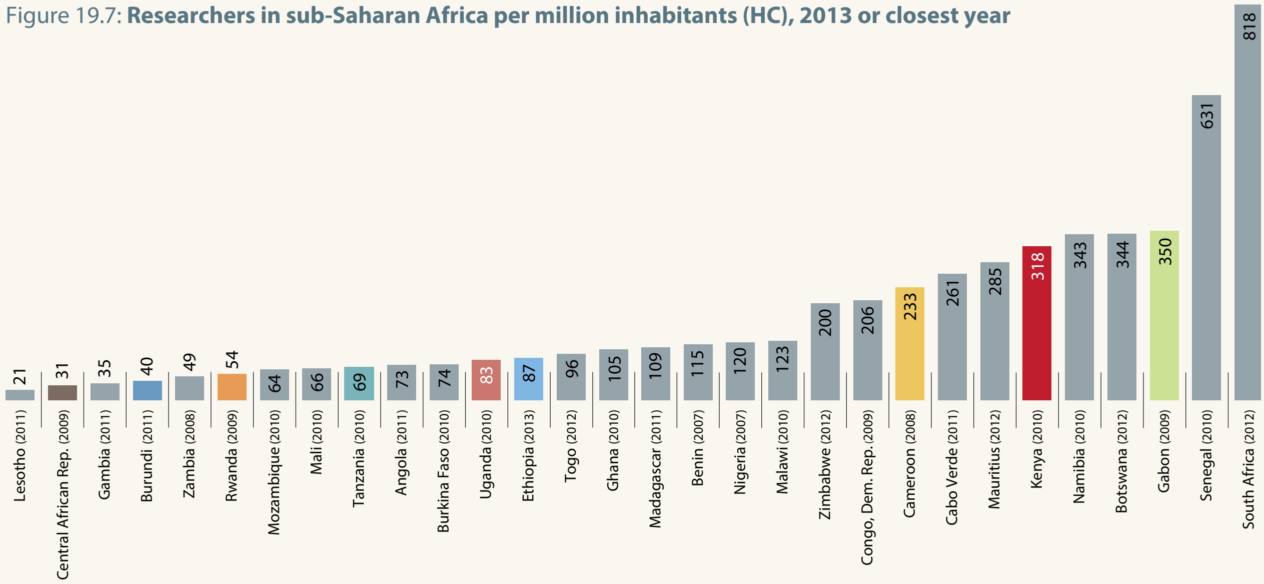
Available countries



*Whenever data do not add up to 100% for this indicator, it is because part of the data remain unattributed.

Source: UNESCO Institute for Statistics, April 2015

Figure 19.7: **Researchers in sub-Saharan Africa per million inhabitants (HC), 2013 or closest year**



Source: UNESCO Institute for Statistics, April 2015

Table 19.5: **GERD in sub-Saharan Africa, 2011**

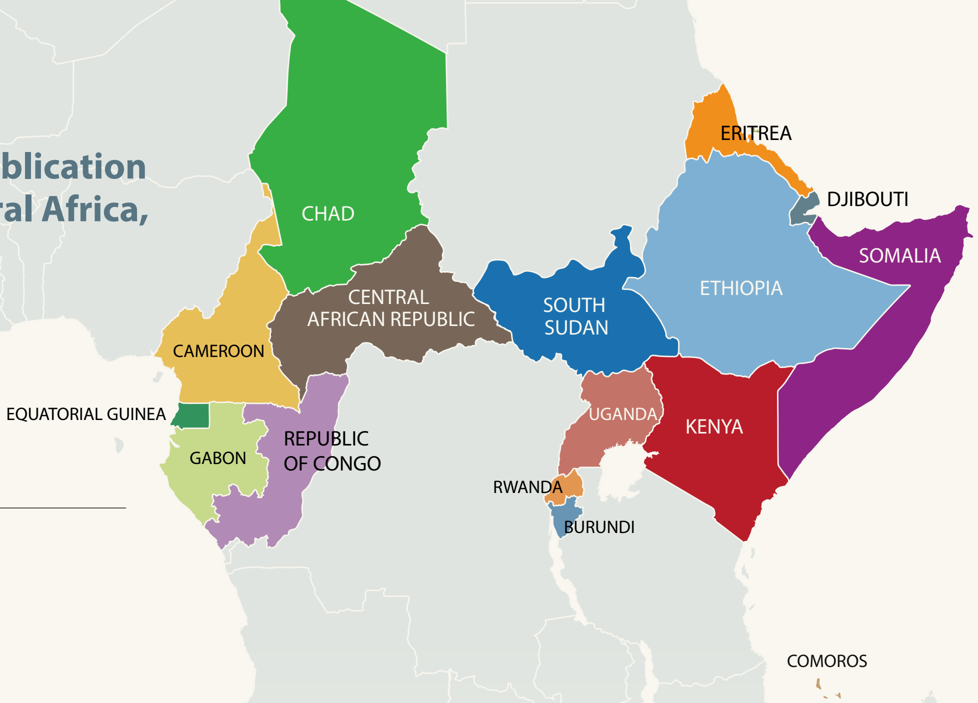
	GERD (% of GDP)	GERD per capita (current PPP$)	GERD per researcher (HC) in current PPP$ thousands	GERD by source of funds (%), 2011*				
				Business	Government	Higher education	Private non-profit	Abroad
Botswana	0.26^{+2}	37.8^{+2}	109.6^{+2}	5.8^{+2}	73.9^{+2}	12.6^{+2}	0.7^{+2}	6.8^{+2}
Burkina Faso	0.20^{-2}	2.6^{-2}	–	11.9^{-2}	9.1^{-2}	12.2^{-2}	1.3^{-2}	59.6^{-2}
Burundi	0.12	0.8	22.3	–	59.9^{-3}	0.2^{-3}	–	39.9^{-3}
Cabo Verde	0.07	4.5	17.3	–	100	–	–	–
Congo, Dem. Rep.	0.08^{-2}	0.5^{-2}	2.3^{-2}	–	100	–	–	–
Ethiopia	0.61^{+2}	8.3^{+2}	95.3^{+2}	0.7^{+2}	79.1^{+2}	1.8^{+2}	0.2^{+2}	2.1^{+2}
Gabon	0.58^{-2}	90.4^{-2}	258.6^{-2}	29.3^{-2}	58.1^{-2}	9.5^{-2}	-	3.1^{-2}
Gambia	0.13	2.0	59.1	–	38.5	–	45.6	15.9
Ghana	0.38^{-1}	11.3^{-1}	108.0^{-1}	0.1^{-1}	68.3^{-1}	0.3^{-1}	0.1^{-1}	31.2^{-1}
Kenya	0.79^{-1}	19.8^{-1}	62.1^{-1}	4.3^{-1}	26.0^{-1}	19.0^{-1}	3.5^{-1}	47.1^{-1}
Lesotho	0.01	0.3	14.3	–	–	44.7	–	3.4
Madagascar	0.11	1.5	13.3	–	100.0	–	–	–
Malawi	1.06^{-1}	7.8^{-1}	–	–	–	–	–	–
Mali	0.66^{-1}	10.8^{-1}	168.1^{-1}	–	91.2^{-2}	–	–	8.8-1
Mauritius	0.18^{+1}	31.1^{+1}	109.3^{+1}	0.3^{+1}	72.4^{+1}	20.7^{+1}	0.1^{+1}	6.4^{+1}
Mozambique	0.42^{-1}	4.0^{-1}	60.6^{-1}	-	18.8^{-1}	–	3.0^{-1}	78.1^{-1}
Namibia	0.14^{-1}	11.8^{-1}	34.4^{-1}	19.8^{-1}	78.6^{-1}	–	–	1.5^{-1}
Nigeria	0.22^{-4}	9.4^{-4}	78.1^{-4}	0.2^{-4}	96.4^{-4}	0.1^{-4}	1.7^{-4}	1.0^{-4}
Senegal	0.54^{-1}	11.6^{-1}	18.3^{-1}	4.1^{-1}	47.6^{-1}	0.0^{-1}	3.2^{-1}	40.5^{-1}
Seychelles	0.30^{-6}	46.7^{-6}	290.8^{-6}	–	–	–	–	–
South Africa	0.73^{+1}	93.0^{+1}	113.7^{+1}	38.3^{+1}	45.4^{+1}	0.8^{+1}	2.5^{+1}	13.1^{+1}
Tanzania	0.38^{-1}	7.7^{-1}	110.0^{-1}	0.1^{-1}	57.5^{-1}	0.3^{-1}	0.1^{-1}	42.0^{-1}
Togo	0.22^{+1}	3.0^{+1}	30.7^{+1}	-	84.9^{+1}	0.0^{+1}	3.1^{+1}	12.1^{+1}
Uganda	0.48^{-1}	7.1^{-1}	85.2^{-1}	13.7^{-1}	21.9^{-1}	1.0^{-1}	6.0^{-1}	57.3-^{1}
Zambia	0.28^{-3}	8.5^{-3}	172.1^{-3}	–	–	–	–	–

-n/+n: data refer to *n* years before or after reference year
*Whenever data do not add up to 100% for this indicator, it is because part of the data remain unattributed.

Note: Data are missing for some countries.

Source: UNESCO Institute for Statistics, April 2015; for Malawi: UNESCO (2014) *Mapping Research and Innovation in the Republic of Malawi* (p. 57)

Figure 19.8: **Scientific publication trends in East and Central Africa, 2005–2014**



11.3%

Share of Kenyan papers among 10% most cited, 2008–2012; the G20 average is 10.2%

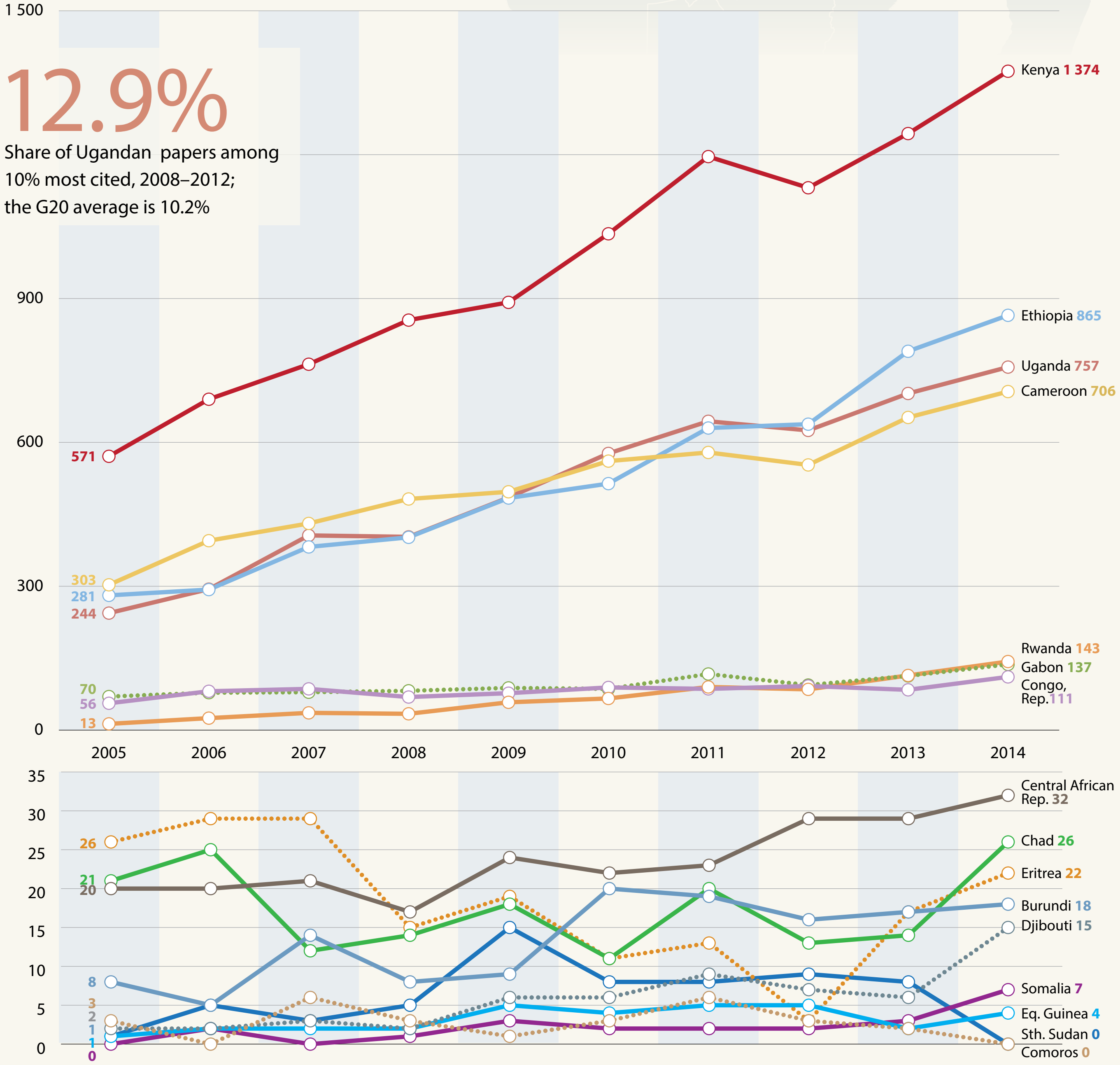
6.3%

Share of Ethiopian papers among 10% most cited, 2008–2012; the G20 average is 10.2%

Kenya, Ethiopia, Uganda and Cameroon produce the most publications

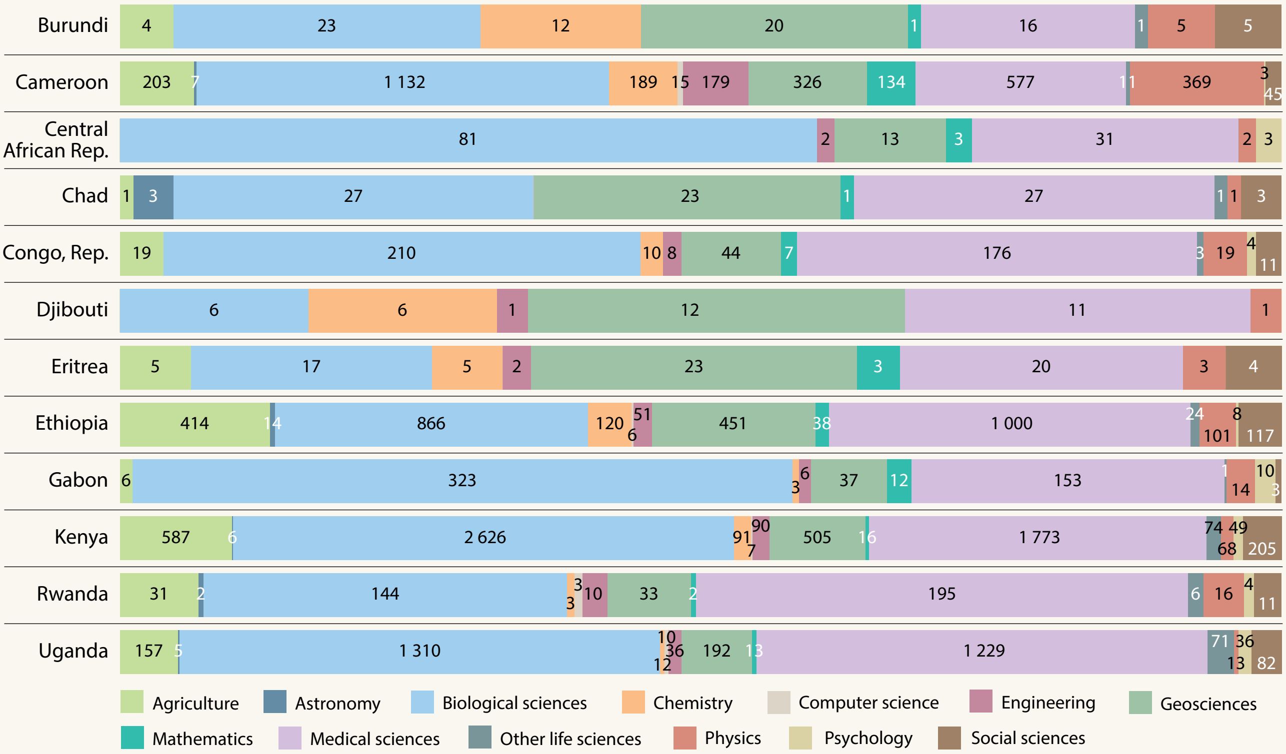
12.9%

Share of Ugandan papers among 10% most cited, 2008–2012; the G20 average is 10.2%



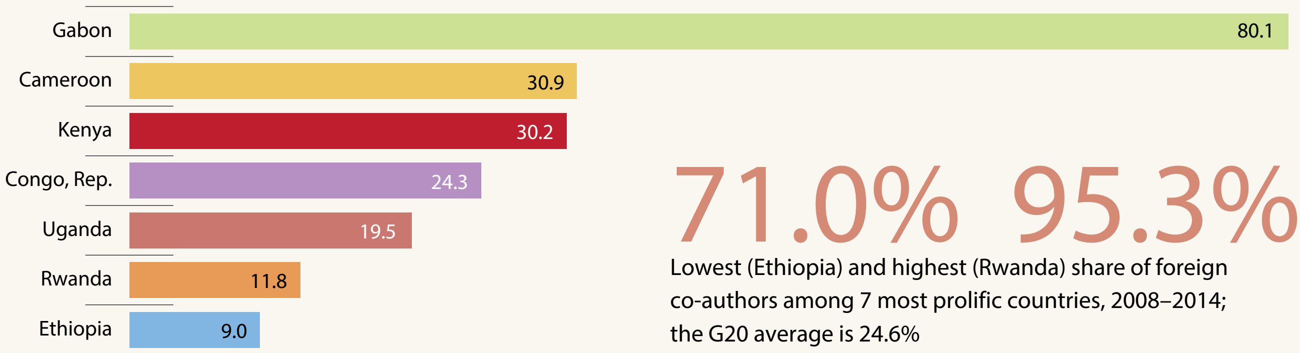
Life sciences dominate research in Central and East Africa

Cumulative totals by field, 2008–2014, for countries which recorded 15 articles or more in the Web of Science in 2014



Gabon was the most productive in 2014

Articles per million inhabitants for the most productive countries



71.0% 95.3%

Lowest (Ethiopia) and highest (Rwanda) share of foreign co-authors among 7 most prolific countries, 2008–2014; the G20 average is 24.6%

Scientists co-author most with partners outside Africa, some also with Kenya and South Africa

Main foreign partners of the 12 countries with the most publications, 2008–2014 (number of papers)

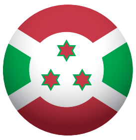
	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Burundi	Belgium (38)	China (32)	USA (18)	Kenya (16)	UK (13)
Cameroon	France (1 153)	USA (528)	Germany (429)	South Africa (340)	UK (339)
Cent. African Rep.	France (103)	USA (32)	Cameroon (30)	Gabon (29)	Senegal (23)
Chad	France (66)	Switzerland (28)	Cameroon (20)	UK/USA (14)	
Congo, Rep.	France (191)	USA (152)	Belgium (132)	UK (75)	Switzerland (68)
Djibouti	France (31)	USA/UK (6)	Canada (5)	Spain (4)	
Eritrea	USA (24)	India (20)	Italy (18)	Netherlands (13)	UK (11)
Ethiopia	USA (776)	UK (538)	Germany (314)	India (306)	Belgium (280)
Gabon	France (334)	Germany (231)	USA (142)	UK (113)	Netherlands (98)
Kenya	USA (2 856)	UK (1 821)	South Africa (750)	Germany (665)	Netherlands (540)
Rwanda	USA (244)	Belgium (107)	Netherlands (86)	Kenya (83)	UK (82)
Uganda	USA (1 709)	UK (1 031)	Kenya (477)	South Africa (409)	Sweden (311)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

Chapter 19

COUNTRY PROFILES

BURUNDI



An STI policy and the launch of R&D surveys
Burundi is a landlocked country with an economy dominated by subsistence agriculture. It has enjoyed a period of political stability and rapid economic development since the end of the civil war a decade ago. The World Bank's *Doing Business* report even named Burundi one of the world's top economic reformers in 2011–2013 for its efforts to streamline business, attract foreign investment and climb out of the league of the world's poorest countries (World Bank, 2013).

In 2010, the Department of Science, Technology and Research was created within the Ministry of Higher Education and Scientific Research to co-ordinate STI across the economy. Burundi then adopted a *National Policy on Science, Research and Technological Innovation* in 2011 (Tumushabe and Mugabe, 2012).

In 2011, Burundi published its *Vision 2025* document. The main targets to 2025 are to:

- achieve universal primary education;
- instigate good governance in a state of law, with regular elections;
- curb population growth from 2.5% to 2% per year to preserve gains in agricultural productivity and arable land, 90% of the population currently living off the land and more than half the population being under 17 years[5] of age;
- halve the current level of poverty (67% of the population) and ensure food security;
- improve the country's capacity to absorb the latest technology, in order to foster growth and competitivity;
- raise GDP per capita from US$ 137 in 2008 to US$ 720 and ensure annual economic growth of 10%;
- expand the urbanized population from 10% to 40% to preserve land;
- make environmental protection and the rational use of natural resources a priority.

The EAC Secretariat commissioned an assessment in 2011, in order to designate five centres of excellence in the community for EAC funding. The National Institute of Public Health in Burundi was one of the five; it provides training, diagnosis and research (Box 19.2).

5. The annual population growth rate in Burundi had accelerated to 3.1% by 2014, see Table 19.1.

Box 19.2: African centres of excellence in biomedical sciences

The EAC commissioned a study in 2011 which designated 19 centres of excellence from five EAC partner states. In October 2014, the 10th ordinary meeting of the EAC Sectorial Council of Ministers responsible for Health selected five of these centres for first-phase EAC funding, namely: the National Institute of Public Health (Burundi), Rift Valley Technical Training Institute (Kenya), University of Rwanda,* Uganda Industrial Research Institute and *Taasisi ya Sanaa na Utamaduni Bagamoyo* (Tanzania).

Complementing the EAC project, the African Development Bank (AfDB) approved bilateral loans in October 2014 amounting to US$ 98 million to finance the first phase of its own East Africa's Centres of Excellence for Skills and Tertiary Education in Biomedical Sciences programme.

The AfDB project will contribute to developing a highly skilled labour force in biomedical sciences to meet the EAC's immediate labour market needs and support implementation of EAC's 'free' labour market protocols. One potential area for growth is medical tourism.

The first phase of the AfDB project will support the creation of specialized centres of excellence in nephrology and urology in Kenya, cardiovascular medicine in Tanzania, biomedical engineering and e-health in Rwanda and oncology in Uganda. During the project's second phase, a centre of excellence will open in Burundi in nutritional sciences. The East Africa Kidney Institute will operate as part of the University of Nairobi and its teaching hospital, Kenyatta National Hospital. The other centres of excellence will be established at the University of Rwanda's College of Medicine and Health Sciences, the Uganda Cancer Institute and, in Tanzania, at Muhimbili University of Health and Allied Sciences. Some 140 master's and 10 PhD students will benefit from the programme, as well as 300 interns.

The centres of excellence will be expected to collaborate with internationally renowned establishments to develop quality curricula, joint research, promote inter-university exchanges and mentoring programmes and to give access to documentary resources.

*formerly the Kigali Institute of Science and Technology

Source: AfDB press release and personal communication; authors

Since joining the African Science, Technology and Innovation Indicators Initiative in August 2013, Burundi has been conducting national surveys of research and innovation to inform policy-making.

CAMEROON

Developing ICTs to catch up

In September 2007, the National Agency for Information and Communication Technologies published the *National Policy for the Development of Information and Communication Technologies*. Several programmes and projects were established under this policy for the post-2010 period, including (IST-Africa, 2012):

- a training programme for state personnel working in ICTs;
- measures to enhance the legal, regulatory and institutional framework governing ICTs, in order to provide a competitive environment for companies offering electronic communications services, catalyse innovation and promote service diversification and cost reduction; and
- an upgrade of the telecommunications network, such as fibre-optic cables.

The policy has spawned the following initiatives to promote the deployment of ICTs, among others (IST-Africa, 2012):

- the Ministry of Scientific Research and Innovation has issued an action plan for an information and knowledge society;
- the Ministry of Higher Education has implemented an ICT development programme in tertiary institutions;
- the Ministry of Secondary Education has built multimedia resource centres at secondary schools;
- mandatory ICT-related programmes have been introduced in primary and secondary schools; and
- the Prime Minister's Office has implemented a National Governance Programme.

The policy's implementation has nevertheless been hampered by a lack of financial resources, the inadequate synergy between the government and external partners and the weak state capacity for project management. Between 2007 and 2013, internet penetration spread only from 2.9% to 6.4% of the population. Despite this, two innovation hubs have been set up in recent years (Box 19.3).

The government is also supporting companies and fostering linkages between research and professional communities, in order to develop an indigenous ICT sector to realize the country's *Vision 2035.* Adopted in 2009, this planning document aims to turn Cameroon into a newly industrialized country by 2035. *Vision 2035* estimates that the informal sector represents 80–90% of the economy. Targets include:

- raising the share of manufacturing from 10% to 23% of GDP (it had almost reached 14% by 2013, see Figure 19.2);
- reducing the share of products from forestry, agriculture and aquaculture from 20.5% to 10% of exports by developing manufacturing;
- raising investment from 17% to 33% of GDP to drive technological development;
- expanding the number of tractors from 0.84 per 100 hectares to 1.2 per hectare;
- raising the proportion of doctors from 7 to 70 per 100 000 inhabitants; similar progress is to be realized among teachers, including in engineering fields: ICTs, civil engineering, agronomists, etc.;

Box 19.3: **ActivSpaces and CiHub: giving start-ups a head-start in Cameroon**

One important complementary scheme to government initiatives has been the creation of community technology and innovation hubs. A pioneer in this field is ActivSpaces; it provides facilities for web and mobile programmers, designers, researchers and entrepreneurs at co-working spaces in two Cameroonian cities, Douala and Buea. The hub aims to promote African-made technology, innovation and entrepreneurship, especially among youth and women.

Since 2015, ActivSpaces has been offering a six-month incubator or accelerator programme called Activation Bootcamp, which provides entrepreneurs with legal advice, mentorship, assistance in registering a start-up company and financial seeding, in return for a 5% share of equity in the venture. ActivSpaces also hosts various events, including a Demonstration Day to allow bootcamp participants to showcase their products and services.

Another innovation hub and incubator, the Cameroon Innovation Hub (CiHub), provides a launchpad for young tech entrepreneurs to develop start-ups based on internet and mobile technology to help address the country's social challenges. CiHub facilitates interactions among developers, entrepreneurs, companies and universities.

Source: compiled by authors

- raising the share of secondary and tertiary students specializing in S&T subjects from 5% to 30%;
- reducing the annual population growth rate from 2.8% to 2.0% through economic development and the emancipation of women, which will in turn encourage family planning;
- increasing access to drinking water from 50% to 75% of the population; and
- doubling energy consumption, mainly through the development of hydropower and gas.

CENTRAL AFRICAN REPUBLIC

The priority: getting child refugees back to school

The civil war since 2012 has severely disrupted the country's social fabric, generating an estimated 200 000 displaced persons. Since President Bozizé fled the country in 2013, first Michael Djotodia then Catherine Samba-Panza have served as interim president, Ms Samba-Panza since January 2014.

With a fragile ceasefire agreement in place since July 2014 and international peacekeepers on the ground, the country has begun rehabilitating infrastructure. The current transitional government and the Ministry of National Education and Higher Education and Scientific Research have been given the mandate of promoting STI for the recovery and sustainable development of the country. The ministry's top priority, however, is to resuscitate the education system from primary to university levels. The greatest challenge facing the education sector are the many school-age children living in refugee camps, compounded by the exodus of educated people, including teachers and professors.

CHAD

Plans to diversify mining

In recent years, Chad has suffered from flooding and drought, as well as conflict on its borders. Relations with Sudan improved after the signing of a non-aggression pact in 2010 but instability in Libya, Nigeria and Central African Republic since 2012 has forced it to raise its defence budget to handle a flood of refugees and counter growing cross-border threats, including that posed by the Boko Haram sect.

The economy has become dependent on oil over the past decade. This has produced erratic growth patterns as oil production has fluctuated. Chad hopes to double production in 2016, thanks to increased output from its Mangara and Badila fields, which are operated by the mining company Glencore Xstrata, and a new field managed by a subsidiary of the China National Petroleum Corporation (CNPC). According to the Minister of Finance, Kordje Bedoumra, Chad has commissioned consultancy firms from France and the Russian Federation to inventory potential mineral deposits of gold, nickel and uranium, in an effort to diversify the economy (Irish, 2014).

Chad is one of the world's least developed countries, ranking 183rd in the 2012 Human Development Index. Despite improvements in school attendance and access to clean drinking water (Tables 19.3 and 19.1), many Chadians still face severe deprivation and most Millennium Development Goals will not be met, according to the World Bank.

Chad has no specific STI policy. However, the law of 2006 mandates the Ministry of Higher Education and Scientific Research to co-ordinate STI.

COMOROS

Mobile phone technology fairly developed

The three small islands which make up Comoros group a population of 752 000, half of whom are under the age of 15. The economy is agrarian (37.1% of GDP), with manufacturing accounting for just 7% of national income. Although less than 7% of the population had access to internet in 2013, nearly one in two inhabitants (47%) subscribed to a mobile phone. Improved sanitation reaches only 17% of the population but 87% have access to clean water (Table 19.1).

In 2008, Comoros devoted a relatively large share of GDP to education (7.6%), one-sixth of which went to higher education (Table 19.2). One in ten (11%) young people attend the country's single public university, the University of Comoros, founded in 2003. By 2012, the university had a student roll of over 6 000, double that in 2007, but no PhD students (Table 19.4).

REPUBLIC OF CONGO

A push to modernize and industrialize

The Republic of Congo was the world's fourth fastest-growing economy in 2010, according to the World Bank. The government plans to turn Congo into an emerging economy by 2025, through *Vision 2025*. Adopted in 2011, this document foresees the diversification and modernization of the economy, which is heavily dependent on oil, and the development of secondary and tertiary education to provide the necessary skills base. To promote the rule of law, emphasis is being laid on strengthening participatory and inclusive democracy. There are programmes to develop physical (transportation) and virtual (ICTs) connections to domestic and foreign markets. Two key infrastructure projects are under way, the construction of a dam at Imboulou (120 MW) and the rehabilitation of the Congo Ocean railway.

Within a three-year agreement signed in December 2014, UNESCO is helping Congo to reinforce research and innovation by mapping Congo's STI ecosystem and developing instruments to ensure better policy implementation and a better status for researchers. One obstacle to innovation has been the lack of awareness of intellectual property rights, which has led to new knowledge being patented by better-informed competitors (Ezeanya, 2013). In 2004, Congo had requested UNESCO's support for the development of a national science and technology[6] policy. This led to the adoption of an action plan for 2010–2016. The new agreement reinforces existing programmes by focusing on modernization and industrialization.

To reflect the importance accorded to STI, the Ministry of Scientific Research and Technological Innovation has been separated from the Ministry of Higher Education, the Ministry of Primary and Secondary Education and the Ministry of Technical and Vocational Education. In January 2012, the Ministry of Scientific Research and Technological Innovation entered into a partnership with the Congolese company ISF Technologies to develop and integrate ICT solutions with business intelligence to optimize the performance of enterprises.

In Congo, university–industry ties tend to spring from initiatives by individual universities to support small enterprises. For example, the private non-profit ICAM School of Engineering in Pointe-Noire and Douala established a programme in November 2013 offering SMEs technical support.

DJIBOUTI

Education a priority

Expenditure on public education accounted for 4.5% of GDP in 2010. Schooling is free and seven out of ten children now attend primary school, although the ratio is higher for boys than for girls (Table 19.3). Until the founding of the University of Djibouti in 2006, students had to go abroad to study and could apply for a government sponsorship, a situation which fostered brain drain. In May 2014, the university launched an e-campus in the presence of the Minister of Higher Education and Research. The university plans to organize an international seminar on geohazards in early 2016. It is currently establishing an observatory to monitor climate change in East Africa, in collaboration with Yale University and the Massachusetts Institute of Technology in the USA.

Eight out of ten citizens work in the services sector, with manufacturing accounting for just 2.5% of GDP in 2007 (Figure 19.2). Djibouti's transformation into a modern hub is increasingly dependent on how well it can acquire technology from the global economy and adapt this to its level of development. FDI comes mainly from the Middle East and is high (19.6% of GDP in 2013) but tends to flow to the country's strategic port on the Red Sea. Investment projects with the potential for technology transfer and local capacity-building need strengthening. Greater statistical capability in STI indicators would also help the government to monitor improvements in this area.

Since joining the World Intellectual Property Organisation in 2002, Djibouti has enacted a law on the Protection of Copyright and Neighbouring Rights (2006) and a second law on the Protection of Industrial Property (2009).

EQUATORIAL GUINEA

International commitment, little domestic output

Founded in 1995, the National University of Equatorial Guinea is the country's main tertiary institution. It has faculties of agriculture, business, education, engineering, fisheries and medicine.

In 2012, President Obiang Nguema Mbasogo made funds available for the UNESCO–Equatorial Guinea International Prize for Research in the Life Sciences. In addition to rewarding research undertaken by individuals, institutions or other entities, the prize promotes the establishment and development of centres of excellence in the life sciences. The fact that the prize is international in character rather than aimed at citizens of Equatorial Guinea has attracted criticism within the country, which has high levels of poverty, despite being classified as a high-income country thanks to its oil-rent economy.

In February 2013, Equatorial Guinea applied to the African Union to host the African Observatory for Science, Technology and Innovation, the mandate of which is to collect data on the continent's STI capabilities. Having offered US$ 3.6 million and being the only applicant, Equatorial Guinea won the bid. Progress in establishing the facility has since been hampered by various administrative and political obstacles.

6. For details of UNESCO's work with the Republic of Congo since 2004, see the *UNESCO Science Report 2010*.

Despite these two high-profile international commitments, there is little information available on STI policy and implementation in Equatorial Guinea and, somewhat ironically, the country does not participate in STI data surveys. The Web of Science catalogued just 27 scientific articles from Equatorial Guinea between 2008 and 2014, placing Equatorial Guinea on a par with Comoros and Somalia for this indicator (Figure 19.8).

ERITREA

Urgent development challenges

Eritrea faces numerous development challenges. Just 0.9% of the population had access to internet in 2013 and 5.6% a mobile phone subscription (Table 19.1). There is also little access to improved sanitation (9%) and clean water (43%). To compound matters, the population is growing at one of the fastest rates in sub-Saharan Africa: 3.16% in 2014 (Table 19.1).

Two-thirds of the population worked in the services sector in 2009. With gold accounting for 88% of exports in 2012 (see Figure 18.1), there is an urgent need to diversify the economy to ensure sustainability and attract FDI, which contributed just 1.3% of GDP in 2013. Economic growth has been erratic, attaining 7.0% in 2012 but only 1.3% in 2013.

The Eritrea Institute of Technology is the main institution for higher studies in science, engineering and education. The facilities and capacity of the institute are continually being upgraded, thanks to largely external funding, although the Ministry of Education also contributes. The number of students graduating each year is rising steadily but from a low starting point. In 2010, just 2% of the 18–23 year-old cohort was enrolled in university and there were not as yet any PhD students (Tables 19.3 and 19.4). The number of Eritrean publications in the Web of Science dropped from 29 in 2006 to 22 in 2014 (Figure 19.8).

The National Science and Technology Council (NSTC), Eritrean Science and Technology Development Agency (ESTDA) and National Science and Technology Advisory Board were all established in 2002. The NSTC is responsible for the formulation, review and approval of policies but no specific S&T policy has been published since 2002, as far as can be ascertained. ESTDA is an autonomous corporate body with two main objectives: to promote and co-ordinate the application of S&T for development under the guidance of NSTC and to build the national capability for R&D.

ETHIOPIA

An ambitious plan for growth and transformation

For the past decade, Ethiopia has enjoyed some of the fastest economic growth in Africa among agrarian economies. The government is now focusing on modernization and industrialization to realize its ambition of turning Ethiopia into a middle-income economy by 2025.

The government recognizes that STI will be a prerequisite for realizing its *Growth and Transformation Plan for 2011–2015*. A government report has since mapped progress over the first two years of implementation (MoFED, 2013):

- improved crop and livestock productivity and soil and water preservation through research;
- greater generation and dissemination of geoscience data and more problem-solving research related to mining;
- the development of alternative construction technologies for road-building;
- the start of construction of a national railway network;
- sustainable technology transfer in medium and large-scale manufacturing industries to improve their export capacity, fostered through privatization and measures to attract foreign investors: by 2012, this sub-sector had registered growth of 18.6%, close to the target of 19.2%; there was 13.6% growth in value-added industrial products by 2012 but export earnings from textiles, leather goods, pharmaceuticals and agroprocessing have been disappointing, owing to low productivity and inadequate technological capability, a lack of inputs and other structural problems;
- the development of renewable energy, including through the Ashegoda and Adama-2 wind energy projects, the Great Ethiopian Renaissance Dam on the Blue Nile and the ongoing development of biofuel plants (jatropha, caster, etc.) on 2.53 million hectares of land;
- the development of a *Climate Resilient Green Economy Vision and Strategy*, as well as the enforcement of compliance with environmental laws and capacity-building in the mitigation of greenhouse gases;
- the number of tertiary-level students rose from 401 900 to 693 300 between 2009 and 2011; the target is for 40% of students to be women by 2015;
- a national survey of research and innovation in 2011–2012 found that 0.24% of GDP was being devoted to GERD, the same level as in 2009. The survey also inventoried 91 researchers per million population;

In parallel, the *National Science and Technology Policy* (2007) has been revised with UNESCO support, in order to take the following considerations into account:

- the transformation of the Ethiopian economy from a centralized to an open market economy, with concomitant political power decentralization;
- global advances in the understanding and application of STI and rapid socio-economic changes at national level;
- the imperative of developing a national STI capability, in order to seize the opportunities offered by global progress in scientific knowledge and technology; and
- the fragmented, unco-ordinated and uneconomic use of limited resources which characterized STI at the time.

The revised *National Science, Technology and Innovation Policy* has been operational since 2010. It seeks to 'build competitiveness through innovation.' Its strengths include upgrading the Science and Technology Commission to ministerial level with a consequential name change to Ministry of Science and Technology, advocating an annual government allocation of at least 1.5% of GDP for STI in all sectors and the creation of a centralized innovation fund for R&D resourced from a contribution of 1% of the annual profits realized in all productive and service sectors. As of mid-2015, neither the annual government allocation, nor the innovation fund were yet operational. The GERD/GDP ratio has risen, though, to 0.61% of GDP in 2013 (Figure 19.9), according to the UNESCO Institute for Statistics, which also reported a steep increase in the proportion of women researchers from 7.6% to 13.3% between 2010 and 2013.

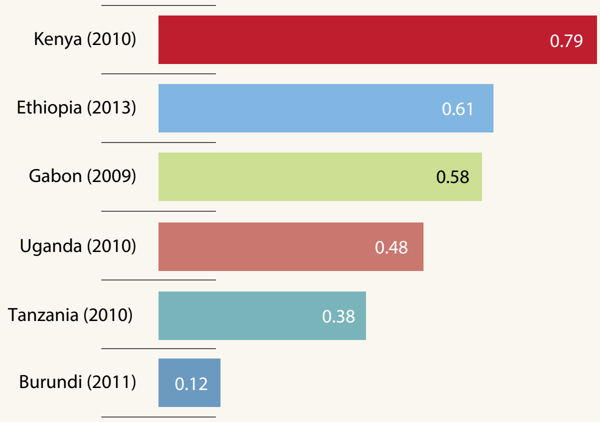
Two programmes stand out:

- the National Priority Technology Capability Programmes launched in 2010 in the areas of agricultural productivity improvement, industrial productivity and quality programmes, biotechnology, energy, construction and material technologies, electronics and microelectronics, ICTs, telecommunications and water technology; and
- the ongoing Engineering Capacity-Building Programme launched in 2005, which is jointly financed and implemented by the governments of Ethiopia and Germany within Ethiopian–German Development Co-operation. Priority sectors include textiles, construction, leather, agro-processing, pharmaceuticals/chemicals and metal.

In 2014, it was decided to place universities specializing in science and technology which have ties with industry under the new Ministry of Science and Technology to promote innovation in academia and stimulate technology-driven enterprises. The first two universities in Addis Ababa and Adama were transferred from the Ministry of Higher Education in 2014.

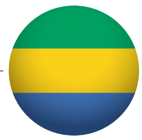
Figure 19.9: **GERD/GDP ratio in East and Central Africa, 2013, or closest year (%)**

Selected countries



Source: UNESCO Institute for Statistics

GABON



A plan to green Gabon by 2025

Gabon is one of the most stable countries in Africa. Despite being one of the continent's rare upper middle-income economies, it is characterized by considerable inequality in income distribution. There is also limited infrastructure, including in the transport, health, education and research sectors (World Bank, 2013).

The economy is dominated by oil but, with production starting to decline, the government has been implementing political and economic reforms since 2009 to transform Gabon into a developed country by 2025. This ambition is encapsulated in the government strategy, *Emerging Gabon: Strategic Plan to 2025*, which aims to set the country on the path to sustainable development, 'which is at the heart of the new executive's policy',[7] according to the *Strategic Plan*. Adopted in 2012, it identifies two parallel challenges: the need to diversify an economy dominated by oil exports (84% in 2012, see Figure 18.2) and the imperative of reducing poverty and fostering equal opportunity.

The three pillars of the plan are:

- *Green Gabon:* to develop the country's natural resources in a sustainable manner, beginning with an inventory of 22 million ha of forest (85% of the land cover), 1 million ha of arable land, 13 national parks and 800 km of coastline;
- *Industry Gabon:* to develop local processing of raw materials and the export of high value-added products;

7. Gabon's President Ali Bongo Ondimba took office in October 2009.

- *Services Gabon:* to foster quality education and training, in order to turn Gabon into a regional leader in financial services, ICTs, green growth, tertiary education and health.

The plan foresees the adoption of a *National Climate Plan* to limit Gabon's greenhouse gas emissions and forge an adaptation strategy. The share of hydropower in Gabon's electricity matrix is to progress from 40% in 2010 to 80% by 2020. In parallel, inefficient thermal power stations are to be replaced with clean ones to bring the share of clean energy to 100%. By 2030, Gabon plans to export 3 000 MW of hydropower to its neighbours. Efforts will also be made to improve energy efficiency and reduce pollution in such areas as construction and transportation.

This new paradigm is to be ensconced in a law on sustainable development which will create a fund compensating the negative effects of development. Moreover, in conformity with the *Gaborone Declaration* (see Box 20.1), natural capital is to be integrated into the national accounting system.

Quality education a priority

Quality education is another priority of the *Strategic Plan* to 2025. Four technical secondary schools offering 1 000 places are to be established to raise the proportion of pupils benefiting from this education from 8% to 20% and thereby provide key economic sectors such as the wood, forestry, mining,[8] metallurgy and tourism industries with skilled personnel.

In order to adapt university curricula to market needs, existing universities will be modernized and a *Cité verte de l'éducation et du savoir* (Green City of Education and Knowledge) will be created in the heart of the country in Booué. Constructed using green materials and running on green energy, this complex will group a campus, research centres and modern housing. Foreign universities will be encouraged to set up campuses on site. A research fund will be created for academic projects selected on a competitive basis and an information technology park will be set up in partnership with the National Agency for Digital Infrastructure and Frequencies.

All primary and secondary schools are to be equipped with a multimedia room and a mechanism will be put in place to enable all teachers and university students to acquire a computer.

In parallel, the plan foresees a broad administrative and legal reform to improve efficiency and foster the rule of law. A number of new bodies will be established to foster quality education, including the Council for Education, Training and Research, which will be responsible for evaluating the implementation of the government's education policy.

Steps taken to implement the *Strategic Plan*

Since 2011, the government has taken a number of steps to implement *Emerging Gabon: Strategic Plan to 2025*, including:

- the creation of a Research Unit on Tuberculosis at the Albert Schweitzer Hospital in Lambaréné in February 2011, in response to the growing prevalence of tuberculosis;
- the creation of a joint Centre for Environmental Research by Gabon and the University of Oregon (USA) in June 2011, with a focus on the mitigation of, and adaptation to, climate change and environmental governance, including the development of ecotourism;
- the construction of a School of Mining and Metallurgy in Moanda in October 2012 to produce more scientists and engineers in these areas;
- the opening of a digital campus at the School of Water Affairs and Forestry in February 2013 to produce more engineers;
- the creation of three new vocational training centres in June 2013;
- the official presentation of the *National Climate Plan* to the president in November 2013 by the National Council on Climate Change, a body created by presidential decree in April 2010;
- the establishment of a Ministry of Higher Education and Scientific Research in April 2014; and
- the adoption of the law on sustainable development in August 2014; this law has raised some concerns in civil society as to whether it will protect the territorial rights of third parties, particularly those of local and indigenous communities (Malouna, 2015).

The government has recently entered into two public–private partnerships. In December 2012, it established a 'fun' approach to learning about HIV which targets youth, called Gaming for HIV Prevention, in partnership with Shell Gabon. In February 2013, the government also partnered with Ireland Blyth Limited to develop the Gabonese seafood and maritime industries.

8. In 2010, Gabon attracted over US$ 4 billion for the wood, agriculture and infrastructure sectors, according to the government.

KENYA

A game-changing act?

STI policy in Kenya has been given a major boost by the Science, Technology and Innovation Act passed in 2013. The act contributes to the realization of *Kenya Vision 2030*, which foresees the country's transformation into a middle-income economy with a skilled labour force between 2008 and 2030. Kenya already hosts[9] several hubs for training and research in life sciences, including the Biosciences Eastern and Central Africa Network (Box 19.1) and the International Centre for Insect Physiology and Ecology. In line with *Vision 2030*, Kenya is participating in the AfDB's East Africa's Centres of Excellence for Skills and Tertiary Education in Biomedical Sciences programme (Box 19.2).

Flagship projects within *Vision 2030* include the following:

- Five industrial parks are being established for SMEs in key urban centres, the majority in agro-processing.
- The Nairobi Industrial and Technology Park is being developed within a joint venture with Jomo Kenyatta University of Agriculture and Technology.
- Konza Technology City is under construction in Nairobi (Box 19.4).
- Geothermal energy is being developed in the Rift Valley, within a programme to increase energy generation to 23 000 MW that is mobilizing private capital for the development of renewable energy (Box 19.5).
- Construction of Africa's largest wind farm began in 2014, within the Lake Turkana Wind Power Project;
- In recognition of the economic potential of ICTs, the government announced in December 2013 that it would be establishing technology incubation hubs in all 47 counties.

Under the Science, Technology and Innovation Act of 2013, the Ministry of Education, Science and Technology is attributed responsibility for formulating, promoting and implementing policies and strategies in higher education, STI in general and R&D in particular, as well as technical, industrial, vocational and entrepreneurship training.

The act established a National Commission for Science, Technology and Innovation, a regulatory and advisory body that is also responsible for quality assurance. Its specific functions include:

- developing priority areas for STI; co-ordinating the implementation and financing of policies with other institutional bodies, including local governments, the new National Innovation Agency and the new National Research Fund (see overleaf);
- providing accreditation for research institutes;
- fostering private-sector involvement in R&D; and
- undertaking annual reviews of scientific research systems.

The act further empowered the National Commission for Science, Technology and Innovation to establish advisory research committees to counsel the commission on specific programmes and projects and maintain a database of these and to foster R&D and education in relevant areas, in particular. The act also establishes a requirement for any person wishing to engage in R&D to obtain a government license.

9. Nairobi is also home to the African Network of Scientific and Technological Institutions (ANSTI), an NGO hosted by UNESCO since its inception in 1980. ANSTI awards PhD and master's scholarships and travel grants. Since 2010, ANSTI has awarded 45 L'Oréal-UNESCO Fellowships for Women in Science to foster research and innovation.

Box 19.4: **Konza Technology City, Kenya's 'Silicon Savannah'**

Konza Technology City was originally designed as a technology park centred on business process outsourcing and information technology-enabled services. The Kenyan government contracted the International Finance Corporation to conduct an initial feasibility study in 2009. However, while the study was being conducted, the consulting design partners recommended that the project be expanded into a technology city. The Kenyan government agreed and has branded Konza the 'Silicon Savannah'.

A 5 000-acre site located some 60 km from Nairobi was procured in 2009 and the new greenfield investment (see glossary, p. 738) commenced. The financing arrangement is based on a public–private partnership model, whereby the government provides basic infrastructure and supporting policy and regulatory frameworks, leaving private investors to build and operate the industrial development. Ultimately, Konza should include a university campus, residential accommodation, hotels, schools, hospitals and research facilities.

Development of the techno-city is being directed by the Konza Technopolis Development Authority, which has authority over marketing, the subleasing of land, guiding real estate development, managing funding from public and private sources and liaising with local authorities to ensure quality services. Construction of Konza Technology City began in early 2013 and is expected to take 20 years. It is hoped to create 20 000 jobs in information technology by 2015 and 200 000 by 2030.

Source: www.konzacity.go.ke; BBC (2013)

The Kenya National Innovation Agency was established under the act to develop and manage the national innovation system. It has been tasked *inter alia* with the following:

- institutionalizing linkages between relevant stakeholders, including universities, research institutions, the private sector and government;
- setting up science and innovation parks;
- promoting a culture of innovation;
- maintaining relevant standards and databases; and
- disseminating scientific knowledge.

The act also created the National Research Fund and made provisions for the fund to receive 2% of Kenya's GDP each financial year. This substantial commitment of funds should enable Kenya to reach its target of raising GERD from 0.79% of GDP in 2010 to 2% by 2014.

Kenya reviewed its *Science, Technology and Innovation Policy* in 2012 but the revised policy is still before parliament. The draft is nonetheless serving as a reference document for the Ministry of Education, Science and Technology.

Towards a digital Kenya

In August 2013, the Ministry of Information, Communication and Technology established a state-owned corporation named the Information and Communication Technology Authority. Its functions include centralized management of all government ICT functions; maintenance of ICT standards across government; and the promotion of ICT literacy, capacity, innovation and enterprise, in accordance with the *Kenya National ICT Master Plan: Towards a Digital Kenya*, which runs from 2014 to 2018.

In the past few years, there has been an explosion in ICT activity in Kenya, often centred on innovation hubs. One pioneer is iHub, set up in Nairobi in 2010 by an independent technologist named Erik Hersman to provide an open space for the technology community, including young tech entrepreneurs, programmers, investors and technology companies. iHub has forged relationships with several multinational corporations, including Google, Nokia and Samsung, as well as with the Kenyan government's ICT Board (Hersman, 2012).

Another innovation hub is @iLabAfrica, established in January 2011 as a research centre within the Faculty of Information Technology at Strathmore University, a private establishment based in Nairobi. It stimulates research, innovation and entrepreneurship in ICTs.

A related development in Kenya is the formation of innovation incubation programmes. A prominent example is NaiLab, an incubator for start-up ICT businesses which offers a three-to-six-month programme in entrepreneurship training. NaiLab started out as a private company in 2011, in collaboration with the crowdfunding platform 1%CLUB and consultancy firm Accenture. In January 2013, the Kenyan government formed a partnership with NaiLab to launch a US$ 1.6 million, three-year technology incubation programme to support the country's burgeoning technology start-up

Box 19.5: Geothermal energy for Kenya's development

Just one in five Kenyans has access to electricity and demand is rising (Table 19.1). Almost half of electricity comes from hydropower but the growing frequency of drought is causing water and power shortages which affect all sectors of the Kenyan economy. As a stop-gap measure, the government has engaged private energy companies which import fossil fuels such as coal and diesel, a costly option which also causes considerable air pollution.

Vision 2030 (2008) has identified energy as being a pillar of the country's development strategy. *Vision 2030* is being implemented through successive five-year medium-term plans. It sets an ambitious goal of increasing the capacity of the national power supply from 1 500 MW at present to about 21 000 MW by 2030.

To address the energy challenge while maintaining a low carbon footprint, Kenya plans to develop its geothermal fields in the Rift Valley. These fields have been inadequately tapped until now, despite their potential to produce an estimated 14 000 MW. Current installed geothermal capacity corresponds to just 1.5% of this potential.

The Geothermal Development Company (GDC) was formed in 2009 under the Energy Act (2006) to implement the *National Energy Policy*. The GDC is a government body which cushions investors from the high capital investment risks associated with drilling geothermal wells. The GDC is expected to drill as many as 1 400 wells to explore steam prospects and make productive wells available to successful bidding investors from both public and private power companies.

In the fiscal year budget for 2012–2013, the Kenyan government allocated US$ 340 million to the exploration and development of geothermal energy and coal. Of this amount, just US$ 20 million went to the GDC.

Source: WWAP (2014)

sector (Nsehe, 2013). These funds will enable NaiLab to broaden its geographical scope to other Kenyan cities and towns, helping start-ups to obtain information, capital and business contacts.

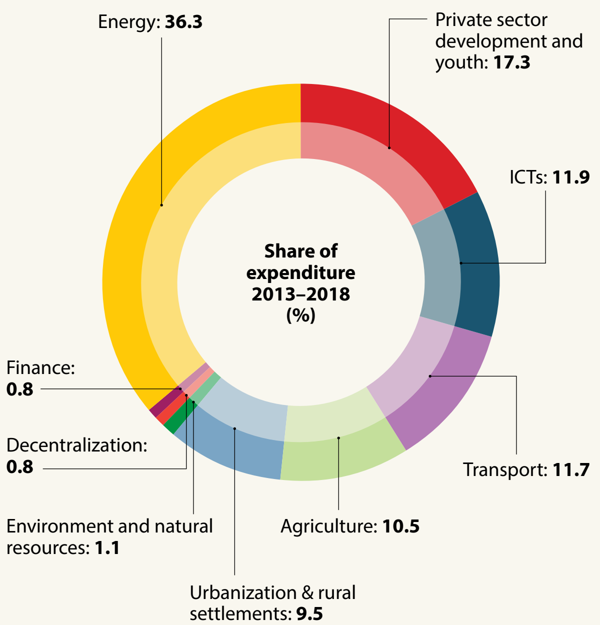
Nairobi is also home to m:Lab East Africa, which provides a platform for mobile entrepreneurship, business incubation, developer-training and application-testing.

RWANDA

Infrastructure, energy and 'green' innovation a priority

In a context of rapid economic and demographic growth, STI holds one of the keys to Rwanda's sustainable development. This conviction is embodied in *Rwanda's Vision 2020* (2000) for becoming a middle-income country by 2020 and in its *National Policy on Science, Technology and Innovation*, published in October 2005 with support from UNESCO and the United Nations University. The priority given to STI is also reflected in Rwanda's *First Economic Development for Poverty Reduction Strategy*, 2007–2012. If STI is not an explicit priority in the *Second Economic Development for Poverty Reduction Strategy*, 2013–2018, it is implicit in the priority given in the document to ICTs, energy and 'green' innovation (Figure 19.10), as well as in the proposal to create a Climate Change and Environment Innovation Centre. The five priorities are to:

Figure 19.10: **Breakdown of priority areas for *Rwanda's Economic Transformation* to 2018**



Source: Government of Rwanda (2013) *Second Economic Development for Poverty Reduction Strategy*, 2013–2018

- invest in hard and soft infrastructure to meet the energy demand of the private sector; in line with the *Energy Policy* (2012), the procurement process will be made more transparent and competitive; public finance will be used to 'de-risk' electricity generation projects for the private sector, in order to attract a wider range of investors on better terms; an energy development fund will be established with donor support to finance feasibility studies on geothermal, peat and methane resources and hydropower; in addition, the Kigali Economic Zone will also be finalized with an associated technopole;
- increase access to public goods and resources in priority economic sectors by building a new international airport, expanding the national airline, Rwandair, and finalizing plans for the establishment of a railway connection; a strategic focus on exports and re-exports to Burundi and eastern Democratic Republic of Congo; investment in hard and soft infrastructure to accelerate growth in the tourism and commodity sectors and expand exports in manufacturing and agro-processing;
- strengthen the investment process by targeting large foreign investors in priority economic sectors, increasing long-term savings and thereby raising the amount of credit available to the private sector to 30% of GDP by 2018, as well as by strengthening the private sector through tax and regulatory reform;
- facilitate and manage urbanization, including the promotion of affordable housing;
- pursue a 'green economy' approach to economic transformation, with a focus on green urbanization and green innovation in public and private industry; a pilot green city is being launched by 2018 to 'test and promote a new approach to urbanization' that employs various technologies to create sustainable cities; in parallel, a green accounting framework is being put in place to assess the economic benefits of environmental protection.

There is no dedicated ministry for science and technology in Rwanda but, in 2009, the Directorate-General of Science, Technology and Research was established under the Ministry of Education to implement the *National Policy on Science, Technology and Innovation*. In 2012, the government officially launched the National Commission for Science and Technology (NCST). The NCST has been strategically positioned in the Prime Minister's Office to serve as an advisory body on matters related to STI across all economic sectors. It became operational in 2014.

The National Industrial Research and Development Agency (NIRDA) was established in June 2013, in line with the *National Industrial Policy* of April 2011. The main mission of this research body is to produce home-grown technological and industrial solutions to meet national and regional market needs.

Plans to become an African ICT hub

In the past five years, Rwanda has put infrastructure in place to enable it to become an ICT hub in Africa. This infrastructure includes the Kigali Metropolitan Network, a fibre optic network linking all government institutions with a high-capacity national backbone connecting the whole country. The national backbone also links Rwanda with neighbouring countries, including Uganda and Tanzania, and through them to the submarine cables SEACOM and EASSy.

The Information Technology Innovation Centre (kLab) was established in 2012. It has been conceived as a place where young software developers and recent university graduates from computer science and engineering programmes can come to work on their entrepreneurial projects. This technology incubator partners with universities, research centres and private companies to provide mentoring for innovative start-ups, helping them to acquire business skills and transfer technology. Since its inception, kLab has been supported by the Rwanda Development Board.

In 2012, Rwanda constructed a state-of-the-art data-hosting facility for public and private institutions, the National Data Centre. A Health Management Information System (TRACnet) has also been deployed since 2005 to increase the efficiency of Rwanda's HIV and AIDS programme and enhance the quality of patient care country-wide.

The government is currently developing an ICT park in Kigali, in partnership with Carnegie Mellon University and the AfDB, for a total investment of US$ 150 million. The park will support growth of the following clusters: energy; internet, multimedia and mobile telecommunications; knowledge; e-government; finance; and ICT services and exports.

Towards more scientists and engineers with better skills

In 2012, Carnegie Mellon University in Rwanda was established as a regional centre of excellence in ICTs. It is the first US research institution to offer degrees in Africa through an in-country presence. The government decided to partner with this leading private research university in the USA, in order to produce ICT engineers and leaders who understand the balance between technology, business and innovation to meet the needs of industry.

Rwanda had only 11.8 articles per million inhabitants indexed in the Web of Science in 2014 (Figure 19.8). In September 2013, parliament passed a law establishing the University of Rwanda as an autonomous academic research institution. This large university is the product of the merger of seven public institutions of higher learning into a single university. The philosophy behind creating the University of Rwanda was to produce better-trained graduates and to strengthen the research capacity of Rwanda's higher education system. The University of Rwanda has already entered into an agreement with the Swedish International Development Agency to produce 1 500 PhDs between 2012 and 2022.

In October 2013, UNESCO's Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste (Italy) established a branch in Rwanda. Hosted by the College of Science and Technology at the University of Rwanda, ICTP Rwanda aims to increase the number of scientists graduating at master's and PhD levels in strategic areas of science, technology, engineering and mathematics. In 2012, the government adopted a policy of allocating 70% of university scholarships to students enrolled in S&T fields to increase the number of graduates. Moreover, through the Presidential Scholarship Programme established in 2006, pupils from science streams who excel in their secondary schooling get the chance to study in the USA in science or engineering. In 2013, two-thirds of graduates at bachelor level

Table 19.6: **University graduates in Rwanda, 2012/2013**

	Bachelor's		Master's		PhD	
	Male	Female	Male	Female	Male	Female
Education	763	409	3	3	0	0
Humanities and arts	187	60	0	0	1	0
Social sciences, business and law	3 339	3 590	261	204	0	0
Science	364	204	1	6	0	0
Engineering, manufacturing and construction	462	205	39	11	0	0
Agriculture	369	196	0	0	0	0
Health and welfare	125	211	5	4	0	0
Services	171	292	0	0	0	0
TOTAL	**5 780**	**5 167**	**309**	**228**	**1**	**0**

Source: Government of Rwanda

obtained their degree in social sciences, business and law, compared to 19% in S&T fields: 6% in engineering, 5% each in science and agriculture and 3% in health and welfare. Among graduates in S&T fields, engineering students were the most likely to enrol in a master's programme (Table 19.6).

Schemes to boost innovation and a green economy

The Rwanda Innovation Endowment Fund was established in 2012 by the Ministry of Education, in partnership with UNECA. The fund supports R&D to develop innovative market-oriented products and processes in three priority sectors of the economy: manufacturing, agriculture and ICTs. For the initial phase, seed funding of US$ 650 000 was provided: US$ 500 000 by the government and the remainder by UNECA. The first call for project proposals drew 370 applications, leading to the selection of just eight projects, which each received about US$ 50 000 in May 2013. After this proof of concept, it was decided to conduct a second round which is expected to fund ten inventions by March 2015.

In January 2013, the Ministry of Education established the Knowledge Transfer Partnership programme, in collaboration with the AfDB to foster industrial development. So far, the programme has sponsored five partnerships between private companies and the University of Rwanda's two Colleges of Science and Technology and Agriculture and Veterinary Medicine. The company contributes its idea for product or service development and the university provides the appropriate expertise.

In September 2008, Rwanda banned plastic bags. The law prohibits the manufacture, usage, importation and sale of polythene bags in Rwanda. These have been replaced by biodegradable bags made from materials such as cotton, banana and papyrus.

In parallel, the government introduced a National Fund for Environment and Climate Change in Rwanda (FONERWA), which acts as a cross-sectorial financing mechanism to further Rwanda's objectives of green and resilient growth within the *National Green Growth and Climate Resilience Strategy*. For instance, FONERWA is involved in identifying funding for the pilot 'green city' to be launched by 2018.

FONERWA's most recent (sixth) call for proposals resulted in 14 projects receiving funding; these had been put forward by private companies, NGOs, Rwandan districts and the Ministry of Infrastructure. The projects include the provision of solar power to off-the-grid communities, the construction of microhydropower plants, rainwater harvesting and re-use and gardening for urban poor in developed marshlands of Kigali.

SOMALIA

A first innovation hub

Somalia is in the process of state- and peacebuilding. In the run-up to elections in 2016, it is developing a constitution with key provisions on power- and resource-sharing. The government is also pursuing the development of federalism by building the capacity of interim regional administrations and establishing such bodies where none exists. The government has also recently applied to become a member of the EAC.

The Al-Shabaab group continues to terrorize the population in parts of the country under its control. About 730 000 Somalis face acute food insecurity, the vast majority of them internally displaced people. Some 203 000 children require emergency nutrition, mainly due to lack of access to clean water, sanitation infrastructure and better hygiene, according to the United Nations Humanitarian Co-ordinator for Somalia, Philippe Lazzarini, in January 2015.

Agriculture is the mainstay of Somalia's largely informal economy, accounting for about 60% of GDP and employing two-thirds of the labour force. The country continues to rely heavily on international aid and remittances, as well as imports of food, fuel, construction materials and manufactured goods. The more stable parts of the country can nevertheless boast of a vibrant private sector, including as concerns the provision of such vital services as finance, water and electricity.

Somalia's first innovation hub was established in 2012. Somaliland provides mobile and internet services and fosters social enterprise incubation and social and disruptive innovation (see glossary, p. 738), accompanied by training. The hub was set up by Reconstructed Living Lab, a registered social enterprise based in South Africa, with its partner Extended Bits and funding from the Indigo Trust, a UK-based foundation.

SOUTH SUDAN

Priorities: raising education and R&D spending

The world's youngest nation and Africa's 55th country, South Sudan gained independence after seceding from Sudan in July 2011. Its economy is highly dependent on oil, which generates about 98% of government revenue. Part of this revenue goes towards paying Sudan for the right to use its pipelines to transport oil to the sea for export.

With the economy suffering from a dearth of skilled human resources in all the key sectors, education is a government priority. The Education Act (2012) states that 'primary education shall be free and compulsory to all citizens in South

Sudan without discrimination.' The government's education plan is placing emphasis on teachers and on raising public expenditure on education to improve access and learning outcomes. South Sudan has the second-highest rate of population growth in sub-Saharan Africa after Niger (3.84%, see Table 19.1) and there is a big discrepancy in access to primary education: whereas there is universal primary education for boys, the gross enrolment ratio for girls was just 68% in 2011.

Tertiary education in South Sudan is provided by five government-sponsored universities and more than 35 private tertiary institutions. An estimated 20 000 students were enrolled in the country's universities in 2011, according to data from various universities; these data also indicate that enrolment is higher in social sciences and humanities than in S&T fields. The S&T-based faculties are particularly affected by a shortage of teaching staff.

The Ministry of Higher Education, Science and Technology has six directorates, including the Directorate of Technical and Technological Innovation (DTTI). The latter is a programme unit supporting the modernization of South Sudan through investment in technical education and the generation and transfer of technology. DTTI is composed of two departments covering technology and entrepreneurship. Whereas the former is responsible for developing technology policies and managing S&T-based institutions and programmes, the latter is responsible for establishing and managing institutions offering technical, vocational and entrepreneurial training and for laying the foundations for cottage industries. There are no official government statistics available on R&D but the government has expressed the intention of raising spending on research, with emphasis on applied sciences to improve living standards.

UGANDA

Sustainability at the heart of STI policy

The overarching arm of the *National Science, Technology and Innovation Policy* (2009) is to 'strengthen national capability to generate, transfer and apply scientific knowledge, skills and technologies that ensure sustainable utilisation of natural resources for the realisation of Uganda's development objectives.'

The policy precedes *Uganda Vision 2040*, which was launched in April 2013 to transform 'Ugandan society from a peasant to a modern and prosperous country within 30 years,' in the words of the Cabinet. *Uganda Vision 2040* vows to strengthen the private sector, improve education and training, modernize infrastructure and the underdeveloped services and agriculture sectors, foster industrialization and promote good governance, among other goals. Potential areas for economic development include oil and gas, tourism, minerals and ICTs.

A Millennium Science Initiative and innovation fund

The National Council for Science and Technology (NCST) falls under the Ministry of Finance, Planning and Economic Development. The council's strategic objectives include: the rationalization of S&T policy to boost technological innovation; enhancing the national system of research, intellectual property, product development and technology transfer; strengthening public acceptance of science and technology; and upgrading institutional research capacity.

In 2007, the NCST launched the Millennium Science Initiative (2007–2013), which was co-financed by the World Bank. At a time when the economy's formal sector was expanding rapidly and real investment was rising sharply, the NCST considered that continued economic progress would require more and better use of knowledge and more and better qualified human resources for science and technology.[10] The NCST identified the following shortcomings in higher education:

- Very few science degree programmes exist; enrolment in basic sciences is negligible. Laboratories are generally scarce, under-equipped and obsolete.
- Very limited funding exists for capital or recurrent expenses for S&T training; almost all research funding comes from external (donor) sources, making it unsustainable and difficult to ensure a national research for development-driven agenda.
- Despite the burgeoning enrolment, very little systematic attention is being paid to the development of domestic graduate education. Fewer than 500 professors in the entire country have PhDs and fewer than 10 new PhDs are awarded annually in sciences and engineering.
- Fee policies and lack of adequate S&T infrastructure encourage the expansion of undergraduate programmes in arts and humanities, resulting in a dwindling intake for S&T courses and a general lack of interest in, and focus on, S&T.
- The universities and the general tertiary system, be it public or private, lack strategies to improve conditions for research.

To correct these shortcomings, the Millennium Science Initiative incorporated the following components:

- A funding facility provided competitive grants through three windows: top-end research involving both senior researchers and graduate students; the creation of undergraduate programmes in basic science and engineering; and, thirdly, support for co-operation with the private sector, which consisted in company internships for students and grants for technology platforms through

10. see: www.uncst.go.ug/epublications/msi_pip/intro.htm which firms and researchers could collaborate on solving problems of direct interest to industry.

- An Outreach Programme proposed a series of school visits by top scientists and researchers to change negative perceptions that deterred Ugandans from pursuing careers in science. A National Science Week was also established. In parallel, this second component sought to strengthen the institutional capacity of the NCST and Uganda Industrial Research Institute and, more generally, to improve policy implementation, evaluation and monitoring.

In July 2010, the Presidential Initiative on Science and Technology offered a further boost by creating a fund to foster innovation at Makerere University over the next five years (Box 19.6).

Thriving innovation hubs

The Uganda Investment Authority is a parastatal agency that works in conjunction with the government to facilitate private sector investment. One of the authority's most flourishing sectors is ICTs. This sector has seen major investment in recent years to develop Uganda's backbone infrastructure network, which is comprised of fibre-optic cables and related equipment, as well as mobile broadband infrastructure.

Uganda has a thriving innovation hub named Hive Colab, which was launched in 2010 by AfriLabs and is headed by Barbara Birungi. It serves as a collaborative space to facilitate interaction among technology entrepreneurs, web and mobile app developers, designers, investors, venture capitalists and donors. Hive Colab provides facilities, support and advice to members to help them launch successful start-up enterprises. The hub offers a virtual incubation platform that is intended to assist entrepreneurial activity, particularly in rural areas. Its three programme focus areas are ICTs and mobile technologies, climate technologies and agribusiness innovation.

Another incubator, the Consortium for enhancing University Responsiveness to Agribusiness Development Limited (CURAD), is a public–private partnership which targets young innovators in the agribusiness sector with the goal of generating new enterprises and employment. This non-profit company was launched in May 2014 and is based at Makerere University.

In September 2013, the government launched a Business Process Outsourcing Incubation Centre at the Uganda Bureau of Statistics House (Biztech Africa, 2013). The facility can accommodate 250 agents and is run by three private companies. The Government of Uganda has targeted this industry to address youth unemployment and stimulate investment in information-technology-enabled services Business incubation and STI research are also promoted by the Uganda Industrial Research Institute.

Two annual prizes have also incentivized innovation in Uganda. Each year since 2012, Orange Uganda, a division

Box 19.6: **The Presidential Innovations Fund in Uganda**

When President Museveni visited Makerere University in December 2009, he noticed that many undergraduate students had produced interesting prototypes of machines and implements and that PhD students and senior researchers were working on inventions with potential for transforming rural Ugandan society but that innovation was being held back by the lack of modern research and teaching laboratories.

After the visit, he decided to create a Presidential Innovations Fund endowed with UGX 25 billion (*circa* US$ 8.5 million) over five years to support innovation-related projects at the university's College of Engineering, Art, Design and Technology.

The fund became operational in July 2010. It covered the cost of modernizing laboratories and the implementation of ten projects at the university. It also financed undergraduate science and engineering programmes, academia–private sector partnerships, student internships, science policy formulation and science popularization in schools and communities.

By 2014, the projects had developed:

- an academic records management system;
- more than 30 internet laboratories (ilabs) in the Department of Electrical and Computer Engineering;
- a business incubator, the Centre for Technology Design and Development;
- a Centre for Renewable Energy and Energy Conservation;
- more than 30 innovation clusters for metal, salt, coffee, milk, pineapple, etc.;
- appropriate irrigation;
- a vehicle design project (the Kiira EV car), which evolved into the Centre for Research in Transportation Technologies;
- makapads, the only sanitary wear for women in Africa made from natural materials (papyrus and paper), including for maternity use;
- a Community Wireless Resource Centre.

Source: http://cedat.mak.ac.ug/research/presidential-initiative-project.html of France Telecom, has sponsored the Community Innovations Awards, a competition for mobile apps that encourages university students to innovate in the areas of agriculture, health and education. Since 2010, the Uganda Communications Commission has also organized the Annual Communications Innovation Awards, which reward excellence in ICT innovation that contributes to national development goals. The prizes are awarded in several categories, including digital content, ICT for development, service excellence, business excellence and young ICT innovators.

A rise in researchers and R&D spending

Uganda provides quite detailed data on research, making it possible to monitor progress. R&D funding climbed between 2008 and 2010 from 0.33% to 0.48% of GDP. The business enterprise sector's share of R&D funding progressed from 4.3% to 13.7% over this period and spending on engineering from 9.8% to 12.2%, to the detriment of agricultural R&D, which appears to have shrunk from 53.6% to 16.7% of total spending, according to the UNESCO Institute for Statistics.

The number of researchers has climbed steadily over the past decade, even doubling between 2008 and 2010 in head counts from 1 387 to 2 823, according to the UNESCO Institute for Statistics. This represents a leap from 44 to 83 researchers per million inhabitants. One in four researchers is a woman (Figure 19.3).

Enrolment in higher education rose from 93 000 to 140 000 between 2006 and 2011, in a context of strong population growth of 3.3% per year. In 2011, 4.4% of young Ugandans were enrolled at university (Tables 19.1, 19.3 and 19.4).

The number of scientific publications tripled between 2005 and 2014 but research remains focused on life sciences (Figure 19.8). In 2014, the Uganda Industrial Research Institute was selected for a programme which is developing centres of excellence in biomedical sciences (Box 19.2). Interestingly, Kenya and South Africa count among Uganda's top five research partners (Figure 19.8).

CONCLUSION

Social and environmental innovation emerging priorities

The period since 2009 has witnessed a considerable gain in interest for STI in East and Central Africa. Most countries have based their long-term planning ('vision') documents on harnessing STI to development. Most governments are perfectly cognizant of the need to seize the opportunity of sustained growth to modernize and industrialize, in order to participate effectively in a rapidly evolving world economy and ensure sustainability. They know that infrastructure development, better health care, food, water and energy security and economic diversification will require a critical mass of scientists, engineers and medical staff who are currently in short supply. These planning documents tend to reflect a common vision for the future: a prosperous middle-income country (or higher) characterized by good governance, inclusive growth and sustainable development.

Governments are increasingly looking for investors rather than donors. Conscious of the importance of a strong private sector to drive investment and innovation for socio-economic development, governments are devising schemes to support local businesses. As we have seen, the fund developed by Rwanda to foster a green economy provides competitive funds to successful public and private applicants. In Kenya, the Nairobi Industrial and Technology Park is being developed within a joint venture with a public institution, Jomo Kenyatta University of Agriculture and Technology.

In the past few years, governments have witnessed the economic spin-offs from the first technology incubators in Kenya, which have been incredibly successful in helping start-ups capture markets in information technology, in particular. Many governments are now investing in this dynamic sector, including those of Rwanda and Uganda. Spending on R&D is on the rise in most countries with innovation hubs, driven by greater investment by both the public and private sectors.

Most of the social innovation observed in East and Central Africa since 2009 tackles pressing development issues: overcoming food insecurity, mitigating climate change, the transition to renewable energy, reducing disaster risk and extending medical services. The leading technological breakthrough in the region (the MPesa payment service via a mobile phone) had been designed to bridge the rural–urban divide in access to banking services, addressing the financial needs of the poor masses at the bottom of the pyramid. This technology has since permeated virtually all sectors of the East African economy, mobile payments having become a common feature of banking services.

We have seen that both pan-African and regional bodies are themselves now convinced that STI is one of the keys to the continent's development. This is illustrated by the prizes for science and innovation offered by the African Union Commission and COMESA, for instance, and by the programme launched in 2014 by the African Development Bank to develop five centres of excellence in biomedical sciences.

The sources of East and Central Africa's heightened interest in STI are multiple but the global financial crisis of 2008–2009 certainly played a role. It boosted commodity prices and focused attention on beneficiation policies in Africa. The global crisis also provoked a reversal in brain drain, as visions of Europe and North America struggling with low growth rates and high unemployment discouraged emigration and encouraged some to return home. Returnees are today playing a key role in STI policy formulation, economic development and innovation. Even those who remain abroad are contributing: remittances are now overtaking FDI inflows to Africa.

The focus on sustainable development is a fairly new trend. The commodities boom in recent years has brought home to governments that they are sitting on a gold mine – literally, in some cases. Growing foreign interest in the natural endowments of countries such as Burundi, Cameroon, Gabon and Rwanda has made them increasingly conscious of the need to preserve their rare and valuable ecosystems to ensure their own sustainable development.

With 1 billion potential consumers across the continent, one key challenge will be to remove the barriers to intraregional and pan-African trade. An important step forward in this regard would be an overhaul of immigration laws within Africa. Currently, it is much easier for an average British or American citizen, for instance, to travel across Africa than for the average African. Reducing immigration requirements for Africans within Africa would considerably enhance the mobility of skilled personnel and knowledge spillovers.

By modernizing infrastructure, developing manufacturing and value addition, improving the business climate and removing barriers to pan-African trade, countries should be in a position to develop the local industries and jobs they will need to employ their rapidly growing populations. Greater regional integration will not only foster socio-economic development but also better governance and political stability, such as by favouring the multilateral resolution of disputes through dialogue, whenever possible, and through military means whenever unavoidable. The current co-operation between Cameroon, Chad, Niger and Nigeria to combat the Boko Haram terrorist sect illustrates this new paradigm of intra-regional co-operation. Another example is the EAC's decision to send a contingent of medical personnel to West Africa in October 2014 to help combat the Ebola epidemic.

KEY TARGETS FOR CENTRAL AND EAST AFRICA

- Raise GERD to 1% of GDP in countries of the region;
- Raise GERD in Kenya from 0.98% (2009) to 2% of GDP by 2014;
- Countries that signed the *Maputo Declaration* are to devote at least 10% of GDP to agriculture;
- Raise the proportion of Ethiopian women university students to 40%;
- Establish four technical secondary schools to raise the share of Gabonese pupils benefiting from this type of education from 8% to 20% by 2025;
- Raise the share of hydropower in Gabon's electricity matrix from 40% in 2010 to 80% by 2020;
- Establish a Green City of Education and Knowledge in Gabon by 2030, as well as a research fund and information technology park;
- Raise the amount of credit available to the private sector in Rwanda to 30% of GDP by 2018;
- Launch a pilot green city in Rwanda by 2018.

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ACKNOWLEDGMENTS

The authors wish to thank Jeremy Wakeford from the Quantum Global Research Laboratory in Switzerland for contributing information for the country profiles of Cameroon, Comoros, Equatorial Guinea, Kenya and Uganda. Thanks go also to Dr Abiodun Egbetokun from Tshwane University of Technology (South Africa) for his assistance in collecting data for the present chapter.

An important aspect of economic integration would be the transition from national innovation systems to a single regional innovation system.

Erika Kraemer-Mbula and **Mario Scerri**

A humanoid robot directs traffic at a busy intersection in Kinshasa, in the Democratic Republic of Congo. This solar-powered prototype is equipped with four cameras that allow it to record traffic. The information is then transmitted to a centre which analyses traffic infractions. This robot and its twin were designed by a group of Congolese engineers based at the Kinshasa Higher Institute of Applied Techniques (ISTA).
Photo: © Junior D. Kannah/AFP/Getty Images)

20 · Southern Africa

Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe

Erika Kraemer–Mbula and Mario Scerri

INTRODUCTION

Lifting trade barriers to foster regional integration

The Southern Africa Development Community (SADC) is home to 33% of sub-Saharan Africa's population and contributes about 43% of its GDP (US$ 684 billion in 2013). The region combines middle-income countries with some of the fastest-growing economies in Africa[1] and some of the poorest. Nothing underscores the region's diversity more than the fact that one country alone generates about 60% of GDP within the SADC and one-quarter of the continent's GDP: South Africa.

Despite this heterogeneity, there is considerable potential for regional integration, which is being increasingly driven by the Southern African Development Community (SADC). *A Protocol on Trade in Services* signed in 2012 seeks to negotiate progressively the removal of barriers to the free movement of services within the SADC.

Intra-SADC trade is relatively modest and has not grown to any significant degree in the past five years, owing partly to the similarity of the resource-based economies across the region, a cumbersome regulatory framework and inadequate border infrastructure (AfDB, 2013).[2] Nevertheless, compared to other African regional economic communities (see Box 18.2), the SADC bloc still displays the most dynamic intraregional trade of the continent, albeit mostly directed towards South Africa. The SADC trades very little with the rest of Africa, the region's trade being mostly oriented towards the rest of the world.

On 10 June 2015, the 26 countries which make up the three regional communities of SADC, the Common Market for Southern and Eastern Africa (COMESA) and the East African Community (EAC) formally launched a Free Trade Area. This should accelerate regional integration.[3]

Relative political stability

The SADC region enjoys relative political stability and democratic political processes, although internal fragmentation continues to characterize the ruling political parties in most countries. For the past six years, SADC membership has remained relatively stable, with the exception of Madagascar, which was suspended in 2009 following a coup d'état then reintegrated in January 2014 after its return to constitutional government. If Madagascar is now emerging from five years of political turmoil and international sanctions, the Democratic Republic of Congo is still recovering from the violence inflicted by armed groups who were neutralized by a United Nations peacekeeping force in 2013. Political tensions remain in Lesotho, Swaziland and Zimbabwe.

The SADC is striving to maintain peace and security within its member states, including through the SADC tribunal, which was established in Gaborone (Botswana) in 2005 then dismantled in 2010 before being revived by a new protocol in 2014, albeit with a diminished mandate. The SADC Regional Early Warning Centre is also based in Gaborone. This centre was established in 2010 to prevent, manage and resolve conflict, in conjunction with national early warning centres.

In 2014, five SADC countries held presidential elections – Botswana, Malawi, Mozambique, Namibia and South Africa – Namibia being the first African country to cast presidential ballots electronically through an e-voting system. The SADC aims to attain equal representation of men and women in key decision-making positions by 2015, through the *SADC Protocol on Gender and Development*, which entered into force in early 2013 after being signed in 2008. However, only five SADC countries are anywhere near reaching parity in parliament, having gone above the 30% threshold set previously by regional leaders for the representation of women: Angola, Mozambique, Seychelles, South Africa and Tanzania. Of note is that President Joyce Banda of Malawi became the SADC's first woman president in 2012. Three years later, renowned biologist Ameenah Gurib-Fakim made history by becoming Mauritius' first woman president.

Widespread poverty in two-thirds of countries

The population is growing fast, at 2.5% per year on average between 2009 and 2013. By 2013, the region counted a combined population of over 294 million. Human development varies widely, from a high of 0.771 on the UNDP's index in Mauritius to a low of 0.337 in the Democratic Republic of Congo. A promising trend is that ten countries advanced in the overall world ranking from 2008 to 2013. Madagascar, Seychelles and Swaziland, on the other hand, have slipped a few places (Table 20.1).

The SADC's aggregate economy still displays features of a developing region, with worrying unemployment levels in some countries. Poverty and inequality persist, despite

1. The Democratic Republic of Congo, Mozambique, Tanzania, Zambia and Zimbabwe experienced annual average GDP growth of about 7% from 2009 to 2013 but these five countries, along with Angola, Lesotho and Malawi, are also currently listed by the United Nations as being least developed countries.

2. In 2008, intra-SADC imports constituted only 9.8% of the region's total imports and intra-SADC exports 9.9% of SADC's total exports. Being the most diversified economy, South Africa is also the dominant exporter (68.1% of all intra-SADC exports) but only accounted for 14.8% of intra-SADC imports in 2009.

3. For the composition of these regions, see Annex I.

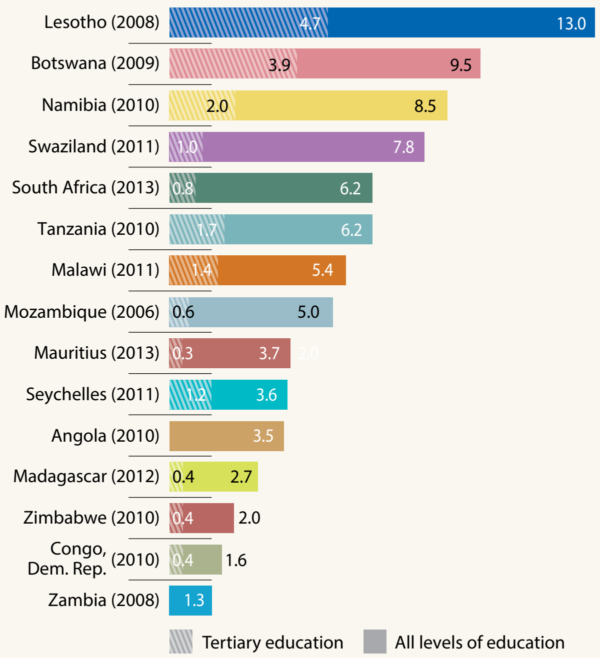
Table 20.1: **Social landscape of Southern Africa**

	Population (millions), 2013	Change since 2009 (%)	HDI ranking, 2013 (change since 2008)	Unemployment rate, 2013 (% of total labour force)	Poverty rate*, 2010 (change since 2000)	Gini, 2010 (change since 2000)
Angola	21.5	13	$149^{(2)}$	6.8	$67.42^{(-)}$	$42.60^{(-)}$
Botswana	2.0	4	$108^{(2)}$	18.4	$27.83^{(-)}$	$60.46^{(-)}$
Congo, Dem. Rep.	67.5	12	$187^{(1)}$	8.0	95.15	44.43
Lesotho	2.1	4	$163^{(0)}$	24.7	$73.39^{(-)}$	$54.17^{(+)}$
Madagascar	22.9	12	$155^{(-3)}$	3.6	$95.1^{(+3)}$	$40.63^{(+)}$
Malawi	16.4	12	$174^{(0)}$	7.6	$88.14^{(-)}$	$46.18^{(+)}$
Mauritius	1.2	1	$63^{(9)}$	8.3	$1.85^{(+)}$	$35.90^{(+)}$
Mozambique	25.8	11	$179^{(1)}$	8.3	$82.49^{(-)}$	$45.66^{(-)}$
Namibia	2.3	7	$127^{(3)}$	16.9	$43.15^{(-)}$	$61.32^{(-)}$
Seychelles	0.1	2	$70^{(-12)}$	–	1.84	65.77
South Africa	52.8	4	$119^{(2)}$	24.9	$26.19^{(-)}$	$65.02^{(-)}$
Swaziland	1.2	6	$148^{(-5)}$	22.5	$59.11^{(-)}$	$51.49^{(-)}$
Tanzania	49.3	13	$160^{(5)}$	3.5	$73.00^{(-)}$	$37.82^{(+)}$
Zambia	14.5	13	$143^{(7)}$	13.3	$86.56^{(+)}$	$57.49^{(+)}$
Zimbabwe	14.1	10	$160^{(16)}$	5.4	–	–
TOTAL SADC	293.8	10	–	–	–	–

* calculated as the share of the population living on less than US $2 per day.
Note: The reference year for the poverty rate and Gini index is 2010 or the closest year; see glossary, p.738.

Source: World Bank's World Development indicators, April 2015; for HDI: UNDP's *Human Development Reports*

Figure 20.1: **Public expenditure on education in Southern Africa as a share of GDP, 2012 or closest year (%)**



Source: UNESCO Institute for Statistics, May 2015

the fact that health and education remain top priorities for most countries, accumulating substantial portions of public expenditure (see Figure 20.1 and Table 19.2). The proportion of the population living on less than US$ 2 a day remains extremely high in ten SADC countries for which data are available (Table 20.1). Moreover, even the Seychelles and South Africa, where a fraction of the population lives beneath the poverty line, report high levels of inequality, which even increased over the period 2000–2010.

Foreign investment has doubled since 2007

Foreign direct investment (FDI) in Southern Africa almost doubled from 2007 to 2013 to US$ 13 billion. This was mainly due to record high inflows to South Africa and Mozambique, mostly for infrastructure development and the gas sector in Mozambique (Table 20.2). The proportion of national investment financed by donors is a good proxy indicator of the degree of economic self-sustainability. Once again, the region shows a high level of disparity in the degree of self-sustainability, with a clear distinction between countries that exhibit virtually no reliance on overseas development assistance (ODA) for national investment requirements and those where ODA is a significant contributor. Lesotho, Malawi and Swaziland show a growing reliance on ODA over the period under study. In other countries, such as Mozambique, Tanzania, Zambia and

Table 20.2: **Economic landscape of Southern Africa**

	GDP per capita in PPP$ millions (2011 constant prices)			GDP growth		Overseas development assistance/GFCF*			Patents, 2008–2013
	2009	2013	5-year change (%)	2009 (%)	2013 (%)	2009 (%)	2013 (%)	FDI inflow, 2013 (% of GDP)	
Angola	7 039	7 488	6.4	2.4	6.8	2.1	1.6	-5.7	7
Botswana	12 404	15 247	22.9	-7.8	5.8	7.8	2.2	1.3	0
Congo, Dem. Rep.	657	783	19.1	2.9	8.5	87.2	38.3	5.2	0
Lesotho	2 101	2 494	18.7	3.4	5.5	26.5	33.0^{-1}	1.9	0
Madagascar	1 426	1 369	-4.0	-4.0	2.4	14.9	30.0	7.9	0
Malawi	713	755	5.9	9.0	5.0	64.3	153.9	3.2	0
Mauritius	15 018	17 146	14.2	3.0	3.2	6.7	5.9	2.2	0
Mozambique	893	1 070	19.7	6.5	7.4	130.8	85.0	42.8	0
Namibia	8 089	9 276	14.7	0.3	5.1	13.1	7.8	6.9	2
Seychelles	19 646	23 799	21.1	-1.1	5.3	9.8	5.2	12.3	2
South Africa	11 903	12 454	4.6	-1.5	2.2	1.7	1.8	2.2	663
Swaziland	6 498	6 471	-0.4	1.3	2.8	17.2	31.9	0.6	6
Tanzania	2 061	2 365	14.7	5.4	7.3	35.6	26.2	4.3	4
Zambia	3 224	3 800	17.8	9.2	6.7	–	17.4^{-3}	6.8	0
Zimbabwe	1 352	1 773	31.2	6.0	4.5	76.7	46.3	3.0	4

-*n* = data refer to *n* years before reference year
*Gross fixed capital formation, see the glossary, p. 738

Source: World Bank's World Development Indicators, April 2015; patent data from USPTO database

Zimbabwe, this reliance has dropped significantly in recent years, even if it remains high.

The SADC economy is highly dependent on natural resources, with mining and agriculture constituting substantial segments of economic activity. From Figure 20.2, we can see that the production structure of most SADC economies tends to be resource-based, with a relatively small manufacturing sector, except in Swaziland. The region is vulnerable to extreme weather events such as cyclical drought and flooding. Angola, Malawi and Namibia have all experienced below-normal rainfall in recent years, affecting food[4] security. In 2014, Madagascar embarked on a nation-wide campaign to contain a locust outbreak which threatened staple crops. There has been a worrying drop in government funding for agricultural R&D by SADC countries and development agents, despite the continent's commitment, in the *Maputo Declaration* (2003), to devoting at least 10% of GDP to agriculture. By 2010, only a handful of SADC countries devoted more than 5% of GDP to agriculture, notably Madagascar, Malawi, Tanzania and Zambia (see Table 19.2).

The region's strong dependence on natural resources has led to wild economic fluctuations and rendered it vulnerable to global economic crises, such as that which led to an economic slowdown in 2009. Since 2010, the region has enjoyed persistent growth, with prospects for a return to pre-2009 growth rates of 5–6% in 2015 (AfDB *et al*., 2014).

Four ratifications of SADC protocol on STI

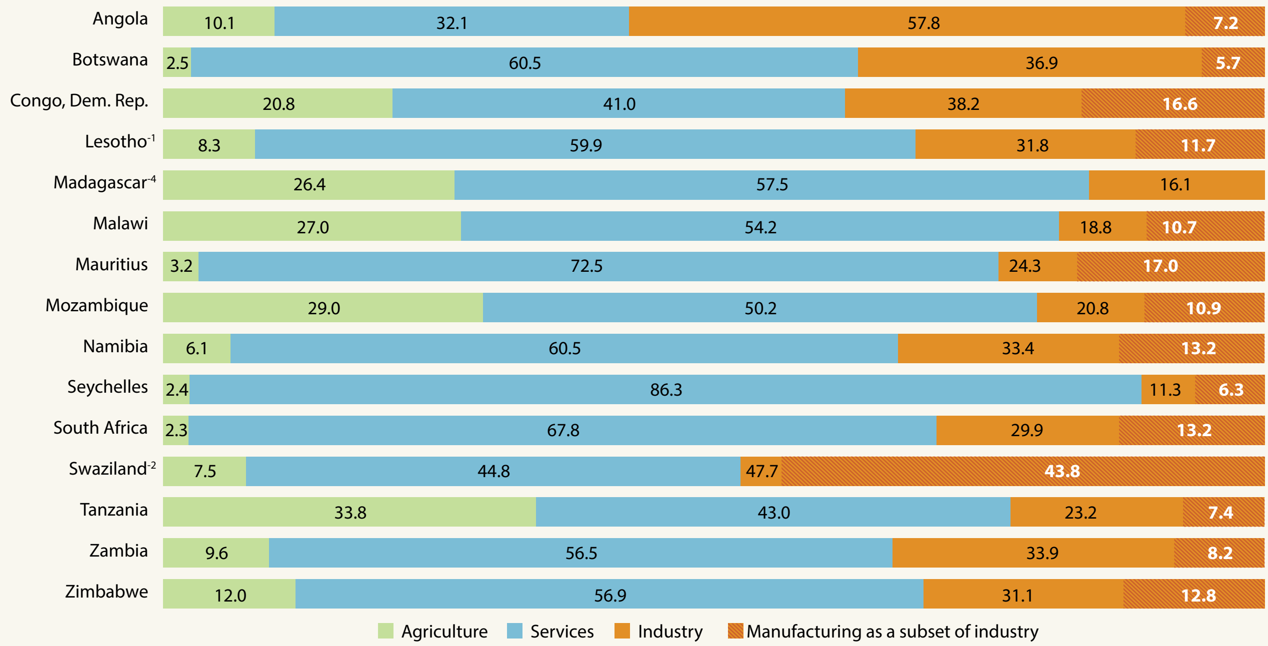
The Southern African Development Community Treaty of 1992 provides the legal framework for co-operation among SADC member states. It has since been enriched by the adoption of 27 protocols in priority areas.[5] In its *Protocol on Science, Technology and Innovation* (2008), the SADC stresses the importance of S&T for achieving 'sustainable and equitable socio-economic growth and poverty eradication'. It provides the basis for the development of institutional mechanisms for regional co-operation and co-ordination in the following areas:

- policy training;
- the role of women in science;
- strategic planning;

4. The Regional Early Warning System, Famine Early Warning System and Climate Services Centre are all based at the SADC centre in Gaborone (Botswana). The SADC Plant Genetic Resource Centre is located in Lusaka (Zambia). All were established about two decades ago. See www.sadc.int

5. The SADC Treaty calls for the harmonization of political and socio-economic policies for the region to attain the objective of sustainable development, whereas the protocols promote legal and political co-operation.

Figure 20.2: **GDP in SADC countries by economic sector, 2013 or closest year**



-n = data refer to *n* years before reference year

Source: World Bank's World Development Indicators, April 2015

- intellectual property rights;
- indigenous knowledge systems;
- climate change; and
- high-performance computing, as exemplified by the Blue Gene project launched by IBM in 1999, which spent the next decade developing supercomputers with low power consumption.

The protocol is based on a broad definition that extends considerably beyond science and technology.[6] A portfolio committee briefing by the South African Department of Science and Technology (RSA, 2011) notes that the protocol is an essential first step towards regional integration, with steady growth in self-financed bilateral co-operation. It considers that the SADC has become Africa's leading regional economic community. However, the briefing also points out that the regional STI desk remains under-resourced and mostly ineffectual. As a result, member states are still reluctant to support it. To date, the protocol has only been ratified by four countries: Botswana, Mauritius, Mozambique and South Africa. For the protocol to enter into force, it must be ratified by two-thirds of member states (10 countries).

6. The term 'national innovation system' refers to 'a set of functioning institutions, organisations and policies which intervene constructively in pursuit of a common set of social and economic objectives', as defined by the SADC Secretariat in 2008.

Two primary policy documents operationalize the SADC Treaty, *the Regional Indicative Strategic Development Plan* for 2005–2020 (RISDP, 2003) and the *Strategic Indicative Plan for the Organ* (SIPO, 2004). The RISDP identifies the region's 12 priority areas for both sectorial and cross-cutting intervention, mapping out goals and setting up concrete targets for each. The four sectorial areas are: trade and economic liberalization, infrastructure, sustainable food security and human and social development. The eight cross-cutting areas are:

- poverty;
- combating the HIV/AIDS pandemic;
- gender equality;
- science and technology;
- information and communication technologies (ICTs);
- environment and sustainable development;
- private sector development; and
- statistics.

Targets include:

- ensuring that 50% of decision-making positions in the public sector are held by women by 2015;
- raising gross domestic expenditure on research and development (GERD) to at least 1% of GDP by 2015;

- increasing intra-regional trade to at least 35% of total SADC trade by 2008 (10% in 2008);
- increasing the share of manufacturing to 25% of GDP by 2015 (Figure 20.2); and
- achieving100% connectivity to the regional power grid for all member states by 2012 (see Table 19.1).

A 2013 mid-term review of RISDP noted that limited progress had been made towards STI targets, owing to the lack of human and financial resources at the SADC Secretariat to co-ordinate STI programmes. In Maputo in June 2014, SADC ministers of STI, education and training adopted the SADC *Regional Strategic Plan on Science, Technology and Innovation for 2015–2020* to guide implementation of regional programmes.

A vulnerable environment despite legal frameworks

The region's commitment to sustainable development is reflected in the SADC Treaty and countries' active participation in major multilateral environmental[7] agreements. Although there has been some progress in environmental management in recent years, Southern Africa remains very vulnerable to climate change; it also suffers from high levels of pollution, biodiversity loss, inadequate access to clean water and sanitation services (see Table 19.1), land degradation and deforestation. It has been estimated that over 75% of land is partially degraded and 14% severely degraded. Soil erosion has been identified as the primary cause of declining agricultural production. For the past 16 years, the SADC has had a protocol governing wildlife, forestry, shared water courses and the environment, including climate change, the *SADC Protocol on Wildlife Conservation and Law Enforcement* (1999).

More recently, SADC has initiated a number of regional and national initiatives to mitigate the impact of climate change. In 2013, ministers responsible for the environment and natural resources approved the development of the SADC Regional Climate Change programme. In addition, COMESA, EAC and SADC have been implementing a joint five-year initiative since 2010 known as the Tripartite Programme on Climate Change Adaptation and Mitigation, or The African Solution to Address Climate Change. Five SADC countries have also signed the *Gaborone Declaration for Sustainability in Africa* (Box 20.1).

Regional policy frameworks, a continental strategy

In 2014, the *Science, Technology and Innovation Strategy for Africa* (STISA–2024) replaced Africa's previous decadal framework, *Africa's Science and Technology Consolidated Plan of Action* (CPA, 2005–2014). The CPA had been the continent's first consolidated attempt to accelerate Africa's transition to an innovation-led knowledge economy. As part of the *Plan of Action,* several networks of centres of excellence have been set up. Within the African Biosciences Initiative, four subregional hubs have been established, including the Southern African Network for Biosciences (SANbio), based at the Council for Scientific and Industrial Research in Pretoria since 2005 (see Box 19.1). SADC countries also participate in the African Biosafety Network of Expertise (see Box 19.1).

However, the CPA implementation raised a number of concerns related to:

- its narrow focus on generating R&D, with less concern for the use of scientific output;
- insufficient funding to allow full implementation of programmes;
- excessive reliance on external financial support targeting short-term activities and solutions; and
- the failure to link it with other pan-African policies such as continent-wide agriculture and environmental protection projects.

STISA emerged in 2014, following a high-level review of the CPA (see p. 505). This strategic framework is the next decadal stepping stone towards the goals of the African Union's *Agenda 2063*, also known as 'the Africa we want.' In *Agenda 2063,* the African Union provides a broad vision and action plan for building a more prosperous and united Africa over the next 50 years. STISA displays a stronger focus on innovation and science for development than its predecessor. It foresees the establishment of an African Science, Technology and Innovation Fund (ASTIF) but the financial sources needed to operate the fund remain undetermined. The lack of committed funds from member states and the broadness of STISA's objectives have raised multiple questions as to the feasibility of its implementation. It will take more than a commitment from member states to devoting 1% of GDP to R&D – the target enshrined in the African Union's *Khartoum Declaration* of 2007 – to make ASTIF operational.

In adopting STISA in 2014, the heads of state and government called upon member states, regional economic communities and development partners to align, connect and use STISA as a reference framework in designing and co-ordinating their own development agendas for STI.

Concerning intellectual property, the proposal to create a Pan-African Intellectual Property Organization (PAIPO) has regained momentum since the idea was first put forward in 2007 at the African Union Summit in Khartoum. However, the development and publication in 2012 of the draft statutes creating PAIPO have been the object of substantial criticism, from questioning the impact of stronger intellectual property protection in Africa to concerns about how PAIPO would

7. such as the UN Framework Convention on Climate Change, UN Convention to Combat Desertification, the UN Convention on Biological Diversity and the Ramsar Convention on Wetlands

Box 20.1 The Gaborone Declaration for Sustainability in Africa

In May 2012, the heads of state of Botswana, Gabon, Ghana, Kenya, Liberia, Mozambique, Namibia, Rwanda, South Africa and Tanzania gathered in Gaborone for a two-day summit, in the company of several public and private partners.

By adopting the *Gaborone Declaration for Sustainability in Africa*, the ten countries engaged themselves in a multi-year process. They recommitted to implementing all conventions and declarations promoting sustainable development and undertook to:

- integrate the value of natural capital into national accounting and corporate planning and reporting processes, policies and programmes;
- build social capital and reduce poverty by transitioning agriculture, extractive industries, fisheries and other natural capital uses to practices that promote sustainable employment, food security, sustainable energy and the protection of natural capital through protected areas and other mechanisms;
- build knowledge, data, capacity and policy networks to promote leadership and a new model of sustainable development and to increase momentum for positive change.

The overall objective of the *Declaration* was 'to ensure that the contributions of natural capital to sustainable economic growth, maintenance and improvement of social capital and human well-being are quantified and integrated into development and business practice.' This statement was propelled by the signatories' realization that GDP has its limitations as a measure of well-being and sustainable growth.

The interim secretariat of this initiative is being hosted by the Department of Environmental Affairs within the Botswanan Ministry of Environment Wildlife and Tourism, with technical support from Conservation International, a non-governmental organization. Conservation International has pledged funding for a situational analysis which will provide baseline information on where the ten countries stand with respect to the agreed actions outlined above and set priorities for moving forward.

Since the 2012 summit, an implementation framework has been drafted to track progress. In 2012, for instance, Gabon adopted a strategic plan to 2025 which foresees integrating natural capital into the national accounting system and the adoption of a national climate plan, among other moves to foster sustainable development (see p. 521).

Source: www.gaboronedeclaration.com

align its mandate with those of the two existing regional organizations, the African Regional Intellectual Property Organisation (ARIPO)[8] and the African Intellectual Property Organisation for French-speaking Africa, which already operate under separate regimes themselves.

The *Swakopmund Protocol on the Protection of Traditional Knowledge and Expressions of Folklore* was adopted in Namibia in April 2010 by nine ARIPO member States: Botswana, Ghana, Kenya, Lesotho, Liberia, Mozambique, Namibia, Zambia and Zimbabwe. The protocol will only enter into force once six ARIPO member states have deposited instruments of ratification (for signatories) or accession (for non-signatories), which was not the case in 2014. Any state that is a member of the African Union or the United Nations Economic Commission for Africa (UNECA) may also sign up to it.

The *AU–NEPAD African Action Plan for 2010–2015* expressly underscores the important role that harmonized regional policies could play in adapting to climate change. Africa's commitment to protecting its unique natural resources is guided at pan-African level by the African Model Law for the Protection of the Rights of Local Communities, Farmers and Breeders and for the Regulation of Access to Biological Resources (2001). The prioritization of biodiversity conservation in pan-African programmes and policies was again manifest in 2011 when the African Union encouraged all member states to adhere to international agreements on biodiversity, including the *Nagoya Protocol on Access to Genetic Resources and Sharing of Benefits Arising from their Utilization* and the *Convention on Biological Diversity* (2010).

TRENDS IN STI GOVERNANCE

Two-thirds of SADC countries have STI policies

Despite the different stages of development in terms of STI governance in Southern Africa, there is a shared and common interest in achieving sustainable development through the promotion of STI. This has engendered a plethora of institutional arrangements and bodies mandated with co-ordinating and supporting STI, as well as widespread formulation of related policies and strategies. Innovation, however, remains a secondary objective of policy formulation and, although policies are intended to support the STI ecosystem,

8. The current members of ARIPO are Botswana, Gambia, Ghana, Kenya, Lesotho, Malawi, Mozambique, Namibia, Sierra Leone, Liberia, Rwanda, São Tomé & Príncipe, Somalia, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe.

they remain firmly linked to the state apparatus for S&T, with little participation by the private sector in policy design. In 2014, 11 out of the 15 SADC countries had STI policies in place (Table 20.3). However, STI policy documents are rarely accompanied by implementation plans and allocated budgets for implementation. Some SADC countries without dedicated policies for STI nevertheless appear to be relatively active in developing programmes to promote university–industry collaboration and innovation. Mauritius is one such example (see p. 551).

A study conducted by UNESCO within its Global Observatory of STI Policy Instruments (GO➞SPIN) found a high correlation between scientific productivity and effective governance. Only seven African countries shared positive values for both government effectiveness and political stability: Botswana, Cabo Verde, Ghana, Mauritius, Namibia, the Seychelles and South Africa. The great majority of African countries had negative values for both indicators, including Angola, the Democratic Republic of Congo, Swaziland and Zimbabwe (UNESCO, 2013).

Disparities in research and development (R&D) are evident across the region. This phenomenon is illustrated by the GERD/GDP ratio, which ranges from a low of 0.01% in Lesotho to a high of 1.06% in Malawi (Figure 20.3). South Africa's own ratio (0.73%) is down from 0.89% in 2008. South Africa filed 96% of SADC patents between 2008 and 2013 and, together with Botswana, counts by far the greatest density of researchers (Figure 20.4). South Africa also stands out for the fairly equal division between the government (45%) and business enterprise (38%) sectors in terms of R&D funding and thus the maturity of industrial R&D in this country (see Table 19.5).

SADC economies have receded in the KEI

Only four SADC countries have conducted national innovation surveys under the African Science, Technology and Innovation Indicators (ASTII) programme, making comparisons subject to caution. What does emerge from the ASTII report published in 2014 is that the percentage of firms describing themselves as being innovation active is quite high, with 58.5% in Lesotho, 65.4% in South Africa, 61.3% in Tanzania and 51% in Zambia.

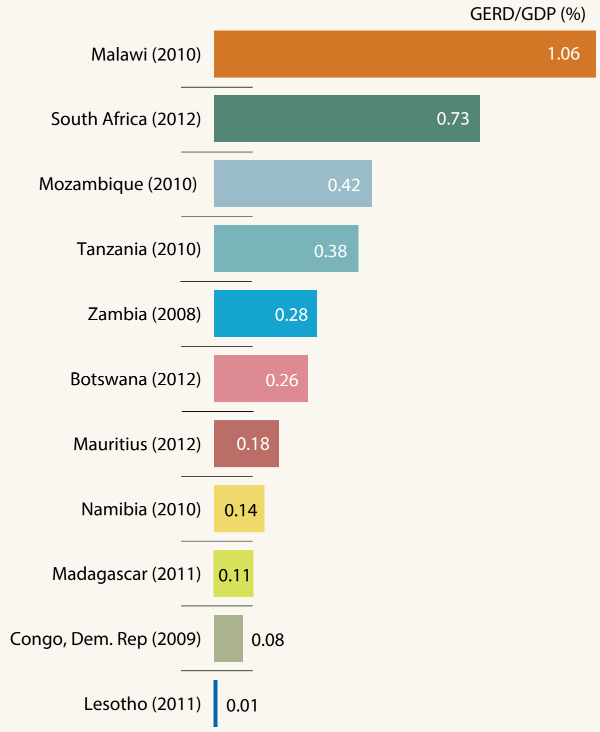
Table 20.4 presents SADC rankings in the World Bank's Knowledge Economy Index (KEI) and Knowledge Index (KI). Although these indices are largely based on the perceptions of the business sector and offer an inevitably biased view of the national innovation system, they do offer a basis for comparison. It is evident from this table that most SADC economies have receded in these international rankings since 2000, with Botswana, South Africa and Lesotho sliding the most. The four countries showing the highest KEI values are Mauritius, South Africa, Botswana and Namibia. South Africa is seen as having the most developed innovation system, whereas Mauritius offers the strongest incentive regime.

Table 20.3: **STI planning in SADC countries**

	STI policy document	Date of adoption/ period of validity
Angola	Yes	2011
Botswana	Yes	1998; 2011
Congo, Dem. Rep.	No	
Lesotho	Yes	2006–2011
Madagascar	Yes	2013
Malawi	Yes	2011–2015
Mauritius	No	
Mozambique	Yes	2003; 2006–2016
Namibia	Yes	1999
Seychelles	No	
South Africa	Yes	2010
Swaziland	(draft)	
Tanzania	Yes	1996; 2010
Zambia	Yes	1996
Zimbabwe	Yes	2002; 2012

Source: compiled by authors

Figure 20.3: **GERD/GDP ratio in Southern Africa, 2012 or closest year**



Source: UNESCO Institute for Statistics, August 2015; for Malawi: UNESCO (2014a)

Gender equity to be enshrined in national constitutions

Gender inequality is still a major social issue in Southern Africa. Women make up more than four out of ten researchers in just three countries: Mauritius, Namibia and South Africa (Figure 20.5). Only three countries report female participation in research across the public and private sectors: Botswana, South Africa and Zambia.

The *SADC Protocol on Gender and Development* (2008)[9] set ambitious targets in this respect. One target stipulates that States Parties are to endeavour to ensure that 'by 2015, at least 50% of decision-making positions in the public and private sectors are held by women, including [through] the use of affirmative action.' Currently, South Africa (42%), Angola (37%), Mozambique (35%) and Namibia (31%) have achieved a participation rate of 30% and above for women in political representation but other countries lag far behind, including Botswana (11%). In Malawi, the proportion of parliamentary seats held by women increased from 14% to 22% between 2004 and 2009.

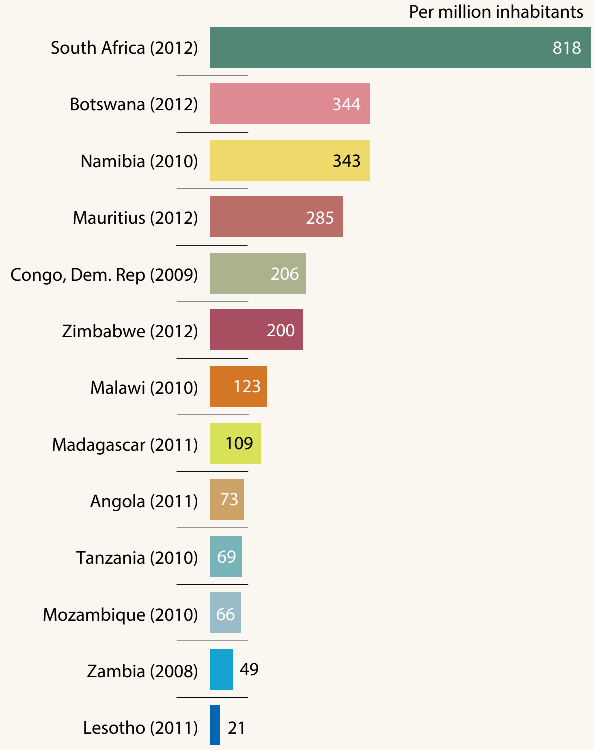
The protocol recommends that gender equity be enshrined in national constitutions by 2015. State Parties are also to enact laws by this date which promote equal access to, and retention at, all levels of education, including tertiary. By 2014, only seven countries had achieved parity in primary education,[10] nine countries[11] had passed the threshold of a minimum of 50% female enrolment in secondary schools and seven counted more young women at university than young men[12] in 2014 (Morna *et al.*, 2014). It is clear that most Southern African countries will not achieve either the targets of the *SADC Protocol on Gender and Development* or the Millennium Development Goal on gender equality by 2015.

SADC students among world's most mobile

'SADC students are among the most mobile in the world, with six out of every 100 tertiary students studying abroad' (UIS, 2012). In 2009, 89 000 SADC students studied outside their home country, representing 5.8% of tertiary enrolment in the region. This ratio is higher than the regional average for sub-Saharan Africa (4.9%) and three times the world average (2.0%).

One explanation can be found in the SADC *Protocol on Education and Training* (1997), which sets out to facilitate mobility. Only three signatory countries (South Africa, Swaziland and Zimbabwe), however, have respected the agreement in the protocol that countries cease charging higher fees for SADC students than for national students, a practice considered a potential barrier to student mobility (UIS, 2012).

Figure 20.4: **Researchers (HC) in Southern Africa per million inhabitants, 2013 or closest year**



Source: UNESCO Institute for Statistics, April 2015

Students who travel abroad from Botswana, Lesotho, Madagascar, Namibia, Swaziland and Zimbabwe tend to be concentrated in a single destination: South Africa.[13] The latter hosted about 61 000 international students in 2009, two-thirds of whom came from other SADC nations. South Africa is not only the leading host country in Africa but also ranks 11th among host countries worldwide. Its higher education sector is well developed, with strong infrastructure and several respected research institutions that appeal to international students. Students from Angola, Malawi, Mozambique, the Seychelles, South Africa, Tanzania and Zambia tend to be dispersed across a wide range of host countries (UIS, 2012).

A growing number of publications

South Africa stands out for having the greatest number of researchers per million inhabitants (Figure 20.4) and by far the greatest output in terms of publications and patents (Figure 20.6 and Table 20.2). When population is taken into account, it comes second only to Seychelles for the number of articles.

9. This protocol was signed by all but three SADC countries: Botswana, Malawi and Mauritius.

10. Botswana, Malawi, Seychelles, South Africa, Swaziland, Tanzania and Zimbabwe

11. Botswana, Lesotho, Madagascar, Mauritius, Namibia, Seychelles, South Africa, Swaziland and Zimbabwe

12. Botswana, Lesotho, Mauritius, Namibia, South Africa, Swaziland and Zambia

13. with the exception of students from Madagascar, who prefer France

Table 20.4: **KEI and KI rankings for 13 SADC countries, 2012**

Rank	Change in rank since 2000	Country	Knowledge Economy Index	Knowledge Index	Economic Incentive Regime	Innovation	Education	ICTs
62	1	**Mauritius**	5.5	4.6	8.22	4.41	4.33	5.1
67	-15	**South Africa**	5.2	5.1	5.49	6.89	4.87	3.6
85	-18	**Botswana**	4.3	3.8	5.82	4.26	3.92	3.2
89	-9	**Namibia**	4.1	3.4	6.26	3.72	2.71	3.7
106	-9	**Swaziland**	3.1	3.0	3.55	4.36	2.27	2.3
115	-4	**Zambia**	2.6	2.0	4.15	2.09	2.08	1.9
119	-6	**Zimbabwe**	2.2	2.9	0.12	3.99	1.99	2.6
120	-12	**Lesotho**	2.0	1.7	2.72	1.82	1.71	1.5
122	-6	**Malawi**	1.9	1.5	3.33	2.65	0.54	1.2
127	-2	**Tanzania**	1.8	1.4	3.07	1.98	0.83	1.3
128	-2	**Madagascar**	1.8	1.4	2.79	2.37	0.84	1.1
129	5	**Mozambique**	1.8	1.0	4.05	1.76	0.17	1.1
142	-1	**Angola**	1.1	1.0	1.48	1.17	0.32	1.4

Note: Rankings are for a total of 145 countries.

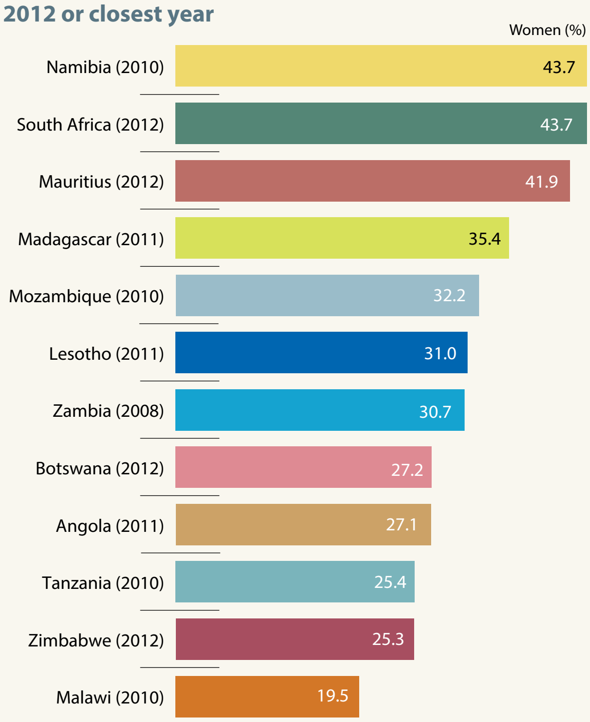
Source: World Bank

South Africa increased the number of its publications by 23% from 2009 to 2014 but the strongest growth rate was recorded by Angola and the Democratic Republic of Congo, albeit from a low base. The most prolific countries can boast of an average citation rate above the G20 average (Figure 20.6).

With nearly one-third of their publications concentrated in chemistry, engineering, mathematics and physics over the 2008–2014 period, Mauritius and South Africa are more akin to developed countries than other SADC countries where research tends to favour health-related sciences. Almost all countries share an inclination for geosciences, however (Figure 20.6).

When it comes to international collaboration, South African and Mauritian scientists stand out once more. Whereas just over half of South African articles (57%) and two-thirds of Mauritian articles (69%) had a foreign author over 2008–2014, the ratio among their SADC neighbours varied from 80% in Botswana to 96% in Mozambique and Zambia.

Figure 20.5: **Women researchers (HC) in Southern Africa, 2012 or closest year**



Note: Data are unavailable for some countries.

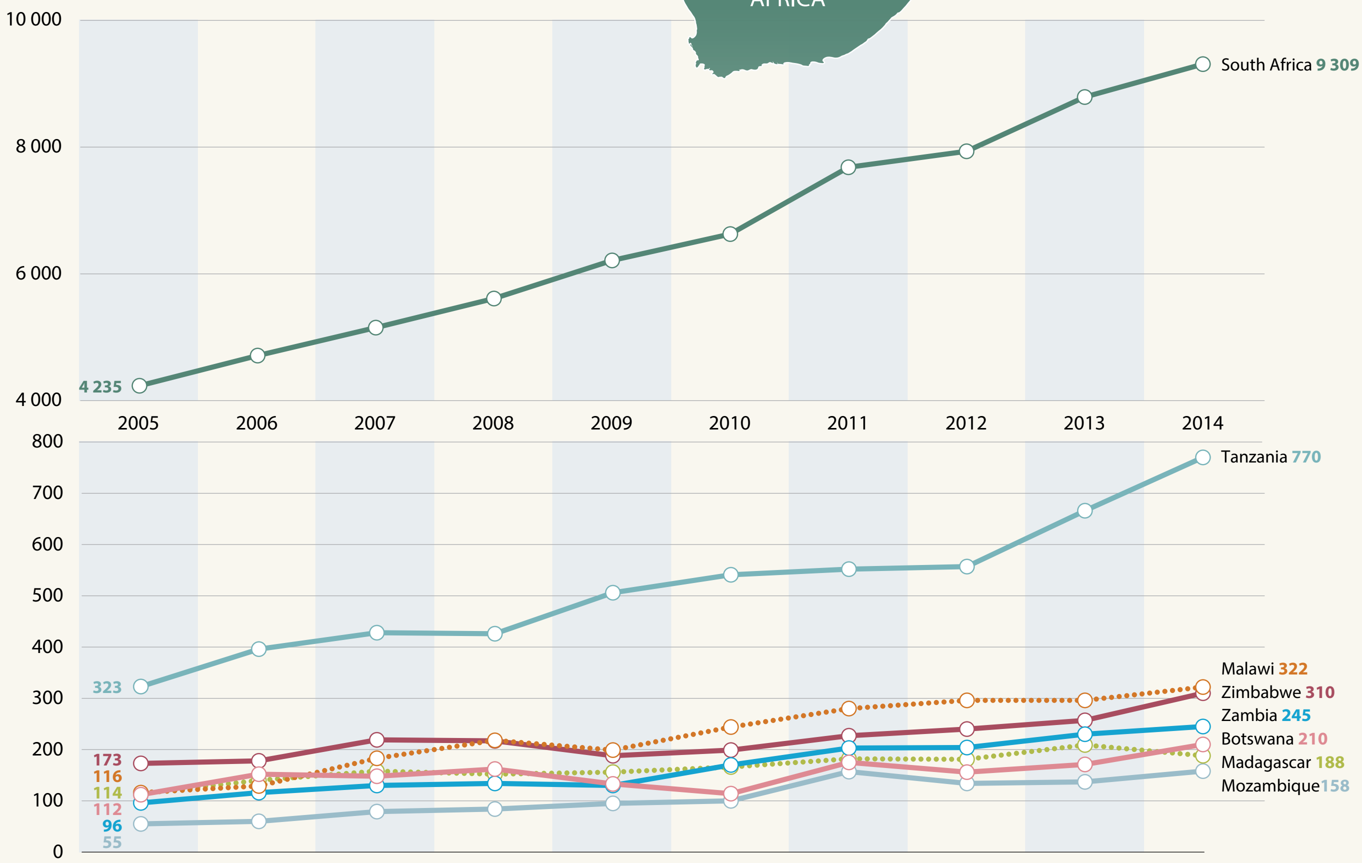
Source: UNESCO Institute for Statistics, April 2015

Figure 20.6: **Scientific publication trends in SADC countries, 2005–2014**

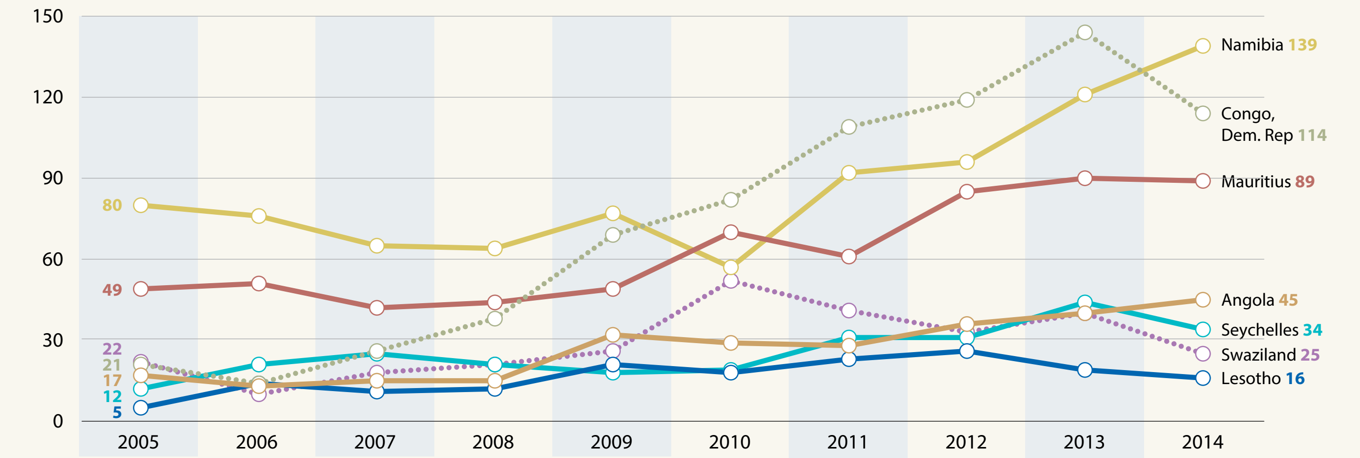
1.20

Average citation rate, 2008–2012, for the four countries with the most output: South Africa, Tanzania, Malawi and Zimbabwe; the G20 average is 1.02

Output from Malawi and Mozambique has almost tripled since 2005

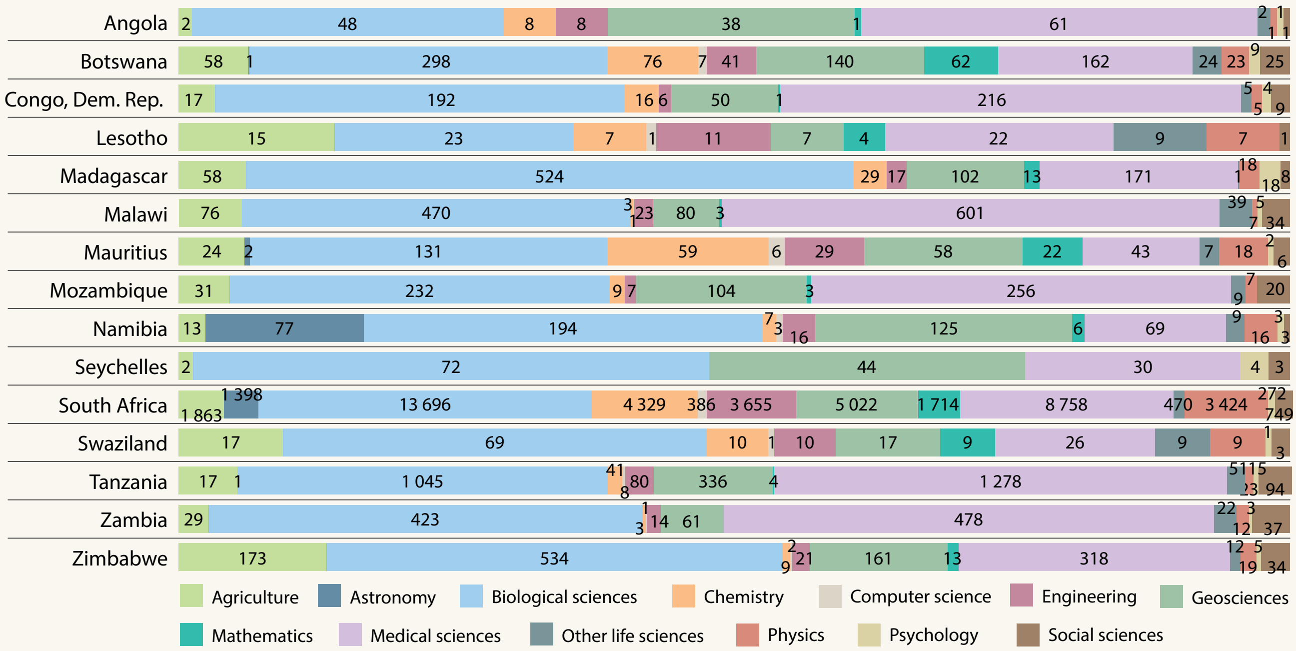


Strong growth in Angola and the Democratic Republic of Congo



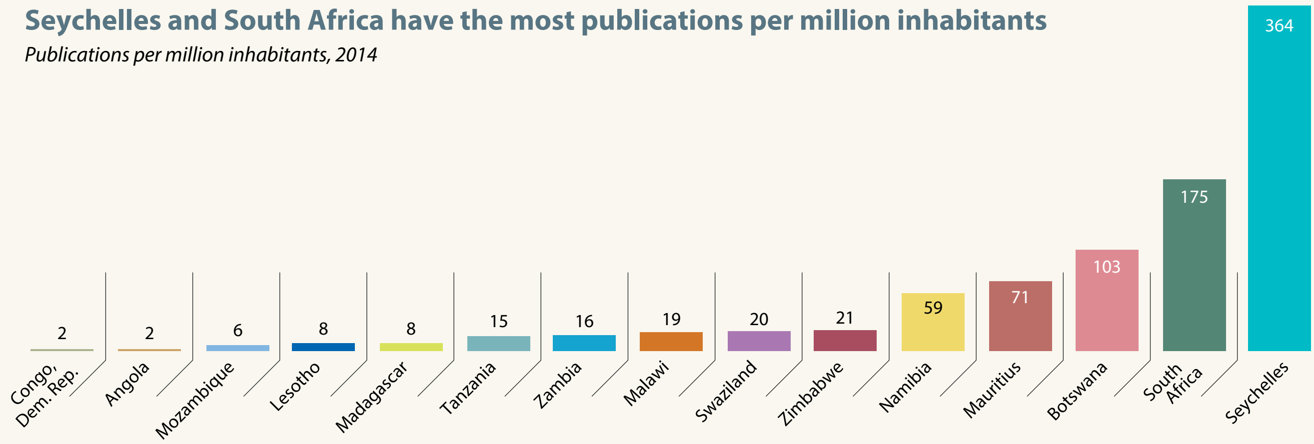
Life sciences and geosciences dominate

Cumulative totals by field, 2008–2014



Seychelles and South Africa have the most publications per million inhabitants

Publications per million inhabitants, 2014



South Africa is a key research partner for most SADC countries

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Angola	Portugal (73)	USA (34)	Brazil (32)	UK (31)	Spain/France (26)
Botswana	USA (367)	South Africa (241)	UK(139)	Canada (58)	Germany (51)
Congo, Dem. Rep.	Belgium (286)	USA (189)	France (125)	UK (77)	Switzerland (65)
Lesotho	South Africa (56)	USA (34)	UK (13)	Switzerland (10)	Australia (8)
Madagascar	France (530)	USA (401)	UK (180)	Germany (143)	South Africa (78)
Malawi	USA (739)	UK (731)	South Africa (314)	Kenya /N.lands (129)	
Mauritius	UK (101)	USA (80)	France (44)	India (43)	South Africa (40)
Mozambique	USA (239)	Spain (193)	South Africa (155)	UK (138)	Portugal (113)
Namibia	South Africa (304)	USA (184)	Germany (177)	UK (161)	Australia (115)
Seychelles	UK (69)	USA (64)	Switzerland (52)	France (41)	Australia (31)
South Africa	USA (9 920)	UK (7 160)	Germany (4 089)	Australia (3 448)	France (3 445)
Swaziland	South Africa (104)	USA (59)	UK (45)	Switz./ Tanzania (12)	
Tanzania	USA (1 212)	UK (1 129)	Kenya (398)	Switzerland (359)	South Africa (350)
Zambia	USA (673)	UK (326)	South Africa (243)	Switzerland (101)	Kenya (100)
Zimbabwe	South Africa (526)	USA (395)	UK (371)	Netherlands (132)	Uganda (124)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

The following section will be analysing the viability of national innovation systems, in terms of their potential to survive, grow and evolve. We shall be employing a broad 'national innovation systems' approach to examining the interconnectedness of STI and development (Table 20.5).

ANGOLA

Progress in higher education, despite governance issues

Angola is considered as having a viable national innovation system (Table 20.5). The biggest obstacle to the country's development prospects lies in governance. Angola ranks poorly on the Corruption Perceptions Index (161st out of 175) and Ibrahim Index of African Governance (44th out of 52, see Table 19.1). A recent UNESCO study has identified a correlation between low scientific productivity and ineffective governance (UNESCO, 2013).

Angola has the advantage of being minimally reliant on donor funding for its investment needs, being the second-largest oil producer in Africa after Nigeria and one of SADC's fastest-growing economies (see Figure 19.1). It ranks in the top half of SADC countries for GDP per capita and saw average annual growth of almost 3% over the period 2008–2013. Angola's income inequality is relatively low among SADC countries but it has a high poverty rate. It is deemed to have medium human development.

Table 20.5: **Status of national innovation systems in the SADC region**

Category	
Fragile	Democratic Republic of Congo, Lesotho, Madagascar, Swaziland, Zimbabwe
Viable	Angola, Malawi, Mozambique, Namibia, Seychelles, Tanzania, Zambia
Evolving	Botswana, Mauritius, South Africa

Note: National innovation systems can be analysed and categorized in terms of their potential to survive, grow and evolve. The assessment of viability thresholds is a complex exercise beyond the scope of the present chapter. The authors nevertheless propose the present set of three categories for a preliminary classification of national innovation systems in the SADC region. **Fragile systems** tend to be characterized by political instability, whether from external threats or internal political schisms. **Viable systems** encompass thriving systems but also faltering ones, albeit in a context of political stability. In **evolving systems**, countries are mutating through the effects of policy and their mutation may also affect the emerging regional system of innovation.

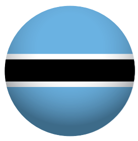
Source: elaborated by authors

There have been concerns over the environmental impact of oil exploration and extraction, particularly the effect of offshore drilling on the fishing industry. Combined with the uncertain sustainability of global oil prices and domestic stocks, not to mention the fact that the oil industry does not generate significant local employment, this concern led the government to create a Sovereign Wealth Fund in 2012 to invest profits from oil sales in the development of a number of local industries, in an effort to diversify the country's economy and spread prosperity (AfDB, 2013).

Full data on R&D expenditure are unavailable but there are few institutions performing research and the number of researchers is low. The country's KEI and KI values are the lowest among SADC countries. In 2011, the Ministry of Science and Technology published the *National Policy for Science, Technology and Innovation*. The policy sets out to organize and develop the national STI system, identify funding mechanisms and to harness STI to sustainable development.

The prolonged civil war (1975–2002) not only left higher education in a time warp but also caused many academics to emigrate. Since the end of the war, the number of universities has mushroomed from two (1998) to over 60 today with a student roll of more than 200 000. In 2013, the government launched *a National Plan for Training Professionals*. Moreover, in a bid to anchor higher education in its development efforts, Angola is hosting the Centre of Excellence for Science Applied to Sustainability, which was established in 2011 and received its first intake of students in 2013. The centre plans to produce 100 PhDs within a decade. The first of its kind in Africa, it provides research and training on sustainable development that is open to all Africans. The centre is located within the University of Agostinho Neto in Luanda (SARUA, 2012).

BOTSWANA



Good governance

Along with Tanzania, Botswana has one of the longest post-independence histories of political stability in Africa. A multiparty democracy, it is deemed the continent's best-performing country by the Corruption Perceptions Index (31st out of 175) and ranks third in Africa in the Ibrahim Index of African Governance (see Table 19.1). Real GDP per capita is relatively high and growing but the country nevertheless ranks second in the SADC for inequality and there is widespread poverty (Table 20.1). Botswana's incidence of HIV (18.5% of the population) is also among the highest in the world, according to the *Botswana AIDS Impact Survey* of 2013.

Botswana is the world's top producer of diamonds, in terms of value. Despite being heavily reliant on the mining sector, Botswana has escaped the 'resource curse' to a large extent by delinking public expenditure and revenue from the mining sector. This revenue is invested in a savings fund to enable an anti-cyclical fiscal policy. Revenue from diamonds has been invested in public goods and infrastructure and the government has long established universal scholarship schemes which fully subsidize education at all levels (AfDB, 2013).

Even before the slump in international demand during the global financial crisis of 2008–2009, diamond mining had been contributing less to economic growth with each plan period. This led the government to make diversifying the economy a priority of the *Tenth National Development Plan* for 2009–2016. The government considers private-sector participation as being 'critical' to the *Tenth Plan*'s success and enhancing the role of R&D as being the most effective way of fuelling entrepreneurship and private-sector growth (UNESCO, 2013).

In 2010, the government published its *Economic Diversification Drive*. A year later, it revised the Companies Act to allow applicants to register their company without the involvement of company secretaries, thereby reducing business start-up costs. The government has also introduced a points-based system to allow skilled expatriates to work in Botswana (UNESCO, 2013).

The centrepiece of the government's strategy is the development of six innovation hubs. The first of these was established in 2008 to foster the commercialization and diversification of agriculture. The second to be set up was the Botswana Diamond Hub. Until recently, rough diamonds accounted for 70% of Botswana's exports. After these exports contracted during the global financial crisis of 2008–2009, the government decided to derive greater benefits from its diamond industry by renegotiating agreements with multinational companies like De Beers in 2011 and setting up a Diamond Technology Park in Gaborone in 2009 as a hub for the local cutting and polishing of diamonds, as well as the manufacture of diamond jewellery. By 2012, the government had licensed 16 diamond polishing and cutting companies (UNESCO, 2013).

Hubs are also being put in place for innovation and the transport and health sectors. As of 2012, the Botswana Innovation Hub's governing bodies had approved and registered 17 entities that will operate in the park. These include academic institutions like the University of Botswana and companies active in such diverse areas as custom design and the manufacture of drilling rigs, specialized mining exploration technologies, diamond jewellery design and manufacturing, as well as ICT applications and software. By 2013, basic services had been installed on the 57-acre plot in Gaborone, such as water mains and electricity, and the site was ready for intensive development (UNESCO, 2013).

In addition, an education hub has been approved by the Government Implementation Co-ordinating Office, with the objective of developing quality education and research training to make Botswana a regional centre of excellence and promote economic diversification and sustainable growth. High unemployment (18.4% in 2013, see Table 20.1) has been linked to the mismatch between skills development and market needs, together with slow private-sector growth. The Botswana Education Hub will be co-ordinating its activities with those of the other five hubs in agriculture, innovation, transport, diamonds and health (UNESCO, 2013).

Botswana has two public and seven private universities. The University of Botswana is primarily a teaching institution, whereas the newly established Botswana International University of Science and Technology, which welcomed its first 267 students in September 2012, is R&D-based and determined to raise the academic qualifications of staff. There has been considerable progress in education over the past decade (SARUA, 2012). Scientific publications also increased from 133 to 210 between 2009 and 2014 (Figure 20.6).

The *National Policy on Research, Science, Technology and Innovation* (2011) is accompanied by an implementation plan (2012). The policy sets the target of raising the GERD/GDP ratio from 0.26% in 2012 to over 2% by 2016 (Republic of Botswana, 2011, p. 6). This target can only be reached within the specified time frame by raising public spending on R&D. The policy has four main thrusts:

- Development of a co-ordinated and integrated approach to STI planning and implementation;
- Development of STI indicators, in accordance with the guidelines of the OECD's *Frascati* and *Oslo Manuals*;
- The launch of regular participatory foresight exercises; and
- The strengthening of institutional structures responsible for policy monitoring and implementation.

The 2011 policy is a revision of the country's first *Science and Technology Policy* (1998). The 2011 policy has been consolidated with the 2005 *Botswana Research, Science and Technology Plan* (2005), following the recommendations of a review conducted by UNESCO in 2009. The main reason for the review was to align Botswana's policy with *Vision 2016* outlined in the *Tenth National Development Plan*. The review concluded that the same obstacles to R&D persisted in 2009, implying that the 1998 policy had made little impact on job and wealth creation (UNESCO, 2013).

In 2013, Botswana initiated the development of a *National Climate Change Strategy and Action Plan*. A climate change policy will be developed first, followed by the strategy. The process will reportedly be highly consultative, with the participation of rural inhabitants.

DEMOCRATIC REPUBLIC OF CONGO

A new academy of science and technology

The ongoing armed conflict in the Democratic Republic of Congo remains a major obstacle to the development of a national innovation system. The country shows the lowest HDI and GDP per capita and the highest poverty rate of any SADC member. The country's dependence on donor funding is high and climbed steeply between 2007 and 2009. The country also scores poorly (40th) in the Ibrahim Index of African Governance (see Table 19.1).

The Democratic Republic of Congo does not have a national STI policy. Scientific research capacity exists mainly in public universities and government-owned research institutes. The Ministry of Scientific Research and Technology supports five research organizations active in the fields of agriculture, nuclear energy, geology and mining, biomedicine, environment and conservation, as well as a geographical institute.

In 2012, the Academy for the Advancement of Science and Technology for Innovation was established in Kinshasa, driven by the community of researchers and financed by members' contributions, donations and legacies, with support from the Ministry of Scientific Research and Technology. Another sign of the scientific community's dynamism is the near-tripling of its research output between 2008 and 2014 (Figure 20.6).

The Democratic Republic of Congo has a relatively large higher education sector, with a total of 36 publicly funded universities, 32 of which were established between 2009 and 2012 (SARUA, 2012). There seems to be little interaction between universities and industry and, to date, a single business incubator has been established in the country.

The Academic Instruction Act (2011) has replaced the former policy framework for higher education dating from 1982. Another influential document is *Vision 2020*, which aims to develop a university curriculum attuned to national development priorities through three key strategies: the promotion of entrepreneurship, the development of technical and vocational skills and the provision of the relevant human capital through improved teacher training. The *Poverty Reduction Strategic Paper* of 2005 had articulated the need for teacher training and better vocational and technical skills and identified higher education as being a central player in meeting national development needs (AfDB *et al*., 2014).

LESOTHO

A compact to develop the private sector and social services

In mid-2014, this mountainous kingdom with a population of two million experienced a political crisis after parliament was suspended, prompting an attempted military coup. The SADC brokered a solution to the crisis which resulted in parliamentary elections being brought forward by two years to March 2015. The party of the outgoing prime minister was returned to power in what the SADC described as a 'free, fair and credible' election.

According to national figures, 62.3 % of the population lives below the national poverty line and unemployment is high, at 25.4% With 23% of 15–49 year-olds infected with HIV,[14] average life expectancy stands at less than 49 years. Human development is low, with Lesotho ranking 158th out of 187 countries in 2012, despite having registered some improvement since 2010 (Government of Lesotho and UNDP, 2014). GDP per capita grew by 18.7% over the period 2009–2013 (Table 20.2).

Three in four inhabitants live in rural areas and are dependent on subsistence agriculture. Since agricultural productivity is low and only 10% of the land is arable, Lesotho relies heavily on imports from South Africa. It also depends on its South African neighbour for employment and for the purchase of its main natural resource: water.

Within the country, the government remains the main employer and greatest consumer, accounting for 39% of GDP in 2013. Lesotho's largest private employer is the textile and garment industry; approximately 36 000 Basotho, mainly women, work in factories which produce garments for export to South Africa and the USA (see Figure 18.2). Diamond mining has grown in recent years and may contribute 8.5% to GDP by 2015, according to current forecasts. Lesotho remains extremely dependent on donor funding.

In 2007, Lesotho signed a six-year US$ 362.5 million Millennium Challenge Account Compact to strengthen the health care system, develop the private sector and broaden access to improved water supplies and sanitation. Thanks to Lesotho's 'strong performance' and 'continued commitment to democratic principles and good governance', the country became eligible in December 2013 to apply for a second compact[15] funded by the Millennium Challenge Account. The process of compact development takes two years, so, if the application is successful, the second compact will become effective in 2017.

14. See: www.unaids.org/en/regionscountries/countries/lesotho

15. See: www.lmda.org.ls

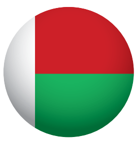
Major obstacles to economic growth, private sector-led entrepreneurship and poverty alleviation in Lesotho relate to the fact that the government has not managed to use its resources efficiently to provide public services that encourage high levels of private investment and entrepreneurship.

Much of STI policy still to be implemented

Lesotho's basic R&D indicators depict a poorly developed STI sub-sector with the lowest GERD/GDP ratio (0.01% in 2011) of any SADC country (Figure 20.3). The country has a single public university, the National University of Lesotho (est. 1945) and a number of other public and private tertiary-level institutions. The private establishments partly compensate for the limited capacity of the public sector to satisfy enrolment needs. Clearly, public resources need to be better utilized at all levels, if STI is to be harnessed to meeting the country's development needs.

The *National Science and Technology Policy* for 2006–2011 envisioned raising government funding of R&D to 1% of the annual national budget and recommended establishing new institutions, including the Lesotho Advisory Commission on Science and Technology to manage S&T policy implementation and the Lesotho Innovation Trust Fund to mobilize funding for STI. The Department of Science and Technology – located in the Ministry of Communications, Science and Technology – is responsible for promoting and co-ordinating STI policy, according to the detailed implementation plan developed in 2010. The plan required that measures be taken to ensure that all segments of society benefit from STI, in keeping with the Basotho spirit of *letsema*. However, to date, the policy remains largely unimplemented and has not been revised.

MADAGASCAR



A research policy oriented towards development

In Madagascar, the coup d'état of 2009 resulted in international sanctions which have curtailed donor funding. Today, the economy is faltering: GDP per capita dropped by 10.5% over the period 2008–2013. Madagascar has the second-highest reported poverty rate within the SADC after the Democratic Republic of Congo, even though it has a median ranking within the community for human development.

In terms of governance, Madagascar actually dropped from 118th to 127th place out of 175 countries between 2013 and 2014 in the Corruption Perceptions Index. All governance indices identify political instability as an aggravating factor for corruption – and vice versa – and as being the main obstacle to creating an enabling and healthy business environment (IFC, 2013). Like many countries, Madagascar observes International Anti-Corruption Day each year on 9 December. The theme in 2013 was 'Zero Corruption, 100% Development'.

Madagascar has a low GERD/GDP ratio (0.11% in 2011). R&D is spread across several research institutes which cover agriculture, pharmaceuticals, oceanography, environment, veterinary sciences, nuclear energy, botany and zoology, among other areas. The country counts six public universities and three technical universities, eight national centres of research and 55 privately funded universities and colleges. Enrolment has increased dramatically since 2005 and doctoral programmes are offered by 29 discipline-based schools or departments within both public and private universities.

The government has identified higher education as a major agent of national development. For example, Challenge 5 of the *Madagascar Action Plan* 2007–2012 identifies the need to transform higher education. Its specific goals are to:

- ensure competitiveness, creativity and the employability of graduates;
- foster research and innovation;
- offer diversified courses to meet national socio-economic needs;
- improve the governance of public universities; and
- develop high-quality private universities and technical institutes.

Between 2000 and 2011, the number of students enrolled in Madagascar's public universities more than doubled from 22 166 to 49 395, according to the Ministry of Education and Scientific Research. Nearly half attended the University of Antananarivo. The great majority of PhD students were enrolled in science and engineering disciplines (SARUA, 2012). The student population at both public and private universities almost doubled between 2006 and 2012 to 90 235 but the number of PhD candidates actually shrank (Table 19.4).

Madagascar does not have a national STI policy but it did adopt a national research policy in December 2013 to promote innovation and the commercialization of research results for socio-economic development. This policy is accompanied by five *Master Plans of Research* related to renewable energies, health and biodiversity, agriculture and food security, environment and climate change. These plans have been identified as priorities for R&D; other plans are being elaborated in 2015–2016.

Moreover, a Competitive Fund for Research and Innovation is currently being set up. It is intended to strengthen the relationship between research and socio-economic benefits and to throw bridges between public researchers and the private sector, as outlined by the national research policy. This fund is financed by the government, as well as by bilateral and multilateral partners.

In 2012, the Ministry of Higher Education and Scientific Research advocated a radical reform, emphasizing the importance of improving the interface between scientific research and the country's development goals.

MALAWI

Wooing investors to diversify the economy

Malawi has been a multiparty parliamentary democracy since 1994. For the past 10 years, the economy has grown annually by 5.6% on average, making it the sixth-fastest growing economy in the SADC. It is projected that, between 2015 and 2019, annual growth in real GDP will range from 6% to 5% (IMF, 2014). Malawi's ratio of donor funding to capital formation rose considerably over the period 2007–2012. At the same time, its attempts to diversify the agriculture sector and move up the global value chain have been seriously constrained by poor infrastructure, an inadequately trained work force and a weak business climate (AfDB *et al*., 2014).

Malawi has one of the lowest levels of human development in the SADC (see Tables 19.1 and 20.2) but it is also one of three African countries that 'are making especially impressive progress for several Millennium Development Goals,' along with Gambia and Rwanda, including with regard to primary school net enrolment (83% in 2009) and gender parity, which has been achieved at primary school level (UNESCO, 2014a).

The economy is heavily dependent on agriculture, which accounts for 27% of GDP (Figure 20.2) and 90% of export revenue. The three most important export crops are tobacco, tea and sugar – with the tobacco sector alone accounting for half of exports (see Figure 18.2). Malawi spends more on agriculture (as a share of GDP) than any other African country (see Table 19.2). Over 80% of the population is engaged in subsistence farming, with manufacturing earning just 10.7% of GDP (Figure 20.2). Moreover, most products are exported in a raw or semi-processed state.

Malawi is conscious of the need to attract more FDI to foster technology transfer, develop human capital and empower the private sector to drive economic growth. FDI has been growing since 2011, thanks to a government reform of the financial management system and the adoption of an *Economic Recovery Plan*. In 2012, the majority of investors came from China (46%) and the UK (46%), with most FDI inflows going to infrastructure (62%) and the energy sector (33%) [UNESCO, 2014a].

The government has introduced a series of fiscal incentives to attract foreign investors, including tax breaks. In 2013, the Malawi Investment and Trade Centre put together an investment portfolio spanning 20 companies in the country's six major economic growth sectors, namely agriculture, manufacturing, energy (bio-energy, mobile electricity), tourism (ecolodges) and infrastructure (wastewater services, fibre optic cables, etc.) and mining (UNESCO, 2014a).

In 2013, the government adopted a *National Export Strategy* to diversify the country's exports (Government of Malawi, 2013). Production facilities are to be established for a wide range of products[16] within the three selected clusters: oil seed products, sugar cane products and manufacturing. The government estimates that these three clusters have the potential to represent more than 50% of Malawi's exports by 2027 (see Figure 18.2). In order to help companies adopt innovative practices and technologies, the strategy makes provision for greater access to the outcome of international research and better information about available technologies; it also helps companies to obtain grants to invest in such technologies from sources such as the country's Export Development Fund and the Malawian Innovation Challenge Fund (Box 20.2) [UNESCO, 2014a].

Productive scientists, few university places

Despite being one of the poorest countries in the world, Malawi devoted 1.06% of GDP to GERD in 2010, according to a survey by the Department of Science and Technology, one of the highest ratios in Africa. Also noteworthy is that Malawian scientists publish more in mainstream journals – relative to GDP – than any other country of a similar population size (UNESCO, 2014a).

Enrolment in higher education struggles to keep up with rapid population growth. Despite a slight improvement, only 0.81% of the age cohort was enrolled in university by 2011. Moreover, although the number of students choosing to study abroad increased by 56% between 1999 and 2012, their proportion decreased from 26% to 18% over the same period (UNESCO, 2014a).

Malawi's first science and technology policy from 1991 was revised in 2002. Despite being approved, the 2002 policy has not been fully implemented, largely due to the lack of an implementation plan and an unco-ordinated approach to STI. This policy has been under revision in recent years, with UNESCO assistance, to re-align its focus and approaches with the second *Malawi Growth and Development Strategy* (2013) and with international instruments to which Malawi is a party (UNESCO, 2014a).

16. including cooking oil, soaps, lubricants, paints, animal feed, fertilizers, snacks and cosmetics

The *National Science and Technology Policy* of 2002 envisaged the establishment of a National Commission for Science and Technology to advise the government and other stakeholders on science and technology-led development. Although the Science and Technology Act of 2003[17] made provision for the creation of this commission, it only became operational in 2011, with a secretariat resulting from the merger of the Department of Science and Technology and the National Research Council. The Secretariat of the National Commission for Science and Technology reviewed the current *Strategic Plan for Science, Technology and Innovation (2011–2015)* but, as of early 2015, the revised STI policy had not yet met with Cabinet approval (UNESCO, 2014a).

Among the notable achievements stemming from the implementation of national STI policies in recent years are the:

- establishment, in 2012, of the Malawi University of Science and Technology and the Lilongwe University of Agriculture and Natural Resources (LUANAR[18]) to build STI capacity. This brings the number of public universities to four, with the University of Malawi and Mzuzu University;
- improvement in biomedical research capacity through the five-year Health Research Capacity Strengthening Initiative (2008–2013) awarding research grants and competitive scholarships at PhD, master's and first degree levels, supported by the UK Wellcome Trust and DfID;
- strides made in conducting cotton confined field trials, with support from the US Program for Biosafety Systems, Monsanto and LUANAR (see Box 18.2).
- introduction of ethanol fuel as an alternative fuel to petrol and the adoption of ethanol technology;
- launch of the *ICT Policy for Malawi* in December 2013, to drive the deployment of ICTs in all economic and productive sectors and improve ICT infrastructure in rural areas, especially via the establishment of telecentres; and
- a review of secondary school curricula in 2013.

17. A Science and Technology Fund was also established by the Science and Technology Act of 2003 to finance research and studies through government grants and loans; it was not yet operational by 2014 (UNESCO, 2014b).

18. LUANAR was delinked from the University of Malawi in 2012.

MAURITIUS

Competing with South Africa as an investment hub

Mauritius is a small island nation with 1.3 million inhabitants. Unemployment is low and the country counts the second-highest GDP per capita in the SADC; it grew by more than 17% over the period 2008–2013. Mauritius also ranks second-highest in the SADC region for human development and has the third-best score in the Corruption Perceptions Index (47th out of 175), behind Botswana (31st) and Seychelles (43rd). In 2012, there were almost twice as many students enrolled in higher education as in 2006 (Table 19.4).

The economy is driven by tourism, textile manufacturing, sugar and financial services. There has been a rapid diversification of the economic base towards ICTs, seafood, hospitality, property development, health care, renewable energy, education and training, which have attracted both local and foreign investors. Mauritius' status as an investment hub for new businesses has also provided significant opportunities for offshore companies. This diversification is largely due to the government's determination to move the economy up the value chain towards an economy based on high skills and technology. The strategy has worked: in 2013, Mauritius overtook South Africa to become the most competitive economy in sub-Saharan Africa.

Box 20.2: **The Malawi Innovation Challenge Fund**

The Malawi Innovation Challenge Fund (MICF) is a new competitive facility, through which businesses in Malawi's agricultural and manufacturing sectors can apply for grant funding for innovative projects with potential for making a strong social impact and helping the country to diversify its narrow range of exports.

The fund is aligned on the three clusters selected within the country's *National Export Strategy*: oil seed products, sugar cane products and manufacturing.

The MICF provides a matching grant of up to 50% to innovative business projects to help absorb some of the commercial risk in triggering innovation. This support should speed up the implementation of new business models and/or the adoption of technologies.

The first round of competitive bidding opened in April 2014.

The fund is endowed with US$ 8 million from the United Nations Development Programme and the UK Department for International Development.

Source: AfDB press release and personal communication; authors

To a large extent, the radical transformation of the Mauritian economy has been informed by a policy document entitled *Maurice Ile Durable (Mauritius: Sustainable Island)*, adopted in 2011. This document anchors economic development firmly in sustainability and has five interlinking foci: energy, the environment, education, employment and equity. Mauritius passed an Energy Efficiency Act in 2011 and has adopted an *Energy Strategy for 2011 –2025* which stresses sustainable building design and transportation, together with the development of renewable energy sources such as solar, geothermal and hydropower.

Mauritius has been a central player in the implementation of the *Programme of Action for the Sustainable Development of Small Island Developing States*, having hosted one of the three landmark meetings[19] which are driving this programme, in 2005. Mauritius led a call, in 2014, for the establishment of a UNESCO centre of excellence on ocean science and innovation for capacity-building and research, as a contribution to the *2030 Agenda for Sustainable Development*. The call was endorsed by the *Mauritius Ministerial Declaration* adopted by Mauritius, Comoros, Madagascar and the Seychelles at the conclusion of a high-level meeting on strengthening STI policy and governance for the sustainable development of small island developing states and their resilience to climate change.

A series of moves to boost R&D

In 2012, Mauritius devoted 0.18% of GDP to GERD (Figure 20.3). About 85% of public R&D expenditure is invested in S&T-related fields. The sectors with the highest expenditure (together accounting for about 20% of total spending on S&T) are agriculture, environment and ocean/marine sciences, followed by health and ICTs, which account for about 4–7% of total spending. Mauritius has set itself the target of increasing public expenditure on R&D to 1% of GDP by 2025 and expects the private sector to contribute at least 50% of national expenditure on R&D by this date.

In 2009, the Mauritius Research Council held a series of consultations. In addition to its advisory role, this government agency co-ordinates and funds research to give industries the edge in innovation. The consultations produced the following proposals for:

- raising private spending on R&D;
- strengthening intellectual property laws;
- promoting market-driven research;
- consolidating the linkages between researchers in the public sector and industry; and
- instituting fiscal measures to attract private investment in R&D.

In response to these recommendations, the government took a series of measures to boost R&D, including the:

- provision, in 2014, of Rs 100 million (*circa* US $3 million) to fund R&D, including through the Public Sector Collaborative Research Scheme and the Small Business Innovation Scheme, operated by the Mauritius Research Council; the main project areas are: biomedicine; biotechnology; energy and energy efficiency; ICTs; land and land use; manufacturing technology; science and technology education; social and economic research; and water resources;
- amendment, in 2014, to the Mauritius Research Council Act to provide for a National Research and Innovation Fund;
- establishment of the International Institute of Technology Research Academy, which moved to its main campus in 2015, through a memorandum of understanding between the Indian Institute of Technology in India and the Mauritius Research Council, in collaboration with the University of Mauritius; and, lastly,
- provision, in 2013, for the recruitment of 30 experienced international lecturers for the country's two universities – the University of Mauritius and the University of Technology[20] – to foster greater research and improve teaching standards.

The Mauritius Research Council is the main co-ordinating agency of the Ministry of Tertiary Education, Science, Research and Technology. The ministry is currently overseeing the formulation of the country's first *National Policy and Strategy on Science, Technology and Innovation* covering the period from 2014 to 2025. The main foci of the draft policy are:

- human competencies in the STI sector;
- the role of the public research sector;
- the link between science and society;
- technology absorption and innovation;
- investment in research and innovation;
- meeting challenges through enhanced research;
- promotion of African STI initiatives; and
- governance and sustainability.

Some challenges remain for policy formation; there is a need to bring coherence and a long-term vision to the forefront of STI governance and to bridge the gap between public research institutions and private businesses.

19. First adopted in Barbados in 1994, this programme was updated in Mauritius in 2005 then again in Samoa in 2014.

20. Three other institutions offer higher education: the Mauritius Institute of Education, the Mahatma Gandhi Institute and the Mauritius College of the Air.

MOZAMBIQUE

An opportunity to accelerate development

Mozambique's high growth rate over the past decade (6.0–8.8% per year) dates from the start of aluminium and natural gas production in the 2000s, which brought in substantial FDI. The country's reliance on donor funding, while still high, decreased dramatically between 2007 and 2012. However, economic growth has not yet translated into human development. Mozambique still ranks 185th out of 187 countries, there having been no change since 2007. Poverty is widespread. This situation is a major obstacle to economic diversification, especially when combined with high financial costs, poor infrastructure and an inhibitive regulatory framework (AfDB, 2013). Mozambique also scores poorly on the Corruption Perceptions Index (119th out of 175) and the Ibrahim Index of African Governance (see Table 19.1).

Neither the country's *Science and Technology Policy* (2003), nor the *Mozambique Science, Technology and Innovation Strategy,* approved in 2006 with a horizon of 10 years, has yet delivered on its promises. The *Strategy* establishes a set of priorities to eradicate extreme poverty, harness economic growth and improve the social well-being of all Mozambicans. It is being implemented in conjunction with international partners. The GERD/GDP ratio (0.42% in 2010) for Mozambique places it in the middle range of SADC countries but the density of researchers is low: just 66 per million inhabitants in 2010 (head count), excluding the business sector.

To foster implementation of the *Science and Technology Policy,* Mozambique created a National Research Fund in 2006 that is operated by the Ministry of Science and Technology. Funding goes to numerous projects for scientific research, innovation and technology transfer in the following areas: agriculture, education, energy, health, water, mineral resources, environmental sustainability, fisheries and marine sciences and botanical sciences.

The country has 16 research institutions, in addition to several national research councils active in the fields of water, energy, agriculture, medicine and ethno-botany, among others. The National Academy of Science dates from 2009.

Mozambique has 26 institutions of higher education, half of which are privately run. However, public institutions account for the majority of students, particularly Eduardo Mondlane University and Universidade Pedagogica. Demand for higher education is growing rapidly: there were four times more students enrolled in 2012 (124 000) than in 2005 (see Table 19.4).

Like several of its neighbours, Mozambique is currently mapping its science system, in partnership with UNESCO's Global Observatory of STI Policy Instruments (GO→SPIN).

The ultimate aim is to use this mapping exercise as the basis for drawing up a revised STI policy that could be applied to such critical areas as mitigating the consequences of climate change; exploring new energy sources; generating innovation to foster social inclusion; promoting the sustainable management and conservation of freshwater; terrestrial resources and biodiversity; and disaster resilience.

With its newfound political stability and income from aluminium, gas and coal, Mozambique has an unprecedented opportunity to accelerate development and improve social welfare. To generate income in a sustainable way, however, wealth must be managed and transformed into assets that can continue to serve the country's long-term interests.

NAMIBIA

A need to diversify the economy

While Namibia is classified as a middle-income country on the basis of its GDP per capita, its Gini coefficient (see the glossary, p. 738) reveals one of the world's highest levels of inequality, despite a modest improvement since 2004. Namibia also suffers from an unemployment rate of 16.9 % (Table 20.1) and widespread poverty, with the majority of the population surviving on subsistence agriculture. To this must be added the impact of long periods of severe drought and a high prevalence of HIV and AIDS. Namibia also ranks 128th out of 186 countries for human development. These indicators point to the formidable obstacles that Namibia must overcome, if it is to shake off its over-reliance on mining (see Figure 18.2), which only employs about 3% of the population.

Namibia's long-term development strategy is guided by *Vision 2030,* a planning document adopted in 2004 to 'reduce inequalities and move the nation significantly up the scale of human development, to be ranked high among the developed countries[21] in the world.' Five 'driving forces' were identified to realize the objectives of *Vision 2030*: education, science and technology; health and development; sustainable agriculture; peace and social justice; and gender equality.

In 2010, Namibia still had a low GERD/GDP ratio (0.14%) but it did count 343 researchers (head count) per million inhabitants, one of the region's better ratios. The country's KEI and KI values are also quite high, even though Namibia dropped nine places between 2000 and 2012. Two factors no doubt explain this relatively good performance: Namibia's market-friendly environment, which benefits from its proximity to South Africa; and its two reputable universities which have produced a critical mass of skilled workers over the past two decades, as well as a small, well-trained professional and managerial class.

21. See: www.gov.na/vision-2030

Two reputable universities

Taken together, the Namibia University of Science and Technology (formerly the Polytechnic of Namibia) and the University of Namibia account for 93% of student enrolment, the remainder being assured by two private institutions.

The University of Namibia boasts a student population of about 19 000 and a network of 12 satellite campuses and 9 regional centres nationwide. It has Faculties of: Agriculture and Natural Resources; Economics and Management Science; Education; Engineering; Health Sciences; Humanities and Social Sciences; Law; and Natural Sciences. The university offers 12 PhD programmes and has so far awarded 122 PhDs. It has put incentives in place to encourage researchers to publish their findings.

The Namibia University of Science and Technology strives to 'enhance innovation, entrepreneurship and competitiveness in Namibia and the SADC region.' It counts seven schools/faculties and 10 centres of excellence, which served a student body of over 12 000 in 2014. A Cooperative Education Unit (CEU) was established in 2010, in order to give graduates the skills required by industry. The CEU collaborates with industry in the design of its curricula and co-ordinates a programme through which students compete for an internship or industrial placement to put what they have learned into practice.

A three-year programme to boast STI

Within the Ministry of Education, it is the Directorate for Research, Science and Technology under the Department of Tertiary Education, Science and Technology which ensures co-ordination of science. In 2013, Namibia established a National Commission on Research, Science and Technology, pursuant to the Research, Science and Technology Act (2004). The commission is mandated to implement the Biosafety Act of 2006. It has also been entrusted with developing a three-year National Research, Science, Technology and Innovation Programme, with UNESCO's[22] assistance. The programme stems from the directives of the *National Policy on Research, Science and Technology*, adopted in 1999.

A national consultative workshop was held in March 2014 to pave the way towards an implementation strategy for the National Research, Science, Technology and Innovation Programme. Participating researchers, innovators and entrepreneurs assisted in identifying national priority fields, taking into consideration *Namibia's Industrial Policy* (2013), its current economic blueprint, the *Fourth National Development Plan* (2012–2017) and *Vision 2030*. The programme will seek to create an environment more conducive to research and innovation in the essential areas of policy, human resource development and the related institutional framework.

In 2013, UNESCO helped Namibia to develop a manual for operationalizing the National Research, Science and Technology Fund. The first disbursement from the fund was made jointly with South Africa in March 2014 (30 projects for a value of N$ 3 million, *circa* US$ 253 000). This was followed by a first national disbursement in May 2014 (27 projects for N$ 4 million). The funds from the second and third national calls for research proposals are due to be disbursed in May 2015. The grant recipients thus far are the University of Namibia, Polytechnic of Namibia, Ministry of Fisheries and Marine Resources, Ministry of Education and an NGO, the Desert Research Foundation of Namibia.

Namibia is also participating in UNESCO's GO→SPIN programme, in order to put a reliable information system in place to monitor STI policy implementation.

SEYCHELLES

A first university and national STI institute

Having recovered from virtual economic collapse in 2007–2008, Seychelles is now a rising star (AfDB *et al*., 2014). It comes out on top in the SADC region for GDP per capita, human development and unemployment and poverty levels. It is also one of the top-scorers for good governance, low corruption and general security. Despite these achievements, not everyone in this small island state is seeing the benefits. The economy is primarily based on tourism, agriculture and fisheries but economic growth has been led almost exclusively by the tourism sector. As a result, Seychelles has the greatest level of inequality of any SADC country.

There are no recent R&D data for Seychelles. In 2005, the country had a low GERD/GDP ratio (0.30%) and, given its population of 93 000, only a handful of researchers: 14. The main research institute is the Seychelles Centre for Marine Research and Technology (est. 1996).

Seychelles' first university dates only from 2009; it welcomed its first 100 students in 2012 (see Table 19.4). Though still in its infancy, the University of Seychelles is developing rapidly. It has already established strong collaboration with other universities in the SADC region (SARUA, 2012).

Parliament passed a bill creating the country's first National Institute of Science, Technology and Innovation in 2014. In January 2015, the government upgraded the Department of Entrepreneurship Development and Business Innovation to ministry status, adding the portfolio of investment.

22. See: http://tinyurl.com/unesco-org-policy-namibia

SOUTH AFRICA

Outward FDI flows have doubled

South Africa is currently Africa's second-largest economy after Nigeria. Despite having a population of only 53 million, it generates about one-quarter of African GDP. It is classified as a middle-income country and has a relatively solid national innovation system. With its regional political influence and growing economic presence in Africa, the country has the potential to drive economic growth across the continent. For the moment, its weight is felt most by its immediate SADC neighbours, through the development of trading partnerships, political agreements, business linkages and movements of people.

South Africa is the main destination for FDI inflows to the SADC region, attracting about 45% of the region's FDI in 2013, a slight decrease from 48% in 2008. South Africa is also establishing itself as a main investor in the region: over the same six-year period, its outward flows of FDI almost doubled to US$ 5.6 billion, powered by investment in telecommunications, mining and retail in mostly neighbouring countries. In 2012, South Africa invested in more new FDI projects in Africa than any other country in the world. Moreover, among emerging economies, it is the second-biggest investor in least developed countries after India, according to the United Nations Conference on Trade and Development.

Through the Department of Science and Technology, South Africa has entered into 21 formal bilateral agreements with other African countries in science and technology since 1997, most recently with Ethiopia and Sudan in 2014 (Table 20.6). Within three-year joint implementation plans which define spheres of common interest, co-operation tends to take the form of joint research calls and capacity-building through information- and infrastructure-sharing, workshops, student exchanges, development assistance and so on.

A negative trade balance in high-tech

South Africa trades mainly with Botswana (21%), Swaziland, Zambia and Zimbabwe (12% each) and Angola (10%). This contrasts with the main destinations for South African FDI, which are Mauritius (44 %), Tanzania (12%) and Mozambique (7%). Table 20.7 shows that South Africa has a consistently high negative trade balance in high-tech products, along with the rest of the SADC economies, making it a peripheral national innovation system in the global arena.

STI to help diversify the economy by 2030

The vision of the *National Development Plan* (2012) is for South Africa to become a diversified economy firmly grounded in STI by 2030. This transition is guided by the *Ten-Year Innovation Plan* (2008–2018) and its five 'grand challenges': biotechnology and the bio-economy (formerly pharmaceuticals); space; energy security; global change; and understanding of social dynamics. Among the achievements so far, we could cite:

- the decision in 2012 to host the € 1.5 billion project to build the world's largest radio telescope in South Africa and Australasia; this is bringing significant opportunities for research collaboration (see Box 20.3), attracting leading astronomers and researchers at all stages of their careers to work in Africa; it is worth noting that South African astronomers co-authored 89% of their publications with foreign collaborators during 2008–2014;
- the *National Bio-economy Strategy*, approved in 2013, which positions bio-innovation as an essential tool for reaching the country's industrial and social development goals;
- within the DST, a reorganization of some programmes in the past five years to give greater emphasis to innovation that addresses social challenges; the Socio-Economic Innovation Partnerships programme within DST is responsible for the downstream innovation chain, through sub-programmes on innovation for inclusive development and the green economy, among others;
- the launch of the DST Technology Top 100 internship programme in 2012, which places unemployed science, technology and engineering graduates in high-tech companies; in 2013 and 2014, one in four of the 105 interns were offered permanent employment with their host companies at the end of the one-year programme; in 2015, a further 65 candidates were placed with companies in the Gauteng and Western Cape Provinces; it is planned to expand the network of private firms involved in the programme.

A fund to boost sagging private sector R&D

South Africa's GERD/GDP ratio (0.73% in 2012) has dropped from a high of 0.89% in 2008. This has been mostly due to a sharp drop in private sector R&D, in spite of rising public spending on R&D. However, South Africa's research output still comprises about 85% of Southern Africa's total output (Lan *et al.*, 2014).

To help reach the target of a GERD/GDP ratio of at least 1%, the Sector-Specific Innovation Fund was launched in 2013. This fund targets specific industrial sectors, which partner with the government through the DST to support the industry's specific research, development and innovation needs, through a co-funding arrangement. This funding instrument also addresses one of the recommendations from the 2012 *Ministerial Review Report*, which called for greater interaction between DST and the private sector.

The R&D tax incentive programme introduced in 2007 and amended in 2012 gives a 150% tax deduction for expenditure on eligible scientific or technological R&D undertaken by

Table 20.6: **South Africa's bilateral scientific co-operation in Africa, 2015**

Joint co-operation agreement (signed)	Human development	Intellectual property	STI policy	Biosciences	Biotechnology	Agriculture /Agro-processing	Space	Laser technology	Nuclear medical technology	Water management	Mining / Geology	Energy	ICTs	Mathematics	Environment and climatechange	Indigenous knowledge	Aeronautics	Material sciences and nanotechnology	Basic sciences	Human and social sciences
Algeria (1998)								●	●								●	●		
Angola (2008)	●																			
Botswana (2005)*					●	●	●			●	●	●	●			●				
Egypt (1997)							●	●										●		●
Ethiopia (2014)																				
Ghana (2012)*					●		●						●							
Kenya (2004)*						●	●						●							
Lesotho (2005)						●														
Malawi (2007)	●		●	●				●								●				
Mali (2006)																				
Mozambique (2006)*	●					●	●						●							
Namibia (2005)*						●	●				●		●			●				
Nigeria (2001)					●		●				●							●		
Rwanda (2009)				●			●					●			●				●	
Senegal (2009)																				
Sudan (2014)																				
Tanzania (2011)		●	●		●								●					●		
Tunisia (2010)					●							●	●							
Uganda (2009)				●			●					●		●	●	●				
Zambia (2007)*							●				●		●			●				
Zimbabwe (2007)	●				●						●		●					●		

*partner of the African Very Long Baseline Interferometry Network and of the Square Kilometre Array

Source: compiled by authors via the DST

enterprises or individuals. The 2012 amendment requires companies to apply for pre-approval of their R&D projects in order to qualify. The programme has grown over the past eight years and has provided tax reductions to nearly 400 claimants, nearly half of which are small and medium-sized enterprises. The programme has managed to leverage more than ten times the value in R&D from a R 3.2 billion government contribution to this incentive.

The earlier DST Innovation Fund (1999) has been transformed into a range of funding instruments grouped under the Technology Innovation programme administered by the Technology Innovation Agency, which has been operative since 2010. Some of the most recently launched funds include the Youth Technology Innovation Fund (2012) targeting innovators between the ages of 18 and 30 who receive vouchers enabling them to access services and/or resources that they could not otherwise afford, and a Seed Fund (2012) to assist universities in bridging financing requirements, in order for them to translate university research output into ideas that can be commercialized.

The Technology and Human Resources for Industry (THRIP) scheme matches investment by industry in projects where researchers from public institutions, including universities, serve as project leaders and students are trained through projects in industry. THRIP was established in 1994 and was the object of an external evaluation in 2013; this was followed by a review of some THRIP processes that has been dubbed the 're-invigoration of THRIP'. This review led to a series of new measures, including the provision of student bursaries for the first time and the introduction of a 'first-come-first-served' rule to accelerate the uptake of awarded funds. From 2010 to 2014, THRIP supported an average of 1 594 students and 954 researchers per year, showing steady growth in the numbers of black and female researchers over the years.

An older scheme which has helped to increase the number of black and female researchers is the South African Research Chairs Initiative (SARChI) established in 2006. SARChI was externally reviewed in 2012 and, by 2014, had awarded a total of 157 chairs. The Centres of Excellence funding scheme launched in 2004 currently has a network of 15 research centres, five of which were established in 2014. One of the most recent is the Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy, the work of which is expected to lead to better decision-making in STI policy and consolidate related national information systems.

The *National Development Plan* (2012) has fixed a target of producing 100 000 PhDs by 2030 to improve the country's capacity for research and innovation. The DST has significantly increased its funding for postgraduate students. By 2014, 34 PhDs were being produced per million inhabitants but this is still below the target of 100 PhDs per million inhabitants fixed by the *Plan*.

Table 20.7: **International trade by the SADC in high-tech products, 2008–2013, in US$ millions**

	TOTAL											
	Import						Export					
	2008	2009	2010	2011	2012	2013	2008	2009	2010	2011	2012	2013
Botswana	251.7	352.9	248.0	274.1	303.7	–	21.1	24.4	15.1	44.6	62.7	–
Lesotho	16.6	28.4	–	–	–	–	0.4	1.6	–	–	–	–
Madagascar	254.1	151.8	177.0	141.6	140.2	–	7.4	10.7	5.5	52.6	2.0	...
Malawi	112.5	148.9	208.3	285.4	–	152.4	1.7	3.4	2.0	22.7	–	11.0
Mauritius	284.3	327.8	256.6	255.2	344.8	343.5	101.1	21.9	6.2	9.8	10.6	6.3
Mozambique	167.3	148.6	125.4	134.1	189.2	1 409.2	6.1	23.8	0.5	71.2	104.7	82.1
Namibia	199.5	403.8	334.9	401.9	354.6	378.9	22.0	42.8	49.3	46.6	108.0	71.7
Seychelles	32.1	–	–	–	–	–	0.2	–	–	–	–	–
South Africa	10 480.4	7 890.5	10 190.3	11 898.9	10 602.2	11 170.9	2 056.3	1 453.3	1 515.6	2 027.3	2 089.1	2 568.6
Tanzania	509.1	532.2	517.4	901.7	698.4	741.6	11.8	18.1	27.4	43.0	98.9	50.0
Zambia	209.7	181.9	236.4	354.9	426.7	371.2	8.8	5.9	4.6	222.0	55.2	40.0
Zimbabwe	116.8	201.1	393.3	343.1	354.2	447.3	80.0	7.3	9.2	9.7	20.4	18.5

Note: Rankings are for a total of 145 countries.

Source: World Bank

Box 20.3: **South Africa wins bid to host radio telescope**

In 2012, South Africa and Australia won a bid to build the world's largest radio telescope, the Square Kilometre Array (SKA), at a cost of € 1.5 billion. As a result, South Africa will work with eight African partners, six of them from within the SADC: Botswana, Madagascar, Mauritius, Mozambique, Namibia and Zambia. The other two are Ghana and Kenya.

South Africa is also co-operating with other SADC countries in skills training, through the African SKA Human Capital Development Programme, which has been operating since 2005. In 2012, the programme awarded about 400 grants for studies in astronomy and engineering from undergraduate to postdoctoral level, while also investing in training programmes for technicians. Astronomy courses are being taught as a result of the SKA Africa project in Kenya, Madagascar, Mauritius and Mozambique.

This work is complemented by an agreement signed in 2009 between Algeria, Kenya, Nigeria and South Africa for the construction of three low-Earth-orbiting satellites within the African Resource Management Constellation (ARMC). South Africa will build at least one out of the three, construction of which (ZA-ARMC1) began in 2013.

The development of qualified personnel and researchers is a critical prerequisite for the successful implementation of the SKA project in South Africa and the construction of new satellites under the ARMC agreement. These initiatives will develop Africa's technological and human capacities in Earth observation, for use in urban planning, land cover mapping, disaster prediction and monitoring, water management, oil and gas pipeline monitoring and so on.

Source: compiled by the authors

A popular destination for scientists and students

Within the SADC, South Africa hosts the largest number of leading scientists, consistent with its leading role in African science. Southern Africa is known for its unhindered circulation of scientific personnel and research mobility, with South Africa playing an important role as a hub for higher education and research in the region. Nearly half of the researchers in South Africa (49%) are transitory, spending fewer than two years in the country's research centres (Lan *et al.,* 2014).

South African universities attracted 61 000 foreign African students in 2009, providing potential human capital for South Africa and facilitating a greater integration with the rest of the continent (UIS, 2012). Students from SADC countries pay the same fees as local students. This is in accordance with the *SADC Protocol on Education and Training* and effectively means that the South African taxpayer subsidizes their studies. Other initiatives, such as the African Institute for Mathematical Sciences (AIMS), further encourage the circulation of students, scientists and researchers in the region and beyond (Box 20.4).

SWAZILAND

STI development undermined by social problems

The Kingdom of Swaziland is the second-smallest country in Southern Africa after the Seychelles, with a population of less than 1.3 million. In spite of being classified as a lower middle-income country, Swaziland shares characteristics with Africa's low-income countries. About 78% of the population derives its livelihood from subsistence agriculture and 63% lives in poverty that is exacerbated by regular food shortages. Unemployment has remained high over the past decade, at about 23% (Figure 20.1). There is also a high prevalence of HIV and AIDS: 26% among the adult population.

The ratio of donor funding to capital formation is high but fell considerably over 2007–2009. Economic growth has been sluggish for over a decade, hovering between 1.3% and a high of 3.5% in 2007. In 2011, the country even slipped into recession (-0.7%). GDP per capita is nevertheless situated at the higher end of the SADC scale (Table 20.1). The economy is closely tied to that of neighbouring South

Box 20.4: **A network of African Institutes for Mathematical Sciences**

The African Institute for Mathematical Sciences (AIMS) is a pan-African network of centres of excellence for postgraduate education, research and outreach in mathematical sciences. The first AIMS institute was founded in Cape Town (South Africa) in 2003.

Four other institutes have since been set up in Senegal (2011), Ghana (2012), Cameroon (2013) and Tanzania (2014). That in Senegal proposes courses in both French and English. So far, these five institutes have produced 731 graduates, one-third of whom are women.

The institutes teach both basic and applied mathematics, covering a large range of mathematical applications in physics (including astrophysics and cosmology), quantitative biology, bioinformatics, scientific computing, finance, agriculture modelling and so on.

The institute in Cape Town was set up with the support of six universities which continue to contribute to the academic programme: Cambridge and Oxford (UK), Paris Sud XI (France) and Cape Town, Stellenbosch and Western Cape (South Africa).

In addition to its academic programmes, AIMS South Africa has a research centre in interdisciplinary areas like cosmology, computing and finance. The institute also directs the AIMS Schools Enrichment Centre for primary and secondary school teachers, which also organizes public lectures, workshops and master classes and supports maths clubs in schools across the country.

The other AIMS institutes also provide community services. AIMS Senegal has developed an innovative teaching module for secondary school maths teachers and has partnered with local businesses to raise funds for the creation of a national contest on computer applications and mathematical modelling, with a focus on finding development-oriented solutions. Scholars and lecturers from AIMS Ghana have equipped teachers at Biriwa Junior High School with an innovative teaching module. AIMS Cameroon is planning to launch its own research centre to host resident and visiting researchers from universities in Cameroon and beyond.

AIMS is the brainchild of South African cosmologist Neil Turok, whose family had been exiled for supporting Nelson Mandela during the Apartheid years. Knowing Mandela's passion for education, Turok had no difficulty persuading him to endorse the project.

After AIMS South Africa won the TED Prize in 2008, Turok and his partners developed the AIMS Next Einstein Initiative, the goal of which is to build 15 centres of excellence across Africa by 2023. The Government of Canada made a US$ 20 million investment in 2010, through its International Development Research Centre, and numerous governments in Africa and Europe have followed suit.

The plan for a vast network is gathering momentum. In October 2015, a forum is taking place in Dakar under the auspices of UNESCO's International Basic Sciences Programme to take the project to the next stage.

Source: www.nexteinstein.org; Juste Jean-Paul Ngome Abiaga, UNESCO

Africa for trade and its currency is pegged on the South African rand.

Nine out of ten adults are literate, one of the continent's highest ratios. By 2010, the Orphaned and Vulnerable Children's Initiative launched in 2002 and the State Funded Primary Education Programme (2009–2013) had together contributed to a 10% increase in primary school enrolment, which stood at 86%.

Swaziland has four universities and five colleges. However, only the University of Swaziland can claim to have research centres and institutes, such as the Swaziland Institute for Research in Traditional Medicine, Medicinal and Indigenous Food Plants.

In 2012, public expenditure on education accounted for 7.8% of GDP. Although only 13% of this went to higher education, this still represents a healthy investment of 1% of GDP (see Table 19.2). Although education remains the top priority, government spending on education has since become a casualty of the poor economic situation.

Enrolment in higher education remains low but is progressing: there were 8 057 tertiary students in 2013, up from 5 692 seven years earlier (see Table 19.4). One key development has been the introduction of PhD programmes in recent years, including one in agriculture at the University of Swaziland since 2012. Some 234 students were enrolled in PhD programmes in 2013.

A survey conducted by the UNESCO Windhoek Office in 2008 found that the University of Swaziland had the highest concentration of researchers, followed by the Energy Department of the Ministry of Natural Resources and Energy and the Agricultural Research Division of the Ministry of Agriculture. Some industries and public enterprises also engage in sporadic research (SARUA, 2009). Swaziland scores highly on the KEI and KI index, despite having dropped nine places between 2000 and 2012.

STI is acknowledged as being a top national priority in the *National Science, Technology and Innovation Policy,* which was drawn up in 2011 but has yet to be approved by parliament. UNESCO has been accompanying this process since 2008, when it prepared a status report of STI in Swaziland at the Ministry of Education's behest. The process has spawned the development of a *National Science, Mathematics and Technology Education Policy*, implemented by the Ministry of Education and Training. A Royal Science and Technology Park is also currently under construction, funded jointly by the Government of Swaziland and Taiwan, China.

In November 2014, a Directorate for Science, Technology and Innovation was established within the Ministry of Information, Communication and Technology. The directorate is responsible for finalizing the *National Science, Technology and Innovation Policy*. A National Commission for Research, Science and Technology is also being established to replace the existing National Research Council.

Funding instruments such as venture capital and tax relief for R&D are non-existent in Swaziland, as donors have tended to focus on providing aid. The draft STI policy acknowledges the need to develop a diverse range of financial instruments and funding bodies to stimulate innovation.

UNITED REPUBLIC OF TANZANIA

Consistently high economic growth

Tanzania has been a multiparty parliamentary democracy since the early 1990s. In common with much of Africa, growing indebtedness and falling commodity prices forced the country to adopt a series of IMF structural adjustment programmes from 1986 until the early 2000s. The country's poor economic performance over this period prompted a progressive abandonment of neoliberalism. Economic indicators have since picked up, with growth averaging 6.0–7.8% per year since 2001. Though still high, donor funding dropped substantially between 2007 and 2012. As the economy becomes less reliant on donor funding, it may gradually diversify.

So far, impressive growth has not significantly altered the country's economic structure, which is still based on agriculture. The latter accounted for 34% of GDP in 2013, compared to 7% for manufacturing. GDP per capita remains low by SADC standards but nevertheless progressed between 2009 and 2013 (Table 20.2). Tanzania is also a member of the East African Community (see Chapter 19), with which its trade more than doubled between 2008 and 2012 (AfDB *et al*., 2014).

Tanzania's low level of human development has improved somewhat in recent years. The country has the lowest level of income inequality within the SADC and little unemployment (just 3.5%) but its poverty rate is the highest among SADC countries with viable national innovation systems.

Policies to harness STI to development

The *Vision 2025* document adopted in 1998 aspires to 'transform the economy into a strong, resilient and competitive one, buttressed by science and technology'. Tanzania's first *National Science and Technology Policy* (1996) was revised in 2010 and renamed the *National Research and Development Policy*. The policy recognizes the need to improve the process of prioritization of research capacities, international co-operation in strategic R&D areas and planning for human resources; it also makes provisions for the establishment of a National Research Fund. This policy was, in turn, reviewed in 2012 and 2013. Tanzania also published a policy on biotechnology in December 2010. It is a member of the African Biosafety Network of Expertise (see Box 18.1).

The main body in charge of STI policy in Tanzania is the Ministry of Communication, Science and Technology and its main co-ordinating agency, the Commission for Science and Technology (COSTECH). COSTECH co-ordinates a number of research institutes engaged with industry, health care, agriculture, natural resources, energy and the environment.

Tanzania occupies the second-lowest rank for the KEI and KI among the viable national innovation systems in the SADC region. Basic R&D indicators send conflicting signals. Despite a GERD/GDP ratio of 0.38% of GDP, there were just 69 researchers (head count) per million population in 2010. One in four researchers is a woman (see Figure 19.3). The UNESCO Dar es Salaam office has been leading the reform of STI in Tanzania within the United Nations Development Assistance Programme for 2011–2015 (formerly the One UN Programme) since 2008. As part of this programme, UNESCO commissioned a series of studies, including one on biotechnology and bio-entrepreneurship (Box 20.5) and another on the participation of women in industries based on science, engineering and technology, which spawned a project to improve Maasai homes (Box 20.6).

Even though Tanzania has eight public institutions of higher education and a plethora of private institutions, fewer than half of secondary school-leavers who qualify for entry obtain a place at university. The establishment of the Nelson Mandela African Institute of Science and Technology in Arusha in 2011 should augment Tanzania's academic capacity considerably. This university has been designed as a research-intensive institution with postgraduate programmes in science, engineering and technology. Life sciences and bio-engineering are some of the initial niche areas, taking advantage of the immense biodiversity in the region. Together with its sister institution set up in Abuja (Nigeria) in 2007, it forms the vanguard of a planned pan-African network of such institutes.

Box 20.5: **Challenges facing Tanzania's bio-industry**

A report commissioned by UNESCO has identified a number of challenges for *Biotechnology and Bio-entrepreneurship in Tanzania* (2011).

It observes, for instance, that, although the first academic degree courses in biotechnology and industrial microbiology were introduced at Sokoine University of Agriculture in 2004 and at the University of Dar es Salaam in 2005, Tanzania still lacks a critical mass of researchers with skills in biotech-related fields like bioinformatics. Even when scientists have been sent abroad for critical training, poor infrastructure prevents them from putting their newly gained knowledge into practice upon their return.

Problems encountered in diagnostics and vaccination stem from the reliance upon biologicals produced elsewhere. Biosafety regulations dating from 2005 prevent confined field trials with genetically modified organisms.

Incentives are lacking for academics to collaborate with the private sector. Obtaining a patent or developing a product does not affect an academic's remuneration and researchers are evaluated solely on the basis of their academic credentials and publications.

The current lack of university–industry collaboration leaves academic research disconnected from market needs and private funding. The University of Dar es Salaam has made an effort to expose students to the business world by creating a Business Centre and setting up the Tanzania Gatsby Foundation's project to fund student research proposals of relevance to SMEs. However, both of these schemes are of limited geographical scope and uncertain sustainability.

Most research in Tanzania is largely donor-funded via bilateral agreements, with donor funds varying from 52% to 70 % of the total. Research has benefited greatly from these funds but it does mean that research topics are preselected by donors.

The conditions for export and business incubation have improved in recent years, thanks to the adoption of an export policy and a Programme for Business Environment Strengthening for Tanzania in 2009. However, no specific fiscal incentives have been envisioned to promote business in the biotechnology sector, resource limitations being given as the principal cause. Private entrepreneurs have appealed for tax regimes to support ideas developed domestically and for the provision of loans and incubation structures to allow them to compete against foreign products.

The report also observes that communication and co-ordination between the relevant ministries may also need optimizing, in order to provide the necessary resources for policy implementation. For example, lack of co-ordination between COSTECH, the Ministry of Health and Social Welfare and the Ministry of Industry, Trade and Marketing appears to be hindering potential implementation and exploitation of patent exemptions related to the agreement on Trade-related Aspects of Intellectual Property Rights.

Source: Pahlavan (2011)

ZAMBIA

Impediments to economic transformation

Zambia's economic growth has been derived mainly from the commodities boom (especially copper), fuelled by demand from China. However, growth has not resulted in job creation and poverty reduction, as Zambia has not yet managed to diversify its resource-based economy by developing manufacturing and adding value to commodities. Copper exports constitute about 80% of foreign exchange earnings but only 6% of total revenue. Although agriculture employs about 85% of the labour force, it contributes only 10% of GDP (see Figure 19.2). Productivity is low, with agriculture representing only about 5% of exports, mostly due to its weak linkages with manufacturing. The combination of poor infrastructure, an inappropriate regulatory and tax regime, limited access to finance, a low level of skills and the generally high cost of doing business are all major impediments to economic transformation in Zambia (AfDB *et al*., 2014).

The higher education sector consists of three public universities, the University of Zambia, Copperbelt University and, since 2008, Mulungushi University. There are also 32 private universities and colleges and 48 public technical institutes and colleges. Demand nevertheless far outstrips supply, as there are only enough places for one-third of qualifying school-leavers. The low remuneration of academic staff relative to other SADC countries has also resulted in an exodus of qualified academics (SARUA, 2012).

Zambia's GERD/GDP ratio is modest (0.28% in 2008) and it counts just 49 researchers per million inhabitants. When indicators for unemployment (13% in 2013), education and poverty (Table 20.1) are taken into account, Zambia's national innovation system is clearly struggling but viable.

A fund to spur research

Zambia's *National Science and Technology Policy* dates from 1996 and the Science and Technology Act from 1997. These milestones have given rise to three key science and technology institutions, the National Science and Technology Council (NSTC), National Technology Business Centre (est. 2002) and National Institute for Scientific and Industrial Research (a research body which replaced the National Council for Scientific Research dating from 1967). The NSTC provides grants through the Strategic Research Fund, Youth

Box 20.6: **Simple technology brings Maasai better homes**

The concept of innovation is often associated with high technology and thus perceived by many African communities as being beyond the reach of the poor. Affordable solutions exist, however, for making life more comfortable.

In 2012, the UNESCO Dar es Salaam office worked with the advocacy group Tanzanian Women in Science and the NGO Tanzanian Women Architects for Humanity to design a series of improvements to the adobe (mud) dwellings of Maasai women in the village of Ololoskwan, at the request of a group of Maasai women.

Home-building tends to fall to the womenfolk in Maasai communities. The architects taught the women a number of techniques for improving the comfort, safety and durability of their homes *(bomas)*. In order to raise the ceiling and strengthen the structure, existing poles were replaced with sturdier, longer ones. To protect the *bomas* from water leakage, the architects designed roofs with eaves and overhangs. Sloping aprons were introduced at the foot of the walls to protect them from splashing rain. Troughs made of ferro-cement were fitted round the roof overhangs to catch rainwater and channel it into drums at the base of the structure.

To ensure the mud plaster would not erode over time, the Maasai women were shown how to add bitumen and kerosene oil to the adobe mixture of clay and sand. The adobe was then blended with cow dung to produce a hard cement. This lengthened the time before the structures would need any maintenance from two to 5–10 years.

The stove in the centre of the room was relocated to a corner and surrounded on two sides by a clay brick wall, in order to help direct smoke upward. A hood or chimney channelled the smoke outside.

The windows were enlarged to let in more light and improve ventilation. Solar panels were introduced to provide lighting. The SunLite Solar Kit (*circa* US$ 50) consists of a solar panel, control-box with charger and battery and a bright LED light; the kit comes with a long cable and wiring that can be connected to most mobile phones, enabling owners to charge their own mobile phones and earn extra income from providing the service to others.

The two Maasai showhomes were completed in August 2012. Nearby villages sent emissaries, many of whom were so impressed that they offered to pay the women to build model homes for them. The women are now contemplating setting up a small construction business.

This project was funded by the United Nations Development Assistance Plan for 2011–2015, within a wider drive to give women a bigger role in harnessing STI to national development.

Source: Anthony Maduekwe, UNESCO

Innovation Fund and Joint Research Fund. It also administers the Science and Technology Development Fund instituted by the Science and Technology Act (1997). This fund encourages research that contributes to the goals of the *Fifth (*2006–2010) and *Sixth National Development Plans* and *Vision 2030 (*2006*)* for a prosperous middle-income nation by 2030, especially projects targeting a better standard of living, innovation, value addition to natural resources and the integration of locally produced technologies in the Zambian industrial sector, not to mention the purchase, maintenance or repair of equipment. For its part, the National Technology Business Centre (est. 2002) administers a Business Development Fund.

A strong commitment to agriculture

A Biosafety Act was adopted in 2007 (see map in Box 18.1). Zambia is surpassed only by Malawi within the SADC region for the level of public expenditure on agriculture: 10% of GDP in 2010. However, the country's main centre for agricultural research, the Zambian Agricultural Research Institute, 'is in a dire situation', having suffered a 30% decline in the staffing table, which counted 120 professional staff, 120 technicians and 340 support staff in 2010. The institute plays an essential role in maintaining laboratories for specialized research, while managing the country's seed bank. Very little donor funding has been forthcoming, leaving the government to shoulder 90–95% of the burden. The private non-profit Golden Valley Agricultural Research Trust[23] is trying to compensate for the staff cuts at its sister institute but it, too, is reliant on government and international donor funding – only 40% of its income comes from commercial farming and contract research (UNESCO, 2014b).

ZIMBABWE

A country emerging from a long crisis

Between 1998 and 2008, the Zimbabwean economy contracted by a cumulative 50.3%, sending GDP per capita plummeting to less than US $400. In July 2008, inflation peaked at 231 000 000%. By this time, 90% of the population was unemployed and 80% were living in poverty. Infrastructure had deteriorated, the economy had become more informal and there were severe food and foreign currency shortages. The economic crisis was accompanied by a series of political crises, including a contested election in 2008 which resulted in the formation of a government of national unity in February 2009 (UNESCO, 2014b).

The economic crisis coincided with the implementation of the Fast-track Land Reform Programme from 2000 onwards which compounded the decline in agricultural production by reducing the cropping area of traditionally large commercial crops such as wheat and maize. In parallel, FDI shrank after the imposition of Western sanctions and the suspension of IMF technical assistance due to the non-payment of arrears. Hyperinflation was only brought under control in 2009 after the adoption of a multicurrency payment system and economic recovery programme. Once stabilized, the economy grew by 6% in 2009 and FDI increased slightly; by 2012, it amounted to US$ 392 million (UNESCO, 2014b).

Zimbabwe continues to score poorly for governance indicators. In 2014, it ranked 156th (out of 175) in the Corruption Perceptions Index and 46th (out of 52) in the Ibrahim Index of African Governance (see Table 19.1). The economy remains fragile, plagued by high external debt, degraded infrastructure and an uncertain policy environment (AfDB *et al*., 2014). The lack of co-ordination and coherence among governance structures has led to poor implementation of existing policies and the multiplication of research priorities (UNESCO, 2014b).

An uncertain policy environment

The *Second Science and Technology Policy* was launched in June 2012, after being elaborated with UNESCO assistance. It replaces the earlier policy dating from 2002 and has six main objectives:

- Strengthen capacity development in STI;
- Learn and utilize emerging technologies to accelerate development;
- Accelerate commercialization of research results;
- Search for scientific solutions to global environmental challenges;
- Mobilize resources and popularize science and technology; and
- Foster international collaboration in STI.

The *Second Science and Technology Policy* cites sectorial policies with a focus on biotechnology, ICTs, space sciences, nanotechnology, indigenous knowledge systems, technologies yet to emerge and scientific solutions to emergent environmental challenges. The policy makes provisions for establishing a National Nanotechnology Programme. There is also a *National Biotechnology Policy* which dates from 2005. Despite poor infrastructure and a lack of both human and financial resources, biotechnology research is better established in Zimbabwe than in most sub-Saharan countries, even if it tends to use primarily traditional techniques.

The *Second Science and Technology Policy* asserts the government commitment to allocating at least 1% of GDP to GERD, focusing at least 60% of university education on developing skills in science and technology and ensuring that school pupils devote at least 30% of their time to studying science subjects (UNESCO, 2014b).

23. The Agricultural Research Trust has also been active in Zimbabwe since 1981.

Following the elections of 2013, the incoming government replaced the *Medium Term Plan 2011–2015* elaborated by its predecessor with a new development plan, the *Zimbabwe Agenda for Sustainable Economic Transformation* (ZimAsset, 2013–2018). One objective of ZimAsset is to rehabilitate and upgrade national infrastructure, including the national power grid, road and railway network, water storage and sanitation, buildings and ICT-related infrastructure (UNESCO, 2014b).

In 2013, the Ministry of Science and Technology Development (dating from 2005) was disbanded and its portfolio relegated to the newly established Department of Science and Technology within the Ministry of Higher and Tertiary Education, Science and Technology Development.

The same year, the government approved four national research priorities proposed by the Research Council of Zimbabwe:

- The social sciences and humanities;
- Sustainable environmental and resource management;
- Promoting and maintaining good health; and
- The national security of Zimbabwe.

A worrying exodus of skills

Zimbabwe has a long research tradition that dates back a century. However, the economic crisis has precipitated an exodus of university students and professionals in key areas of expertise (medicine, engineering, etc.) that is of growing concern. More than 22% of Zimbabwean tertiary students are completing their degrees abroad. In 2012, there were just 200 researchers (head count)[24] employed in the public sector, one-quarter of whom were women. The government has created the Zimbabwe Human Capital Website to provide information for the diaspora on job and investment opportunities in Zimbabwe. Of note is that ZimAsset contains no specific targets for increasing the number of scientists and engineers (UNESCO, 2014b).

Despite the turbulence of recent years, Zimbabwe's education sector remains sound. In 2012, 91% of youth aged 15–24 years were literate, 53% of the population aged 25 years or more had completed secondary education and 3% of adults held a tertiary qualification. The government is planning to establish two new universities with a focus on agricultural science and technology: Marondera and Monicaland State Universities (UNESCO, 2014b).

The long-standing University of Zimbabwe is particularly active in research, producing more than 44% of Zimbabwe's scientific publications in 2013. Productivity is fairly low but the number of publications has grown since 2005 (Figure 20.6).

The past decade has seen an extraordinary rise in the number of copublications with foreign partners, which now represent 75–80% of all Zimbabwean publications in the Web of Science (UNESCO, 2014b).

Poor linkages with industry

Public–private linkages remain weak. With the exception of the long-standing tobacco industry and others oriented towards agriculture, there has traditionally been little collaboration between industry and academia in Zimbabwe. The current regulatory framework hampers the transfer of technology to the business sector and the development of industrial R&D, despite the commercialization of research results being one of the major goals of the *Second Science, Technology and Innovation Policy* (UNESCO, 2014b).

The government is currently analysing new legislation that would promote local cutting and polishing of diamonds to create an estimated 1 700 new jobs. It has already slashed license fees for local cutting and polishing firms. Mining accounts for 15% of GDP and generates about US$ 1.7 billion in exports annually; despite this, the government receives royalties of only US$ 200 million. Currently, the entire stock of diamonds is exported in raw form. The new legislation will require companies to pay a 15% value-added tax but they will incur a 50% discount if they decide to sell their diamonds to the Minerals Marketing Corporation of Zimbabwe (UNESCO, 2014b).

CONCLUSION

From economic integration to a regional innovation system?

To date, intra-African trade remains dismally low, at approximately 12% of total African trade,[25] in spite of the formation of numerous regional economic communities. Both prominent pan-African organizations, such as the African Union (AU) and the New Partnership for Africa's Development (NEPAD), and regional bodies such as SADC have clear visions of the criteria for integration and the rationale behind it. The development of regional STI programmes is high on the list of priorities. However, several factors are hampering economic integration, including the similar economic structure of countries – based on mineral resources and agriculture –, poor economic diversification and low levels of intraregional trade. Nevertheless, the most formidable obstacle of all to regional integration is probably the resistance of individual governments to relinquishing any national sovereignty.

Some argue that the only feasible route to the sustainable socio-economic development that has eluded most African countries is to pursue regional integration.

24. or 95 full-time equivalents

25. compared to about 55% in Asia and 70% in Europe

This counter-argument agitates the promise of a huge internal market and the opportunities that it would offer for the development of economies of scale and scope. Another convincing argument arises from the increasingly urgent requirement for Africa to engage in a unified manner with a world that is increasingly characterized by economic blocs and large emerging economic powers.

An important aspect of economic integration would be the transition from national innovation systems to a single regional innovation system. Along with the establishment of free trade areas in order to construct the planned common market with full mobility of goods and services, capital and people, this would require the convergence of formal institutions, including labour market legislation, environmental regulation and policies governing competition. The opening up of borders to the free movement of people and services would also enable informal cross-border pools of tacit knowledge and social capital to emerge. The ultimate goal would be the emergence of a regional innovation system on the back of the development of an increasingly diversified economic system.

The AU-NEPAD *African Action Plan* for 2010–2015 has identified a number of obstacles to the evolution of national innovation systems across the region which resonate with those identified by the *SADC Regional Indicative Strategic Development Plan* back in 2003, namely:

- SADC economies are dominated by agriculture and mining with a poorly developed manufacturing sector;
- The GERD/GDP ratio is significantly lower in most SADC countries than the 1% benchmark set by the African Union in 2003 for the African continent;
- Governments offer few incentives for private-sector investment in R&D;
- There are serious shortages of scientific and technological skills at all levels (from artisans and technicians to engineers and scientists); this shortage is exacerbated by the ongoing brain drain;
- School education in science and technology is poor, primarily due to a lack of qualified teachers and inappropriate curricula; this type of education is also heavily biased against girls and women;
- There is generally poor protection of intellectual property rights in legislation; and
- There is little co-operation in science and technology across the region.

KEY TARGETS FOR SOUTHERN AFRICA

- Raise GERD in SADC countries to at least 1% of GDP by 2015;
- Ensure that 50% of decision-making positions in the public sector in SADC countries are held by women by 2015;
- Increase trade among SADC countries to at least 35% of total SADC trade, compared to 10% in 2008;
- Increase the share of manufacturing in SADC countries to 25% of GDP by 2015;
- Achieve 100% connectivity to the regional power grid for all SADC member states by 2012;
- Raise the share of public expenditure on agriculture to 10% of GDP in all SADC countries;
- Raise the GERD/GDP ratio in Botswana from 0.26% in 2012 to over 2% by 2016;
- Raise public expenditure on R&D in Mauritius to 1% of GDP by 2025, with a further 0.5% of GDP to come from the private sector;
- Focus at least 60% of university education in Zimbabwe on developing skills in science and technology;
- Generate 100 000 PhDs in South Africa by 2030;
- Generate 100 PhDs by 2024 from Angola's new Centre of Excellence for Science Applied to Sustainability.

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ACKNOWLEDGMENTS

The present chapter has been informed by the valuable input of experts and practitioners from various SADC countries and the SADC Secretariat. Special thanks go to Anneline Morgan, Special Technical Advisor for STI at the SADC Secretariat, for supplying reference materials and for her constructive suggestions.

Without adequate resources, it is unlikely that [research and education] policies will bring about effective change.

Dilupa Nakandala and **Ammar Malik**

Mahfuza answers farmer Nojrul Islam's question about using fertilizer on his crops by showing him a video on her laptop offering advice. In rural Bangladesh, the Info Ladies service brings internet services to men and women who need information but lack the means to access the web.
Photo © GMB Akash/Panos Pictures

21 · South Asia

Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka

Dilupa Nakandala and Ammar Malik

INTRODUCTION

Healthy economic growth

To the outsider, the seven economies of South Asia covered in the present chapter may appear to possess similar characteristics and dynamics. In reality, however, they are quite diverse. Afghanistan, Bangladesh and Nepal are low-income economies, Bhutan, Pakistan and Sri Lanka are lower middle-income economies and the Maldives is an upper middle-income economy.

According to the 2013 UNDP human development index, only Sri Lanka has achieved a high level of human development. Bangladesh, Bhutan and Maldives enjoy medium levels and the remainder are still at a stage of low development. Between 2008 and 2013, human development progressed in Bangladesh, the Maldives, Nepal and Sri Lanka but receded slightly in Pakistan, mainly due to the unstable security situation in parts of the country.

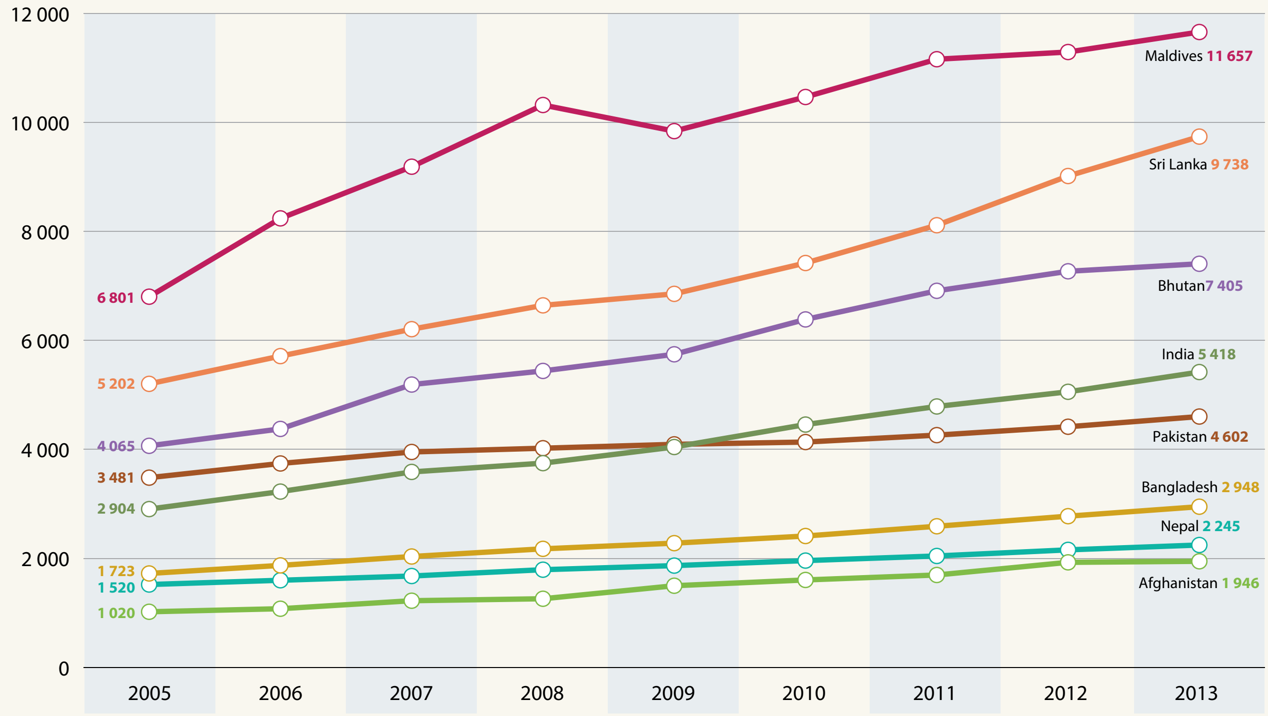
Three out of four South Asians are Indian. This single country accounts for 80% of the region's GDP of US$ 2 368 trillion. As India is the object of a separate chapter (see Chapter 22), the present essay will focus on the other seven members of the South Asian Association for Regional Cooperation (SAARC). Excluding India, GDP grew by a healthy 6.5% in the region in 2013. Sri Lanka reported the fastest progression (7.25%) and the Maldives (3.71%) and Nepal (3.78%) the slowest. GDP per capita, on the other hand, has risen fastest in the Maldives, followed by Sri Lanka (Figure 21.1).

FDI insufficient but trade growing

The rise in export and import trade volumes in recent years confirms the growing integration of South Asia in the global economy. Bangladesh has even managed to outperform its neighbours, with its exports progressing from 16% to 19.5% of GDP between 2010 and 2013. Moreover, Bangladesh managed to maintain a stable level of exports and foreign direct investment (FDI) at the height of the global financial crisis in 2008–2009. Amjad and Din (2010) have identified the insufficient diversification of exports and low domestic consumption as shock amplifiers during the global crisis; for them, sound economic management helped maintain macro-economic stability in Bangladesh, despite global food and fuel price hikes over this period.

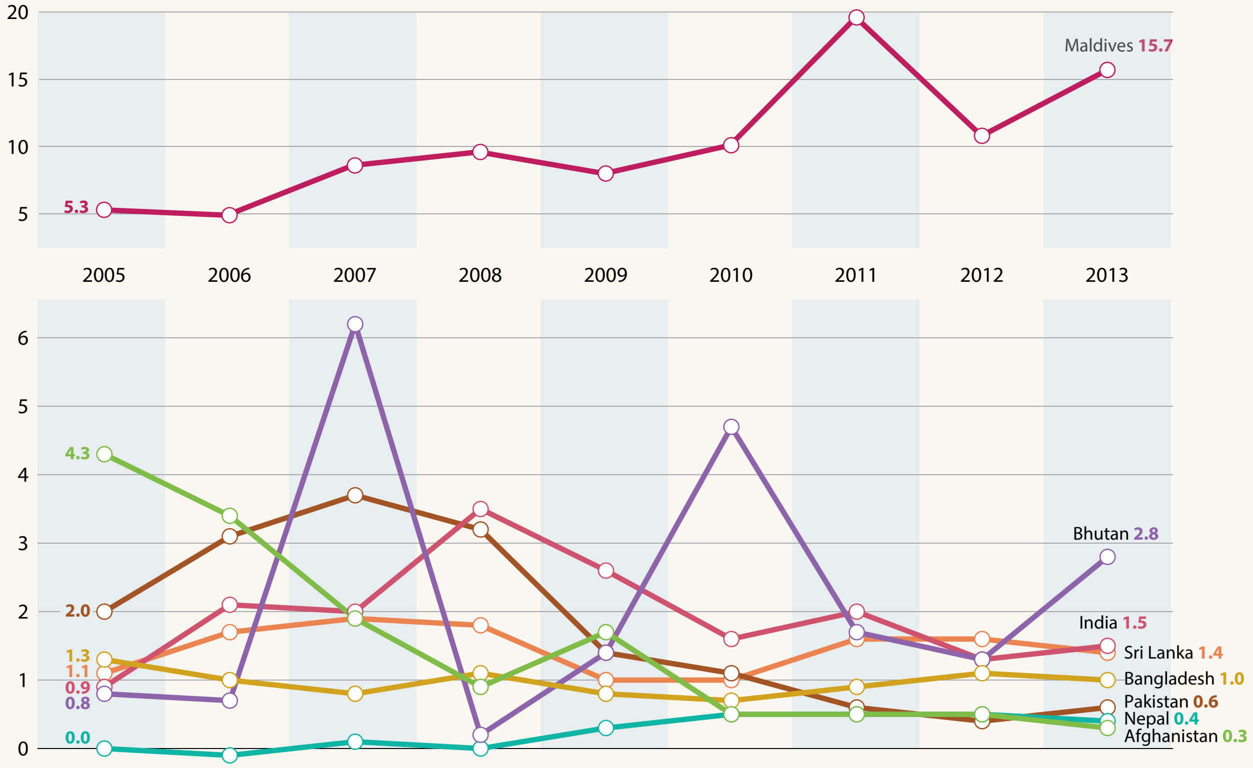
Figure 21.1: **GDP per capita in South Asia, 2005–2013**

In current PPP$



Source: World Bank's World Development Indicators, April 2015

Figure 21.2: **FDI inflows to South Asia as a share of GDP, 2005–2013 (%)**



Source: World Bank's World Development Indicators, accessed April 2015

Afghanistan and Pakistan, in particular, were less fortunate. The Maldives, on the other hand, sailed through the global financial crisis to become an increasingly attractive destination for FDI (Figure 21.2). It is the exception which confirms the rule. With inflows not exceeding 5% of GDP over the past decade in all but Bhutan and the Maldives, South Asia is hardly a pole of attraction for FDI. The total amount of announced greenfield investments (see the glossary, p. 738) in South Asia dropped to US$ 24 million in 2013, down from US$ 87 million in 2008. India hosted 72% of the region's greenfield FDI in 2013.

Political instability has long been a barrier to development in South Asia. Although Sri Lanka emerged from three decades of civil war in 2009 and the Nepalese civil war has been over since 2006, the rehabilitation and reconstruction of these nations will be long-term enterprises. There was a smooth political transition in Sri Lanka in January 2015, when Maithripala Sirisena was elected president in an election called two years ahead of schedule by the incumbent president Mahinda Rajapaksa. Two months later, in the Maldives, former president Mohamed Nasheed was jailed for 13 years following a trial which the United Nations' High Commissioner for Human Rights described as 'a rushed process'. In Afghanistan, civil society has developed considerably since 2001 but the protracted negotiations to form a government after the presidential election of April 2014 reflect the fragility of the ongoing transition to democracy; this process will need to be consolidated by the time the forces of the North Atlantic Treaty Organization (NATO) withdraw from Afghanistan in 2016.

Barriers remain to intra-regional trade

South Asia remains one of the world's least economically integrated regions, with intraregional trade accounting for merely 5% of total trade (World Bank, 2014). It has been nine years since the South Asian Free Trade Area (SAFTA) agreement entered into force on 1 January 2006, committing the eight[1] signatories (with India) to reducing customs duties on all traded goods to zero by 2016.

Nine years on, regional trade and investment remain limited, despite countries having embraced global trade liberalization. This is due to a host of logistical and institutional barriers, such as visa restrictions and the lack of regional chambers of commerce. Even though various studies have argued that greater trade would produce net gains in social welfare, businesses are unable to take advantage of potential synergies, owing to non-tariff barriers such as cumbersome processes for obtaining customs clearance (Gopalan *et al.*, 2013).

1. Afghanistan ratified the agreement in May 2011.

Since its inception in 1985, SAARC has failed to emulate the success of the neighbouring Association of Southeast Asian Nations in fostering regional integration in trade and other areas, including in science, technology and innovation (STI). Tangible results largely elude SAARC, beyond a series of agreements and regular summits involving heads of government (Saez, 2012). Several explanations have been put forward but the most prominent of these remains the persistently tense relations between India and Pakistan, traditional security concerns having been fuelled by the threat of terrorism in recent years. At the November 2014 SAARC summit, Indian Prime Minister Narendra Modi nevertheless invited SAARC members to offer Indian companies greater investment opportunities in their countries, assuring them of greater access to India's large consumer market in return. After a tragic earthquake struck Nepal on 25 April 2015, killing more than 8 000 and flattening or damaging more than 450 000 buildings, all SAARC members were quick to show their solidarity through the provision of emergency aid.

In the past decade, India has assumed responsibility for hosting two regional bodies, the South Asian University (Box 21.1) and the Regional Biotechnology Centre for training and research (see p. 612). These success stories illustrate the potential of STI for fostering regional integration. There are also instances of bilateral co-operation in STI. For instance, an Indo-Sri Lankan Joint Committee on Science and Technology was set up in 2011, along with an Indo-Sri Lankan Joint Research Programme. The first call for proposals in 2012 covered research topics in food science and technology; applications of nuclear technology; oceanography and Earth science; biotechnology and pharmaceuticals; materials science; medical research, including traditional medical systems; and spatial data infrastructure and space science. Two bilateral workshops were held in 2013 to discuss potential research collaboration on transdermal drug delivery systems and clinical, diagnostic, chemotherapeutic and entomological aspects of Leishmaniasis, a disease prevalent in both India and Sri Lanka that is transmitted to humans through the bite of infected sandflies.

Box 21.1: **The South Asian University: shared investment, shared benefits**

The South Asian University opened its doors to students in August 2010. It plans to become a centre of excellence with world-class facilities and staff. It currently offers seven PhD and master's programmes in applied mathematics, biotechnology, computer science, development economics, international relations, law and sociology.

Students come predominantly from the eight SAARC countries and enjoy heavily subsidized tuition fees. Some students from non-SAARC countries may also be admitted on a full cost-recovery basis. Admission is governed by a quota system, whereby each member country is entitled to a specific number of seats in each programme of study. Every year, the university conducts a SAARC-wide entrance test in all the major cities of South Asia. PhD aspirants also have to present their thesis proposal and undergo a personal interview. In 2013, the university received 4 133 applications for its programmes from all eight South Asian countries, double the number in 2012. There were 500 applications alone for the 10 places on offer for the doctoral programme in biotechnology.

The university is being temporarily hosted by the Akbar Bhawan Campus in Chanakyapuri, New Delhi, before moving to its 100-acre campus in Maidan Garhi in South Delhi by 2017. The task of designing the campus has been entrusted to a Nepalese firm of architects through a competitive bidding process.

The capital cost of establishing the university is being covered by the Indian government, whereas all eight SAARC member countries share the operational costs in mutually agreed proportions.

The university focuses on research and postgraduate level programmes. It will ultimately have 12 postgraduate faculties, as well as a Faculty of Undergraduate Studies. At full strength, the university will count 7 000 students and 700 teachers. There are also plans to establish an Institute of South Asian Studies on campus.

Degrees and certificates awarded by the university are recognized by India's University Grants Commission and by other SAARC countries.

Attractive salary packages and benefits have been designed to attract the best teachers. Although they tend to come from the eight SAARC countries, up to 20% may come from other countries.

The idea of a South Asian University was mooted by the Prime Minister of India at the 13th SAARC Summit in Dhaka in 2005. Prof. Gowher Rizvi, a well-known historian from Bangladesh, was then entrusted with the task of preparing the concept paper, in consultation with SAARC countries. An interministerial Agreement for the Establishment of the South Asian University clinched the deal on 4 April 2007 during the following SAARC Summit in New Delhi.

Source: www.sau.ac.in

TRENDS IN EDUCATION

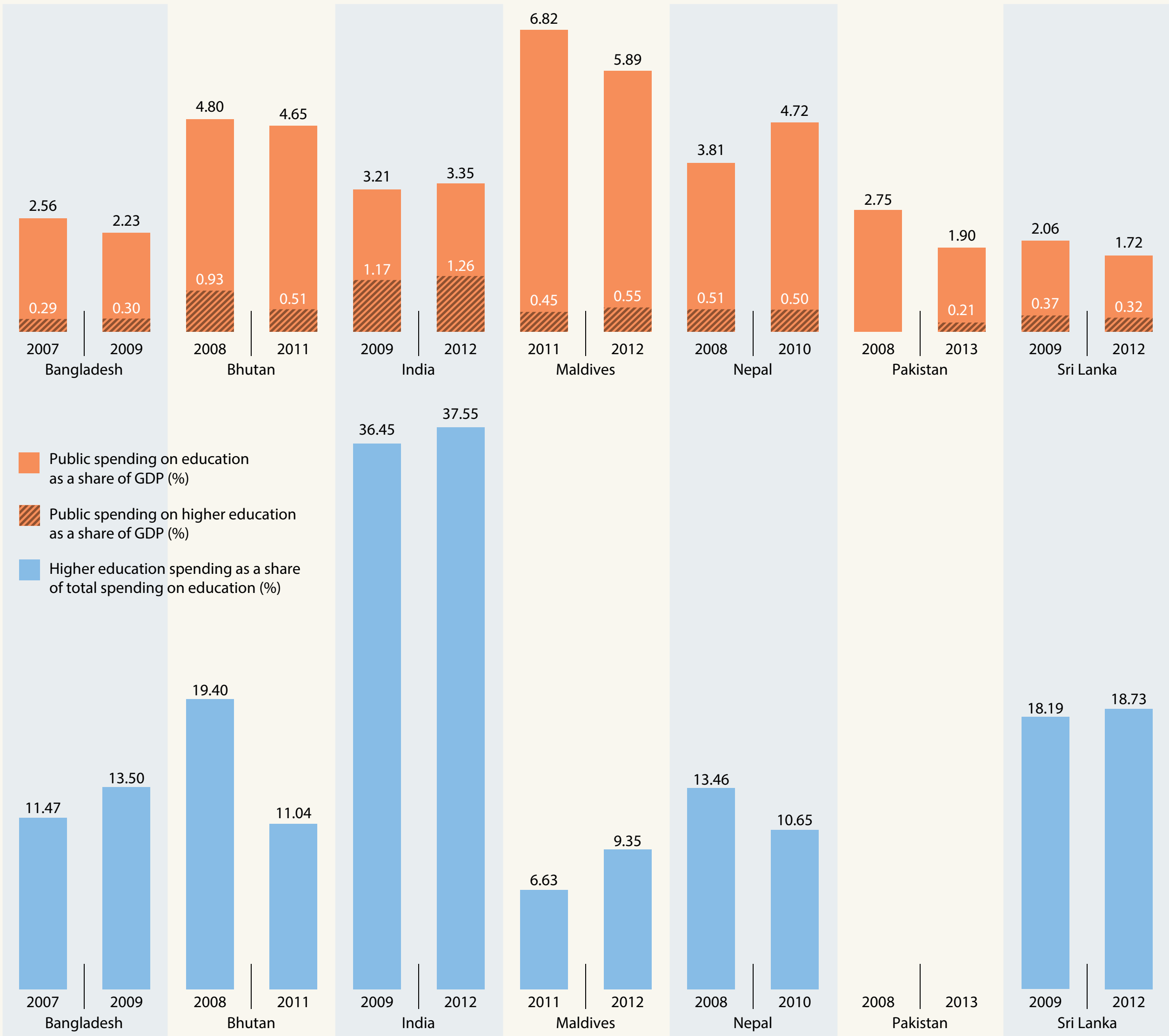
Underfunded reforms of higher education

Over the past decade, South Asian countries have embarked on an energetic drive to achieve the Millennium Development Goal (MDG) of universal primary education by 2015. Despite having rapidly achieved this target, the Maldives has consistently devoted between 5% and 7% of GDP to education over this period, more than any of its neighbours (Figure 21.3).

In all countries, higher education has had to take a back seat during this drive; the most recent data available reveal that spending on higher education amounts to just 0.3–0.6% of GDP, compared to 1.3% of GDP in India in 2012. Now that countries are on the verge of achieving universal primary education, there are growing calls for them to spend more on higher education, particularly since modernization and diversification of the economy are at the heart of their current development strategies. However, in all but Nepal, spending on education has actually been curtailed in recent years and, even in Nepal, the share allocated to higher education has stagnated (Figure 21.3).

Afghanistan is pursuing an ambitious reform of its higher education system that is yielding some impressive results, despite dependence on uncertain donor funding. Between 2010 and 2015, student enrolment doubled, for instance, as

Figure 21.3: **Public expenditure on education in South Asia, 2008 and 2013 or closest years**



Note: Data are unavailable for Afghanistan.

Source: UNESCO Institute for Statistics, April 2015; for Pakistan in 2013: Ministry of Finance (2013) *Federal Budget 2014–2015: Budget in Brief*. See: http://finance.gov.pk/budget/Budget_in_Brief_2014_15.pdf did the number of faculty members in public universities. The government adopted a gender strategy in 2013 to raise the ratio of women among students and faculty (see p. 579).

Available data for Bangladesh on tertiary enrolment show a steep rise in PhD students in engineering between 2009 and 2011 (from 178 to 521), despite a modest government investment. In Sri Lanka, the number of PhD students has climbed equally rapidly in engineering but also in science and agriculture. There is no breakdown by field of study for Pakistan but the number of PhD students also shows rapid growth (Tables 21.1 and 21.2). Pakistan and Sri Lanka now have the same share of university students enrolled in PhD programmes (1.3%) as Iran (see Figure 27.5).

ICT policies but infrastructure needs to catch up

In recent years, South Asian governments have developed policies and programmes to foster the development and use of information and communication technologies (ICTs). For instance, the Digital Bangladesh programme is central to realizing the country's vision of becoming a middle-income economy by 2021 (see p. 581). The World Bank and others are partnering with governments to accelerate the movement. Examples are the Youth Solutions! Competition for budding entrepreneurs (Box 21.2) and Bhutan's first information technology (IT) park (see p. 584).

Nowhere is this drive more visible than in education. In 2013, Bangladesh and Nepal published national plans to mainstream ICTs in education. Sri Lanka has adopted a similar plan and Bhutan is currently developing its own but work still needs to be done in the Maldives to develop a policy on ICTs in education (UIS, 2014b). The realities of a patchy, unreliable electricity supply are often fundamental obstacles to the diffusion of ICTs in rural and remote areas. In Pakistan, just 31% of rural primary schools have a reliable electricity supply, compared to 53% in urban centres, and power surges and brownouts are common in both. In Nepal, only 6% of primary schools and 24% of secondary schools had electricity in 2012 (UIS, 2014b). Another factor is the poor provision of telecommunication services through a fixed telephone line, cable connection and mobile phone technology, making it difficult to connect school computer systems with the wider network. With the exception of the Maldives, these critical pieces of ICT infrastructure are not universally available in the region. In Sri Lanka, for instance, only 32% of secondary schools have telephones.

As shown in Figure 21.4, the number of mobile phone subscribers is much higher in South Asia than the number of internet users. Mobile phone technology is increasingly being used by teachers in developing economies for both educational and administrative purposes (Valk *et al.*, 2010).

Table 21.1: **Tertiary enrolment in Bangladesh, Pakistan and Sri Lanka, 2009 and 2012 or closest years**

	Total	Post-secondary diploma	Bachelor's and master's degrees	PhD
Bangladesh (2009)	1 582 175	124 737	1 450 701	6 737
Bangladesh (2012)	2 008 337	164 588	1 836 659	7 090
Pakistan (2009)	1 226 004	62 227	1 148 251	15 526
Pakistan (2012)	1 816 949	92 221	1 701 726	23 002
Sri Lanka (2010)	261 647	12 551	246 352	2 744
Sri Lanka (2012)	271 389	23 046	244 621	3 722

Source: UNESCO Institute for Statistics, April 2015

Table 21.2: **University enrolment in Bangladesh and Sri Lanka by field of study, 2010 and 2012 or closest years**

	Science		Engineering		Agriculture		Health	
	Bachelor's and master's degrees	PhD	Bachelor's and master's degrees	PhD	Bachelor's and master's degrees	PhD	Bachelor's and master's degrees	PhD
Bangladesh (2009)	223 817	766	37 179	178	14 134	435	23 745	1 618
Bangladesh (2012)	267 884	766	62 359	521	21 074	445	28 106	1 618
Sri Lanka (2010)	24 396	250	8 989	16	4 407	56	8 261	1 891
Sri Lanka (2012)	28 688	455	14 179	147	3 259	683	8 638	1 891

Source: UNESCO Institute for Statistics, April 2015

Box 21.2: **South Asia Regional Youth Grant competitions**

A competition launched in 2013 in Bangladesh, the Maldives, Nepal and Sri Lanka offers young people from each country the opportunity to win a grant of US$ 10 000–20 000 to implement an innovative project of one year's duration in the field of IT.

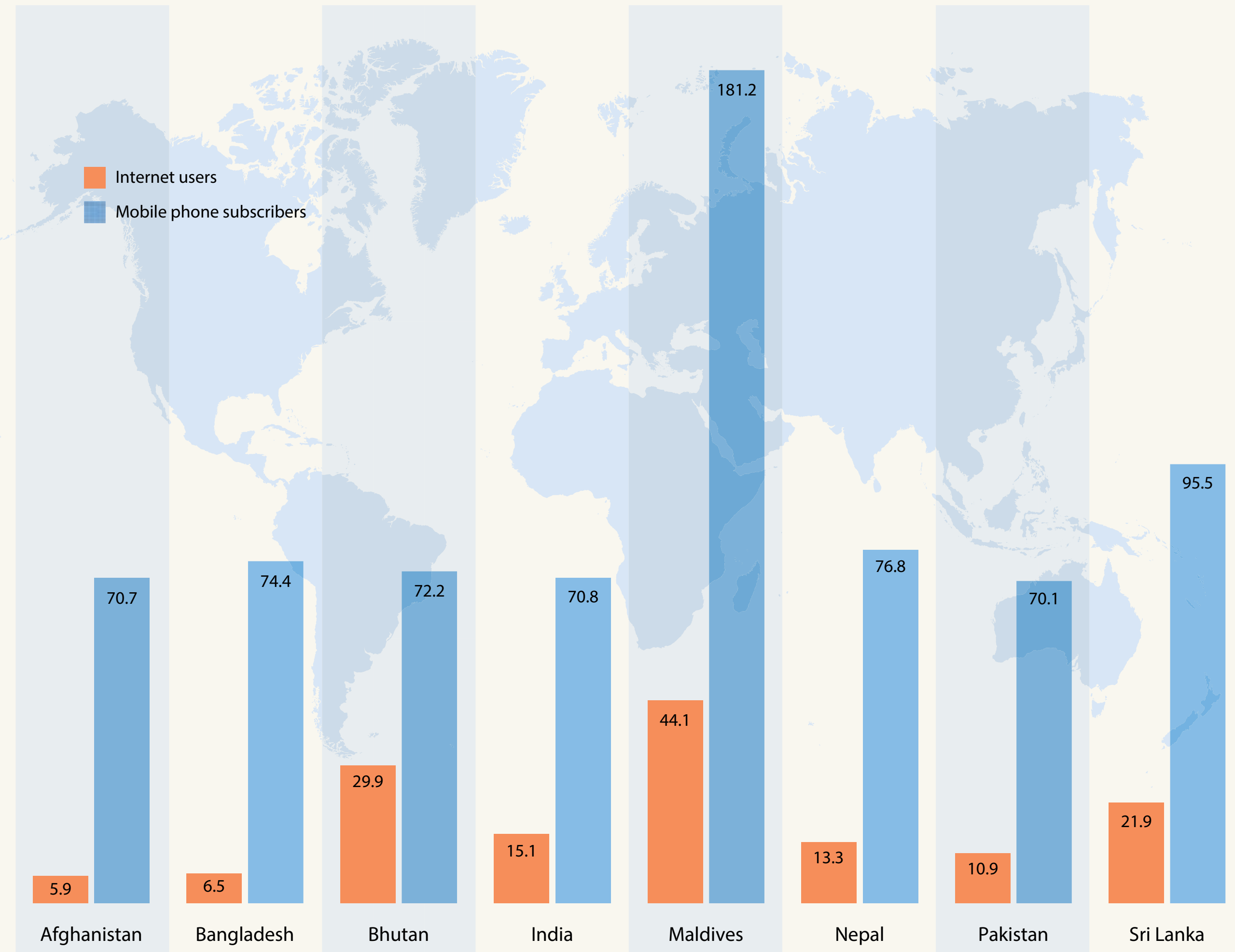
The aim is to identify innovative ideas that are ripe for the picking and allow their young creators to develop these. The competition targets rural youth-led social enterprises. Youth-led organizations and non-governmental organizations with two years of operation are eligible to apply, each proposal needing to have a strong focus on sustainability. The ultimate goal is to augment and diversify employment opportunities for the young.

The theme of the first grant competition was Youth Solutions! Technology for Skills and Employment (2013) and that of the second Coding Your Way to Opportunity (2014).

The scheme is the fruit of a partnership formed in March 2013 by the World Bank, Microsoft Corporation and Sarvodaya Fusion of Sri Lanka, the latter being the implementing partner. Microsoft and the World Bank, meanwhile, shortlist the innovative proposals with the support of an external evaluation panel, based on criteria that include the use of ICTs as a tool; skills development; the provision of employment opportunities; novelty; sustainability; the participatory nature; and the measurability of the outcome.

Source: World Bank

Figure 21.4: **Internet users and mobile phone subscribers per 100 inhabitants in South Asia, 2013**



Source: International Telecommunications Union

TRENDS IN R&D

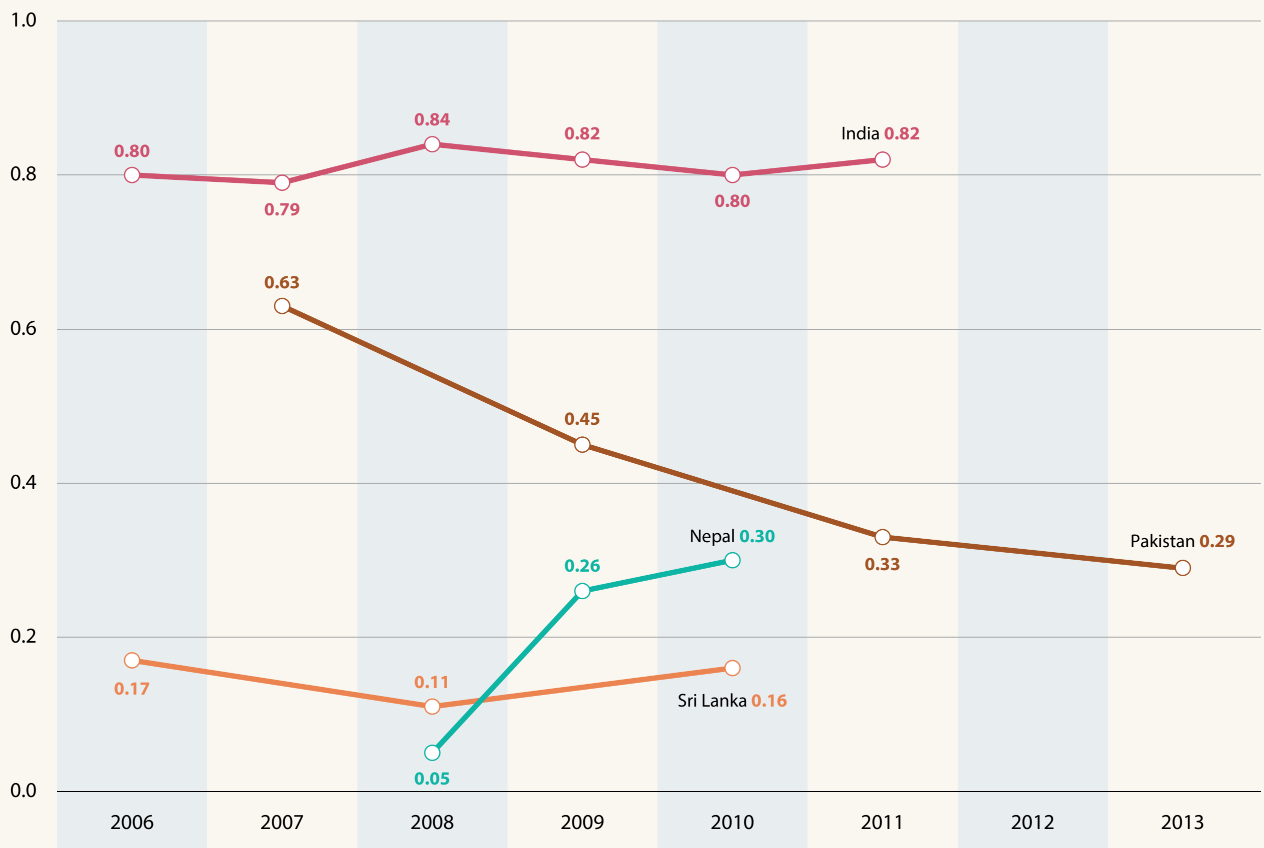
A modest R&D effort

By international standards, countries in South Asia spend modest amounts on research and development (R&D). Gross domestic expenditure on R&D (GERD) even dropped in Pakistan between 2007 and 2013 from 0.63% to 0.29% of GDP, although the government did not survey the business enterprise sector (Figure 21.5); this trend has been accompanied by an attempt in Pakistan to decentralize higher education and research spending, devolving it to the provincial level. In Sri Lanka, investment remains stable but low, at 0.16% of GDP in 2010, less than the R&D intensity of Nepal (0.30%), which has improved markedly since 2008, and far below that of India (0.82%). This lack of investment correlates with low researcher intensity and limited integration in global research networks.

As shown in Figure 21.6, the majority of countries in the region lie within a narrow range in terms of their ranking for private-sector expenditure on R&D in the World Economic Forum's Global Competitiveness Index, at between 2.28 and 3.34 in 2014, with Sri Lanka recording the best performance. Since 2010, only Nepal has shown a marginal improvement in private-sector spending on R&D. With the exception of Bangladesh and Nepal, South Asia's private sector is more implicated in R&D than in sub-Saharan Africa (average of 2.66) but less so than in emerging and developing countries, in general (3.06 on average), the notable exception being Sri Lanka. Above all, the countries of the Organisation for Economic Co-operation and Development (OECD) are streets ahead of South Asia, with an average score of 4.06, reflecting the higher level of market development in industrialized economies.

Overall, R&D spending in South Asia has not kept pace with economic growth over the past five years. The fact that both the public and private sectors exhibit similar trends is indicative of the broader lack of capacity and failure to prioritize research. This is also attributable to the relatively low levels of disposable income and commercial market development, as well as the limited margin for manoeuvre in government budgets when it comes to allocating funds to R&D.

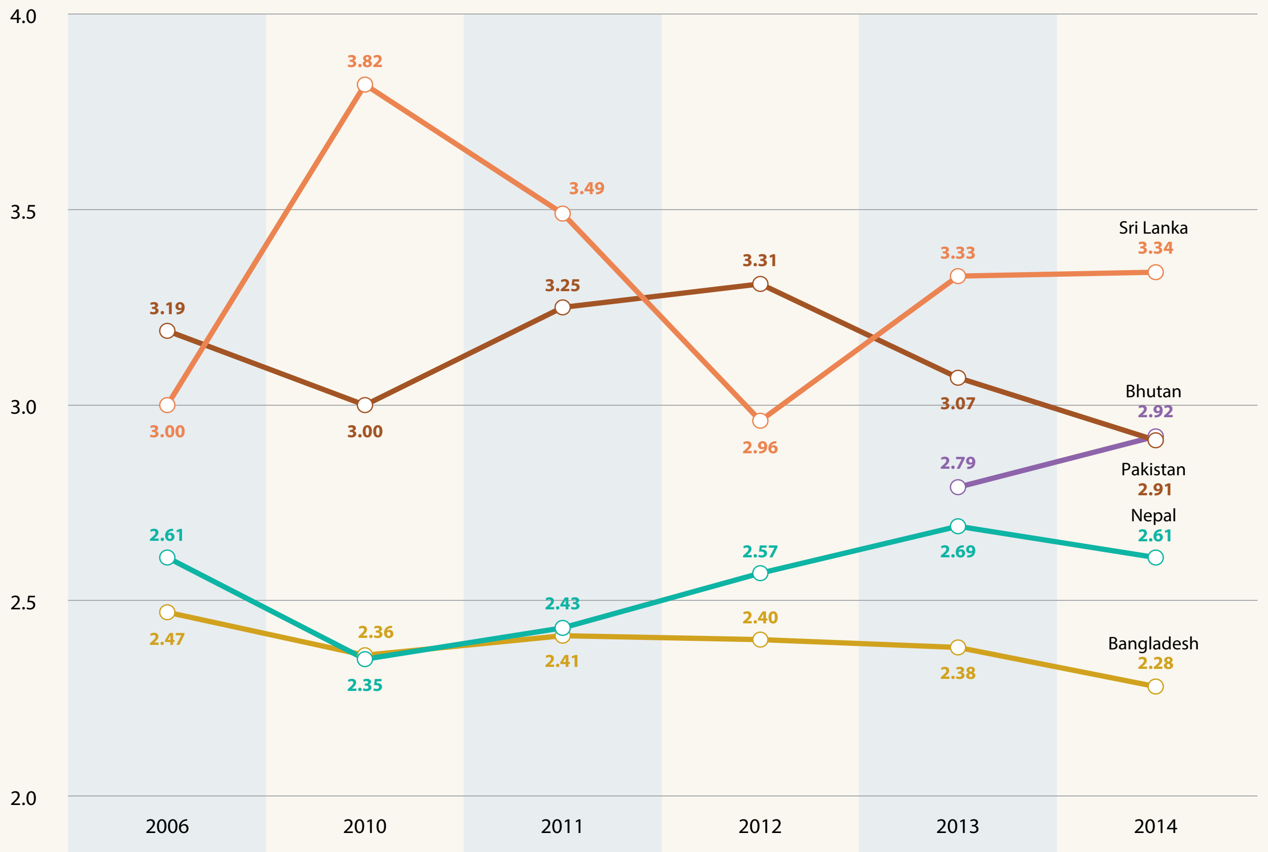
Figure 21.5: **GERD/GDP ratio in South Asia, 2006–2013**



Note: Data are unavailable for Bhutan, Bangladesh and the Maldives. The data for Nepal are partial and relate to Government R&D budget instead of R&D expenditure; those for Pakistan exclude the business enterprise sector.

Source: UNESCO Institute for Statistics, June 2015

Figure 21.6: **South Asian ranking for private-sector expenditure on R&D, 2010–2014**



Source: World Economic Forum Global Competitiveness Index, accessed December 2014

Nepal catching up to Sri Lanka for researcher density

With recent data on researchers being available only for Nepal, Pakistan and Sri Lanka, it would be hazardous to draw any conclusions for the region as a whole. However, the available data do reveal some interesting trends. Nepal is catching up to Sri Lanka in terms of researcher density but the share of women in the Nepalese research pool is low and, in 2010, was almost half that in 2002 (Figure 21.7). Sri Lanka has the greatest share of women researchers but their participation rate is lower than before. Pakistan has the greatest researcher density of the three but also the lowest density of technicians; moreover, neither indicator has progressed much since 2007.

R&D output up, despite low investment

In terms of patent applications, all countries appear to have made progress in the past five years (Table 21.3). India continues to dominate, thanks in part to the dynamism of foreign multinationals specializing in ICTs (see Chapter 22), but Pakistan and Sri Lanka have also made confident strides. Interestingly, statistics from the World Intellectual Property Organization (WIPO) for 2013 reveal that more non-resident Bangladeshis, Indians and Pakistanis are filing patent applications than before. This suggests the presence of strong diaspora communities in developed countries and/or of foreign multinationals in these countries.

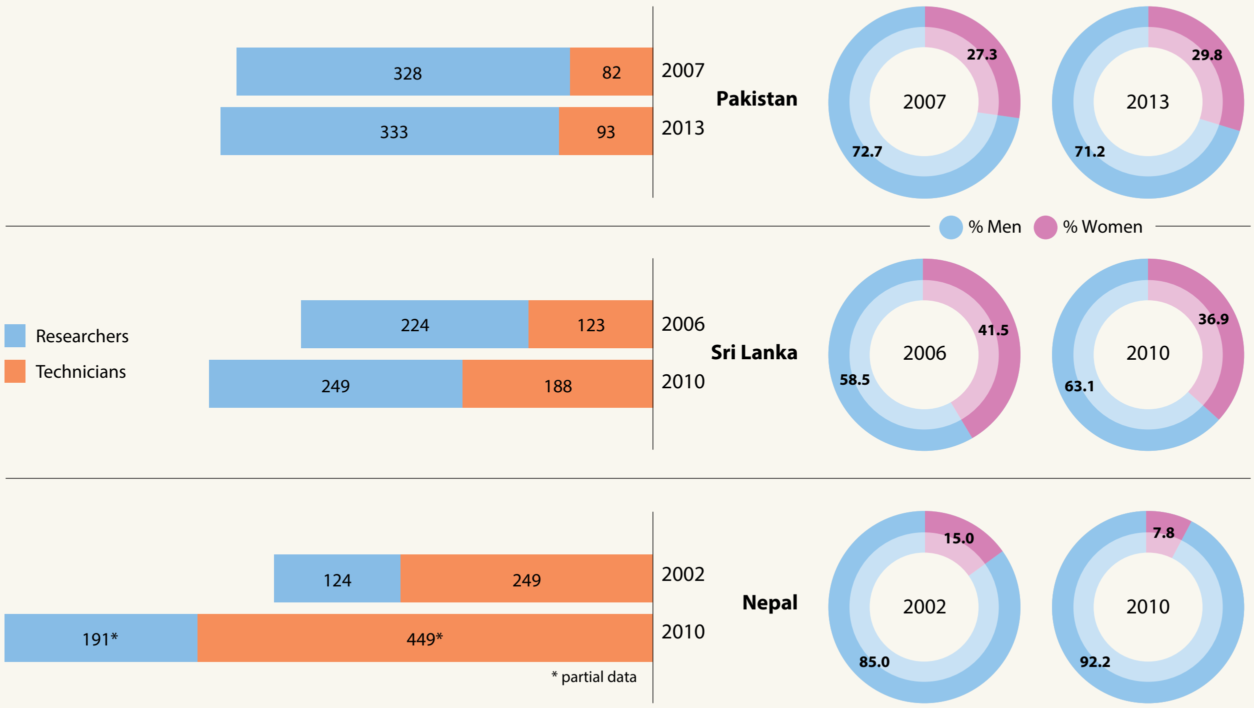
High-tech exports remain insignificant, with only India, Nepal, Pakistan and Sri Lanka reporting measureable figures: 8.1%, 0.3%, 1.9% and 1.0% respectively of their manufactured exports in 2013. However, in recent years, communications- and computer-related exports, including international telecommunications and computer data services, have dominated service exports by Afghanistan, Bangladesh and Pakistan; as for Nepal, it has shown impressive growth in this area of 36% in 2009 and 58% in 2012 as a share of service exports. Whereas Afghanistan and Nepal trade mostly with their South Asian neighbours, the other countries profiled in the present chapter limit their level of imports and exports within the region to about 25% of the total. This is essentially due to the narrow range of exports, weak consumer purchasing power within the region and insufficient regional efforts to foster the innovation needed to meet the unserved demand.

The number of scientific papers from South Asia (including India) registered in the Web of Science rose by 41.8% between 2009 and 2014 (Figure 21.8). The most spectacular progress was observed in Pakistan (87.5%), Bangladesh (58.2%) and Nepal (54.2%). In comparison, Indian publications rose by 37.9% over the same period.

Despite the stagnation in spending on higher education in Pakistan since 2008 (as a share of GDP), the momentum generated by reforms during the first decade of the century has not slowed. Meanwhile, in Nepal, the rapid increase in R&D spending between 2008 and 2010 appears to be reflected in the rise in research output, which accelerated after 2009.

Despite this progress, South Asia's research output remains modest relative to other parts of the world, be it in terms of international patents or publications in peer-reviewed journals. This lower scale of research activity is directly attributable to the lack of measureable R&D input, both from the public and private sectors. The region's academic capacity for teaching and research is also among the lowest in the world.

Figure 21.7: **Researchers (HC) and technicians in South Asia per million inhabitants and by gender, 2007 and 2013 or closest years**



Note: Data for Pakistan exclude the business enterprise sector.

Source: UNESCO Institute for Statistics, June 2015

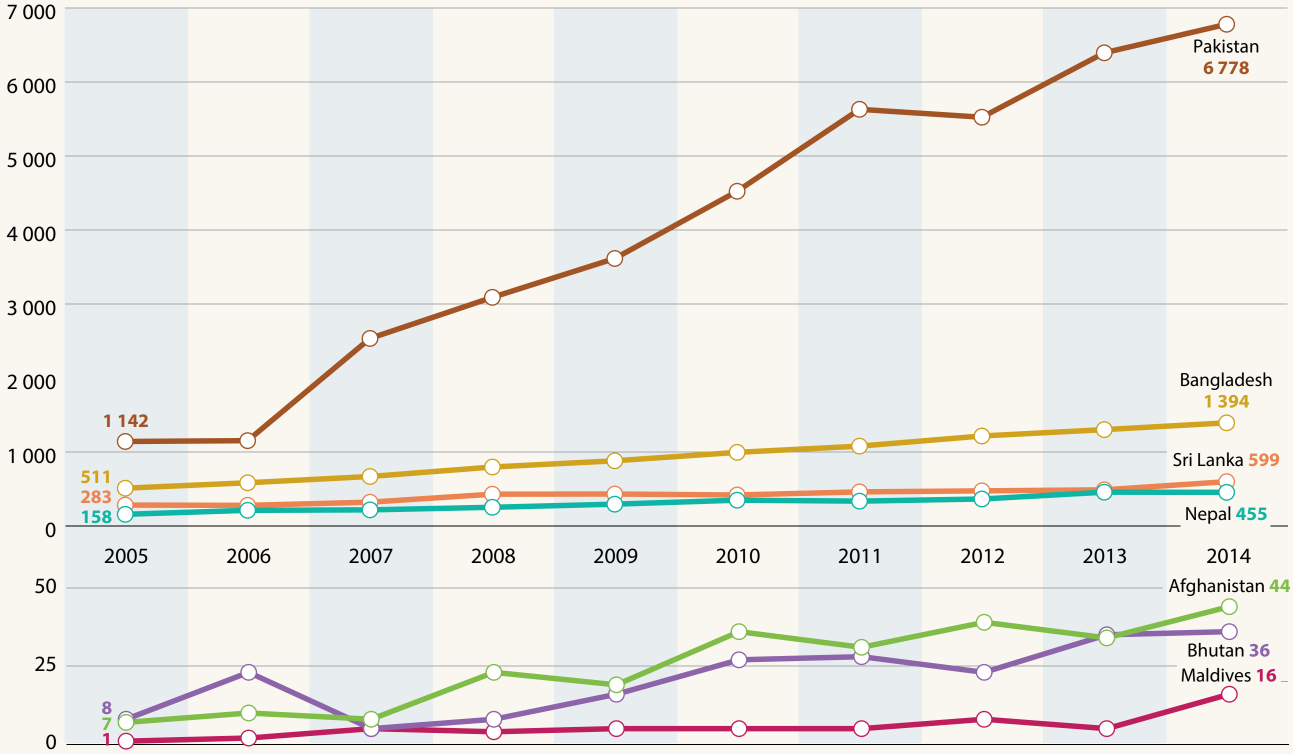
Table 21.3: **Patent applications in South Asia, 2008 and 2013**

	2008			2013		
	Total resident	Resident applications per million inhabitants	Total non-resident	Total resident	Resident applications per million inhabitants	Total non-resident
Bangladesh	29	0.19	270	60	0.39	243
Bhutan	0	0	0	3	3.00	1
India	5 314	4.53	23 626	10 669	8.62	32 362
Nepal	3	0.12	5	18	0.67	12
Pakistan	91	0.55	1 647	151	0.84	783
Sri Lanka	201	10.0	264	328	16.4	188

Source: WIPO Statistics Database, accessed April 2015

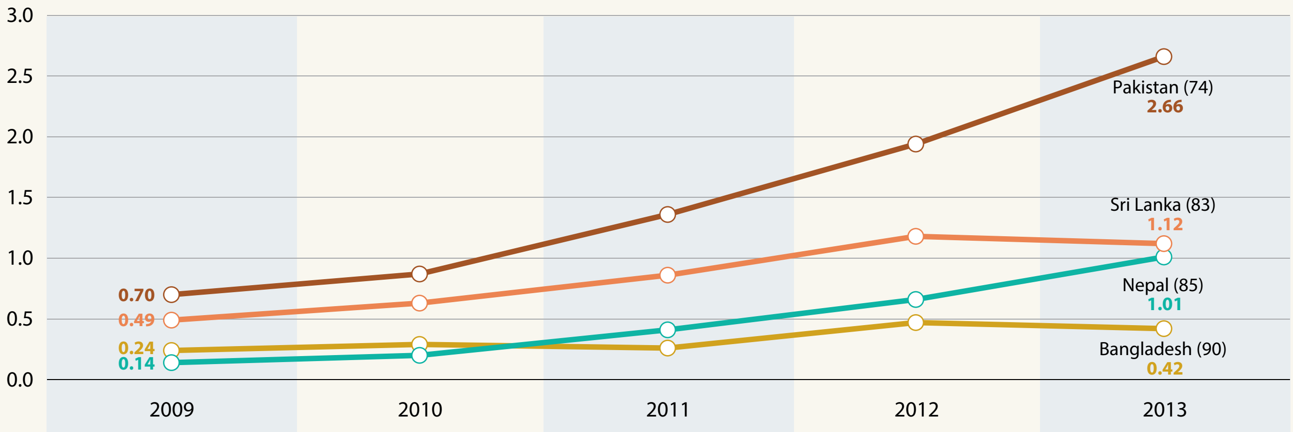
Figure 21.8: **Scientific publication trends in South Asia, 2005–2014**

Strong growth in Bangladesh, Nepal and Pakistan since 2009



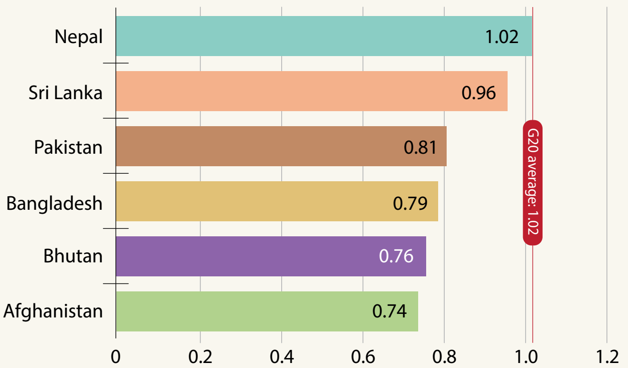
Pakistan produces the most articles related to nanotechnology per million inhabitants

Countries' world rank is shown between brackets

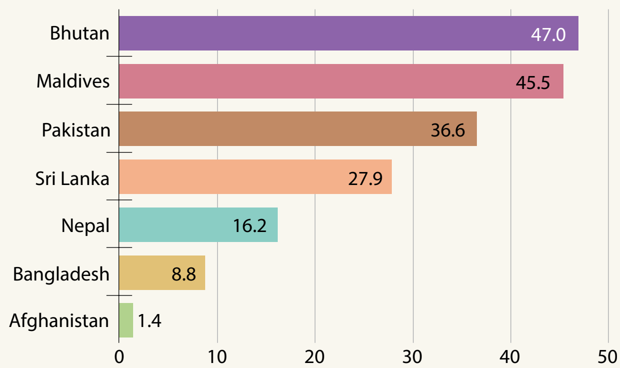


Among high-population countries, Pakistan has the greatest publication intensity

Average citation rate, 2008–2012

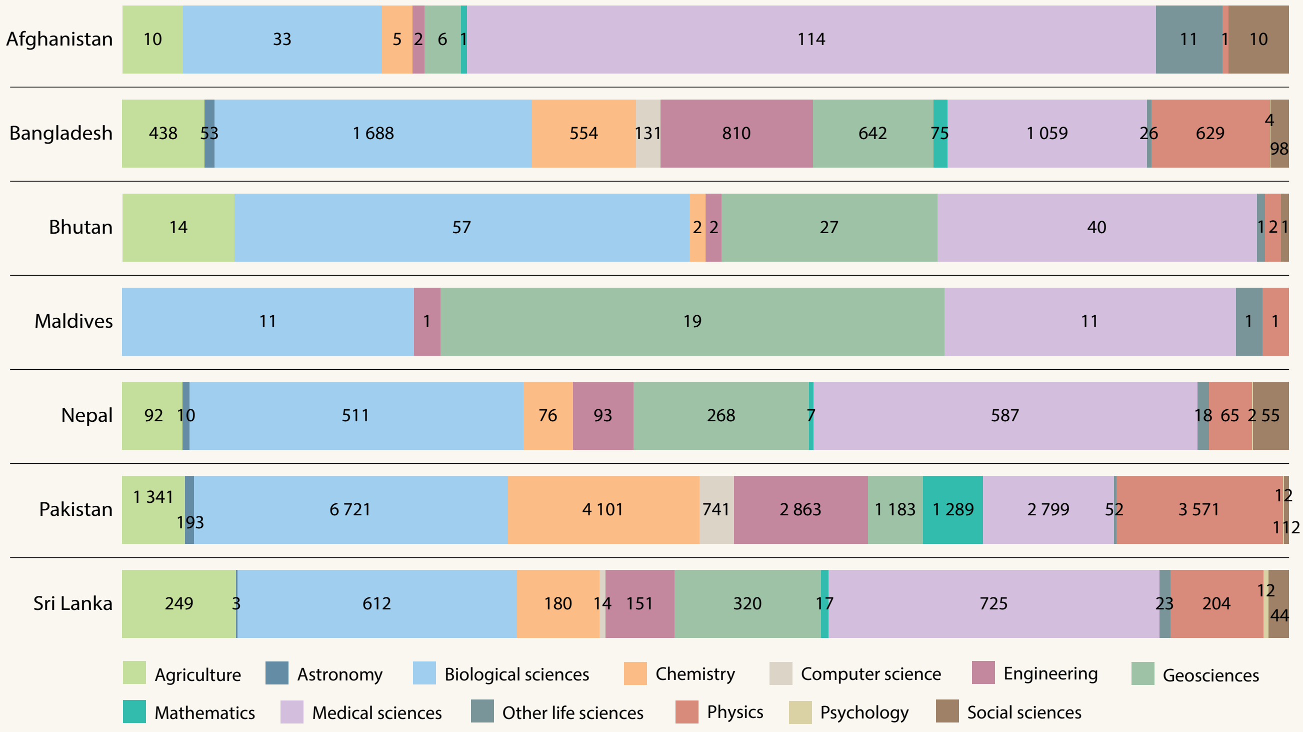


Publications per million inhabitants, 2014



Life sciences dominate in South Asia, Pakistan also specializes in chemistry

Cumulative totals by field, 2008–2014



Note: Unclassified articles are excluded from the totals.

Fellow Asians figure among South Asians' main foreign partners

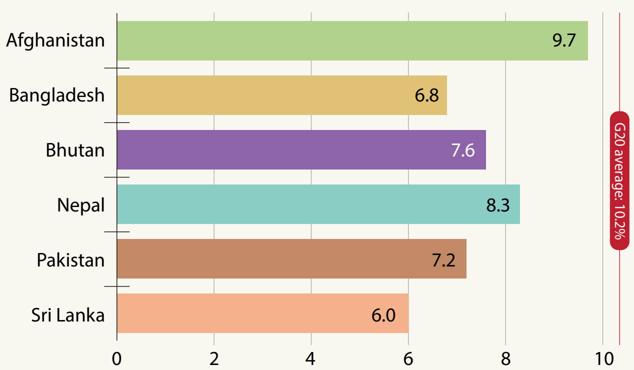
Top five collaborators, 2008–2014 (number of articles)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Afghanistan	USA (97)	UK (52)	Pakistan (29)	Egypt/Japan (26)	
Bangladesh	USA (1394)	Japan (1218)	UK (676)	Malaysia (626)	Rep. of Korea (468)
Bhutan	USA (44)	Australia (40)	Thailand (37)	Japan (26)	India (18)
Maldives	India (14)	Italy (11)	USA (8)	Australia (6)	Sweden/Japan/UK (5)
Nepal	USA (486)	India (411)	UK (272)	Japan (256)	Rep. of Korea (181)
Pakistan	USA (3 074)	China (2 463)	UK (2 460)	Saudi Arabia (1 887)	Germany (1 684)
Sri Lanka	UK (548)	USA (516)	Australia (458)	India (332)	Japan (285)

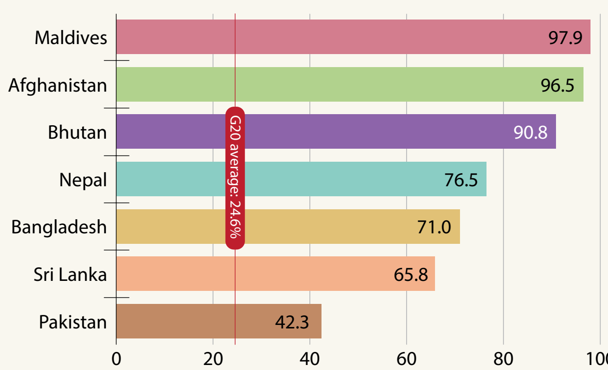
Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

The majority of articles have foreign partners in all but Pakistan

Share of South Asian papers among 10% most-cited, 2008–2012 (%)



Share of papers with foreign co-authors, 2008–2014 (%)



Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix; for nano-articles: statnano.com, see Figure 15.5

COUNTRY PROFILES

AFGHANISTAN

Rapid gains in girls' education

Afghanistan has one of the lowest literacy rates in the world: about 31% of the adult population. Some 45% of men and 17% of women are literate, with wide variations from one province to another. In 2005, the country committed to achieving universal primary education by 2020. Energetic efforts to achieve gender parity have been rewarded by a steep increase in the net enrolment ratio for girls from just 4% in 1999 to an estimated 87% in 2012. By 2012, there was a net intake of 66% of girls and 89% of boys in primary education; boys could expect to complete 11 years of schooling and girls seven years, according to UNESCO's *Education for All Monitoring Report* (2015).

Infrastructure not keeping pace with student rolls

The two key goals of the *National Higher Education Strategic Plan: 2010–2014* devised by the Afghan Ministry of Higher Education were to improve quality and broaden access to higher education, with an emphasis on gender equity. According to a progress report by the same ministry, the number of women students tripled between 2008 and 2014, yet women still represent just one in five students (Figure 21.9). Girls still encounter more difficulties than boys in completing their schooling and are penalized by the lack of university dormitories for women (MoHE, 2013).

The Ministry of Higher Education has largely surpassed its target for raising university enrolment, which doubled between 2011 and 2014 (Figure 21.9). A shortfall in funding has prevented the construction of facilities from keeping pace with the rapid rise in student rolls, however. Many facilities also still need upgrading; there were no functioning laboratories for physics students at Kabul University in 2013, for instance (MoHE, 2013). Only 15% of the US$ 564 million in funding requested of donors by the ministry has materialized since 2010.[2]

Within its *Higher Education Gender Strategy* (2013), the ministry has developed an action plan to augment the number of women students and faculty (Figure 21.9). A pillar of this plan is the construction of women's dormitories. With help from the US State Department, one was completed in Herat in 2014 and another two are planned for Balkh and Kabul. They should house about 1 200 women in total. The ministry also requested funds from the National Priority Programme budget for the construction of ten additional dormitories for 4 000 women students; six of these were completed in 2013.

Part of the growth in university student rolls can be attributed to 'night school', which extends access to workers and young mothers. Having a 'night shift' also makes use of limited space that would otherwise be vacant in the evenings. The night shift is proving increasingly popular, with 16 198 students enrolling in 2014, compared to just 6 616 two years earlier. Women represented 12% (1 952) of those attending evening classes in 2014.

New master's programmes offer more choices

By 2014, the Curriculum Commission had approved the curricular reviews and upgrades for one-third of Afghanistan's public and private faculties. Progress in meeting recruitment goals has also been steady, since staffing is covered by the regular budget allocations (Figure 21.9).

One of the ministry's priorities has been to increase the number of master's programmes (Figure 21.9). This will broaden opportunities for women, in particular, given the difficulties they face in going abroad for master's and PhD training: in the two new master's programmes in education and public administration, half of the students are women. Five of the eight master's degrees granted by Kabul University between 2007 and 2012 were also obtained by women (MoHE, 2013).

Another priority is to increase the share of faculty with a master's degree or PhD. The wider choice of programmes has enabled more faculty to obtain a master's degree but doctoral students still need to study abroad, in order to increase the small pool of PhDs in Afghanistan. The share of master's and PhD-holders has dropped in recent years, as the number of faculty members at Afghan universities has risen; the drop in the share of PhD-holders from 5.2% to 3.8% between 2008 and 2014 was also due to a wave of retirement (Figure 21.9).

Two schemes enable faculty to study abroad. Between 2005 and 2013, 235 faculty members completed their master's degree abroad, thanks to the World Bank's Strengthening Higher Education Programme. In 2013 and 2014, the Ministry of Higher Education's development budget funded the study abroad of 884 faculty working towards their master's degree and 37 faculty enrolled in doctoral programmes.

Grants to revive the research culture

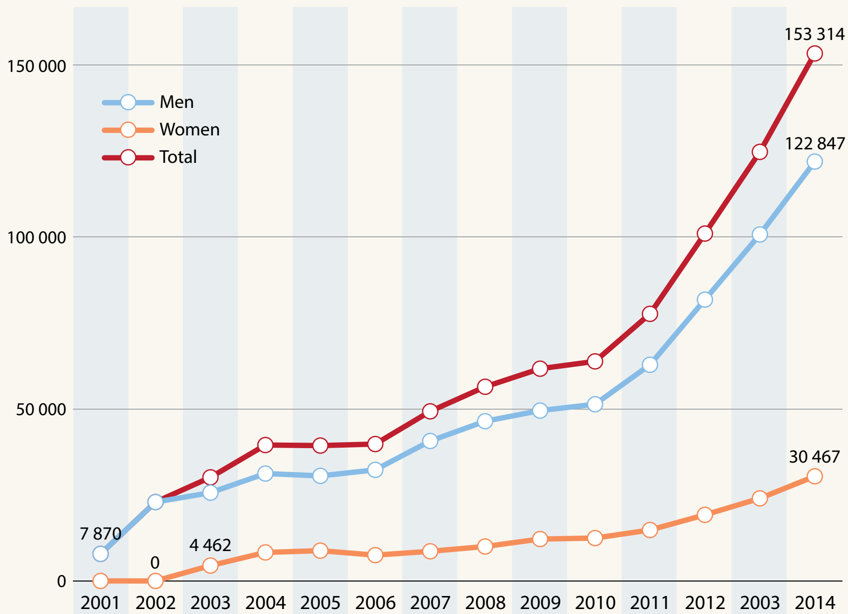
In order to revive Afghanistan's research culture, research units have been installed at 12 universities[3] as part of the World Bank's Higher Education Systems Improvement Project. In parallel, the Ministry of Higher Education developed a digital library in 2011 and 2012 which provides

2. The main donors are the World Bank, USAID, US State Department, NATO, India, France and Germany.

3. Kabul University, Kabul Polytechnic University, Herat University, Nangarhar University, Balkh University, Kandahar University, Kabul Education University, Albiruni University, Khost University, Takhar University, Bamyan University and Jawzjan University.

Figure 21.9: **Afghanistan's ambitious university reform**

Enrolment in public universities doubled between 2011 and 2014



63 837
Afghan university student population in 2010

153 314
Afghan university student population in 2014

20.5%
Share of women university students in 2010

19.9%
Share of women university students in 2014

Afghanistan is making headway towards its higher education targets

	Target	Current situation
National Higher Education Strategic Plan: 2010–2014 (published 2010)	US$ 564 million to be obtained in funding to implement the plan	15% (US$ 84.13 million) received from donors as of 2014
	The number of students at public universities to double to 115 000 by 2015	153 314 students were enrolled in 2014 (target reached)
	Higher education to represent 20% of the education budget by 2015, equivalent to US$ 800 per student in 2014 (corresponding to a budget of US$ 80 million for 2012) and US$ 1 000 by 2015.	The approved budget for 2012 for higher education was US$ 47.1 million, equivalent to US$ 471 per student
	The number of faculty members in public universities to increase by 84% by 2015 to 4 372 and the number of staff by 25% to 4 375	By October 2014, there were 5 006 faculty members; by 2012, there were 4 810 other university staff (target reached)
	The number of master's programmes in Afghanistan to rise	A total of 8 master's programmes were available in 2013 and 25 in 2014 (target reached)
	The share of faculty with a master's degree (31% in 2008) or PhD (5.2% in 2008) to rise	The share of master's degrees and PhDs has dropped slightly, owing to the steep increase in the number of faculty and a wave of retirement among PhD-holders: by October 2014, 1 480 faculty held a master's degree (29.6%) and 192 a PhD (3.8%); 625 faculty members were studying for a master's degree and were expected to graduate by December 2015
	The Ministry of Higher Education to establish Commission on Curriculum	Commission established (target reached); by 2014, it had helped 36% of public faculties (66 out of 182) and 38% of private faculties (110 out of 288) to review and upgrade their curricula
Higher Education Gender Strategy (published 2013)	Women to represent 25% of students by 2014 and 30% by 2015	In 2014, women represented 19.9% of students
	13 women's dormitories to be built	By 2014, seven had been completed
	The number of Afghan women with a master's degree to rise	As of October 2014, 117 women (23% of the total) were pursuing a master's degree in Afghan universities, compared to 508 men
	The proportion of women faculty members to rise to 20% by 2015	By October 2014, 690 faculty members were women (14%), out of a total of 5 006
	The number of women faculty with a master's and PhD degree to rise	By October 2014, 203 women faculty held a master's degree (compared to 1 277 men) and 10 women a PhD

Source: MoHE (2013); MoHE communication in October 2014 all faculty, students and staff with access to about 9 000 academic journals and 7 000 e-books (MoHE, 2013). Participation in research is now a requirement for the promotion of faculty at every level. In the first round of competitive bidding in 2012, research grants were approved for projects proposed by faculty members from Kabul University, Bamyan University and Kabul Education University. Projects concerned the use of IT in learning and research; challenges of the new middle school mathematics curriculum; the effect of automobile pollution on grapevines; integrated management of nutrients in wheat varieties; traditional ways of blending concrete; and the effect of different methods of collecting sperm from bulls (MoHE, 2013).

The research committee established at each of the 12 universities approved 9 research proposals in 2013 and a further 12 in 2014. The ministry is currently working with the Asian Institute of Technology in Thailand to develop joint educational programmes. As part of this collaboration, 12 university faculty members were seconded to the institute in 2014. Work began on drafting a national research policy the same year (MoHE, 2013).

Financial autonomy for universities?

A major goal of the Ministry of Higher Education is to grant some financial autonomy to universities, which are currently not entitled to charge tuition fees or keep any income. The ministry cites a World Bank study from 2005 of Pakistan, which repealed similar restrictive legislation about a decade ago. 'Now, Pakistani universities, on average, earn 49% of their budget (with some as high as 60%) from income they raise and gifts,' observes the ministry (MoHE, 2013).

The aim of the reform is to foster entrepreneurship, university–industry ties and the universities' capacity to provide services. The ministry has prepared a proposal which would allow higher education institutions to keep funds that they earn from entrepreneurial activities, such as drugs analysis done by the Faculty of Pharmacy at Kabul University for the Ministry of Public Health. They would also be able to keep income from night courses and donations from benefactors and alumni. In addition, they would be entitled to set up foundations which could accumulate funds for major projects (MoHE, 2013).

The ministry's position was vindicated by the outcome of a pilot project implemented in 2012 which gave universities in Kabul greater authority over procurement and expenditure below a certain financial threshold. The ministry's plans have been put on hold, however, by the failure of parliament to pass the Higher Education Law, which was approved by the Education Committee in 2012.

BANGLADESH

Great strides in education

The *Bangladesh Education Sector Review 2013* commissioned by the World Bank recognizes significant achievements in primary education since 2010. Net enrolment rates have risen steadily, attaining 97.3% in 2013. Over the same period, the completion rate at primary level rose from 60.2% to 78.6%. Gender parity at both primary and secondary levels has been achieved well ahead of the MDG target set for 2015. The percentage of girls attending school has even surpassed that of boys in recent years.

The quality of education has also improved: according to the Bangladesh Bureau of Educational Information and Statistics, class sizes in secondary schools reportedly shrank from 72 to 44 pupils per class between 2010 and 2013. Repetition rates at primary school level dropped from 12.6% to 6.9% over the same period, with a parallel improvement in the pass rate for the Secondary School Certificate examination and the closing of the gender gap for this indicator. By mid-2014, over 9 000 primary school classrooms had been built or rehabilitated, with the installation of water and sanitary facilities.

Among the drivers of this positive change, the *Education for All 2015 National Review* identifies the conditional cash transfer to children from poor families at primary level and to rural girls at secondary level; the use of ICTs in education; and the distribution of free textbooks to schools, which can also be downloaded free of charge from the government's e-book website.[4]

Among the remaining challenges identified by the *Education Sector Review* (2013), about five million children are still not attending school and the rate of progression from primary to secondary school (60.6% in 2013) has not improved. The review estimates that education plans should target the hardest-to-reach populations. It also pinpoints the need for a substantial rise in budgetary allocations to secondary and higher education. In 2009, the last year for which data are available, just 13.5% of the education budget went to higher education, representing 0.3% of GDP (Figure 21.3).

Despite low levels of funding, enrolment in bachelor's and master's degrees rose from 1.45 million to 1.84 million between 2009 and 2012, with particularly strong growth in S&T fields. Growth was most impressive in engineering (+68%), where enrolment in PhD programmes almost tripled between 2009 and 2012 (Table 21.2). This augurs well for the government's strategy of fostering industrialization and economic diversification. Some 20% of university students are enrolled in a master's programme, one of the highest ratios in Asia, but only 0.4% enrol in a PhD programme (see Figure 27.5).

4. See: www.ebook.gov.bd

ICTs at heart of education policies

After several unsuccessful attempts, the first formal *National Education Policy* was adopted in 2010. Key strategies include providing one year of pre-primary schooling for all children; extending compulsory primary education from Grade 5 to Grade 8 by 2018; expanding vocational/technical training and curricula; making all pupils ICT-literate by the completion of primary school; and updating the syllabuses of higher education to meet international standards.

Both the *National Education Policy* and *National Information and Communication Policy* (2009) underscore the importance of using ICTs in education. For instance, the *National Education Policy* makes ICTs a compulsory subject of vocational and technical education curricula; universities are to be equipped with computers and relevant curricula; and training facilities specializing in ICTs are to be developed for teachers.

The *Master Plan for ICT in Education* for 2012 –2021 sets out to generalize the use of ICTs in education. ICTs were introduced in 2013 as a compulsory subject for higher secondary school pupils intending to sit public examinations in 2015. According to the Bangladesh Bureau of Educational Information and Statistics, the share of secondary schools with computer facilities rose from 59% to 79% between 2010 and 2013 and the percentage of secondary schools with internet shot up from 18% to 63%.

Science and ICTs for middle-income status by 2021

The *Perspective Plan of Bangladesh to 2021* was finalized in 2012 to operationalize the country's blueprint for becoming a middle-income economy by 2021, *Vision 2021*; one thrust of the *Perspective Plan* is to improve the quality of education, with an emphasis on science and technology. Curricula are to be upgraded and the teaching of mathematics, science and information technology encouraged. 'An innovative people will be the backbone of the envisioned society in 2021,' observes the *Plan*, thanks to 'a strong learning system from pre-primary to university levels and the application of research and STI.' Innovation is to be promoted in education and at work. Vast efforts will be made to develop IT through the Digital Bangladesh programme, one of the pillars of *Vision 2021*, in order to foster a 'creative' population (Planning Commission, 2012).

In order to provide the necessary impetus to achieve a Digital Bangladesh by 2021, the Ministry of Science and Information and Communication Technology has been divided into two separate ministries. In its medium-term strategy for 2013–2017, the new Ministry of Information and Communication Technology evokes the development of a high-tech park, an IT village and a software technology park. To this end, the Bangladesh High-tech Authority was created in 2010 by act of parliament. The ministry is currently revising the *National Information and Communication Policy* (2009) and the Copyright Act (2000) to ensure that the rights of local software designers are protected.

The country's first *Science and Technology Policy* was adopted in 1986. It was revised between 2009 and 2011 and is currently under revision once more, in order to ensure that it contributes effectively to realizing the goals of *Vision 2021* (Hossain *et al.,* 2012). Some key targets of *Vision 2021* are to (Planning Commission, 2012):

- establish more institutes of higher learning in science and technology;
- raise GERD 'significantly' from the current level of 0.6% of GDP;
- increase productivity in all spheres of the economy, including micro-enterprises and small and medium-sized enterprises (SMEs);
- establish a National Technology Transfer Office (Box 21.3);

Box 21.3: Quality higher education for Bangladesh

The Higher Education Quality Enhancement Project (2009–2018) funded by the World Bank aims to improve the quality and relevance of the teaching and research environment in Bangladesh by encouraging both innovation and accountability within universities and by enhancing the technical and institutional capacity of the higher education sector.

The mid-term project review reported satisfactory progress in 2014. This included connecting 30 public and private universities to the Bangladesh Research and Education Network and continuous funding allocated on the basis of the performance of academic research projects which had already received funding.

This project is supported by a competitive funding mechanism known as the Academic Innovation Fund (AIF). AIF has clear selection criteria and allocates resources through four competitive funding streams: improvement of teaching and learning and enhancement of research capabilities; university-wide innovation, including the establishment of a National Technology Transfer Office; and collaborative research with industry. In 2014, 135 sub-projects were awarded AIF grants. Earlier projects have also reported satisfactory progress.

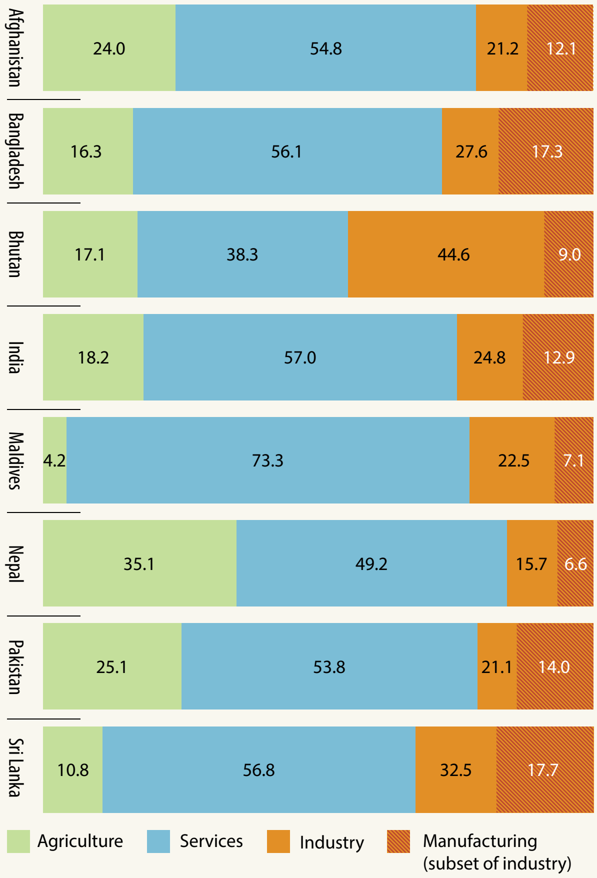
Source: World Bank

- attain self-sufficiency in food production;
- reduce the proportion of people employed in agriculture from 48% to 30% of the labour force;
- raise the contribution of manufacturing to about 27% of GDP and that of industry to about 37% of GDP (Figure 21.10);
- make ICT education compulsory at secondary level by 2013 and at primary level by 2021;
- increase teledensity to 70% by 2015 and 90% by 2021.

The Ministry of Science and Technology describes its current mission as being to:

- expand peaceful use of nuclear energy through the establishment of an atomic power plant and centres of nuclear medicine;
- foster research on biotechnology and develop related human resources;
- develop environment-friendly, sustainable technology for the poor through R&D, such as arsenic-free water, renewable energy and energy-saving cookers;
- develop infrastructure for conducting oceanographic research to enable use of the vast resources of the Bay of Bengal;
- enable the Scientific Documentation Centre to furnish relevant S&T and industrial data to policy-makers and decision-makers; and
- inculcate a scientific attitude in the general public and create interest in astronomy through entertainment.

Figure 21.10: **GDP per economic sector in South Asia, 2013**



Source: World Bank's World Development Indicators, April 2015

Box 21.4: **Agricultural technology to boost productivity in Bangladesh**

The *Perspective Plan of Bangladesh to 2021* observes that 'flood-resistant crops are a must for the country with chronic floods, little arable land and a rapidly growing population' (1.2% annual growth in 2014). It also acknowledges that, for Bangladesh to become a middle-income country by 2021, industrial expansion must go hand-in-hand with more productive agriculture.

The National Agricultural Technology Project funded by the World Bank (2008–2014) set out to improve yields through research and technology transfer. The World Bank funded the research grants awarded by the government-sponsored Krishi Gobeshana Foundation (Agricultural Research Foundation), which had been set up in 2007. Some of these research projects developed the genotypes of spices, rice and tomato for release by the National Seed Board. Research focused on promoting climate-smart agriculture and agro-ecological approaches to farming in demanding ecosystems, such as floodplains and saline soils. By 2014, the project had clocked up the following achievements:

- 47 demonstrated new technologies had been adopted by 1.31 million farmers;
- 200 applied research projects had been funded;
- Scholarships had been awarded to 108 male and female scientists to pursue higher studies in agriculture;
- 732 farmers information and advisory centres had been established;
- 400 000 farmers had been mobilized into over 20 000 common interest groups linked to markets; and
- 34 improved post-harvest technologies and management practices had been adopted by over 16 000 farmers.

Source: World Bank; Planning Commission (2012)

Revamping industry

Although Bangladesh's economy is based predominantly on agriculture (16% of GDP in 2013), industry contributes more to the economy (28% of GDP), largely through manufacturing (Figure 21.10). The *National Industrial Policy* (2010) sets out to develop labour-intensive industries. By 2021, the proportion of workers employed in industry is expected to double to 25%. The policy identifies 32 sectors with high-growth potential. These include established export industries such as the ready-made garment sector, emerging export industries such as pharmaceutical products and SMEs.

The *National Industrial Policy* also recommends establishing additional economic zones, industrial and high-tech parks and private export processing zones to drive rapid industrial development. Between 2010 and 2013, industrial output already grew from 7.6% to 9.0%. Exports remain largely dependent on the ready-made garment sector, which contributed 68% of all exports in 2011–2012, but other emerging sectors are growing, including shipbuilding and the life sciences. This industrialization policy is in line with the current Sixth *Five-year Plan* (2011–2015), which sees industrialization as a means of reducing poverty and accelerating economic growth.

Three months after the Rana Plaza tragedy in April 2013, in which more than 1 100 mainly female workers in the garment industry perished when a multi-storey factory collapsed, the International Labour Organization, European Commission and the Governments of Bangladesh and the USA signed the Sustainability Compact agreement. This agreement set out to improve labour, health and safety conditions for workers and to encourage responsible behaviour by businesses in the Bangladeshi ready-made garment industry.

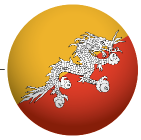
The government has since amended the Labour Act. The amendments include the adoption of a national occupational safety and health policy and standards for safety inspections and the strengthening of laws in support of freedom of association, collective bargaining and occupational safety and health. Safety inspections have been performed in export-oriented garment factories and public factory inspection services have been given more resources. The findings of their ongoing inspections are being made public. For its part, the private sector has put in place an *Accord on Factory and Building Safety in Bangladesh* and an *Alliance for Bangladesh Worker Safety* to facilitate factory inspections and improve working conditions.

Poor infrastructure a deterrent for investors

According to the *World Investment Report 2014*, Bangladesh was one of the top five host countries for FDI in South Asia in 2012 and 2013. FDI net inflows nearly doubled from US$ 861 million in 2010 to US$1 501 million in 2013. Although FDI outflows were low, they did increase from US$ 98 million in US$ 130 million over the same period.

However, UNCTAD's *Investment Policy Review* of Bangladesh (2013) observed that, when FDI inflows were analysed relative to population and as a share of GDP, they were consistently lower in Bangladesh than in some more populous countries such as India and China. The FDI stock of Bangladesh was even lower in 2012 than that of smaller countries such as Cambodia and Uganda. The *Investment Policy Review* found that FDI was instrumental in mobile telephony, substantial in power generation and catalytic but not predominant in garments. The study also found that the poor quality of infrastructure was a major deterrent for potential investors. It suggested that better infrastructure and an improved regulatory framework would foster sustainable investment through FDI.

BHUTAN



Happiness in times of social change

The Kingdom of Bhutan's approach to all aspects of national development is guided by its focus on the overarching concept of gross national happiness. This concept is encapsulated in *Bhutan 2020: A Vision for Peace, Prosperity and Happiness,* the country's development blueprint since 1999. *Bhutan 2020* identifies five principal development objectives: human development; culture and heritage; balanced and equitable development; governance; and environmental conservation.

The Bhutanese have the third-highest level of income in South Asia after the Maldives and Sri Lanka. Per-capita GDP rose steadily between 2010 and 2013 (Figure 21.1). Over the past decade, the traditional, mainly agricultural economy has become more industrialized (Figure 21.10). As the contribution from other sectors has risen, the role of agriculture has declined.

Traditionally, Bhutanese women have held a relatively elevated position in society; they tend to have greater property rights than elsewhere in South Asia, with women rather than men inheriting property in some areas. Industrial development over the past decade appears to have had a negative impact on the traditional place of women in society and their participation in the labour force. The employment gap had been narrowing since 2010 but started widening again in 2013, by which time 72% of men were in gainful employment, compared to 59% of women, according to the *National Labour Force Survey Report (2013).* The unemployment rate nevertheless remains low, at just 2.1% of the population in 2012.

A focus on the green economy and IT

Bhutan's private sector has thus far played a limited role in the economy. The government plans to change this by improving the investment climate through policy and institutional reform and by developing the IT sector, in particular. In 2010, the government revised its *Foreign Direct Investment Policy* (dating from 2002) to bring it into line with its *Economic Development Policy* adopted the same year.

The *Foreign Direct Investment Policy* (2010) identifies the following priority areas for FDI:

- Development of a green and sustainable economy;
- Promotion of socially responsible and ecologically sound industries;
- Promotion of cultural and spiritually sensitive industries;
- Investment in services which promote Brand Bhutan; and
- Creation of a knowledge society.

The policy identifies the following sectors and sub-sectors as being priority areas for investment that merit fast-track approval, among others:

- *Agro-based production*: organic farming; biotechnology, agro-processing, health food, etc.;
- *Energy*: hydropower, solar and wind energy;
- *Manufacturing*: electronics, electrical, computer hardware and building materials.

In 2010, the government published its *Telecommunications and Broadband Policy*. The policy announces the adoption of a *Human Resource Development Plan* to help the ICT sector grow. It also foresees collaboration with the university sector to bridge the gap between curricula and the needs of the IT sector. A revised version of the policy was published in 2014 to reflect the dynamism of this rapidly evolving sector.

Bhutan's first IT park

The Private Sector Development Project (2007–2013) funded by the World Bank is also helping to develop the IT industry. It has three thrusts: fostering the development of enterprises in the IT services sector; enhancing related skills; and improving access to finance. The project has spawned the first IT park in Bhutan, Thimphu TechPark, which was commissioned in May 2012. This is an unprecedented public–private partnership for infrastructure development in Bhutan. The Bhutan Innovation and Technology Centre, which houses Bhutan's first business incubator, has since been established at Thimpu Tech Park.[5]

Industrialization highlights skills mismatch

Illiteracy has long been an issue in Bhutan. In 2010, 53.6% of the labour force was illiterate, 55% of whom were women. Overall illiteracy had declined to 46% by 2013 but remains extremely high. Adding to this picture, only 3% of employees hold a university degree.

In 2012, skilled agricultural and fisheries workers represented 62% of the labour force, compared to only 5% in manufacturing and 2% in mining and quarrying. The agricultural sector, with its inherent bias towards entrepreneurial self-employment, offers untapped potential for developing more value-added products and economic diversification. Appropriate skills training and vocational education will be necessary to nurture the country's industrial development.

The Bhutanese government's eleventh *Five-year Plan* (2013–2018) acknowledges the current shortage of skills in highly specialized professions and the mismatch between curricula and the skills required by industry. It also highlights the challenge posed by the limited resources for developing school infrastructure and the low interest in teaching as a profession: nearly one in ten (9%) teachers was an expatriate in 2010, although this share had dropped to 5% by 2014.

Unlike in other South Asian countries, there are no major gender inequality issues in the Bhutanese education system; primary school enrolment of girls is even higher than that of boys in many urban areas. Net primary school enrolment had reached 95% by 2014, thanks to the development of the secular school system, which has provided pupils living in remote areas with access to education. The government also aims to use ICTs to improve the quality of education (Box 21.5).

Although 99% of children acceded to secondary level education in 2014, three out of four later dropped out (73%). The *Annual Education Statistics Report* (2014) suggests that

5. See:www.thimphutechpark.com/bitc

Box 21.5: Using ICTs to foster collaborative learning in Bhutan

Launched in March 2014, the i-school project in Bhutan is a joint initiative of the Ministry of Education, Bhutan Telecom Limited, Ericsson and the Indian government. The project strives to give children quality education through the use of mobile broadband, cloud computing and the like. The collaborative learning and teaching made possible through this project is based on connectivity to other schools across the country and around the world.

Six schools are participating in the first 12-month pilot phase of the project. Two are located in Thimphu, one in Punakha, one in Wangduephodrang, one in P/Ling and another in Samtse.

Source: compiled by authors

many may be opting for vocational training at this stage of their education. The *National Human Resource Development Policy* (2010) announced that vocational education would be introduced in schools from Grades 6 to 10 and that public–private partnerships would be put in place to improve the quality of training at vocational and technical institutes.

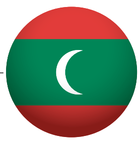
A national council proposed to frame research

The *Tertiary Education Policy* (2010) fixed the target of raising university enrolment from 19% to 33% of 19 year-olds by 2017. The policy observed that mechanisms needed putting in place to measure the level of research activity in Bhutan and recommended an initial scoping exercise. The policy identified the following challenges for research:

- National priorities for research need to be established and a system for determining such a strategy needs to be put in place. Different organizations undertake research but it is not based on an agreed understanding of national priorities.
- Research needs to be encouraged through funding, direction, career structures and access to networks of other researchers. It is also crucial to establish easy connections between research centres with government and industry. Funding could be of two types: seed funds to develop a research culture and more substantial funds to encourage research that attempts to address national problems.
- Facilities, including laboratories and libraries with up-to-date information are needed for research. Currently, there is no government organization responsible for overseeing the interaction between all of the actors within the research and innovation system.

To overcome these shortcomings, the policy stated that a National Council for Research and Innovation would be established. As of 2015, this was not the case.

REPUBLIC OF MALDIVES



Special circumstances call for sustainable solutions

The Republic of Maldives remains heavily reliant on fossil fuels, despite the obvious advantages of local energy generation for the archipelago. A number of initiatives have been taken to promote the uptake of solar and wind–diesel hybrid systems for electricity generation, which are financially feasible (Van Alphen *et al.,* 2008). A study by the Republic of Maldives (2007a) identified a number of constraints, including deficient regulatory frameworks which weaken public–private partnerships and limited technical and managerial capacities in energy transmission and distribution. Similar conclusions can be drawn for the transportation sector, which is fast expanding in the islands due to tourism (Republic of Maldives, 2007b), or the sustainability of the capital, Malé, considered one of the world's most crowded metropolises.

Signs of a greater focus on science

The Maldives has had a tertiary learning institution since 1973 in the form of an Allied Health Services Training Centre. First transformed into the Maldives College of Higher Education in 1999 then into the Maldives National University in February 2011, it remains the country's only tertiary public degree-granting institution. In 2014, the university inaugurated its Faculty of Science, with the introduction of degree programmes in general sciences, environmental science, mathematics and information technology. In addition, postgraduate programmes on offer include a Master of Science in Computing and a Master of Science in Environmental Management. The university also has its own journal, the *Maldives National Journal of Research*, but the focus appears to be on pedagogy rather than the university's own research.

Research output remains modest, with fewer than five articles being published each year (Figure 21.8). The fact that nearly all publications in the past decade involved international collaboration nevertheless bodes well for the development of endogenous science.

A commitment to education spending

The Maldives devoted 5.9% of GDP to education in 2012, the highest ratio in the region. It faces a number of challenges in developing its human capital that have been compounded by the political turmoil since 2012. Other challenges include the large share of expatriate teachers and the mismatch between curricula and the skills employers need.

Although the Maldives had achieved universal net primary enrolment by the early 2000s, this had fallen back to 94% by 2013. Nine out of ten pupils went on to secondary school (92.3%) in 2014 but only 24% stayed on at the higher secondary level. There are more girls than boys at the primary and lower secondary levels but boys overtake girls at the higher secondary level.

The Ministry of Education is eager to improve the quality of education. Between 2011 and 2014, UNESCO implemented a project in the Maldives for Capacity-building in Science Education, with financial support from Japan and the involvement of the Centre for Environment Education in India. The project developed teaching guides and prepared modules and hands-on activity kits to foster creative thinking and the scientific method. In-service teacher training was also organized for students at the Maldives National University.

The Ministry of Education and Ministry of Human Resources, Youth and Sport began implementing a one-year Hunaru ('skills') Project for vocational and technical training in 2013. The aim is to train 8 500 young people in 56 occupational fields, with the government paying a fixed amount per student. Both public and private institutions can apply to run these courses.

The government is intensifying public–private partnerships by offering land and other incentives to private companies to set up institutions offering higher education in selected locations. One such partnership was under way on Lamu Atoll in 2014, where the Indian company Tata has agreed to set up a medical college and to develop a regional hospital.

NEPAL

Moderate growth, falling poverty

Despite its prolonged political transition since the end of the civil war in 2006, Nepal has registered a moderate rate of growth averaging 4.5% over 2008–2013, as compared to the low-income country average of 5.8%. Nepal was hardly affected by the global financial crisis of 2008–2009, as it remains poorly integrated in global markets. Exports of goods and services as a share of GDP nevertheless fell from 23% to 11% between 2000 and 2013. Contrary to what one would expect from a country at Nepal's stage of development, the share of manufacturing has also gone down slightly in the five years to 2013, to just 6.6% of GDP (Figure 21.10).

The country is on track to reach a number of MDGs, particularly those in relation to the eradication of extreme poverty and hunger, health, water and sanitation (ADB, 2013). Nepal will need to do much more, though, to reach the MDGs relating to employment, adult literacy, tertiary education or gender parity in employment, which are more germane to science and technology. The country has some key advantages, notably high remittances from abroad – 20.2% of GDP between 2005 and 2012 – and the country's proximity to high-growth emerging market economies such as China and India. Nepal lacks an effective growth strategy, though, to harness these advantages to accelerated development. The Asian Development Bank's *Macroeconomic Update of Nepal* underlined in February 2015 the deficient investment in R&D and innovation by the private sector as being key constraints to supply capacity and competitiveness.

The government is cognizant of the problem. Nepal has had a specific ministry in charge of science and technology since 1996. The responsibilities of this ministry have been combined with those of the environment since 2005. Partly as a result, the country's modest efforts in science and technology are heavily focused on environmental issues, which is broadly defensible, given Nepal's high vulnerability to natural disasters and climate-related risks. The current *Three-Year Plan* (2014–2016) includes a number of priority areas that are relevant to S&T policies and outcomes (ADB, 2013, Box 1):

- Increasing access to energy, especially a rural electrification programme based on renewable sources (solar, wind, and hybrids) and miniature run-of the river hydropower plants;
- Increasing agricultural productivity; and
- Climate change adaptation and mitigation.

Realizing these goals, while addressing Nepal's competitiveness and growth challenges more broadly, will depend heavily on the uptake of clean and environmentally sound technologies. Successful technology absorption will, in turn, be conditional on the adequate development of local S&T capacities and human resources.

Three new universities since 2010

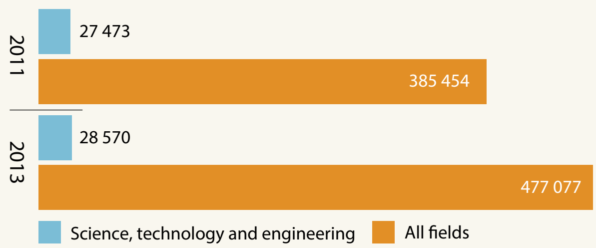
The *UNESCO Science Report 2010* attributed the lack of development in S&T capabilities to the low priority given to education in basic sciences, at the expense of applied fields such as engineering, medicine, agriculture and forestry. Nepal's oldest university, Tribhuvan University (1959) has since been joined by eight other institutions of higher learning, the last three of which were established in 2010: the Mid-western University in Birendranagar, the Far-western University in Kanchanpur and Nepal Agriculture and Forestry University in Rampur, Chitwan.

Despite this development, official statistics suggest that enrolment in S&T fields is not progressing as fast as tertiary enrolment overall. Science and engineering students accounted for 7.1% of the student body in 2011 but only 6.0% two years later (Figure 21.11).

Striking a balance between basic and applied sciences

It is justifiable for a low-income country like Nepal to focus on applied research, provided it has sufficient connectivity to be able to tap into basic scientific knowledge generated elsewhere. At the same time, a greater capability in basic

Figure 21.11: **Students enrolled in higher education in Nepal, 2011 and 2013**



Source: UNESCO Institute for Statistics, June 2015

sciences would help the country to absorb and apply knowledge and inventions produced abroad. The exact balance of policy focus in this area is a difficult call to make in the absence of a more in-depth review of Nepal's innovation constraints and options. Moreover, whereas the *UNESCO Science Report 2010* and national studies (such as NAST, 2010) have advocated a greater focus on basic research in Nepal, some of the country's more recent policy pronouncements establish the priority of learning in applied science and technology over pure science; this is the case, for example, of the declared objectives of the planned Nanotechnology Research Centre (Government of Nepal, 2013a).

A leap forward in Nepal's R&D effort

The *UNESCO Science Report 2010* had also underlined the low level of private sector investment in R&D. Half a decade on, Nepal still does not measure the business sector's R&D effort. However, official statistics suggest a leap in the government budget for R&D since 2008, from 0.05% to 0.30% of GDP in 2010, a greater effort than that of the relatively richer economies of Pakistan and Sri Lanka. Considering that 25% of researchers (by head count) worked in the business sector, higher education or non-profit sector in 2010, total GERD in Nepal is likely to be closer to 0.5% of GDP. Indeed, the data also suggest a 71% increase[6] in the number of researchers between 2002 and 2010 to 5 123 (or 191 per million population), as well as a doubling of technicians over the same period (Figure 21.7).

Potential to attract the diaspora

The *UNESCO Science Report 2010* had noted the low number of PhD students in Nepal and the modest level of scientific production. In 2013, there were still only 14 PhD degrees awarded in Nepal.

At the same time, Nepal has a relatively large tertiary student population abroad, numbering 29 184 in 2012. That year, the Nepalese represented the eighth-largest foreign student population in natural and social sciences and engineering disciplines in the USA[7] and the sixth-largest in Japan, according to the National Science Foundation's *Science & Engineering Indicators, 2014*. Between 2007 and 2013, 569 Nepalese nationals earned PhDs in the USA. Likewise, there are sizeable Nepalese tertiary student communities in Australia, India, the UK and Finland[8]. There is a potential to harness this expatriate talent for the development of Nepal's future S&T potential, provided the right circumstances and momentum can be provided to woo them back home.

6. although there was a break in the data series between 2002 and 2010

7. after China, the Republic of Korea, Saudi Arabia, India, Canada, Viet Nam and Malaysia

8. www.uis.unesco.org/Education/Pages/international-student-flow-viz.aspx

Ambitious plans to 2016

The Nepalese government is confident that the period of the *Twelfth Three-Year Plan* covering 2010–2013 has made a difference. This period has been marked by the start of DNA testing in Nepal, the establishment of a science museum, the expansion of forensic science services, the consolidation of research laboratories and the inception of three-cycle studies (Government of Nepal, 2013b). The government also claims to have minimized brain drain.

In the field of disaster risk reduction, two projects were implemented within the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia. The first sought to develop a flood forecasting system for Nepal (2009–2011) and the second to expand climate risk management through technical assistance. As events so cruelly recalled in April 2015, Nepal does not have an earthquake early warning system which would have given citizens forewarning of about 20 seconds of the impending disaster. Moreover, the number of lives lost in recent floods, despite the existence of a flood warning system, indicates the need for a more integrated solution.

The *Thirteenth Three-Year Plan* covering 2013–2016 goes a step farther by articulating specific objectives to enhance the contribution of science and technology to economic development, including by:

- checking and reversing the brain drain of scientists and technicians;
- encouraging the formation of research and development units within industries;
- harnessing atomic, space, biological and other technologies, as required, for development;
- developing capacities in biological sciences, chemistry and nanotechnologies, in particular to benefit from Nepal's rich biodiversity; and
- mitigating the effects of natural disasters and climate change, through early warning systems and other mechanisms, in part through the use of space technology.

In this context, the Ministry of Science, Technology and Environment plans to set up four technology centres in the near future, namely a National Nuclear Technology Centre, a National Biotechnology Centre, a National Space Technology Centre and a National Nanotechnology Centre. Some of these research areas have obvious relevance for Nepal's sustainable development, such as the use of space-related technologies for environmental surveying and disaster monitoring or weather forecasting. The Nepalese government needs to elaborate further the rationale and context behind other initiatives, such as its plans for nuclear technology development.

PAKISTAN

Plans to boost higher education spending

Since 2010, Pakistan's economy has remained relatively depressed, owing to the uncertain security situation and ongoing political power crisis. More than 55 000 civilians and military personnel have perished in hundreds of major and minor terrorist attacks across major urban centres since 2003.[9] Between 2010 and 2013, Pakistan's annual growth rate averaged 3.1%, compared to 7.2% in India and 6.1% in Bangladesh. The economic impact of the security situation manifests itself in consistently falling investment levels: FDI inflows accounted for 2.0% of GDP in 2005 but only 0.6% in 2013. In addition, tax revenue stood at 11.1% of GDP in 2013, according to the World Bank, one of the lowest rates in the region, limiting the government's ability to invest in human development.

During the 2013–2014 fiscal year, government spending on education stood at merely 1.9% of GDP, just 0.21% of which was earmarked for higher education. Education spending has shrunk each year since peaking at 2.75% of GDP in 2008. As part of Pakistan's effort to create a knowledge economy, *Vision 2025* (2014) has fixed the target of achieving universal primary school enrolment and raising university enrolment from 7% to 12% of the age cohort and the number of new PhDs per year from 7 000 to 25 000 over the next decade. In order to reach these targets, the government has proposed devoting at least 1% of GDP to higher education alone by 2018 (Planning Commission, 2014).

Vision 2025 was developed by the Ministry of Planning, Development and Reform and approved by the National Economic Council in May 2014. It identifies seven pillars for accelerating the pace of economic growth, including through the creation of a knowledge economy:

- Putting people first: developing human and social capital;
- Achieving sustained, indigenous and inclusive growth;
- Governance, institutional reform and modernization of the public sector;
- Energy, water and food security;
- Private sector-led growth and entrepreneurship;
- Developing a competitive knowledge economy through value addition; and
- Modernization of transportation infrastructure and greater regional connectivity.

Within this vision, the first and sixth pillars are directly relevant to the STI sector, whereas the overall global competitiveness of the country will depend on innovation in certain competitive sectors. Moreover, government-led infrastructure projects being planned as part of this vision include the construction of a highway linking Lahore and Karachi, the Peshawar Northern Bypass, Gawadar Airport and the Gawadar Free Economic Zone.

The government plans to reconfigure the current energy mix to overcome power shortages. About 70% of energy is generated using furnace oil, which is costly and has to be imported. The government plans to convert furnace oil plants to coal and is investing in several renewable energy projects, which are one of the priorities of *Vision 2025*.

Energy is one focus of the new Pakistan–China Economic Corridor Programme. During the Chinese president's April 2015 visit to Pakistan, 51 memoranda of understanding were signed between the two governments for a total of US$ 28 billion, much of it in the form of loans. Key projects within this programme include developing clean coal-based power plants, hydropower and wind power, a joint cotton biotech laboratory to be run by the two ministries of science and technology, mass urban transportation and a wide-ranging partnership between the National University of Modern Languages in Islamabad and Xinjiang Normal University in Urumqi. The programme takes its name from the planned corridor that is to link the Pakistani port of Gwadar on the Sea of Oman to Kashgar in western China near the Pakistani border, through the construction of roads, railway lines and pipelines.

In January 2015, the government announced two policies to facilitate the deployment of solar panels across the country, including the removal of taxes on imports and sales of solar panels. After these taxes were introduced in 2013, the volume of solar panel imports had shrunk from 350 MW to 128 MW. Through the second policy, the State Bank of Pakistan and the Alternative Energy Development Board will allow home-owners to leverage their mortgage to pay for the installation of solar panels for a value of up to five million rupees (*circa* US$50 000), with comparatively low interest rates (Clover, 2015).

Pakistan's first STI policy

Among the most critical determinants for the success of any country's STI sector are the institutional and policy systems responsible for managing relevant public policies. The Federal Ministry of Science and Technology has overseen the S&T sector since 1972. However, it was not until 2012 that Pakistan's first *National Science, Technology and Innovation Policy* was formulated: this was also the first time that the government had formally recognized innovation as being a long-term strategy for driving economic growth. The policy principally emphasizes the need for human resource

9. according to the Institute for Conflict Management, South Asia Terrorism Portal; see: www.satp.org/satporgtp/icm/index.html.

development, endogenous technology development, technology transfer and greater international co-operation in R&D. However, it is not clear whether any part of the policy has been implemented since its release.

The policy was informed by the technology foresight exercise undertaken by the Pakistan Council for Science and Technology from 2009 onwards. By 2014, studies had been completed in 11 areas: agriculture, energy, ICTs, education, industry, environment, health, biotechnology, water, nanotechnology and electronics. Further foresight studies are planned on pharmaceuticals, microbiology, space technology, public health (see a related story in Box 21.6), sewage and sanitation, as well as higher education.

R&D intensity to triple by 2018

Following the change of government in Islamabad after the May 2013 general election, the new Ministry of Science and Technology issued the draft *National Science, Technology and Innovation Strategy 2014–2018,* along with a request for comments from the public. This strategy has been mainstreamed into the government's long-term development plan, *Vision 2025*, a first for Pakistan. The central pillar of the draft *National Science, Technology and Innovation Strategy* is human development. Although the pathway to implementation is not detailed, the new strategy fixes a target of raising Pakistan's R&D spending from 0.29% (2013) to 0.5% of GDP by 2015 then to 1% of GDP by the end of the current government's five-year term in 2018. The ambitious target of tripling the GERD/GDP ratio in just seven years is a commendable expression of the government's resolve but ambitious reforms will need to be implemented concurrently to achieve the desired outcome, as greater spending alone will not translate into results.

Little change in the R&D sector

In Pakistan, the government is very present in the R&D sector, both through public investment in defence and civilian technologies and through state-operated bodies. According to the R&D survey undertaken by the Pakistan Council for Science and Technology in 2013, the government's R&D organizations receive nearly 75.3% of national R&D spending.

The share of the population engaged in R&D dropped between 2007 and 2011, be they researchers or technicians. However, growth then picked up between 2011 and 2013; these trends correlate with the relatively static levels of government spending in the R&D sector through its various organizations, which has not kept pace with economic growth.

In the public sector, about one in four researchers are engaged in the natural sciences, followed by the agricultural sciences and engineering and technology. Almost one in three researchers were female in 2013. Women made up half of researchers in medical sciences, about four out of ten in natural sciences but only one in six engineers and one in ten agricultural scientists. The great majority of state researchers work in the higher education sector, a trend that has become more pronounced since 2011 (Table 21.4).

The fact that the business enterprise sector is not surveyed does not augur well for monitoring progress towards a knowledge economy. Moreover, neither *Vision 2025,* nor the draft *National Science, Technology and Innovation Strategy 2014– 2018* proposes strong incentives and clear roadmaps for fostering the development of industrial R&D and university–industry ties.

Chapter 21

Box 21.6: **An app tracks a dengue outbreak in Pakistan**

In 2011, Pakistan's largest province, Punjab, experienced an unprecedented dengue epidemic which infected over 21 000 citizens and resulted in 325 deaths. With the provincial health system in crisis mode, the authorities were rapidly overwhelmed, unable to track simultaneous interventions being undertaken by multiple departments, let alone predict locations where dengue larvae might appear.

At this point, the Punjab Information Technology Board stepped in. A team led by Professor Umar Saif, a former academic from the University of Cambridge (UK) and Massachusetts Institute of Technology (USA), designed a smartphone application to track the epidemic.

The application was pre-installed on 15 000 low-cost Android phones for as many government officials, who were required to upload before and after photographs of all their anti-dengue interventions. The entire data set was then geo-coded and displayed on a Google Maps-based dashboard, freely accessible to the public via internet and to senior government officials through smartphones. Teams of surveyors were despatched throughout the Lahore district, the provincial capital with the most dengue cases, to geo-code high-risk locations with dengue larvae, particularly around the homes of dengue-infected patients. The steady stream of geospatial data was then entered into a predictive algorithm to become an epidemic early warning system accessible to policy-makers at the highest level of government.

The project enabled the authorities to control the spread of the disease. The number of confirmed cases fell to 234 in 2012, none of which were fatal.

Source: High (2014); Rojahn (2012)

Table 21.4: **Researchers (FTE) in Pakistan's public sector by employer, 2011 and 2013**

	Government	Women (%)	Higher education	Women (%)	Share of total researchers working in government (%)	Share of total researchers working in higher education (%)
2011	9 046	12.2	17 177	29.6	34.5	65.5
2013	8 183	9.0	22 061	39.5	27.1	72.9

Note: Data for Pakistan exclude the business enterprise sector. FTE refers to full-time equivalents.

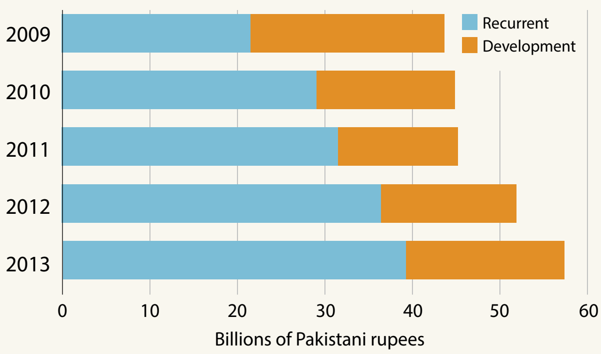
Source: UNESCO Institute for Statistics, June 2015

Decentralization of higher education governance

In 2002, the University Grants Commission was replaced with the Higher Education Commission (HEC), which has an independent chairperson. The HEC has been charged with reforming Pakistan's higher education system by introducing better financial incentives, increasing university enrolment and the number of PhD graduates, boosting foreign scholarships and research collaboration and providing all the major universities with state-of-the-art ICT facilities.

Between 2002 and 2009, the HEC succeeded in increasing the number of PhD graduates to 6 000 per year and in providing up to 11 000 scholarships for study abroad. It also introduced an e-library and videoconferencing facilities, according to the *UNESCO Science Report 2010*. The number of Pakistani publications recorded in the Web of Science leapt from 714 to 3 614 over the same period. The range of achievements during the reform period remains unprecedented in the history of Pakistan's higher education and R&D sectors. Moreover, publications in the Web of Science have since pursued their progression (Figure 21.8). This progress in scientific productivity appears to be due to the momentum generated by the larger numbers of faculty (Table 21.4) and student scholarships for study abroad, as well as the swelling ranks of PhD graduates.

Figure 21.12: **Pakistani Higher Education Commission's budgetary allocations, 2009–2014**



Source: Higher Education Commission of Pakistan

Despite these dramatic quantitative improvements across a variety of indicators, critics argue that this so-called 'numbers game' has compromised quality, a claim supported by the stagnation of Pakistani universities in global education rankings (Hoodbhoy, 2009).

Irrespective of this disagreement, the HEC found itself on the brink of dissolution in 2011–2012 in the face of the 18th amendment to the Constitution, which devolved several governance functions to provincial governments, including that of higher education. It was only after the Supreme Court intervened in April 2011, in response to a petition from the former Chair of the HEC, that the commission was spared from being divided up among the four Provinces of Baluchistan, Khyber–Pakhtunkhwa, Punjab and Sindh.

Notwithstanding this, the HEC's developmental budget – that spent on scholarships and faculty training, etc. – was slashed by 37.8% in 2011–2012, from a peak of R. 22.5 billion (*circa* US$ 0.22 billion) in 2009–2010 to Rs 14 billion (*circa* US$ 0.14 billion). The higher education sector continues to face an uncertain future, despite the marginal increase in developmental spending wrought by the new administration in Islamabad: Rs. 18.5 billion (*circa* US$ 0.18 billion) in the 2013–2014 budget.

In defiance of the Supreme Court ruling of April 2011, the provincial assembly of Sindh Province passed the unprecedented Sindh Higher Commission Act in 2013 creating Pakistan's first provincial higher education commission. In October 2014, Punjab Province followed suit as part of a massive restructuring of its own higher education system.

In sum, Pakistan's higher education sector is in transition, albeit with legal complications, towards a devolved system of governance undertaken at the provincial level. Although is too early to assess the potential impact of these developments, it is clear that the momentum of growth in spending and graduates in the higher education sector during the first decade of the century has now been lost. According to HEC statistics, the organization's budget as a percentage of national GDP has consistently fallen from the 2006-2007 peak of 0.33% to 0.19% in 2011–2012. In the interests of *Vision 2025*'s stated goal of building a knowledge economy, Pakistan's public policy apparatus will need to undertake a fundamental reprioritization of development spending, such as by giving itself the means to reach the target of devoting 1% of GDP to higher education.

Despite the turbulence caused by the legal battle being waged since the 2011 constitutional amendment discussed earlier, the number of degree-awarding institutions continues to grow throughout the country, both in the private and public sectors. Student rolls has been rising in tandem, from only 0.28 million in 2001 to 0.47 million in 2005, before crossing the 1.2 million mark in 2014. Just under half of universities are privately owned (Figure 21.13).

STI mainstreamed into development

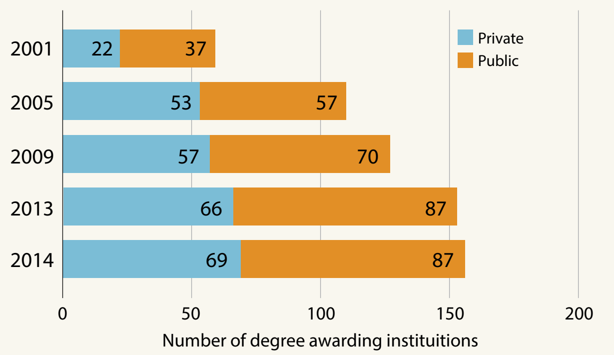
The overall picture of the STI sector in Pakistan is at best a mixed one. While the higher education sector faces an uncertain future, the government's mainstreaming of STI thinking into the national development narrative could signal a turnaround. Although indicators clearly show growth in higher education, they do not necessarily imply that the quality of education and research has also improved.

Moreover, the growth in PhD graduates and scientific publications does not appear to be having a discernible impact on innovation, as measured by patent activity. According to the World Intellectual Property Rights Organization (WIPO), patent applications[10] from Pakistan increased from 58 to 96 between 2001 and 2012 but the proportion of successful applications over the same period fell from 20.7% to 13.5%. This poor performance indicates a lack of a meaningful relationship between the university reforms and their impact on industry (Lundvall, 2009). As discussed above, the public sector continues to play a dominant role in the STI market, whereas the private sector appears to be lagging (Auerswald *et al*., 2012). This is also indicative of the non-existence of an appropriate entrepreneurial avenue (or culture), which is affecting Pakistan's global economic competitiveness.

Despite the mainstreaming of the national STI policy within national development policy, its potential impact on programmatic interventions remains far from clear. In order to achieve its goal of becoming a knowledge economy, Pakistan still requires a bolder vision from decision-makers at all levels of government.

10. These statistics are based on data collected from IP offices or extracted from the PATSTAT database. Source: www.wipo.int

Figure 21.13: **Growth in number of Pakistani universities, 2001–2014**



Source: Higher Education Commission of Pakistan

SRI LANKA

Strong growth since conflict's end

Mahinda Chintana: Vision for the Future 2020 (2010) is the overarching policy setting Sri Lanka's development goals to 2020; it aims to turn Sri Lanka into a knowledge economy and one of South Asia's knowledge hubs. The newfound political stability since the end of the prolonged civil war in 2009 has spawned a building boom since 2010, with the government investing in strategic development projects to build or expand motorways, airports, seaports, clean coal plants and hydropower. These projects are designed to turn Sri Lanka into a commercial hub, naval/maritime hub, aviation hub, energy hub and tourism hub. The Strategic Investment Projects Act of 2008 (amended in 2011 and 2013) was introduced to provide a tax-free period for the implementation of strategic development projects.

In order to attract FDI and technology transfer, the government has signed a series of agreements with foreign governments, including those of China, Thailand and the Russian Federation. Within an agreement signed in 2013, for instance, the Russian State Atomic Energy Corporation (ROSATOM) is assisting Sri Lanka's Atomic Energy Authority in developing nuclear energy infrastructure and a nuclear research centre, as well as providing training for workers. In 2014, the government signed an agreement with China for the expansion of the Port of Colombo and the development of infrastructure (port, airport and motorway) in Hambantota, which the government plans to turn into Sri Lanka's second urban hub after the capital. The agreement with China also covers technical co-operation on the Norochcholai Coal Power Project.

Between 2010 and 2013, GDP increased by 7.5% per year on average, up from 3.5% in 2009. In parallel, GDP per capita grew by 60% from US$2 057 to US$ 3 280 between 2009 and 2013. Although Sri Lanka's rank in the knowledge economy index dropped from 4.25 to 3.63 between 1999 and 2012, it remains higher than for all other South Asian countries.

Sri Lanka has made the transition from an agricultural economy to one based on services and industry (Figure 21.10) but the proportionate supply of science and engineering graduates from local universities is lower than for other disciplines.

Higher education reforms seek to expand capacity

Sri Lanka is likely to achieve universal primary education and gender parity by 2015, according to UNESCO's *Education for All Global Monitoring Report* (2015). One concern is the low level of public spending on education, which even dropped between 2009 and 2012 from 2.1% to 1.7% of GDP, the lowest level in South Asia (Figure 21.3).

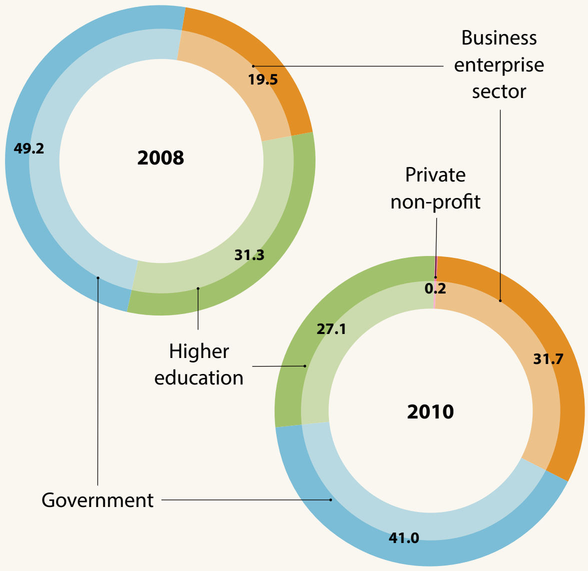
Sri Lanka counts 15 state-controlled universities which operate under the University Grants Commission (UGC) and a further three under the Ministries of Defence, Higher Education and Vocational and Technical Training. These 18 state universities are complemented by 16 registered private universities offering bachelor's or master's degrees.

At 0.3% of GDP, Sri Lanka's public spending on higher education is one of the lowest in South Asia, on a par with that of Bangladesh. According to the UGC, only 16.7% of the students who qualified for university could be admitted for the year 2012–2013. These factors explain the relatively low proportion of researchers in Sri Lanka – a head count of just 249 per million inhabitants in 2010 – , and the modest progress in recent years (Figure 21.7). Of note is that the share of researchers working in the business enterprise sector (32% in full-time equivalents for 2010) is approaching that of India (39% in 2010), a trend which augurs well for the development of a dynamic private sector in Sri Lanka (Figure 21.14). In 2012, the Sri Lankan government announced tax incentives for private companies undertaking R&D and for the use of public research facilities.

The government has spent the past few years addressing the insufficient number of university places. This is one of the objectives of the Higher Education for the Twenty-first Century Project (2010–2016), which aims to ensure that universities are in a position to deliver quality services aligned with the country's socio-economic needs. The mid-term review in 2014 identified the following achievements:

- progressive implementation of the Sri Lanka Qualification Framework (SLQF, est 2012) by national institutes and universities; it regulates the ten levels of qualification offered by public and private post-secondary institutions to enhance equity in higher education, training and job opportunities and facilitate lateral and vertical mobility in the university system; the SLQF integrates the National Vocational Qualification Framework (2005) and identifies pathways for ensuring mobility between vocational and higher education by providing a nationally consistent basis for recognizing prior learning and the transfer of credits;

Figure 21.14: **Sri Lankan researchers (FTE) by sector of employment, 2008 and 2010**



Source: UNESCO Institute for Statistics, June 2015

- implementation of University Development Grants to improve the skills of students at all universities in relation to information technology (IT), English and soft skills, such as conscientiousness or leadership qualities, which are valued by employers at all target 17 universities;
- implementation of Innovatory Development Grants for university students enrolled in the arts, humanities and social sciences at all target 17 universities;
- award of Quality and Innovation Grants (QIG), which enhance the quality of academic teaching, research and innovation, to 58 study programmes, exceeding the project target of 51; nearly all QIGs are performing well;
- enrolment of over 15 000 students in advanced technological institutions, surpassing the current project target of 11 000;
- commencement of master's or PhD degree programmes by over 200 academics from universities and the Sri Lanka Institute of Advanced Technological Education, exceeding the project target of 100 master's/PhD degrees; and
- about 3 560 beneficiaries of short-term professional development activities targeting university administrators and managers, academics and technical and support staff.

Greater mobility for Sri Lankan engineers

In June 2014, the premier body for engineers in Sri Lanka, the Institution of Engineers, became a signatory of the Washington Accord, along with its Indian counterpart. The Washington Accord is an international agreement by which bodies responsible for accrediting engineering degree programmes recognize the graduates of other signatory bodies as having met the academic requirements for entry into the engineering profession. This recognition offers future Sri Lankan and Indian engineers easy mobility throughout the signatory countries.[11]

Sri Lanka's first STI policy

Sri Lanka's first comprehensive *National Science and Technology Policy* was adopted in June 2009, following a thorough consultative process with all stakeholders, as outlined in the *UNESCO Science Report 2010*. These consultations identified the need to develop a science and innovation culture, build human resource capabilities and promote R&D and technology transfer. Participants also felt that the policy should foster sustainability and indigenous knowledge, propose a defined system of intellectual property rights and promote the application of science and technology for human welfare, disaster management, adaptation to climate change, law enforcement and defence.

Under the objective of 'Enhancing Science and Technology Capability for National Development', the policy identifies strategies for increasing ' the state sector investment in science and technology to 1% of GDP by 2016 and facilitating the non-state sector investment in R&D to at least 0.5% of the GDP by 2016.' This is an ambitious target, since the government devoted just 0.09% of GDP to GERD in 2010 and the business enterprise sector (public and private) a further 0.07%.

Approved by the Cabinet in 2010, the *National Science, Technology and Innovation Strategy* (2011–2015) serves as the roadmap for implementing the *National Science and Technology P*olicy. The body responsible for piloting the strategy, the Co-ordinating Secretariat for Science, Technology and Innovation (COSTI), was set up for this purpose in 2013. COSTI is currently preparing an evaluation of the national research and innovation ecosystem.

The *National Science, Technology and Innovation Strategy* (2011–2015) identifies four broad goals:

- Harness innovation and technology to economic development through focused R&D and dynamic technology transfer to increase the share of high-tech products for export and the domestic market; the main target of the Advanced Technology Initiative is to raise the share of high-tech products among exports from 1.5% in 2010 to 10% by 2015;
- Develop a world-class national research and innovation ecosystem;
- Establish an effective framework to prepare the population of Sri Lanka for a knowledge society; and
- Ensure that the sustainability principle is entrenched in all spheres of scientific activity to ensure socio-economic and environmental sustainability.

A better quality of life through R&D

Adopted in July 2014, the *National Investment Framework for Research and Development for 2015–2020* identifies ten focus areas for investment in R&D to improve the quality of life. Relevant government ministries and other public and private institutions were asked to take part in the study, in order to recommend national R&D priorities.

The ten focus areas are:

- Water;
- Food, nutrition and agriculture;
- Health;
- Shelter;
- Energy;
- Textile industry;
- Environment;
- Mineral resources;
- Software industry and knowledge services;
- Basic sciences, emerging technologies and indigenous knowledge.

Nanotechnology a priority

Development of the industrial sector has accelerated since the Cabinet approved[12] the *National Biotechnology Policy* in 2010 and the *National Nanotechnology Policy* in 2012.

Nanotechnology got its first institutional boost in 2006 with the launch of the National Nanotechnology Initiative. Two years later, the government established the Sri Lanka Institute of Nanotechnology (SLINTEC) in an unprecedented joint venture with the private sector (Box 21.7). In 2013, the Nanotechnology and Science Park opened, along with the Nanotechnology Centre of Excellence, which provides high quality infrastructure for nanotechnology research. In 2013, Sri Lanka ranked 83rd for the number of nano-articles in the Web of Science per million inhabitants (Figure 21.8). It trails Pakistan (74th), India (65th) and Iran (27th) for this indicator (for India and Iran, see Figure 15.5).

11. Among the other signatories are Australia, Canada, Ireland, Japan, Rep. Korea, Malaysia, New Zealand, Russia, Singapore, South Africa, Turkey, the UK and USA. See: www.iesl.lk

12. A third sectorial policy on human genetic material and data was still in draft form at the time of writing in mid-2015.

Box 21.7: Developing smart industry through the Sri Lanka Institute of Nanotechnology

The Sri Lanka Institute of Nanotechnology (SLINTEC) was established in 2008 as in a joint venture between the National Science Foundation and Sri Lankan corporate giants that include Brandix, Dialog, Hayleys and Loadstar. Its aims are to:

- build a national innovation platform for technology-based economic development by helping to raise the proportion of high-tech exports from 1.5% to 10% of total exports by 2015 and through the commercialization of nanotechnology;
- deepen collaboration between research institutes and universities;
- introduce nano-aspects of leading technologies and industries to make Sri Lankan products more competitive globally and add value to Sri Lanka's natural resources;
- bring nanotechnology research and business enterprises together; and
- attract expatriate Sri Lankan scientists by creating a sustainable ecosystem.

Less than one year after its inception, SLINTEC filed five international patents with the United States Patent and Trademark Office, a remarkable achievement. Two additional patent applications were filed in 2011 and 2012. These inventions include a process for the preparation of carbon nanotubes from vein graphite; compositions for sustained release of agricultural macronutrients and related processes; a cellulose-based sustained release macronutrient composition for fertilizer application; a process for reinforcing elastomer-clay nano-composites; a process for preparing nanoparticles from magnetite ore; a nanotechnology-based sensor unit; a composition for stain and odour removal from bio-polymeric fabrics, etc.

Gunawardena (2012) identified the focus areas of SLINTEC as:

- *Smart agriculture:* nanotechnology-based slow release fertilizer; potential expansion to sensors and next generation fertilizers;
- *Rubber nano-composites:* high-performance tyres;
- *Apparel and textile:* high-end fabrics, smart yarns and other technologies;
- *Consumer products:* a nanotechnology-based external medical sensor with a view to enabling remote health monitoring, detergents, cosmetics, etc.;
- *Nano-materials:* ilmenite, clay, magnetite, vein quartz and vein graphite to develop titanium dioxide, montmorillonite, nanomagnetite, nanosilica and graphite nanoplatelets.

Source: http://slintec.lk

Schemes to foster innovation

The National Science Foundation has instituted two technology grant schemes to encourage innovation. The first (Tech D) helps universities, research institutes, private firms and individuals develop their ideas, whereas the second focuses on start-ups based on novel technologies. In 2011, five Tech D grants and one start-up grant were awarded.

In 2013, the Ministry of Technology and Research organized its third Technology Marketplace exhibition to provide a forum where scientific research and industry could meet. The ministry has directed its five research bodies to focus on demand-driven research: the Industrial Technology Institute, National Engineering Research and Development Centre, Atomic Energy Board, SLINTEC and the Arthur C. Clarke Institute for Modern Technologies.

In 2010, the USA-based Blue Ocean Ventures launched the Lankan Angels Network. By 2014, the investors operating within this network had injected US$1.5 million into 12 innovative Sri Lankan companies, within a partnership with the Sri Lankan Inventors Commission (est. 1979). The Ministry of Technology and Research reported in 2013 that the Commission had disbursed just LKR 2.94 million (*circa* US$ 22 000) in grants through its own Inventor's Fund the same year.

Smart people, smart island

The first framework for generalizing ICTs was the e-Sri Lanka roadmap launched in 2002, which spawned the Information and Communication Technology Act and the founding of the government-owned Information and Communication Technology Agency (ICTA) in 2003. ICTA implemented the government's e-Sri Lanka Development Project, which sought to bring ICTs to every village, until the project's end in 2013. By 2013, 22% of the population had access to internet, compared to just 6% in 2008, and 96% had a mobile phone subscription.

Phase 2 of the e-Sri Lanka Development Project was launched by ICTA in 2014, in order to spur economic development through innovation in ICTs. Known as Smart Sri Lanka, the project is expected to run for about six years. Its slogan is 'smart people, smart island.' Its goals could be summed up as: smart leadership, smart government, smart cities, smart jobs, smart industries and a smart information society.

Smart Sri Lanka reposes on six programmatic strategies to achieve its goal:

- ICT policy, leadership and institutional development;
- Information infrastructure;
- Re-engineering government;
- ICT human resource development;
- ICT investment and private sector development; and
- The e-society.

In parallel, ICTA has set up telecentres *(nenasalas)* across the country, in order to connect communities of farmers, students and small entrepreneurs to information, learning and trading facilities. These telecentres provide people with access to computers, internet and training in IT skills. The *nenasalas* also provide access to local radio broadcasts of market prices and agricultural information for farmers; e-health and telemedecine facilities for rural patients; and digital 'talking books' (audio books) for the visually impaired. Three types of *nenasala* have been implemented: rural knowledge centres; e-libraries; and distance and e-learning centres. As of August 2014, there were 800 *nenasalas* across the country.[13]

CONCLUSION

A need to blend local and external capacity

There have been some significant improvements in education since 2010 in South Asia, along with more modest progress in developing national innovation systems. In both areas, low levels of public funding have been an obstacle to development but, in the case of education, government efforts have been supplemented by projects funded by international donor agencies. Despite gains in net primary school enrolment, uptake to secondary-level education enrolment nevertheless remains relatively low: the most populous countries, Bangladesh and Pakistan, have reported levels of only 61% (2013) and 36% (2012) respectively.

Universal primary and secondary education is only the first step towards developing the requisite professional and technical skills that countries will need to realize their ambition of becoming a knowledge economy (Pakistan and Sri Lanka) or middle-income country (Bangladesh, Bhutan and Nepal) within the next decade. Building an educated labour force will be a prerequisite for developing the high-value-added industries needed to undertake the desired industrial diversification. Education planning will need to include investment in infrastructure, programmes to improve teaching skills and the development of curricula that match skills with employment opportunities.

13. See: www.nenasala.lk

In order to exploit a broad spectrum of opportunities, national innovation systems should be designed to enable both the development of local capacity in research and innovation and the acquisition of external knowledge and technologies which can generally be found in locally operated, technologically advanced firms. Whereas the majority of industries in South Asia are not yet technologically advanced, there are nevertheless a few local firms that have become internationally competitive, particularly in Pakistan and Sri Lanka. Given the heterogeneity among firms in terms of their technological innovativeness, the national innovation system will need to be sufficiently flexible to support their different technological requirements. Whereas local innovation systems are usually designed to support R&D-led innovation, countries that are able to capitalize systemically on the accumulated capabilities of high-performing local firms and implanted multinationals to nurture their industries are likely to generate broader innovative capabilities.

Economic development through FDI requires a high level of local responsiveness and absorptive capacity, in particular with regard to technology diffusion. The FDI inflows to the South Asian economies reviewed in the present chapter have not significantly contributed to their growth, in comparison with countries in East Asia. Technologically advanced economic sectors where value chain activities are able to utilize existing local knowledge, skills and capabilities have an opportunity to upgrade their local industries.

Governments need to ensure that sufficient funds are available for the implementation of national research and education policies. Without adequate resources, it is unlikely that these policies will bring about effective change. Governments are aware of this. Pakistan has set targets to increase its investment in R&D to 1% of GDP by 2018 and Sri Lanka plans to increase its own investment to 1.5% of GDP by 2016, with a public sector contribution of at least 1%. These targets look good on paper but have governments put in place the mechanisms to reach them? Spending on R&D also has to be prioritized, if limited financial and human resources are to make the desired impact.

Public–private partnerships can be an important ally in policy implementation – as long as the private sector is sufficiently robust to shoulder part of the burden. If not, tax incentives and other business-friendly measures can give the private sector the boost it needs to become an engine of economic development. Public–private partnerships can create synergies between firms, public R&D institutes and universities for industry-led innovation, one obvious example in this respect being SLINTEC (Box 21.7).

The lack of infrastructural capacity to support the use of internet remains a challenge for many South Asian countries. This leaves them unable to connect their own internal urban and rural economies or with the rest of the world. All countries have made efforts to include ICTs in education but the availability and quality of the electricity supply in rural areas and the deployment of ICTs are still major concerns. Mobile phone technology is widespread, being used by farmers, school children, teachers and businesses; this almost ubiquitous, easily accessible and affordable technology represents an enormous but still underutilized opportunity for information- and knowledge-sharing, as well as for the development of commercial and financial services across urban and rural economies.

KEY TARGETS FOR SOUTH ASIAN COUNTRIES

- Raise the share of higher education to 20% of the Afghan education budget by 2015;
- Ensure that women represent 30% of Afghan students and 20% of faculty by 2015;
- Raise the contribution of industry to 40% of GDP in Bangladesh and increase the share of workers employed by industry to 25% of the labour force by 2021;
- Reduce the share of workers employed in agriculture in Bangladesh from 48% of the labour force in 2010 to 30% in 2021;
- Create a National Council for Research and Innovation in Bhutan;
- Broaden access to higher education in Pakistan from 7% to 12% of the age cohort and increase the number of new PhDs per year from 7 000 to 25 000 by 2025;
- Raise Pakistan's GERD to 0.5% of GDP by 2015 and to 1% of GDP by 2018;
- Increase expenditure on higher education to at least 1% of GDP in Pakistan by 2018;
- Raise Sri Lanka's GERD from 0.16% of GDP in 2010 to 1.5% of GDP by 2016, to which the private sector should contribute 0.5% of GDP, compared to 0.07% in 2010;
- Augment the share of Sri Lankan high-tech products from 1.5% (2010) to 10% of exports by 2015.

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ACKNOWLEDGMENTS

The authors wish to thank Prof. Hari Sharma, Director of the Alliance for Social Dialogue in Nepal, for his insights into STI development of Nepal, and Prof. Sirimali Fernando, CEO of the Coordinating Secretariat for Science, Technology and Innovation in Sri Lanka, for sharing information on current dynamics related to the implementation STI strategies in Sri Lanka.

They would also like to thank Drs Atta ur Rahman and Mukhtar Ahmed, respectively former and current Chairs of the Higher Education Commission of Pakistan, for providing valuable insights into the reform of higher education in Pakistan. Thanks go also to Mr Mustafa Naseem at the Information Technology University Punjab for his assistance in preparing the case study on dengue fever.

The authors also take this opportunity to thank the Afghan Ministry of Higher Education and Ahmad Zia Ahmadi from the UNESCO Kabul office for supplying the information and data on the status of higher education reform in Afghanistan. Thanks go also to the editor of the present report, Susan Schneegans, for her role in developing the country profile of Afghanistan.

The government needs to support the emergence of technology-based start-ups to broaden the innovation culture in India.
Sunil Mani

The majority of pharmaceutical patents are owned by Indian firms, whereas foreign firms established in India tend to own the majority of patents in computer software.
Photo © A and N photography/Shutterstock.com

22 · India

Sunil Mani

INTRODUCTION

Jobless growth: an emerging concern

For the first time in its history, India's economy grew at around 9% per annum between 2005 and 2007. Ever since, GDP has been progressing at a much slower pace of around 5%, primarily as a corollary of the global financial crisis in 2008, even though it did bounce back briefly between 2009 and 2011 (Table 22.1).

India has experienced mixed fortunes in recent years. On the positive side, one could cite the systematic reduction in poverty rates, improvements in the macro-economic fundamentals that nurture economic growth, a greater flow of both inward and outward foreign direct investment (FDI), the emergence of India since 2005 as the world leader for exports of computer and information services and the country's evolution into a hub for what are known as 'frugal innovations', some of which have been exported to the West. On the down side, there is evidence of growing inequality in income distribution, a high inflation rate and current deficit, as well as sluggish job creation despite economic growth, a phenomenon that goes by the euphemism of 'jobless growth'. As we shall see, public policy has strived to reduce the deleterious effects of these negative features without imperilling the positive ones.

Come manufacture in India!

In May 2014, the Bharatiya Janata Party became the first party in 30 years to win a majority of parliamentary seats (52%) in the general elections, allowing it to govern without the support of other parties. Prime Minister Narendra Modi will thus have considerable freedom in implementing his programme between now and the next general elections in 2019.

In his speech delivered on Independence Day on 15 August 2014, the prime minister argued for a new economic model based on export-oriented manufacturing. He encouraged both domestic and foreign companies to manufacture goods for export in India, proclaiming several times, 'Come manufacture in India!' Today, India's economy is dominated by the services sector, which represents 57% of GDP, compared to 25% for industry, half of which comes from manufacturing[1] (13% of GDP in 2013).

The new government's shift towards an East Asian growth[2] model with a focus on the development of manufacturing and heavy infrastructure is also driven by demographic trends: 10 million young Indians are joining the job market each year and many rural Indians are migrating to urban areas. The services sector may have fuelled growth in recent

1. The *National Manufacturing Policy* (2011) advocated raising the share of manufacturing from 15% to about 25% of GDP by 2022. The policy also proposed raising the share of high-tech products (aerospace, pharmaceuticals, chemicals, electronics and telecommunications) among manufactured products from 1% to at least 5% by 2022 and augmenting the current share of high-tech goods (7%) among manufactured exports by 2022.

2. The East Asian growth model implies a strong role for the state in raising the domestic investment rate as a whole and specifically in manufacturing industries.

Table 22.1: **Positive and disquieting features of India's socio-economic performance, 2006–2013**

	2006	2008	2010	2012	2013
Rate of real GDP growth (%)	9.3	3.9	10.3	4.7	4.7
Savings rate (% of GDP)	33.5	36.8	33.7	31.3	30.1
Investment rate (% of GDP)	34.7	38.1	36.5	35.5	34.8
Population living below poverty line (%)	37.20^{-1}	–	–	21.9	–
Population without access to improved sanitation (%)	–	–	–	64.9^{-1}	–
Population without access to electricity (%)	–	–	–	24.7^{-1}	–
Inward net FDI inflow (US$ billions)	8.90	34.72	33.11	32.96	30.76^{+1}
Outward net FDI outflow (US$ billions)	5.87	18.84	15.14	11.10	9.20^{+1}
India's world share of exports of computer software services (%)	15.4	17.1	17.5	18.1	–
Inflation, consumer prices (%)	6.15	8.35	11.99	9.31	10.91
Income inequality (Gini index)	33.4		35.7	–	–
Jobless growth (growth ratio of employees in organized sector)	0.20	0.12	0.22	–	–

+n/-n: data refer to *n* years before or after reference year

Source: Central Statistical Organization; Reserve Bank of India; UNDP (2014); World Water Assessment Programme (2014) *World Water Development Report: Water and Energy* years but it has not created mass employment: only about one-quarter of Indians work[3] in this sector. One challenge will be for the government to create a more business-friendly fiscal and regulatory environment. India will also need to raise its fixed investment ratio well above the current 30%, if it is to emulate the success of the East Asian model (Sanyal, 2014).

In his speech, Modi also announced the disbanding of the nation's Planning Commission. This represents one of the most significant policy shifts in India since the release of the *UNESCO Science Report 2010*. This decision has effectively sounded a death knell to the planned form of development pursued by India over the past six and a half decades, which has resulted in a long series of medium-term development plans with explicit targets. On 1 January 2015, the government announced that the Planning Commission would be replaced by the National Institution for Transforming India (NITI Ayog). The role of this new think tank on development issues will be to produce reports on strategic issues for discussion by the National Development Council, in which all the chief ministers participate. In a departure from past practice, NITI Ayog will accord India's 29 states a much greater role in policy formulation and implementation than the erstwhile Planning Commission. The new think tank will also play an active role in implementing schemes sponsored by the central government.

Despite this development, the *Twelfth Five-Year Plan* (2012–2017) will still run its course. Up until now, the Planning Commission has co-ordinated India's wide spectrum of institutions supporting technological change, essentially through these five-year plans. These institutions include the Scientific Advisory Council to the Prime Minister, the National Innovation Council and the Ministry of Science and Technology. The new think tank will take over this co-ordination role.

In 2014, the new government made two proposals with regard to science. The first was for India to adopt a comprehensive policy on patents. The second was for senior researchers from government laboratories to work as science teachers in schools, colleges and universities as a way of improving the quality of science education. A committee of experts was subsequently appointed to draw up the policy on patents. However, the draft report submitted by the committee in December 2014 does not call for an overhaul of the existing policy. Rather, it encourages the government to popularize a patent culture among potential inventors from both the formal and informal economic sectors. It also recommends that India adopt utility models in its patent regime, in order to incite small and medium-sized enterprises (SMEs) to be more innovative.

3. The low level of job creation may be explained by the fact that the services sector is dominated by retail and wholesale trade (23%), followed by real estate, public administration and defence (about 12% each) and construction services (about 11%). See Mukherjee (2013).

India's foreign policy will not break with the past

The Modi government's foreign policy is unlikely to depart from that of previous governments which have considered, in the words of India's first prime minister, Jawaharlal Nehru, that 'ultimately, foreign policy is the outcome of economic policy.' In 2012–2013, India's three biggest export markets were the United Arab Emirates, USA and China. It is noteworthy, however, that Narendra Modi is the first Indian prime minister to have invited all the heads of government of the South Asian Association for Regional Cooperation (SAARC)[4] to his swearing-in ceremony on 26 May 2014. All accepted the invitation. Moreover, at the November 2014 SAARC summit, Prime Minister Modi appealed to SAARC members to give Indian companies greater investment opportunities in their countries, in return for better access to India's large consumer market (see p. 569).

When it comes to innovation, Western nations will no doubt remain India's primary trading partners, despite India's ties to the other BRICS countries (Brazil, Russia, China and South Africa), which resulted in the signing of an agreement in July 2014 to set up the New Development Bank (or BRICS Development Bank), with a primary focus on lending for infrastructure projects.[5]

Three factors explain India's continued reliance on Western science and technology (S&T). First among them is the growing presence of Western multinationals in India's industrial landscape. Secondly, a large number of Indian firms have acquired companies abroad; these tend to be in developed market economies. Thirdly, the flow of Indian students enrolling in science and engineering disciplines in Western universities has increased manifold in recent years and, as a result, academic exchanges between Indian and Western nations are very much on the rise.

Economic growth has driven dynamic output in R&D

All indicators of output from research and development (R&D) have progressed rapidly in the past five years, be they for patents granted nationally or abroad, India's share of high-tech exports in total exports or the number of scientific publications (Figure 22.1). India has continued building its capability in such high-tech industries as space technology, pharmaceuticals and computer and information technology (IT) services.

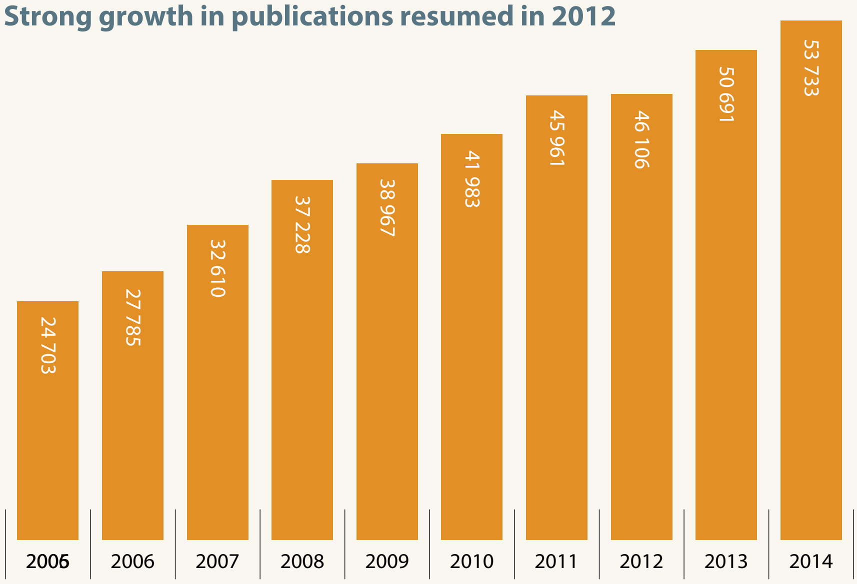
Two recent achievements illustrate the distance India has travelled in recent years: its position as world leader since 2005 for exports of computer and information services and

4. See Box 21.1 for details of the South Asian University, a SAARC project.

5. Each of the five BRICS contributes an equal financial share to the bank, which is to be endowed with initial capital of US$ 100 billion. The bank is headquartered in Shanghai (China), with India holding the presidency and a regional antenna in South Africa.

Figure 22.1: **Scientific publication trends in India, 2005–2014**

Strong growth in publications resumed in 2012



0.76

Average citation rate for Indian scientific publications, 2009–2012; the G20 average is 1.02

6.4%

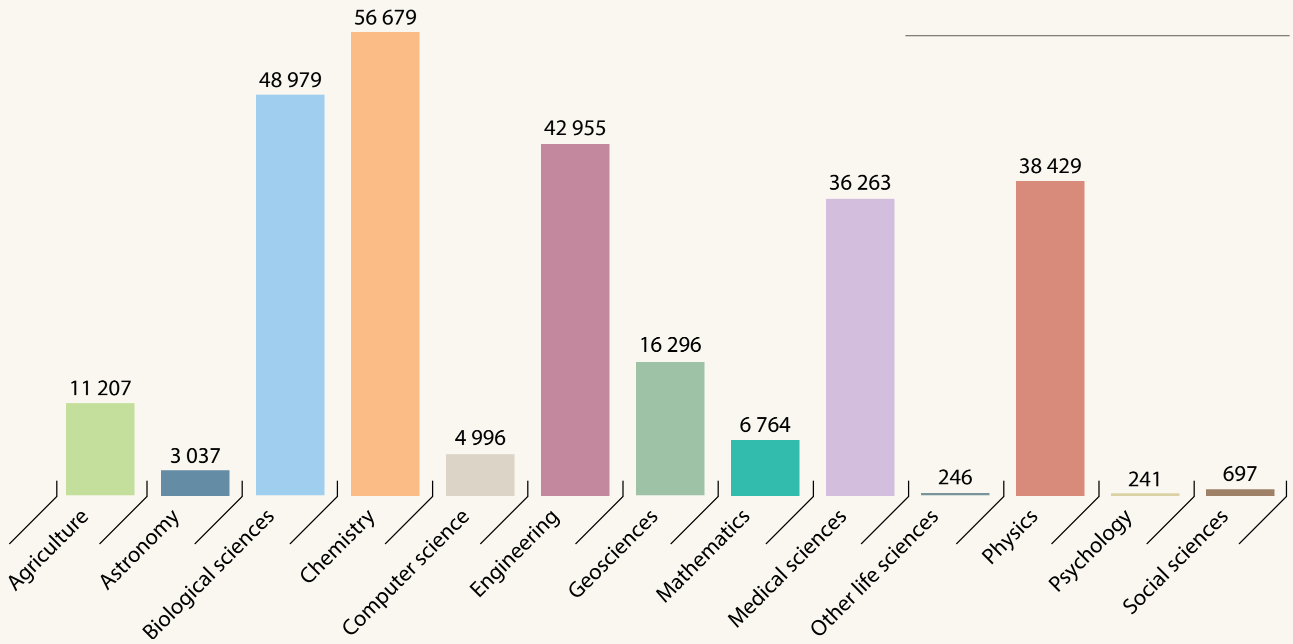
Share of Indian papers among 10% most cited papers, 2009–2012; the G20 average is 10.2%

21.3%

Share of Indian papers with foreign co-authors, 2008–2014; the G20 average is 24.6%

Indian scientific output is fairly diversified

Cumulative totals by field 2008–2014



The USA remains India's main scientific collaborator

Main foreign partners 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
India	USA (21 684)	Germany (8 540)	UK (7 847)	Korea, Rep. of (6 477)	France (5 859)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

the success of its maiden voyage to Mars[6] in September 2014, which carried frugal innovation to new heights: India had developed its Mangalyaan probe at a cost of just US$ 74 million, a fraction of the cost of the US$ 671 million Maven probe developed by the US National Aeronautics and Space Administration (NASA), which arrived in Mars' orbit just three days ahead of Mangalyaan. Until this feat, only the European Space Agency, USA and former Soviet Union had got as far as Mars' atmosphere; out of 41 previous attempts, 23 had failed, including missions by China and Japan.

India is also collaborating on some of the most sophisticated scientific projects in the world. India's Atomic Energy Commission participated in the construction of the world's largest and most powerful particle accelerator, the Large Hadron Collider (LHC), which came on stream in 2009 at the European Organization for Nuclear Research (CERN) in Switzerland; several Indian institutions are involved in a multiyear experiment[7] which uses the LHC. India is now participating in the construction of another particle accelerator in Germany, the Facility for Antiproton and Ion Research (FAIR), which will host scientists from about 50 countries from 2018 onwards. India is also contributing to the construction of the International Thermonuclear Experimental Reactor in France by 2018.

Indian science has nonetheless had its ups and downs and the country has historically given more importance to producing science than technology. As a result, Indian companies have had less success in manufacturing products which require engineering skills than in science-based industries like pharmaceuticals.

In recent years, the business enterprise sector has become increasingly dynamic. We shall begin by analysing this trend, which is rapidly reshaping the Indian landscape. The three biggest industries – pharmaceuticals, automotive and computer software – are all business-oriented. Even frugal innovation tends to be oriented towards products and services. Among government agencies, it is the defence industry which dominates R&D but, up until now, there has been little transfer of technology to civil society. That is about to change.

In order to sustain India's high-tech capacity, the government is investing in new areas such as aircraft design, nanotechnology and green energy sources. It is also using India's capabilities in information and communication technologies (ICTs) to narrow the urban–rural divide and setting up centres of excellence in agricultural sciences to reverse the worrying drop in yields of some staple food crops.

In recent years, industry has complained of severe shortages of skilled personnel, as we saw in the *UNESCO Science Report 2010*. University research has also been in decline. Today, universities perform just 4% of Indian R&D. The government has instigated a variety of schemes over the past decade to correct these imbalances. The latter part of this essay will be devoted to analysing how effective these schemes have been.

TRENDS IN INDUSTRIAL RESEARCH

Business R&D is growing but not R&D intensity overall

The only key indicator which has stagnated in recent years is the measure of India's R&D effort. Sustained economic growth pushed gross domestic expenditure on research and development (GERD) up from PPP$ 27 billion to PPP$ 48 billion between 2005 and 2011 but this growth of 8% per annum (in constant PPP$) was only sufficient to maintain the country's GERD/GDP ratio at the same level in 2011 as six years earlier: 0.81% of GDP.

India's Science and Technology Policy of 2003 has thus failed to realize its objective of carrying GERD to 2.0% of GDP by 2007. This has forced the government to set back its target date to 2018 in the latest *Science, Technology and Innovation Policy* (2013). China, on the other hand, is on track to meet its own target of raising GERD from 1.39% of GDP in 2006 to 2.50% by 2020. By 2013, China's GERD/GDP ratio stood at 2.08%.

The *Science and Technology Policies* of both 2003 and 2013[8] have emphasized the importance of private investment to develop India's technological capability. The government has used tax incentives to encourage domestic enterprises to commit more resources to R&D. This policy has evolved over time and is now one of the most generous incentive regimes for R&D in the world: in 2012, one-quarter of industrial R&D performed in India was subsidized (Mani, 2014). The question is, have these subsidies boosted investment in R&D by the business enterprise sector?

Public and private enterprises are certainly playing a greater role than before; they performed nearly 36% of all R&D in 2011, compared to 29% in 2005. Approximately 80% of all foreign and domestic patents granted to Indian inventors

6. Launched from Sriharikota spaceport on India's east coast, the Mangalyaan probe is studying the red planet's atmosphere in the hope of detecting methane, a potential sign of life. It will keep sending the data back to Earth until the spacecraft's fuel runs out.

7. In November 2014, the Indian Institute of Technology in Madras was accepted by CERN as a full member of its Compact Muon Selenoid (CMS) experiment, famous for its discovery of the Higgs Boson in 2013. The Tata Institute of Fundamental Research in Mumbai, Bhabha Atomic Research Centre and the Delhi and Panjab Universities have been full CMS members for years.

8. 'Achieving [a GERD/GDP ratio of 2.0%] in the next five years is realizable if the private sector raises its R&D investment to at least match the public sector R&D investment from the current ratio of around 1:3. This seems attainable, as industrial R&D investment grew by 250% and sales by 200% between 2005 and 2010... While maintaining current rates of growth in public R&D investments, a conducive environment will be created for enhancing private sector investment in R&D' (DST, 2013).

(excluding individuals) went to private enterprises in 2013. As a corollary of this trend, research councils are playing a smaller role than before in industrial R&D.

Innovation is dominated by just nine industries

More than half of business R&D expenditure is distributed across just three industries: pharmaceuticals, automotive and IT (Figure 22.3) [DST, 2013]. This implies that the subsidies have not really helped to spread an innovation[9] culture across a wider spectrum of manufacturing industries. The subsidies simply seem to have enabled R&D-intensive industries like pharmaceuticals to commit even more resources than before to R&D. The government would do well to commission a serious study into the effectiveness of these tax incentives. It should also envisage the idea of providing the business sector with grants to encourage it to develop specific technologies.

Six industries concentrate about 85% R&D. Pharmaceuticals continue to dominate, followed by the automotive industry and IT (read computer software). It is interesting to note that computer software has come to occupy an important place in the performance of R&D. Leading firms have adopted a conscious policy of using R&D to keep them moving up the technology ladder, in order to remain competitive and generate fresh patents.

Within these six industries, R&D is concentrated in a handful of large firms. For instance, five firms account for over 80% of the R&D reported by the pharmaceutical industry: Dr Reddy's, Lupin, Ranbaxy, Cadila and Matrix Laboratories. In the automotive industry, two firms dominate: Tata Motors and Mahindra. In IT, there are three dominant firms: Infosys, Tata Consultancy Services and Wipro.

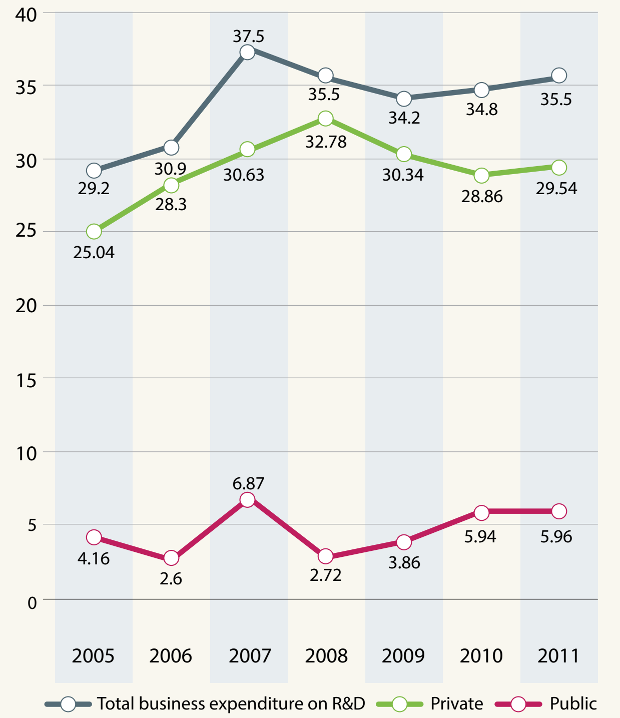
The government needs to support the emergence of technology-based start-ups to broaden the innovation culture in India. Technological progress has brought down traditional barriers which prevented SMEs from accessing technology. What SMEs need is access to venture capital. In order to encourage the growth of venture capital, the union government in its budget for 2014–2015 proposes setting up a fund of Rs 100 billion (*circa* US$ 1.3 billion) to attract private capital that could provide equity, quasi-equity, soft loans and other risk capital for start-ups.

Innovation is concentrated in just six states

We have seen that innovation is concentrated in just nine industries. Manufacturing and innovation are also concentrated in geographical terms. Just six Indian states out of 29 account for half of R&D, four-fifths of patents and three-quarters of FDI. Moreover, even within each state, only one or two cities are research hubs (Table 22.2), despite a vigorous regional development policy in the decades leading up to the adoption by India of an economic liberalization policy in 1991.

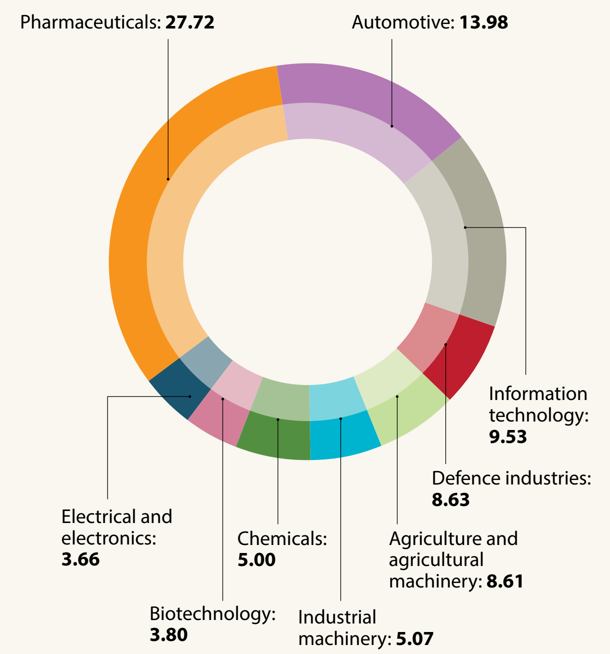
9. The consultations evoked in the *UNESCO Science Report 2010* (p. 366) did not give rise to a national innovation act, as the draft bill was never presented to parliament.

Figure 22.2: **R&D trends in Indian public and private enterprises, 2005–2011 (%)**



Source: UNESCO Institute of Statistics; DST (2013)

Figure 22.3: **India's main industrial performers, 2010 (%)**
In terms of R&D expenditure



Note: Percentages may not add up to 100 on account of rounding.
Source: DST (2013)

Chapter 22

Table 22.2: **Distribution of innovative and manufacturing activity within India, 2010**

State	Major cities	R&D expenditure (% of total)	Patents granted (% of total)	Value-added manufacturing (% of total)	FDI (% of total)
Maharashtra	Mumbai, Pune	11	31	20	39
Gujarat	Ahmedabad, Vadodara, Surat	12	5	13	2
Tamil Nadu	Chennai, Coimbatore, Madurai	7	13	10	13
Andhra Pradesh*	Hyderabad, Vijayawada, Visakhapatnam	7	9	8	5
Karnataka	Bangalore, Mysore	9	11	6	5
Delhi	Delhi	–	11	1	14
Total for the above		46	80	58	78

Note: Andhra Pradesh was divided into two states, Telangana and Andhra Pradesh, on 2 June 2014. Located entirely within the borders of Telangana, Hyderabad is to serve as the joint capital for both states for up to 10 years.

Source: Central Statistical Organization; DST (2013); Department of Industrial Policy and Performance

Pharma companies are home-grown, IT companies are foreign

An interesting picture emerges when we analyse the output of firms in terms of the number and type of patents granted to Indians by the United States Patent and Trademark Office (USPTO). The data reveal a steep increase both in overall patenting by Indian inventors and in the share of high-tech patents; there has also been a discernible shift in technological specialization, with pharma receding in importance and IT-related patents filling the gap (Figure 22.4).

The important point here is whether these patents are owned by domestic or foreign enterprises. Almost all of the USPTO patents secured by Indian inventors do indeed belong to domestic pharmaceutical companies. As noted in the *UNESCO Science Report 2010*, domestic pharmaceutical companies increased their patent portfolio even after the international agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS) was translated into Indian law in 2005. In fact, for every single indicator[10] of innovative activity, Indian pharmaceutical firms have done exceedingly well (Mani and Nelson, 2013). However, the same cannot be said for computer software or IT-related patents; as can be seen from Figure 22.4, almost all these patents are secured by multinational companies which have established dedicated R&D centres in India to take advantage of the skilled, yet cheap labour on the market in software engineering and applications. The growing importance of software-related patents among total patents indicates that foreign ownership of Indian patents has increased significantly. This is part of the trend towards a globalization of innovation, in which India and, indeed, China have become important players. We shall be discussing this important trend in more detail below.

The surge in the creation of knowledge assets at home has not reduced India's dependence on foreign knowledge assets. This is best indicated by observing India's trade in technology, as exemplified by the charges that India receives and pays for technology transactions. The difference between the technology receipts and payments gives us the technology trade balance (Figure 22.5).

India is surfing the globalization wave to develop innovation

Thanks to a surge in FDI in both manufacturing and R&D over the past five years, foreign multinational companies have been playing a growing role in innovation and patenting in India. In 2013, foreign companies represented 81.7% of domestic patents obtained from the USPTO; in 1995, they had accounted for just 22.7% of the total (Mani, 2014).

The main policy challenge will be to effect positive spillovers from these foreign companies to the local economy, something that neither the *Science, Technology and Innovation Policy* (2013), nor current FDI policies have explicitly factored into the equation.

At the same time, Indian companies have acquired knowledge assets from abroad through a wave of cross-border mergers and acquisitions. In the first wave, there was Tata's acquisition of the Corus Group plc (today Tata Steel Europe Ltd) in 2007, giving Tata access to car-grade steel technology; this was followed by the acquisition of German wind turbine manufacturer Senvion (formerly REpower Systems) by Suzlon Energy Ltd in December 2009. More recent examples are:

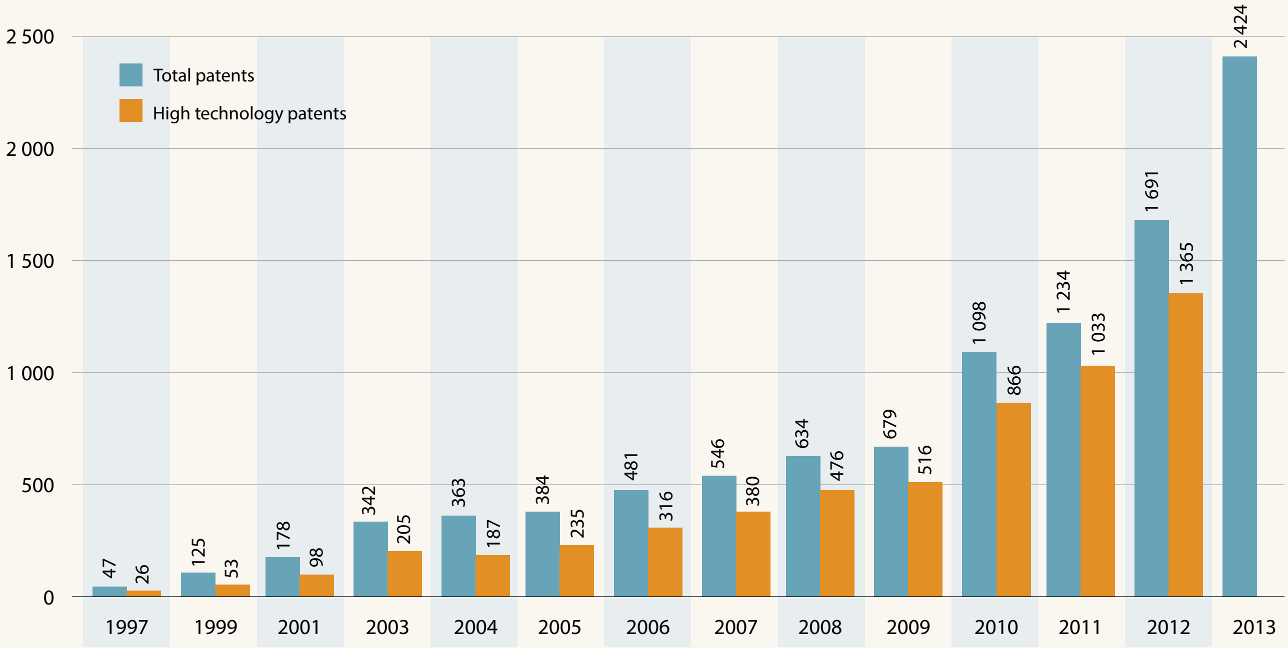
- Glenmark Pharmaceuticals' opening of a new monoclonal antibody manufacturing facility in La Chaux-de-Fonds, Switzerland, in June 2014, which supplements Glenmark's existing in-house discovery and development capabilities and supplies material for clinical development;
- Cipla's announcement in 2014 of its fifth global acquisition deal within a year, by picking up a 51% stake for US$ 21 million in a pharmaceuticals manufacturing and distribution business in Yemen;
- The acquisition by Motherson Sumi Systems Ltd of Ohio-based Stoneridge Inc.'s wiring harness business for US$ 65.7 million in 2014;

10. Be it the indicator for exports, net trade balance, R&D expenditure, patents granted within and without India or the number of Abbreviated New Drug Applications approved by the US Food and Drug Administration (implying technological capability in generic drug capability)

Figure 22.4: **Trends in Indian patents, 1997–2013**

Most patents granted to Indian inventors are in high-tech

Utility patents granted by USPTO



Source: USPTO; NSB (2014)

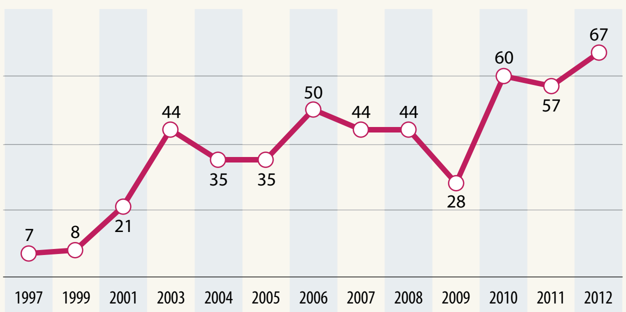
IT firms in India tend to be foreign-owned

	IT-related patents (number)			Share (%)	
	Domestic	Multi-national companies	Total	Domestic	Multi-national companies
2008	17	97	114	14.91	85.09
2009	21	129	150	14.00	86.00
2010	51	245	296	17.23	82.77
2011	38	352	390	9.74	90.26
2012	54	461	515	10.49	89.51
2013	100	1 268	1368	7.30	92.71

Source: Computed from USPTO, 2014

The number of biotech patents has doubled in a decade

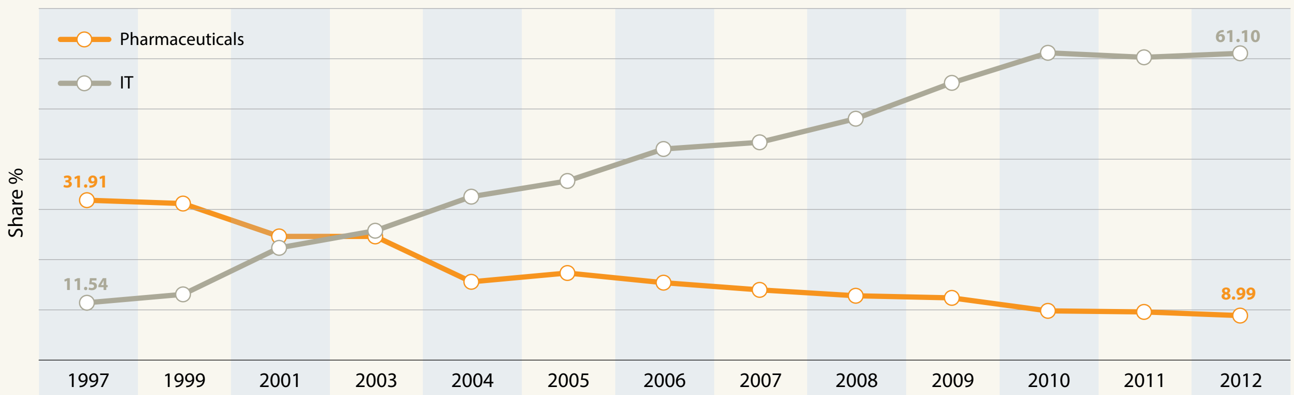
Utility patents granted by USPTO, 1997–2012



Source: based on data provided in Appendix Table 6-48, NSB (2014)

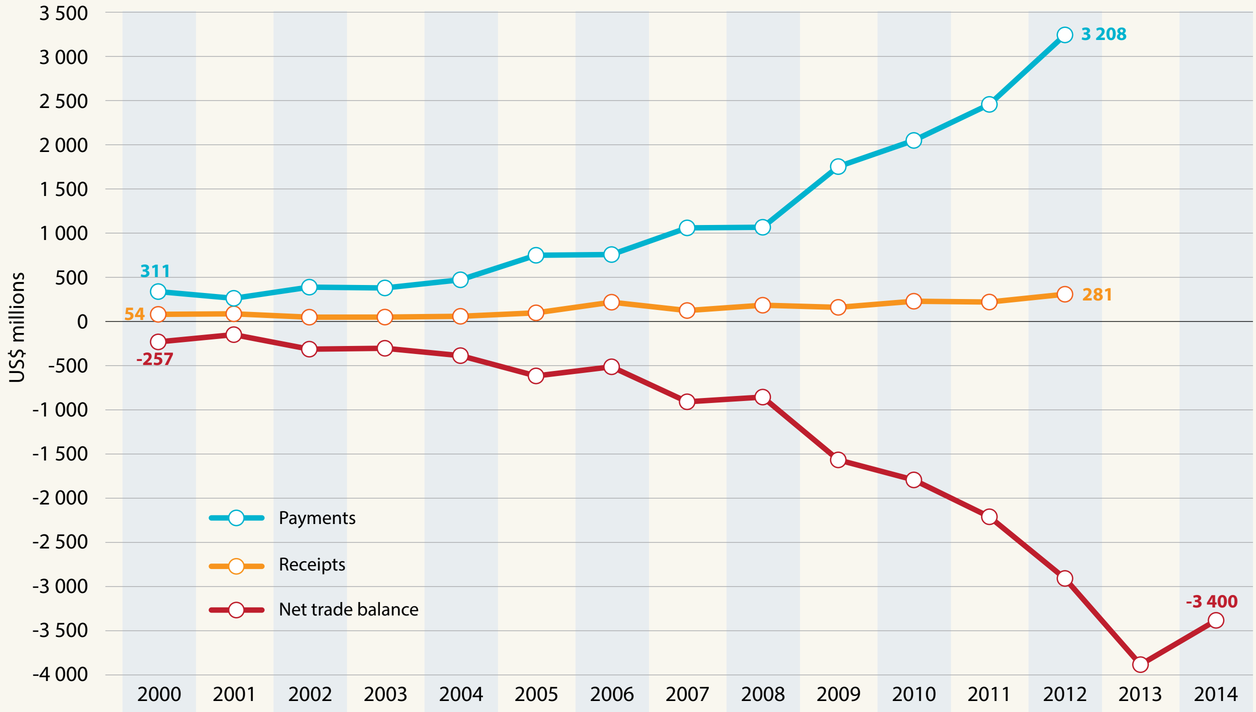
Six out of 10 patents are now in IT, one in ten in pharma

Utility patents granted by USPTO (%)



Source: Computed from USPTO, 2014

Figure 22.5: **Receipts, payments and net trade balance in the use of IPRs in India, 2000–2014**



Source: Computed from Reserve Bank of India (various issues)

- Mahindra Two Wheelers made a binding offer in October 2014 to buy a 51% stake in Peugeot Motocycles, the world's oldest manufacturer of motorized two-wheelers, from French car-maker Peugeot S.A. Group, for € 28 million (about Rs 217 crore).

This trend is very pronounced in manufacturing industries such as steel, pharmaceuticals, automotive, aerospace and wind turbines. It is also very visible in service industries such as computer software development and management consulting. In fact, these mergers and acquisitions allow late-comer firms to acquire knowledge assets 'overnight'. The government encourages firms to seize this window of opportunity through its liberal policy on FDI in R&D, its removal of restrictions on outward flows of FDI and its tax incentives for R&D. The growing globalization of innovation in India is a great opportunity, for it is turning the country into a key location for the R&D activities of foreign multinationals (Figure 22.6). In fact, India has now become a major exporter of R&D and testing services to one of the world's largest markets for these, the USA (Table 22.3).

India has become a hub for frugal innovation

Meanwhile, India has become a hub for what is known as frugal innovation. These products and processes have more or less the same features and capabilities as any other original product but cost significantly less to produce. They are most common in the health sector, particularly in the form of medical devices. Frugal innovation or engineering creates high-value products at an extremely low cost for the masses, such as a passenger car or a CAT scanner. Firms of all shapes and sizes employ frugal methods: start-ups, established Indian companies and even multinationals. Some multinationals have even established foreign R&D centres in India, in order to incorporate frugal innovation into their business model.

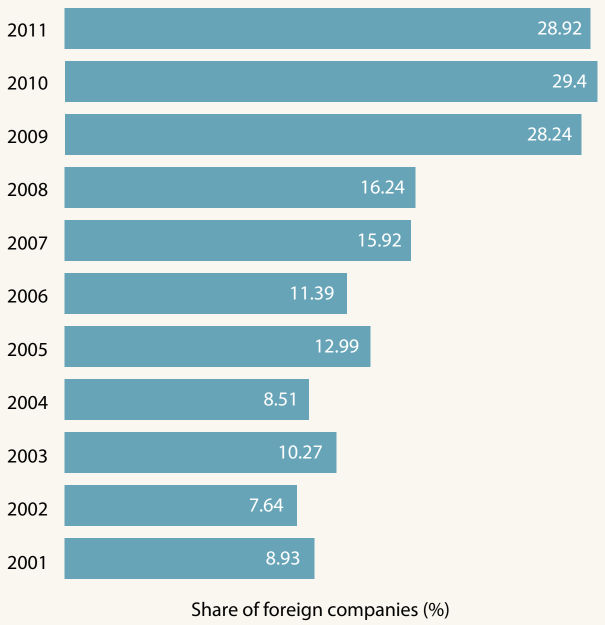
Table 22.3: **Exports of R&D and testing services from India and China to the USA, 2006–2011**

	Exports (millions of US$)			Share of national exports (%)	
	From India to the USA	From China to the USA	Total US exports from India & China	India	China
2006	427	92	9 276	4.60	0.99
2007	923	473	13 032	7.08	3.63
2008	1 494	585	16 322	9.15	3.58
2009	1 356	765	16 641	8.15	4.60
2010	1 625	955	18 927	8.59	5.05
2011	2 109	1 287	22 360	9.43	5.76

Note: This table lists only those R&D services exported from India and China by the affiliates of US multinational companies to their parent company in the USA

Source: National Science Board (2014)

Figure 22.6: **Share of foreign companies performing R&D in India (%), 2001–2011**



Source: Mani (2014)

India has not only become a hub for frugal creations; it is also codifying them then exporting them to the West.

Despite the overwhelming popularity of frugal innovation, innovation policies in India do not explicitly encourage frugal innovation. This oversight needs addressing. Nor is the phenomenon sufficiently documented. Radjou *et al*. (2012) have nevertheless managed to identify a series of goods and services which qualify as frugal innovation. These are summarized in Box 22.1 and Table 22.4.

There are seven characteristics which typify frugal innovation:

- Most products and services have emanated from large, organized firms in manufacturing and the service sector, some of which are multinationals;
- Manufactured items tend to involve a fair amount of formal R&D;
- Their diffusion rate has varied quite significantly, although relevant data are hard to come by; some of the most celebrated examples of frugal innovation, like Tata's micro-car, the Nano, do not seem to have been accepted by the market;
- Whenever frugal engineering implies the removal of key features, it is unlikely to succeed; it is this which may explain the poor sales of the first Nano car; the latest model, the Nano Twist, comes with a number of features found in more expensive models, such as an electric power-assisted steering system;
- Frugal services tend not to involve any R&D, or not of a sophisticated nature at least, nor any new investments or technology; they may simply be an innovation in the way the supply chain is organized;
- Services or processes may be very location-specific and as such not replicable elsewhere; for instance, the celebrated *Mumbai Dabbawalas* (lunch box delivery service in Mumbai) has never spread to other Indian cities, despite being considered an efficient process for managing the supply chain; and
- Among the known products transferred to the West from India, most concern medical devices.

Box 22.1: **Frugal innovation in India**

Making do with less in goods manufacturing and services has long been an accepted and inescapable reality in India. Following the proverbial idiom, 'necessity is the mother of invention', improvisation – better known by its Hindi equivalent of *jugaad* – has always been a way of getting things done.

Although poverty rates in India have come down, one in five Indians still lives below the poverty line (Table 22.1). India remains the country with the largest number of poor citizens: more than 270 million in 2012.

To serve the mass of consumers at the bottom of the pyramid, India's quality goods and services need to be affordable. This has given rise to what is increasingly being termed frugal innovation or frugal engineering.

Although frugal innovations are spread across a range of manufacturing and service industries, they most often take the form of medical devices. This phenomenon has received a fillip from the Stanford–India Biodesign Project (SIBDP) involving the University of Stanford in the USA. Initiated in 2007, this programme has spawned a number of entrepreneurs whose innovative medical devices have low production costs (Brinton *et al*., 2013), qualifying them as frugal innovations. In its eight years of existence, SIBDP has produced four particularly interesting start-ups in medical devices in India. These have developed a novel integrated neonatal resuscitation solution, a non-invasive safe device for screening newborns for a hearing impairment, low-cost limb immobilization devices for treating road traffic accident injuries and an alternative to difficult intravenous access in medical emergencies.

Source: compiled by author

Table 22.4: **Examples of frugal innovation in India**

INNOVATION	COMPANY INVOLVED IN DEVELOPMENT	DIFFUSION
GOODS		
MICRO-PASSENGER CAR, THE TATA NANO This product has a virtual monopoly in its niche market. The original Nano cost about US$ 2 000.	**Tata**	Very low acceptance rate, as indicated by the declining sales. The car was marketed from 2009 onwards. Sales peaked at 74 521 in 2011–2012. The following year, they fell to 53 847 then to just 21 130 in 2013–2014.
SOLAR-POWERED GSM BASE STATION This system enables people in rural areas to use mobile phones. The World Global System for Mobile Communications (WorldGSM™) is the first commercially viable GSM system that is independent of the power grid. It runs exclusively on solar power and requires no backup from a diesel generator. It is also designed for simple delivery and deployment by local, untrained workers.	**VNL Limited**	No data on its deployment
PORTABLE ELECTROCARDIOGRAM (ECG) MACHINE This machine (GE MAC 400) costs about US$ 1 500 and weighs about 1.3 kg, compared to US$ 10 000 and about 6.8 kg for a regular ECG machine.	**General Electric Healthcare**	There are no data on its diffusion. However, the product is very well accepted by the market and General Electric has exported this technology to its parent firm in the USA.
PORTABLE TOP LOADING REFRIGERATOR It has a capacity of 35 litres, runs on batteries and is priced at about US$ 70. It can be used in villages for storing fruit, vegetables and milk. It is known as *Chotukool*.	**Godrej**, an Indian company	In order to diffuse the technology, Godrej has joined forces with India Post. There are unconfirmed reports of 100 000 pieces having been sold in the first two years of production.
LOWEST POWER-CONSUMING AUTOMATIC TELLER MACHINE (ATMS) This machine is solar-powered and goes by the name of Gramateller.	**Vortex**, an Indian company, and the **Indian Institute of Technology Madras**	Leading banks such as the State Bank of India, HDFC and Axis Bank have adopted Vortex-designed and manufactured ATMs to service their rural customers.
ALTERNATIVE HOME-COOKING FUEL AND STOVE Oorja combines a micro-gasification device or stove with a biomass-based pellet fuel.	**First Energy**, an Indian company	According to the company's website, it has about 5 000 customers.
SERVICES		
LARGE-SCALE, CHEAP EYE SURGERY	**Arvind Eye Care System**	During 2012–2013, the hospital performed 371 893 surgical acts.
LOW-COST MATERNITY HOSPITALS These hospitals provide quality maternity health care at 30–40% of the market price.	**Life Spring**	Life Spring currently operates 12 hospitals in the city of Hyderabad, with plans to expand to other cities.
LOW-COST FINANCIAL SERVICES Eko leverages existing retail shops, telecom connectivity and banking infrastructure to extend branchless banking services to the person in the street. Eko also partners with institutions to offer payment, cash collection and disbursal services. Customers can walk up to any Eko counter (retail outlet) to open a savings account, deposit and withdraw cash from the account, send money to any part of the country, receive money from any part of the world, buy mobile talk-time or pay for a host of services. A low-cost mobile phone acts as the transaction device for retailers and customers.	**Eko**	Detailed number of Eko counters opened and functioning unavailable

Source: compiled by author

TRENDS IN GOVERNMENT RESEARCH

The government sector is the main employer of scientists

If you take a group of 100 researchers in India, 46 will work for the government, 39 for industry, 11 for academia and 4 for the private non-profit sector. This makes the government the main employer. The government sector also spends the majority of the R&D budget (60%), compared to 35% for industry and just 4% for universities.

The government organizes its R&D through 12 scientific agencies and ministries. These have performed about half of GERD since 1991 but much of their output has little connection with business enterprises in either the public or private sectors. One-quarter of research in the government sector is devoted to basic research (23.9% in 2010).

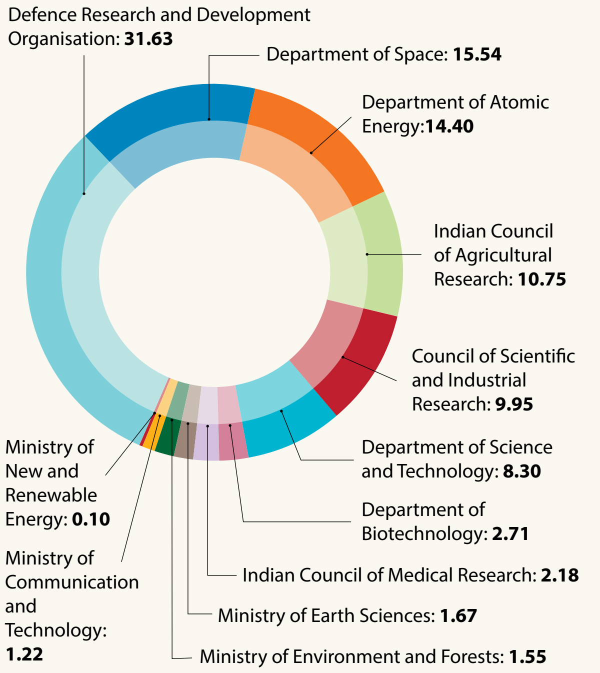
The Defence Research and Development Organisation (DRDO)[11] alone accounts for about 17% of GERD and just under 32% of the government outlay in 2010, twice as much as the next biggest agency, the Department of Atomic Energy, which nevertheless increased its share from 11% to 14% between 2006[12] and 2010, at the expense of DRDO and the Department of Space. The government has raised funding levels for the Council of Scientific and Industrial Research (CSIR) slightly (9.3% in 2006), at the expense of the Indian Council of Agricultural Research (11.4% in 2006). The smallest slice of the pie continues to go to the Ministry of New and Renewable Energy (Figure 22.7).

A first: defence technologies will be adapted to civilian use

Almost the entire output of defence R&D goes to the military for the development of new forms of weaponry, like missiles. There are very few recorded instances of defence research results being transferred to civilian industry, unlike in the USA where such transfers are legendary. One example of this wasted technological capability is the loss to India's aeronautical industry, where a considerable amount of technological capability has been built around military aircraft without any transfer to civilian craft.

This state of affairs is about to change with the launch of a joint initiative in 2013 by DRDO and the Federation of Indian Chambers of Commerce and Industry (FICCI) for Accelerated Technology Assessment and Commercialization[13]. The aim is to create a commercial channel for orienting technologies developed by DRDO towards national and international commercial markets for civilian use. This programme is the first of its kind for DRDO. As many as 26 DRDO labs across India were participating in the programme in 2014, while FICCI assessed over 200 technologies from sectors as diverse as electronics, robotics, advanced computing and simulation, avionics, optronics, precision engineering, special materials, engineering systems, instrumentation, acoustic technologies, life sciences, disaster management technologies and information systems.

Figure 22.7: **Government outlay for India's major science agencies, 2010 (%)**



Source: DST (2013)

A new Academy of Scientific and Innovative Research

The CSIR has a network of 37 national laboratories which undertake cutting-edge research across a vast spectrum of fields, including radio and space physics, oceanography, drugs, genomics, biotechnology, nanotechnology, environmental engineering and IT. CSIR's 4 200 scientists (3.5% of the country's total) bat above their weight, authoring 9.4% of India's articles in the Science Citation Index. The rate of commercialization of patents emanating from CSIR laboratories is also above 9%, compared to a global average of 3–4%.[14] Despite this, CSIR scientists interact little with industry, according to the Comptroller and Auditor General.

In order to improve its profile, the CSIR has put in place three broad strategies since 2010. The first consists in combining the skill sets in a range of its laboratories to create networks for the execution of a specific project. The second strategy consists in setting up a series of innovation complexes to foster interaction with micro-enterprises and SMEs, in particular. So far, three

11. India has the world's 3rd-biggest armed forces and is the 10th-biggest spender on defence. The defence budget represented 2.4% of GDP in 2013, compared to 2.9% in 2009, according to the World Bank.

12. See the *UNESCO Science Report 2010* for the complete 2006 data (p. 371).

13. This programme is one of four executed by the Centre for Technology Commercialization, which was set up by FICCI in 2006. For details, see: https://thecenterforinnovation.org/techcomm-goes-global

14. These figures are based on an answer to question no. 998 in the upper house of India's parliament, the *Rajya Sabha*, on 17 July 2014.

innovation complexes have been established in Chennai, Kolkatta and Mumbai. The third strategy consists in offering postgraduate and doctoral degrees in highly specialized fields where such training is not easily available in traditional universities; this led to the establishment of the Academy of Scientific and Innovative Research in 2010, which recently awarded its first master's degrees and PhDs in science and engineering.

India's scientific councils can call upon the services of the National Research and Development Corporation (NRDC). It functions as a link between scientific organizations and industries eager to transfer the fruits of endogenous R&D to industry. The NRDC has a number of intellectual property and technology facilitation centres and, on campuses around the country in major Indian cities, university innovation facilitation centres. The NRDC has transferred approximately 2 500 technologies and approximately 4 800 licensing agreements since its inception in 1953. The number of technologies licenced by NRDC increased from 172 during the *Eleventh Five-year Plan* period (2002–2007) to 283 by 2012. Despite these apparent instances of technology transfer, NRDC is not generally considered as having been successful in commercializing technologies generated by the CSIR system.

Funding not an issue in falling food crop yields

Since the turn of the century, wheat yields have dropped and rice yields have stagnated (Figure 22.8). This worrying trend does not seem to be tied to any cutbacks in funding. On the contrary, agricultural funding has increased, whatever the point of comparison: in nominal and real terms, aggregate and per capita terms and against public funding of industrial research. Even the percentage share of agricultural research in agricultural GDP shows an increase over time. So funding *per se* does not appear to be an issue.[15] An alternative explanation for this drop in yield may well be the observed decline in the numbers of agricultural scientists in India, including lower enrolment ratios in graduate degree programmes in agriculture. This state of affairs has prompted the government to propose two key measures in the union budget for 2014–2015 for the training of agricultural scientists and engineers:

- The establishment of two more centres of excellence, modelled on the lines of the Indian Agricultural Research Institute, one in the city of Assam and a second in Jharkhand, with an initial budget of Rs 100 crores (*circa* US$ 16 million) for 2014–2015; an additional amount of Rs 100 crores is being set aside for the establishment of an AgriTech Infrastructure Fund;
- The establishment of two universities of agriculture in Andhra Pradesh and Rajasthan and a further two universities of horticulture in Telangana and Haryana; an initial sum of Rs 200 crores has been allocated for this purpose.

15. This statement is corroborated by Pal and Byerlee (2006) and Jishnu (2014).

Growing private investment in agricultural R&D

Another interesting aspect is the rising share of private R&D in agriculture, primarily in seeds, agricultural machinery and pesticides. This trend does not have the same implications as an increase in public-sector investment in agricultural R&D would have, as the products generated by private R&D are likely to be protected by various mechanisms governing intellectual property rights, thereby increasing the cost of their diffusion to farmers.

The diffusion of genetically modified organisms (GMOs) among food crops has been curtailed for health and safety reasons by the Genetic Engineering Appraisal Committee of the Ministry of Environment and Forests. The only GM crop approved in India is *Bt* cotton, which was authorized in 2002. The area cultivated with *Bt* cotton had progressed to saturation level by 2013 (Figure 22.8). India has become the world's top exporter of cotton and its second-biggest producer; cotton is a thirsty crop, however, and water a scarce commodity in India. Moreover, despite the increase in the average yield of cotton, there have been sharp fluctuations from one year to the next. The use of fertilizer and the spread of hybrid seeds may also have contributed to the rise in yield since 2002. More recently, the Indian Council of Agricultural Research has developed a *Bt* cotton variety cheaper than Monsanto's with re-usable seeds.

The proposed extension of GMOs to food crops like *brinjals* (aubergine) has met with stiff resistance from NGOs and elicited words of caution from the parliamentary Committee on Agriculture in 2012. India's own GMO research has been focusing on a range of food crops but with an emphasis on vegetables: potato, tomato, papaya, watermelon, castor, sorghum, sugar cane, groundnut, mustard, rice, etc. As of early 2015, no GM food crops had been released for cultivation pending clearance from the regulatory agencies.

A sustainable farming method challenges modern technologies

Sustainable forms of agriculture have been reported from isolated parts of the country. The world's most productive rice paddy farmer even comes from the state of Bihar in northeastern India. The farmer in question broke the world record not through modern scientific technologies but rather by adopting a sustainable method pioneered by NGOs known as the System of Rice Intensification. Despite this feat, diffusion of this method has been very limited (Box 22.2).

The biotech strategy is beginning to pay off

Biotechnology is the eighth of India's nine high-tech industries (Figure 22.3) and receives 2.7% of the government's outlay for the 12 science agencies (Figure 22.7). Consistent policy support over the past two decades has allowed India to develop sophisticated R&D and a production capability to match. The Department of Biotechnology's strategy has three

Box 22.2: The world's most productive paddy farmer is Indian

Sumant Kumar, an illiterate young farmer from the village of Darveshpura in the State of Bihar, is now acknowledged as being the most productive paddy farmer in the world. He managed to grow 22 tonnes of rice from a single hectare, compared to a world average of 4 tonnes, by adopting the System of Rice Intensification (SRI). The previous record of 19 tonnes was held by a Chinese farmer.

SRI allows farmers to produce more from less. In other words, it is an example of frugal innovation. Five key characteristics differentiate it from conventional practices:

- the use of a single seedling instead of clumps;
- the transplanting of seedlings at a young age of less than 15 days;
- wider spacing in square planting;
- rotary weeding; and
- a greater use of organic manures.

The application of these five elements promises numerous advantages, including higher yield and a lesser requirement for both seeds and water.

SRI is thus ideally suited for countries like India where farmers are poor and water is extremely scarce.

SRI's origins date back to the early 1980s when Henri de Laulanié, a French Jesuit priest and agronomist, developed the method after observing how villagers grew rice in the uplands of Madagascar.

According to a study by Palanisami *et al.* (2013) of 13 major rice-growing states in India, fields which have adopted SRI have a higher average productivity than those which have not.

Out of the four core SRI components typically recommended, 41% of SRI farmers have adopted one component, 39% two or three components and only 20% all the components. Full adopters recorded the highest yield increase (3%) but all adopters had yields higher than conventional farmers. They also had higher gross margins and lower production costs than non-SRI fields.

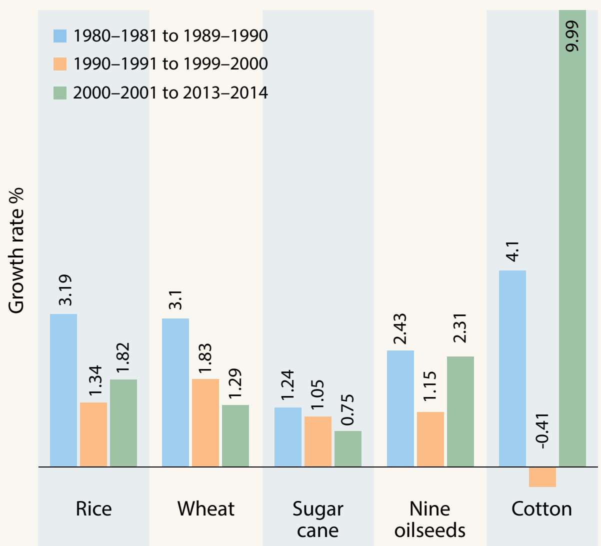
Although India's rice yield could significantly increase under SRI and modified SRI practices, a number of hurdles will first have to be overcome, according to the authors, namely a lack of skilled farmers available in time for planting operations, poor water control in the fields and unsuitable soils. Moreover, farmers also feel that the transaction (managerial) cost, although insignificant, still limits full adoption of SRI. Government intervention will thus be necessary to overcome these constraints.

Source: SRI International Network Resource Center (USA); Palanisami *et al.* (2013); www.agriculturesnetwork.org

Chapter 22

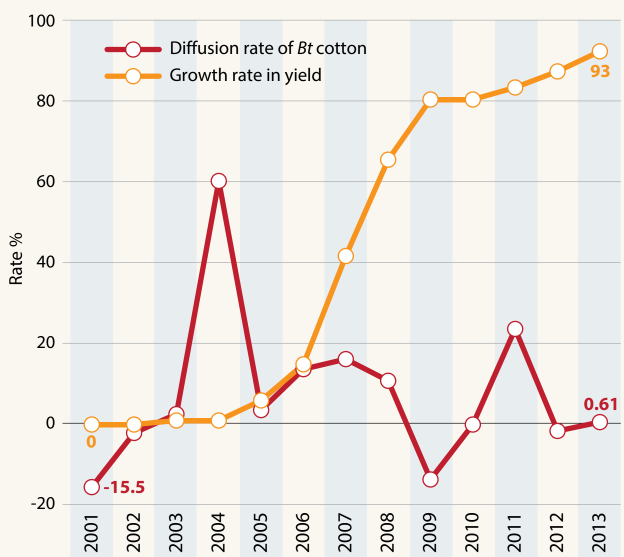
Figure 22.8: **Changes in agricultural yields in India, 1980–2014**

Average annual growth in yield for key food crops in India, 1980–2014 (%)



Source: Based on Table 8.3, Ministry of Finance *(2014) Economic Survey 2013–2014*

Diffusion rate of Bt cotton and growth in cotton yield, 2001–2013



Note: The diffusion rate for *Bt* cotton resembles the familiar S-shaped pattern noted by many observers of the rate of diffusion of new technologies.

Source: VIB (2013)

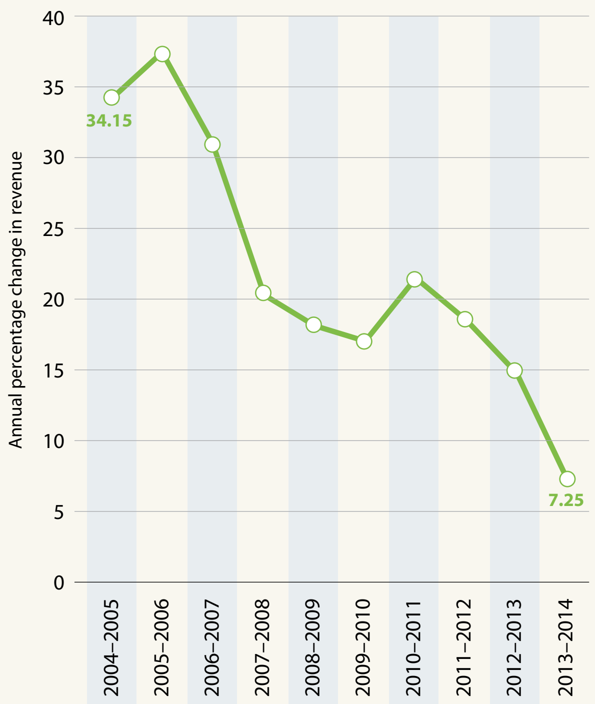
thrusts: improving the quantity and quality of human resources in biotechnology; establishing a network of laboratories and research centres to work on relevant R&D projects; and creating enterprises and clusters to produce biotechnology products and services. Apart from the central government, several state governments have explicit policies for developing this sector. This has led to a surge in biotech-related publications and patents (Figure 22.4).

The biotechnology industry has five subsectors: biopharmaceutical (63% of total revenue in 2013–2014), bioservices (19%), agricultural biotech (13%), industrial biotech (3%) and bioinformatics (1%). The biotechnology industry grew by an average rate of 22% per annum between 2003 and 2014, although year-on-year growth rates show a declining trend (Figure 22.9).[16] Approximately 50% of output is exported. The Department of Biotechnology is building a Biotech Science Cluster in Faridabad on the outskirts of the capital. The cluster includes the Translational Health Science Technology Institute and the Regional Centre for Biotechnology, the first of its kind in South Asia. The regional centre functions under the auspices of UNESCO, offering specialized training and research programmes in 'new opportunity areas' such as cell and tissue engineering, nanobiotechnology and bioinformatics. The emphasis is on interdisciplinarity, with future physicians taking courses in biomedical engineering, nanotechnology and bio-entrepreneurship.

16. These rates are computed using sales revenue in Indian rupees at current prices. However, if one were to convert these to US dollars and recompute the growth rates, the industry would have been near-stagnant since 2010. There are, however, no official surveys or data on the size of India's biotechnology industry.

Figure 22.9: **Growth of the Indian biotechnology industry, 2004–2014**

Based on sales revenue at current prices



Source: Computed from the Association of Biotech Led Enterprises (ABLE), Biospectrum Survey changes in sales revenue at current prices

India is making a foray into aircraft manufacturing

Exports of high-tech manufactured products are increasing and now account for about 7% of manufactured exports (World Bank, 2014). Pharmaceuticals and aircraft parts account for almost two-thirds of the total (Figure 22.10). India's technological capability in pharmaceuticals is fairly well known but her recent forays into the manufacturing of aircraft parts are a step into the unknown.

Recent elaborations of the Defence Purchase Policy[17] and the policy on offsets seem to have encouraged local manufacturing. For instance, India is developing a regional transport aircraft through a mission-mode National Civil Aircraft Development project. Although largely initiated by the public sector, the project envisages participation by domestic private sector enterprises as well.

India is also continuing to improve its capability in the design, manufacture and launch of satellites[18] and has ambitious plans for sending people to the Moon and exploring Mars.

India is deploying more high-tech services

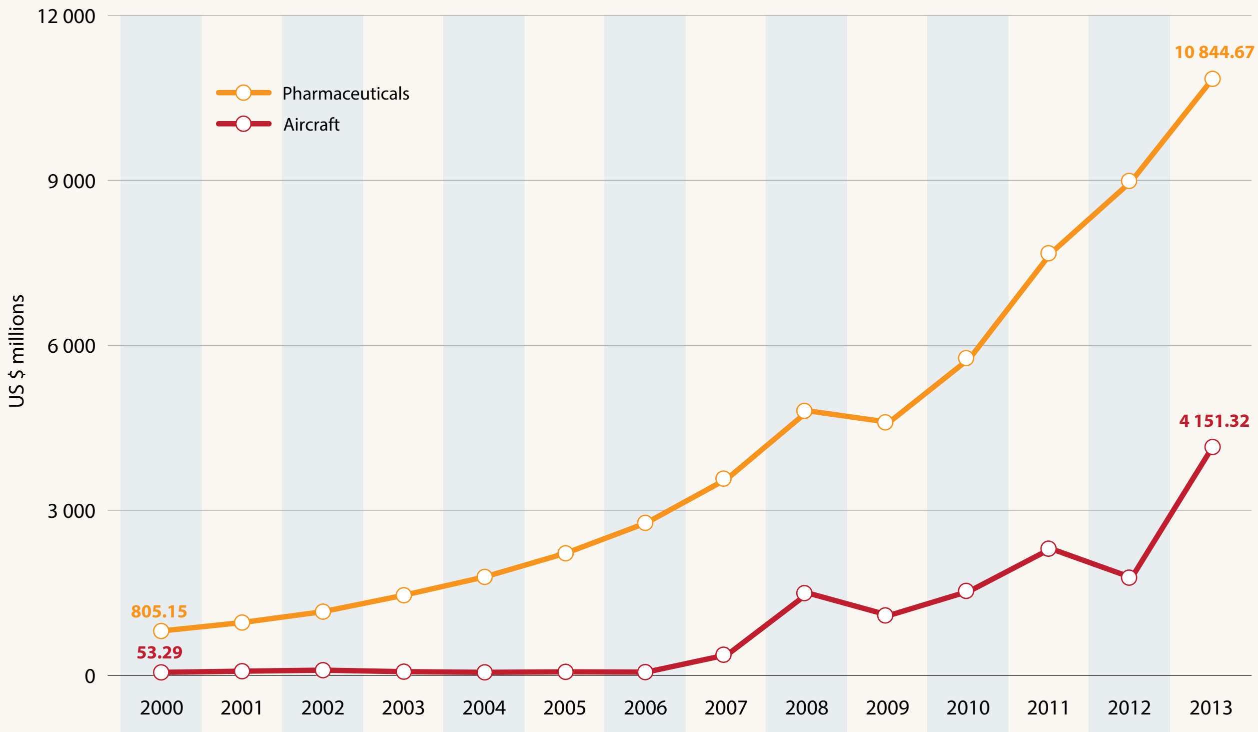
Considerable improvements have been made in both the astronautic and even in the aeronautical segments of the IT industry. Leveraging capabilities in communication technologies and remote sensing, the country has made big strides in diffusing distance education and public health interventions. Over the years, the Indian Space Research Organisation's telemedicine network has expanded to connect 45 remote and rural hospitals and 15 highly specialized hospitals. The remote/rural nodes include the offshore islands of Andaman and Nicobar and Lakshadweep, the mountainous and hilly regions of Jammu and Kashmir, including Kargil and Leh, Medical College hospitals in Orissa and some of the rural / district hospitals in the mainland states.

Big strides have been made in telecommunications services as well, especially in rural areas. India has shown by example that the best way of diffusing telecommunications in rural areas is to foster competition between telecom service providers, which react by lowering their tariffs.

17. India procures about 70% of its equipment needs abroad. The government adopted a defence procurement policy in 2013 which gives preference to indigenous production by Indian firms or within joint ventures.

18. For more on India's space programme, see the box entitled A Space Odyssey in the *UNESCO Science Report 2010*, p. 367.

Figure 22.10: **Exports of high-tech manufactured products from India, 2000–2013**



Source: Compiled from UN Comtrade database and World Bank's World Development Indicators

The consequence has been a dramatic improvement in teledensities, even in rural areas. This is best indicated by the rising ratio of rural to urban teledensities, which grew from 0.20 to 0.30 between 2010 and 2014.

Plans to become a nanotech hub by 2017

In recent years, the government has paid growing attention to nanotechnology.[19] A Nano Mission Project was launched in India by the *Eleventh Five-Year Plan* (2007–2012), with the Department of Science and Technology serving as a nodal agency. A sum of Rs 100 billion was sanctioned over the first five-year period to build R&D capabilities and infrastructure in nanotechnology.

The *Twelfth Five-Year Plan* (2012–2017) aims to take this initiative forward, in order to make India a 'global knowledge hub' in nanotechnology. To this end, a dedicated institute of nanoscience and technology is being set up and postgraduate programmes in 16 universities and institutions across the country are due to be launched. The Nano Mission Project is also funding a number of basic research projects[20] centred on individual scientists: for 2013–2014, about 23 such projects were sanctioned for a three-year period; this brings the total number of projects funded since the Nano Mission's inception to about 240.

The Consumer Products Inventory maintains a live register of consumer products that are based on nanotechnology and available on the market (Project on Emerging Nano Technologies, 2014). This inventory lists only two personal care products that have originated from India and the firm which developed these products is a foreign multinational. However, the same database lists a total of 1 628 products around the world, 59 of which come from China.

In 2014, the government set up a nanomanufacturing technology centre within the existing Central Manufacturing Technology Institute. In its union budget for 2014–2015, the government then announced its intention to strengthen the centre's activities through a public–private partnership.

In short, nanotechnology development in India is currently oriented more towards building human capacity and physical infrastructure than the commercialization of products, which remain minimal. As of 2013, India ranked 65th worldwide for the number of nano-articles per million inhabitants (see Figure 15.5).

19. See Ramani et al. (2014) for a survey of nanotechnology development in India.

20. The Nano Mission has so far produced 4 476 papers published in SCI journals, about 800 PhDs, 546 M.Tech and 92 MSc degrees (DST, 2014, p. 211). See also: http://nanomission.gov.in and, for the top 30 worldwide for the volume of nano-related articles in 2014, Figure 15.5

Eight states out of 29 have explicit green energy policies

India's innovation policy seems to be independent from other important economic development strategies like the *National Action Plan on Climate Change (2008)*. The level of public investment in green energy sources is also modest, with the budget for the Ministry of New and Renewable Energy representing just 0.1% of the total government outlay in 2010 (Figure 22.7). The government is nevertheless encouraging power generation through various renewable energy programmes, such as wind, biomass, solar and small hydropower. It has also designed a mix of fiscal and financial incentives and other policy/regulatory measures to attract private investment. However, all this is confined to the central government level; only eight states[21] out of 29 have explicit green energy policies.

Some Indian enterprises have acquired considerable technological capability in the design and manufacture of wind turbines, which is by far the most important source of grid-connected green technologies (76%). India, with an installed capacity of 18 500 MW, is the fifth-largest wind energy producer in the world, with considerable research and manufacturing capabilities. In 2013, three-quarters of India's installations were based on wind technology, the remainder being in small hydropower and biomass (10% each) and solar energy (4%). Since 2010, the number of patents granted in green technologies has risen sharply (Figure 22.11).

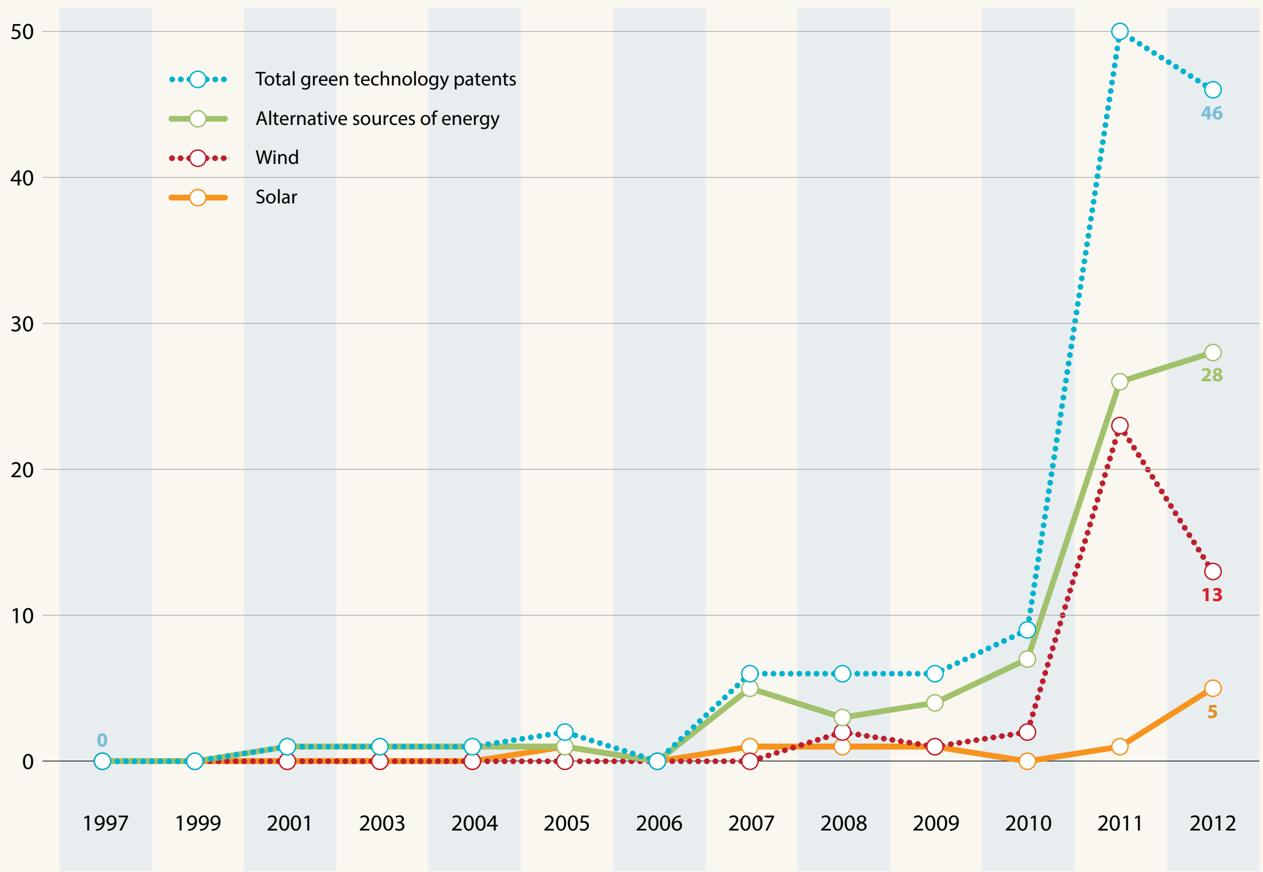
A first green bond to enrich the domestic energy mix

In February 2014, the Indian Renewable Energy Development Agency (IREDA)[22] issued its first 'green bond,' with terms of 10, 15 and 20 years and interest rates of just over 8%. The tax-free bond is open to both public and private investors. The Modi administration is targeting an investment of US$ 100 billion to help reach its goal of installing 100 gigawatts of solar energy across India by 2022. It has announced plans to train a 50 000-strong 'solar army' to staff new solar projects. In addition, a new National Wind Mission was announced in 2014 which is likely to be modelled on the National Solar Mission implemented by IREDA since 2010 (Heller *et al.*, 2015).

21. Andhra Pradesh, Chattisgarh,, Gujarat, Karnataka, Madhya Pradesh, Rajasthan, Tamil Nadu and Uttar Pradesh

22. Established in 1987, IREDA is a government enterprise administered by the Ministry of New and Renewable Energy. See: www.ireda.gov.in

Figure 22.11: **Green energy technology patents granted to Indian inventors, 1997–2012**



Source: Based on appendix tables 6-58, 6.64 and 66 in NSB (2014)

TRENDS IN HUMAN RESOURCES

The private sector is hiring more researchers

If the number of R&D personnel[23] in India increased annually by 2.43% between 2005 and 2010, this was entirely due to the 7.83 % increase each year in R&D personnel working for private companies. Over the same period, the number of government employees engaged in R&D actually declined, even though the government remains the largest employer of R&D personnel (Figure 22.12). This trend further substantiates the claim that India's national innovation system is becoming increasingly business-oriented.

23. The term R&D personnel encompasses researchers, technicians and support staff.

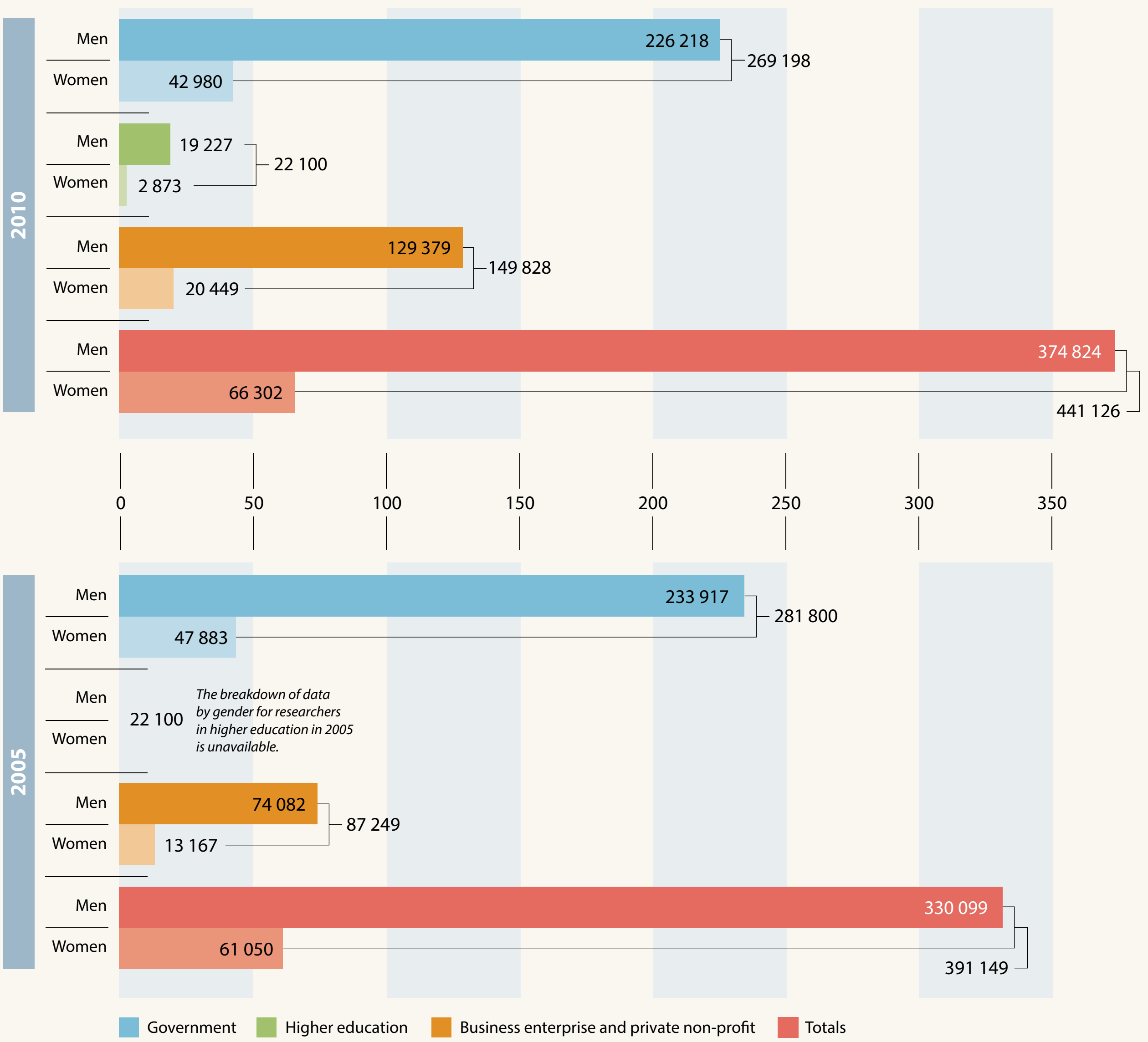
This translates into a rise in the number of R&D personnel per 10 000 labour force from 8.42 in 2005 to 9.46 in 2010. This means that India still has a long way to go to reach the density achieved by developed countries and China.

Spectacular growth in the number of engineering students

The shortage of R&D personnel could hold India back on its climb up the technology ladder. Policy-makers are fully cognisant of this problem[24] and have been putting in place a host of policies to boost university student rolls in science and

24. Two of the key elements of the *Science, Technology and Innovation Policy of 2013* are: enhancing skills for applications of science among the young from all social strata; and making careers in science, research and innovation attractive for talented and bright minds.

Figure 22.12: **Indian FTE researchers by sector of employment and gender, 2005 and 2010**



Source: DST (2009; 2013)

engineering programmes. One of these schemes, INSPIRE, focuses in particular on developing a vocation for science among the young (Box 22.3).

Historically, India has tended to produce eight scientists for every engineer. This is partly a consequence of the uneven distribution of engineering colleges across different states, a situation which has prompted the government to double the number of Indian Institutes of Technology to 16 and to set up five Indian Institutes for Science Education and Research.[25] Whereas there were 1.94 scientists for every engineer in 2006, this ratio had dropped to 1.20 by 2013.

In 2012, there were 1.37 million graduates in science, engineering and technology (Figure 22.13). Men made up about 58% of the total. Female students tend to be more concentrated in science streams, where they even outnumbered their male counterparts in 2012. There is already a sizeable share of engineering and technology students but it will be important for the country to raise the number of graduates in these fields, if it wishes to forge ahead with the desired expansion in manufacturing.

A need to give employers the skills they want

The employability of scientists and engineers has been a nagging worry for policy-makers for years and, indeed, for prospective employers. The government has put in place a number of remedial measures to improve the quality of higher education (Box 22.3). These include a stricter control over universities, regular audits of the curriculum and facilities and faculty improvement programmes. The establishment of the Science and Engineering Research Board in 2010 has further fluidified the availability of research grants in the public science system.

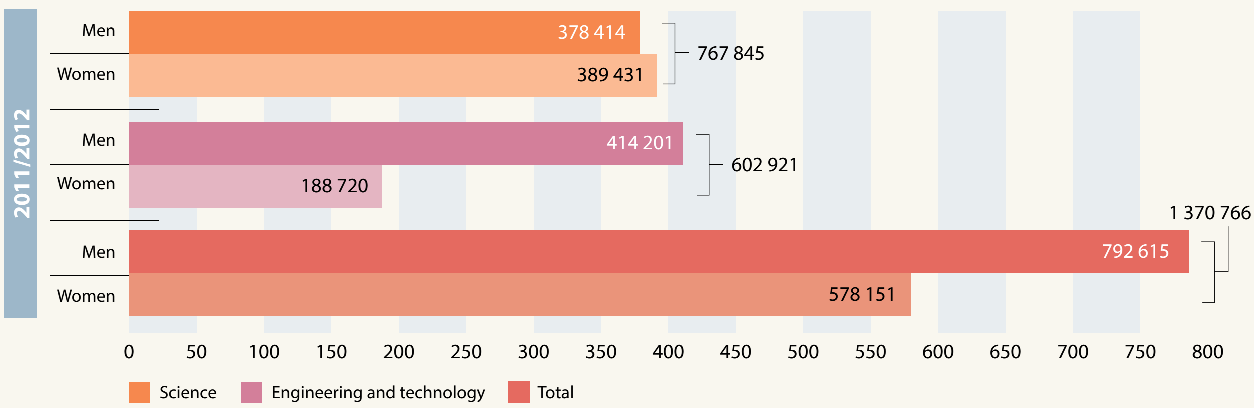
The government is also experimenting ways of fostering university–industry ties. In 2012, for example, it partnered with the Confederation of Indian Industry to incite doctoral students to team up with industry for their doctoral thesis. Successful applicants are awarded twice the usual amount for doctoral fellowships for their thesis, as long as the project is initiated by their industrial partner.

The diaspora is being wooed for technology-based projects

Another age-old issue concerns the migration of highly skilled workers. Although this phenomenon has been around since India gained independence in the 1940s, globalization has accentuated this trend over the past two decades or so. Mani (2012) has shown that, although high skilled migration may diminish the supply of scientists and engineers, it does generate a fair amount of remittances. In fact, India has become the largest receiver of remittances in the world. Skilled Indians living abroad have also helped India's high-tech industries to grow, particularly its computer software services industry. A number of schemes have been put in place to encourage the diaspora to participate in technology-based projects. One of the most long-running of these is the Ramalingaswami Re-Entry Fellowship in biotechnology, set up in 2006. In 2013, 50 researchers from the diaspora were offered a place in Indian institutions as part of this scheme.

25. In all, 172 universities were established between March 2010 and March 2013, bringing the total to 665 (DHE, 2012; 2014). None of the new institutions is a designated 'innovation university,' despite the government's intention of setting up 14 such universities. See the *UNESCO Science Report 2010*, p. 369.

Figure 22.13: **Indian science, engineering and technology graduates, 2011/2012**



Note: Graduates include undergraduates, postgraduates, MPhil and PhD holders

Source: Compiled from Department of Higher Education (2012) *All India Survey of Higher Education 2011/2012*, Tables 36 and 37

Box 22.3: Schemes to improve higher education in India

Indian universities are absent from the top places in international rankings. There is also a general feeling in India that the quality of the higher education system leaves much to be desired. Prospective employers have been complaining recently about the employability of the graduates churned out by local universities and colleges. In addition, just 4% of R&D in India is performed by the university sector. The government has put various schemes in place in the past decade to improve the quality of both university teaching and research. The following are some examples:

Rashtriya Uchchatar Shiksha Abhiyan (RUSA) was launched by the Ministry of Human Resource Development in October 2013. It aims to ensure that public universities and colleges conform to prescribed norms and standards and that they adopt accreditation as a mandatory quality assurance framework. Certain academic, administrative and governance reforms are a precondition for receiving funding under RUSA. All funding disbursed under RUSA is norm-based and outcome-dependent;

Further to the recommendations of the *Eleventh Five-Year Plan* (2007–2012), the University Grants Commission (UGC) introduced the semester system and a Choice-based Credit System at undergraduate level to give students a wider range of choices beyond their study discipline, offer them exposure to the world of work through internships and vocational training and enable them to transfer credits to another university.

In 2010, UGC issued regulations on *Minimum Qualifications for the Appointment of Teachers and other Academic Staff in Universities and Colleges and Measures for the Maintenance of Standards in Higher Education*. Two years later, it issued regulations for the *Mandatory Assessment and Accreditation of Higher Educational Institutions*.

The UGC implements the Universities with Potential for Excellence scheme, which dates from the *Ninth Five-Year Plan*; by 2014, 15 universities were receiving funding under this scheme and the UGC was making a fresh call for proposals to extend this opportunity to 10 more hopefuls, including private universities.

The UGC runs the Faculty Research Promotion Programme to reinvigorate basic research in the university sector, including in medical and engineering sciences. This programme provides three types of support: a research grant for entry-level faculty and for mid-career faculty and a fellowship for senior faculty nearing retirement whose proven track record argues in favour of keeping them on staff to mentor younger faculty.

The Department of Science and Technology (DST) contributes to the cost of research, staffing costs, equipment purchase and so on, through its programme for the Promotion of University Research and Scientific Excellence (PURSE), which has provided 44 universities with research grants over the past decade on the basis of their publication record.

The DST administers the Fund for the Improvement of Science and Technology Infrastructure in Higher Educational Institutions (FIST), which dates from 2001 and supported 1 800 departments and institutions between 2010 and 2013.

Since 2009, the DST has improved research infrastructure at six of India's universities for women, via the Consolidation of University Research for Innovation and Excellence (CURIE) programme. The second phase of the programme got under way in 2012.

The DST introduced the Innovation in Science Pursuit for Inspired Research (INSPIRE) programme in 2009 to stimulate a vocation for science. INSPIRE runs science camps and presents awards to 10–15 year-olds and internships to 16–17 year-olds. By 2013, it had also awarded 28 000 scholarships for undergraduate studies in the sciences, 3 300 fellowships to complete a PhD and 378 faculty awards to researchers under the age of 32, 30% of which went to the diaspora returning home to India to take up research positions.

The DST programme for Intensification of Research in High Priority Areas (IRHPA) was launched during the *Sixth Five-Year Plan*. It has set up core groups, centres of excellence and national facilities in frontline and emerging fields of science and engineering, such as neurobiology, solid state chemistry, nanomaterials, materials science, surface science, plasma physics or macromolecular crystallography.

Institutions receiving funding from the Department of Biotechnology and the Department of Science and Technology are obliged to set up an institutional repository for articles written by their staff; in turn, the Ministry of Science and Technology has undertaken to set up a central harvester linking each institutional repository.

Source: Lok Sabha (parliament), answer by Minister of Human Resource Development to question number 159, 7 July 2014; DST (2014); government website

CONCLUSION

Incentives have failed to create a broad innovation culture

From the foregoing, we can see that India's national innovation system faces several challenges. In particular, there is a need to:

- spread responsibility for attaining a GERD/GDP ratio of 2% by 2018 between the government and business enterprise sectors: the government should use this opportunity to raise its own share of GERD to about 1% of GDP by investing more heavily in university research, in particular, which currently performs just 4% of R&D, in order to enable universities to fulfil their role better as generators of new knowledge and providers of quality education;
- improve the training and density of scientists and engineers engaged in R&D: in recent years, the government has multiplied the number of institutions of higher education and developed a vast array of programmes to improve the quality of academic research; this is already producing results but more needs to be done to adapt curricula to market needs and to create a research culture at universities; none of the new universities established since 2010 is a designated 'innovation university,' for instance, despite the declared intention of creating 14 such universities in the *Eleventh Five-Year Plan* (2007–2012);
- initiate a government assessment of the effectiveness of tax incentives for R&D: despite India having one of the most generous tax regimes for R&D in the world, this has not resulted in the spread of an innovation culture across firms and industries;
- orient a greater share of government research grants towards the business sector: currently, most grants target the public research system, which is divorced from manufacturing; there are no large research grants which target the business enterprise sector to develop specific technologies, with the notable exception of the pharmaceutical industry; the Technology Development Board, for instance, has been disbursing more subsidized loans than grants. In this regard, the Science and Engineering Research Board set up in 2010 to feed research grants into the wider science system is a step in the right direction, as is the scheme for the Intensification of Research in High Priority Areas;
- support the emergence of technology-based enterprises by giving this type of SME greater access to venture capital; although there has been a venture capital industry in India since the late 1980s, its role has remained restricted of late to providing mainly private equity. In this regard, it is promising that the union government's budget for 2014–2015 proposes setting up a fund of Rs 100 billion (*circa* US$ 1.3 billion) to catalyse private equity, quasi equity, soft loans and other risk capital for start-ups;
- link technological capabilities in pharmaceutical and satellite technologies to the provision of services in health and education to the average Indian citizen: up until now, there has been little research on neglected tropical diseases and there has been a somewhat stultified use of satellite technologies to bring educational services to remote areas.

The biggest challenge of all for Indian policy-makers will be to tackle each of the aforementioned imperatives within a reasonable period of time.

KEY TARGETS FOR INDIA

- Raise GERD from 0.8% (2011) to 2.0% of GDP by 2018, half of which is to come from the private sector;
- Turn India into a global hub for nanotechnology by 2017;
- Raise the share of manufacturing from 15% (2011) to about 25% of GDP by 2022;
- Raise the share of high-tech products (aerospace, pharmaceuticals, chemicals, electronics and telecommunications) among manufactured products from 1% to at least 5% by 2022;
- Raise the share of high-tech goods among manufactured exports (currently 7%) by 2022;
- Install 100 gigawatts of solar energy across India by 2022.

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The 'new normal' [of slower but steadier economic growth] highlights the urgency for China to transform its economic development model from one that is labour-, investment-, energy- and resource-intensive to one that is increasingly dependent upon technology and innovation.

Cong Cao

A high-speed train in Shanghai station in June 2013; the latest trains can clock a speed of up to 487 km/h in test conditions.
Photo © Anil Bolukbas/iStockPhoto

23 · China

Cong Cao

INTRODUCTION

The 'new normal'

China's socio-economic situation has evolved since 2009[1] in a climate of uncertainty caused first by the global financial crisis of 2008–2009 then by the domestic transtion in political leadership in 2012. In the immediate aftermath of the US subprime mortgage crisis in 2008, the Chinese government took swift action to limit the shockwaves by injecting RMB 4 trillion (US$ 576 billion) into the economy. Much of this investment targeted infrustructure projects such as airports, motorways and railroads. Combined with rapid urbanization, this spending spree on infrastructure drove up the production of steel, cement, glass and other 'building-block' industries, prompting concern at the potential for a hard landing. The construction boom further damaged China's environment. For example, outdoor air pollution alone contributed to 1.2 million premature deaths in China in 2010, nearly 40% of the world total (Lozano *et al.,* 2012). When China hosted the Asia–Pacific Economic Cooperation (APEC) summit in mid-November 2014, factories, offices and schools in Beijing and surrounding areas were all closed for several days to ensure blue skies over the capital for the duration of the summit.

The post-2008 economic stimulus package was also compromised by the failure of the government's policy to support the development of so-called strategic emerging industries. Some of these industries were export-oriented, including manufacturers of wind turbines and photovoltaic panels. They were hard hit by the slump in global demand during the global financial crisis but also by the anti-dumping and anti-subsidy measures introduced by some Western countries. The manufacturing glut that ensued bankrupted some of the global leaders in solar panel manufacturing, such as Suntech Power and LDK Solar, which were already ailing by the time the Chinese government cut back on its own subsidies in order to rationalize the market.

Despite these hiccups, China emerged triumphantly from the crisis, maintaining average annual growth of about 9% between 2008 and 2013. In terms of GDP, China overtook Japan in 2010 to become the world's second-largest economy and is now catching up with the USA. When it comes to GDP per capita, however, China remains an upper middle-income country. In a reflection of its growing role as an economic superpower, China is currently spearheading three major multilateral initiatives:

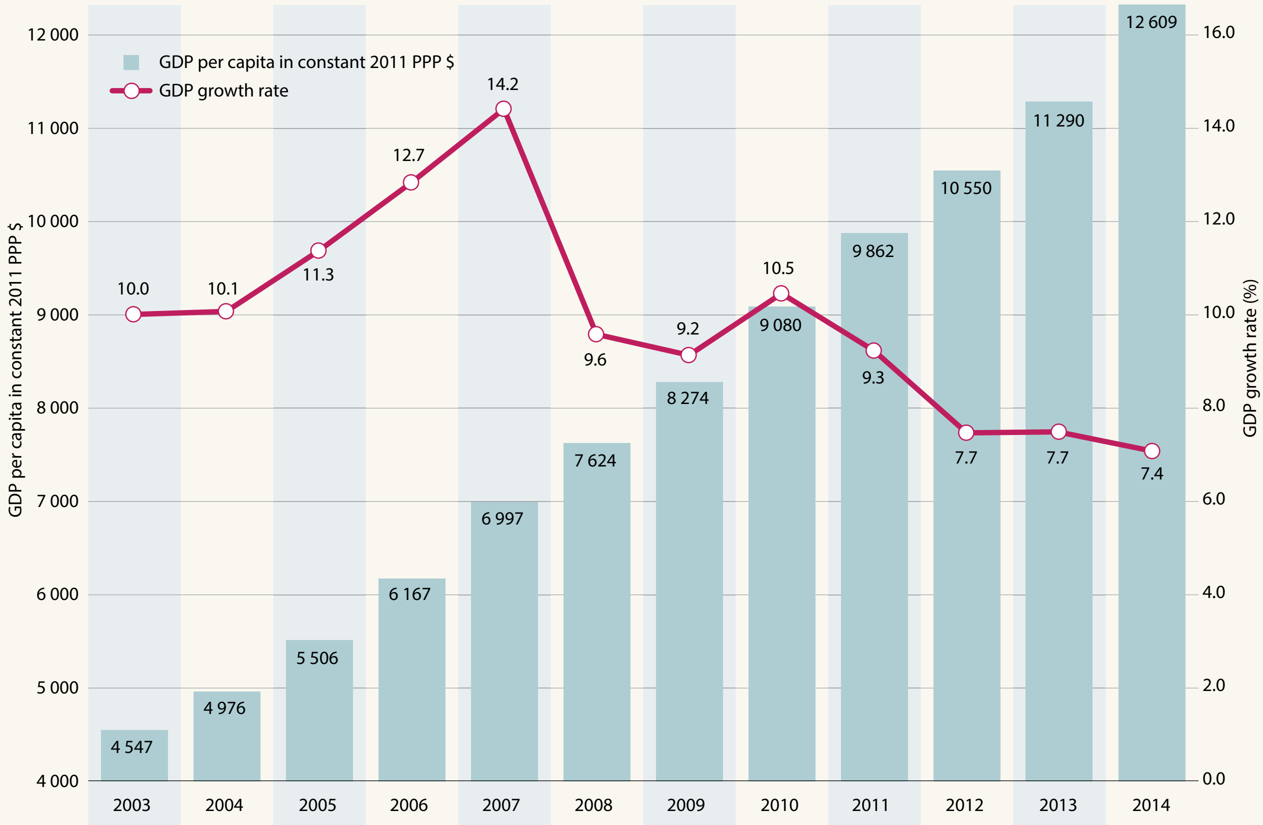
- the creation of the Asian Infrastructure Investment Bank to finance infrastructure projects, which will be based in Beijing and should be operational by the end of 2015; more than 50 countries have already expressed interest in joining, including France, Germany, the Republic of Korea and the UK;
- the approval by Brazil, the Russian Federation, India, China and South Africa (BRICS) in July 2014 of the New Development Bank (or BRICS Development Bank), with a primary focus on lending for infrastructure projects; it will be based in Shanghai; and
- the creation of an Asia–Pacific Free Trade Area, which, according to China's vision, would override existing bilateral and multilateral free trade agreements in the region; in November 2014, the APEC summit endorsed the Beijing Roadmap for completing a feasibility study by late 2016.

Meanwhile, China initiated a change in its political leadership in November 2012, when Xi Jinping acceded to the post of General Secretary of the Central Committee of the Chinese Communist Party (CCP) at the 18th CCP National Congress. At the first session of the 12th National People's Congress, held in March 2013, Xi Jinping and Li Keqiang took over the state presidency and premiership respectively. The Xi–Li administration inherited the legacy of an economy which had been growing at almost 10% on average for the past decade, as China vigorously pursued its open-door policy initiated by reformist leader Deng Xiaoping back in 1978. Today, China's economy seems to have reached a plateau, or a 'new normal' (*xin changtai*), characterized by steadier, albeit slower growth: GDP progressed by just 7.4% in 2014, the lowest rate in 24 years (Figure 23.1). China is gradually losing its status as 'the world's factory,' as rising costs and stringent environmental regulations make its manufacturing sector less competitive than in countries paying lower wages and offering less environmental protection. The 'new normal' therefore also highlights the urgency for China to transform its economic development model from one that is labour-, investment-, energy-, and resource-intensive into one that is increasingly dependent upon technology and innovation. The 'smart cities' initiative is one example of how the Chinese leadership is tackling this challenge (Box 23.1).

China faces other challenges which range from inclusive, harmonious and green development to an ageing society and the 'middle income trap.' All these call for the acceleration of the reform, which seems to have been delayed up until now by China's response to the global financial crisis. That may be about to change. The new leadership has put forward an ambitious and comprehensive reform agenda, in addition to launching an unprecedented anti-corruption campaign targeting some high-ranking government officials.

1. Total debt in China stood at about 210% of GDP by the end of 2014: household debt accounted for 34% of GDP, government debt 57% and corporate debt, including both loans and bonds, for 119%, according to the UNESCO Institute for Statistics.

Figure 23.1: **Trends in GDP per capita and GDP growth in China, 2003–2014**



Source: World Bank's World Development Indicators, March 2015

Box 23.1: **China's smart cities**

The 'smart city' takes its origin from the concept of 'smart planet' created by IBM. Today, the term 'smart cities' refers to futuristic urban centres where the use of information technology and data analysis improves infrastructure and public services so as to engage more effectively and actively with citizens. The development of smart cities takes advantage of synergic innovation around existing technologies cutting across many industries – transportation and utility infrastructure, telecommunications and wireless networks, electronic equipment and software applications, as well as emerging technologies such as ubiquitous computing (or the internet of things), cloud computing and 'big data' analytics. In a word, smart cities represent a new trend of industrialization, urbanization and informatization.

China is embracing the idea of smart cities to tackle challenges in government services, transportation, energy, environment, health care, public safety, food safety and logistics.

The *Twelfth Five-Year Plan* (2011–2015) specifically calls for the development of smart city technologies to be encouraged, thus stimulating the initiation of programmes and industrial alliances, such as the:

- China Strategic Alliance of Smart City Industrial Technology Innovation, managed by the Ministry of Science and Technology (MoST) since 2012;
- China Smart City Industry Alliance, managed by the Ministry of Industry and Information Technology (MoIIT) since 2013; and the
- Smart City Development Alliance, managed by the National Development and Reform Commission (NDRC) since 2014.

The most far-reaching effort has been led by the Ministry of Housing and Urban and Rural Development (MoHURD). By 2013, it had selected 193 cities and economic development zones to be official smart city pilot sites. The pilot cities are eligible for funding from a RMB 1 billion (US$ 16 billion) investment fund sponsored by the China Development Bank. In 2014, MoIIT also announced a RMB 50 billion fund to invest in smart city research and projects. Investment from local government and private sources has also been growing fast. It is estimated that total investment over the *Twelfth Five-Year Plan* period will reach some RMB 1.6 trillion (US$ 256 billion).

TRENDS IN R&D

The world's biggest R&D spender by 2019?

Over the past decade, China has been following a sharp uphill trajectory in science, technology and innovation (STI), at least in quantitative terms (Figures 23.2 and 23.3). The country has been spending a growing share of its burgeoning GDP on research and development (R&D). Gross domestic expenditure on R&D (GERD) stood at 2.08% in 2013, surpassing that of the 28-member European Union (EU), which managed an average intensity of 2.02% in 2013 (see Chapter 9). China's indicator nudged farther ahead to 2.09% of GDP in 2014. According to the biennial *Science, Technology and Industry Outlook 2014* (OECD, 2014), China will outpace the USA as the world's leading R&D spender by around 2019, reaching another important milestone in its endeavour to become an innovation-oriented nation by 2020. The policy focus on experimental development over the past 20 years, to the detriment of applied research and, above all, basic research, has resulted in enterprises contributing more than three-quarters of GERD. Since 2004, the bias in favour of experimental development has become even more pronounced (Figure 23.4).

China's S&T talent has been growing, with institutions of higher education turning out an increasing number of well-prepared graduates, especially in science and engineering. In 2013, the number of postgraduate students reached 1.85 million, on top of the 25.5 million undergraduates (Table 23.1). The number of researchers in China is unequivocally the world's highest: 1.48 million full-time equivalents (FTE) in 2013.

China's State Intellectual Property Office received more than half a million applications for invention patents in 2011, making it the world's largest patent office (Figure 23.5). There has also been a steady increase in the number of international papers by Chinese scientists in journals catalogued in the *Science Citation Index*. By 2014, China ranked second in the world after the USA, in terms of volume (Figure 23.6).

Some outstanding achievements

Chinese scientists and engineers have chalked up some outstanding achievements since 2011. In basic research, frontier discoveries include the quantum anomalous Hall effect, high-temperature superconductivity in iron-based materials, a new kind of neutrino oscillation, a method of inducing pluripotent stem cells and the crystal structure of the human glucose transporter GLUT1. In the area of strategic high technology, the Shenzhou space programme has pursued inhabited space flights. The first Chinese spacewalk dates from 2008. In 2012, the Tiangong-1 space module docked in space for the first time, allowing the first woman *taikongnaut* to go for a spacewalk. In December 2013, Chang'e 3 became the first spacecraft to land on the Moon since the Soviet Union's craft in 1976. China has also made breakthroughs in deep-ground drilling and supercomputing. China's first large passenger aircraft, the ARJ21-700 with a capacity for 95 passengers, was certified by the national Civil Aviation Administration on 30 December 2014.

Given such an attraction, a growing number of Chinese citizens will be clamouring for their city to climb on the 'smart city' bandwagon.

In early 2014, the ministries involved in the smart city initiative joined forces with the Standardization Administration of China to create working groups entrusted with managing and standardizing smart city development.

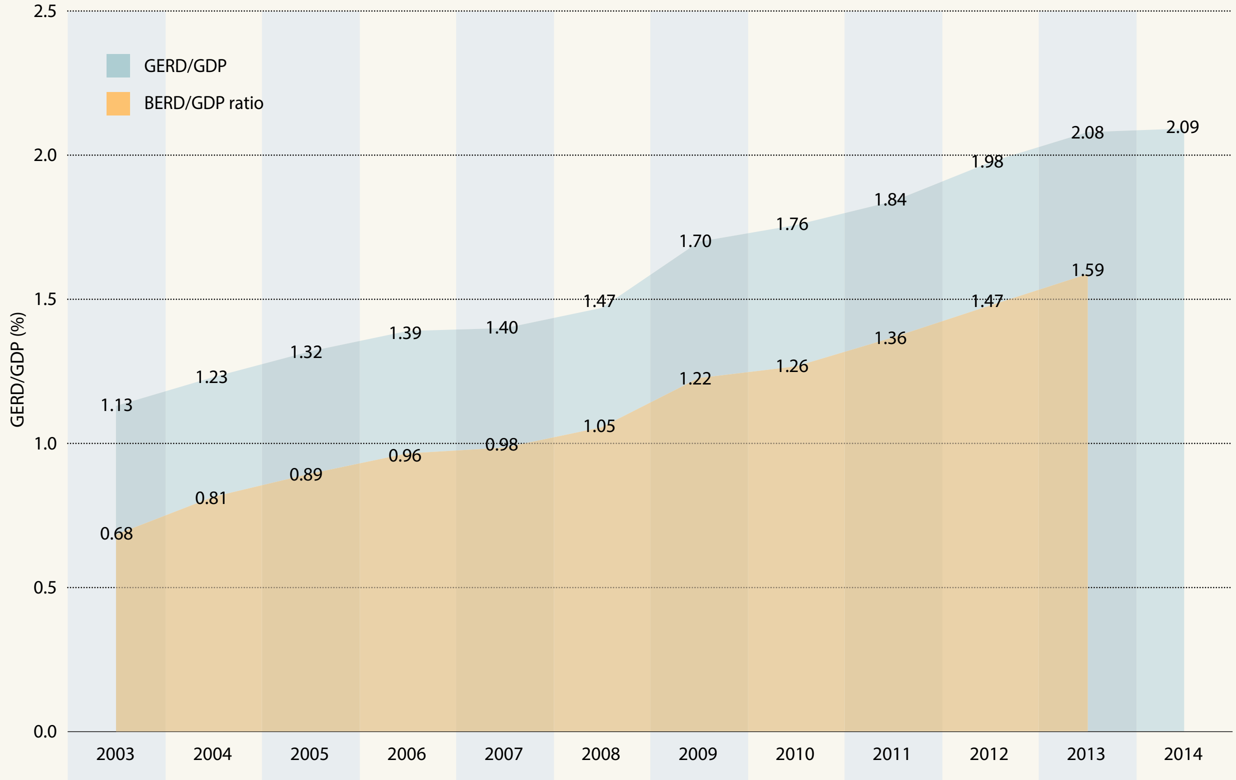
Apparently, it is the smart city boom which drove eight government agencies to issue a joint guide in August 2014, in order to improve co-ordination and communication between industrial participants and between industry and government agencies, entitled *Guidance on Promoting the Healthy Development of Smart Cities.* The document proposed establishing a number of smart cities with distinctive characteristics by 2020 to lead the development of smart cities across the country. The eight government agencies were the NDRC and seven ministries: MoIIT, MoST, Public Security, Finance, Land Resources, MoHURD and Transportation.

Companies such as IBM have not only used the smart city concept as their marketing strategy but also seized upon the opportunity to develop their businesses in China. As early as 2009, IBM launched a 'smart city' programme in the northeastern city of Shenyang in Liaoning province, hoping to showcase its strengths. It has also worked with Shanghai, Guangzhou, Wuhan, Nanjing, Wuxi and other cities on their own smart city initiatives. In 2013, IBM set up its first Smart Cities Institute in Beijing as an open platform for experts from the company, as well as its partners, clients, universities and other research institutions to work on joint projects related to smart water resources, smart transportation, smart energy and smart new cities.

Chinese firms that have also been adept at mastering technologies and shaking up markets include Huawei and ZTE, both telecommunications equipment manufacturers, as well as China's two electric grid companies, State Grid and Southern Grid.

Source: www.chinabusinessreview.com

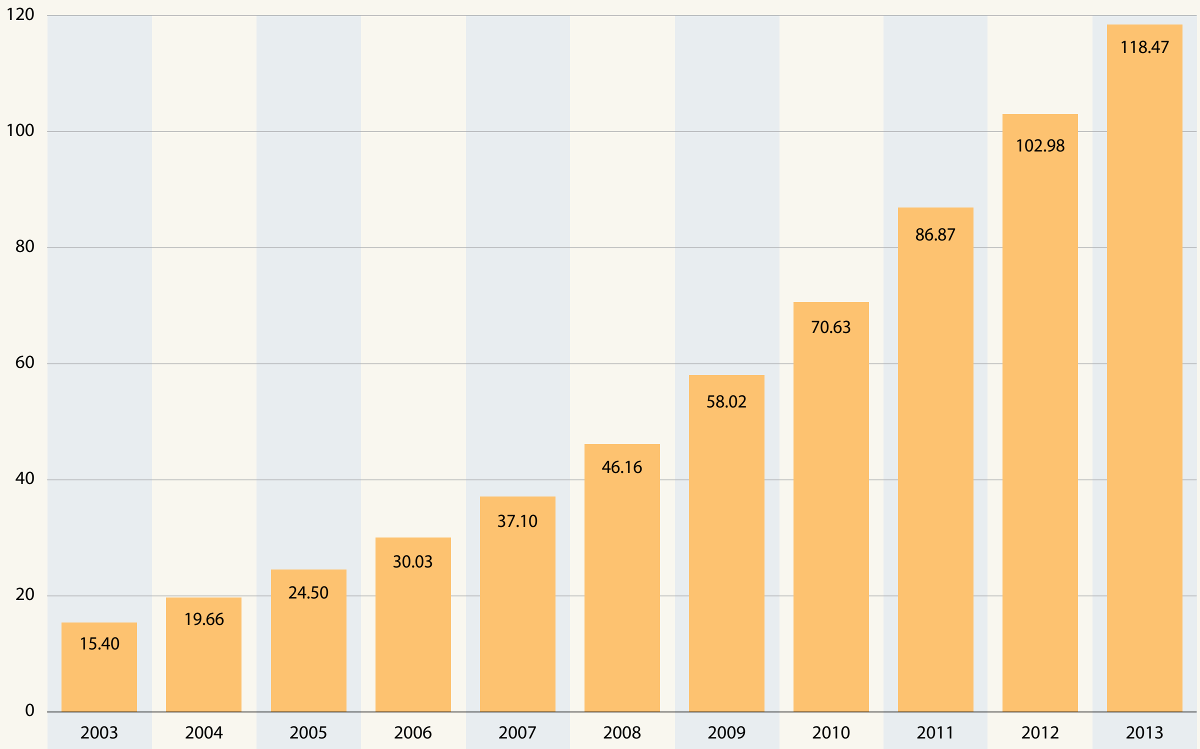
Figure 23.2: **Chinese GERD/GDP ratio and BERD/GDP ratio, 2003–2014 (%)**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

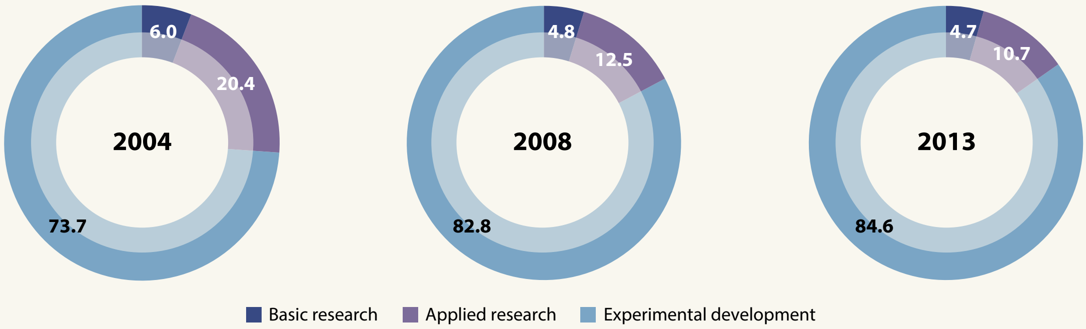
Figure 23.3: **Growth in Chinese GERD, 2003 –2013**

In RMB 10 billions



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

Figure 23.4: **GERD in China by type of research, 2004, 2008 and 2013 (%)**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

Table 23.1: **Trends in Chinese human resources in S&T, 2003–2013**

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
FTE research personnel ('000s)	1 095	1 153	1 365	1 503	1 736	1 965	2 291	2 554	2 883	3 247	3 533
FTE research personnel per million inhabitants	847	887	1 044	1 143	1 314	1 480	1 717	1 905	2 140	2 398	2 596
Graduate student enrolment ('000s)	651	820	979	1 105	1 195	1 283	1 405	1 538	1 646	1 720	1 794
Graduate student enrolment per million inhabitants	504	631	749	841	904	966	1 053	1 147	1 222	1 270	1 318
Undergraduate student enrolment (millions)	11.09	13.33	15.62	17.39	18.85	20.21	21.45	22.32	23.08	23.91	24.68
Undergraduate student enrolment per million inhabitants	8 582	10 255	11 946	13 230	14 266	15 218	16 073	16 645	17 130	17 658	18 137

Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

A number of major gaps in technology and equipment have been filled in recent years, especially in information and communication technologies (ICTs),[2] energy, environmental protection, advanced manufacturing, biotechnology and other strategic emerging industries for China.[3] Large facilities such as the Beijing Electron-Positron Collider (est. 1991), Shanghai Synchrotron Radiation Facility (est. 2009) and Daya Bay neutrino oscillation facility have not only yielded significant findings in basic science but also provided opportunities for international collaboration. The Daya Bay Neutrino Experiment, for example, which began collecting data in 2011, is being led by Chinese and American scientists, with participants from the Russian Federation and other countries.

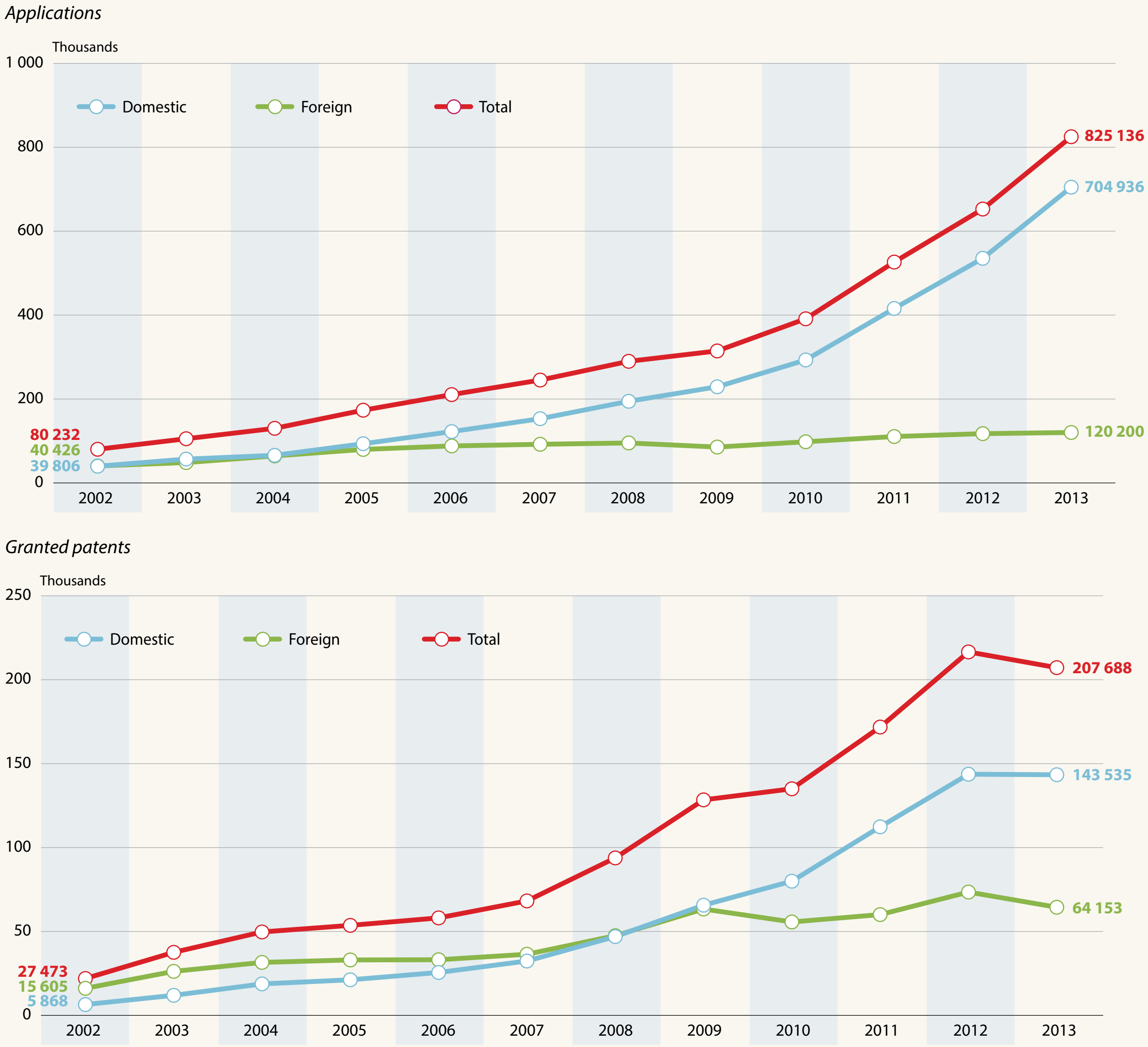
A leap forward in medical sciences

China has made leaps and bounds in medical sciences in the past decade. Publications in this field more than tripled between 2008 and 2014 from 8 700 to 29 295, according to the Web of Science. This progression has been much faster than in China's traditional strengths of materials science, chemistry and physics. According to the Institute of Scientific and Technical Information of China, which is affiliated with the Ministry of Science and Technology (MoST), China contributed about one-quarter of all articles published in materials science and chemistry and 17% of those published in physics between 2004 and 2014 but just 8.7% of those in molecular biology and genetics. This nevertheless represents a steep rise from just 1.4% of the world share of publications in molecular biology and genetics over 1999–2003. In the early 1950s, Chinese research in genetics came to a standstill after the country officially adopted Lysenkoism, a doctrine developed by Russian peasant plant-breeder Trofim Denisovich Lysenko (1898–1976) which had already stalled genetic research in the Soviet Union. Essentially, Lysenkoism dictated that we are what we learn. This environmentalism denied the role played by genetic inheritance in evolution. Although Lysenkoism was discarded in the late 1950s, it has taken Chinese geneticists decades to catch up (UNESCO, 2012). China's participation in the Human Genome Project at the turn of the century was a turning point. More recently, China has thrown its support behind the Human Variome Project, an international endeavour to catalogue human genetic variation worldwide, in order to improve diagnosis and treatment, with support

2. 649 million Chinese inhabitants had access to internet by the end of 2014.

3. China defines strategic emerging industries as: energy-saving and environment-friendly technologies, new generation ICTs, biotechnology, advanced manufacturing, new energy, new materials and automobiles powered by new energy sources.

Figure 23.5: **Applications and patents granted to Chinese and foreign inventors, 2002–2013**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

from UNESCO's International Basic Sciences Programme. In 2015, the Beijing China Health Huayang Institute of Gene Technology committed *circa* US$ 300 million to the Human Variome Project; the funds will be used over the next ten years to build 5 000 new gene- and disease-specific databases and to establish the Chinese node of the Human Variome Project.

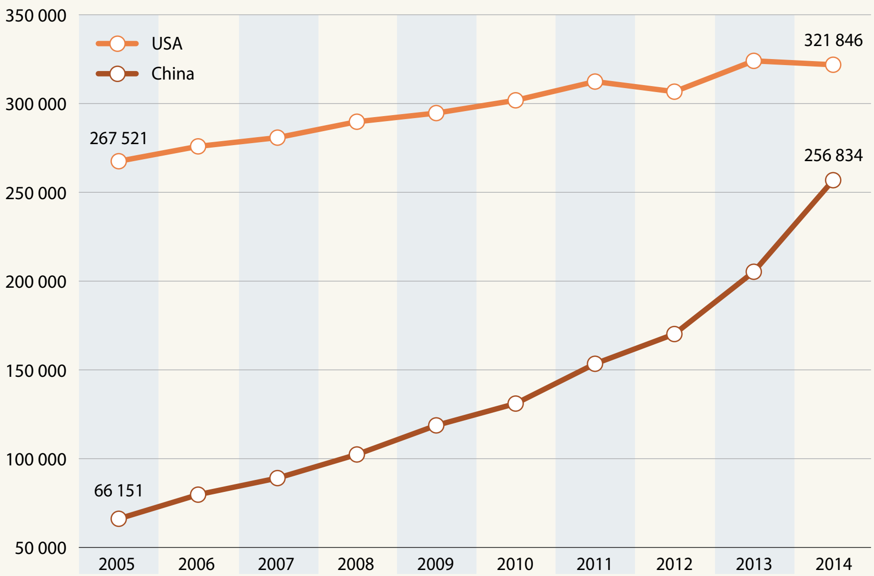
Two new regional centres for training and research

Other opportunities for international collaboration have arisen from the establishment of two regional centres for research and training since 2011, which function under the auspices of UNESCO:

- the Regional Training and Research Centre on Ocean Dynamics and Climate was launched on 9 June 2011 in Qingdao City. It is hosted by the First Institute of Oceanography, part of the State Oceanic Administration, and trains young scientists from Asian developing countries, in particular, at no cost to the beneficiary;
- the International Research and Training Centre for Science and Technology Strategy was inaugurated in Beijing in September 2012. It designs and conducts international co-operative research and training programmes in such areas as S&T indicators and statistical analysis, technology foresight and road-mapping, financing policies for innovation, the development of small and medium-sized enterprises, strategies for addressing climate change and sustainable development, etc.

Figure 23.6: **Scientific publication trends in China, 2005–2014**

China could become world's largest scientific publisher by 2016



0.98

Average citation rate for Chinese scientific publications, 2008–2012; the OECD average is 1.08; the G20 average is 1.02

10.0%

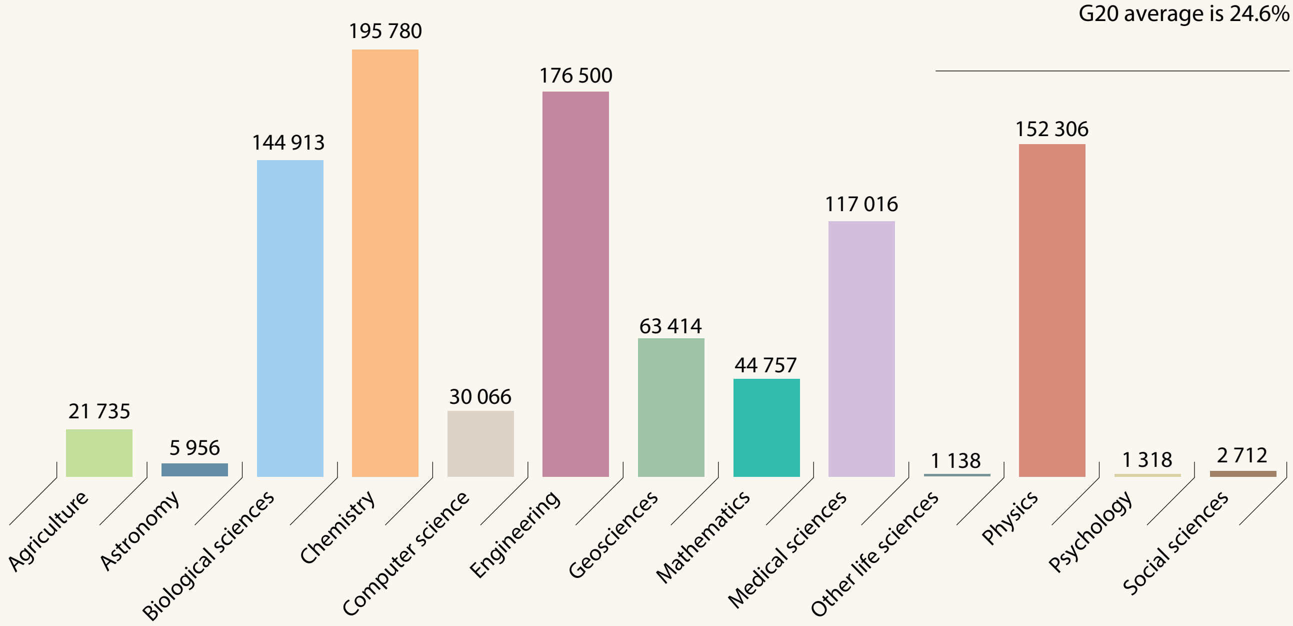
Share of Chinese papers among 10% most cited, 2008–2012; the OECD average is 11.1%; the G20 average is 10.2%

24.4%

Share of Chinese papers with foreign co-authors, 2008–2014; the OECD average is 29.4%; the G20 average is 24.6%

Chemistry, engineering and physics dominate Chinese science

Cumulative totals by field 2008–2014



Note: The totals exclude 180 271 unclassified publications.

The USA outstrips all others as China's main partner

Main foreign partners 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
China	USA (119 594)	Japan (26 053)	UK (25 151)	Australia (21 058)	Canada (19 522)

Note: The statistics for China do not include Hong Kong SAR or Macao SAR.

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

TRENDS IN STI GOVERNANCE

Reform driven by engineers turned politicians

China's astonishing progress in STI can be attributed to a series of policies adopted during the reformist open-door era since 1978, from 'rejuvenating the nation with science, technology and education' (*kejiao xingguo*), in 1995, 'empowering the nation with talent' (*rencai qiangguo*), in 2001, and 'building up an endogenous innovation capability' (*zizhu chuangxin nengli*) to 'turning China into an innovation-oriented nation' (*chuangxin guojia*) in 2006, a strategy ensconced in the *National Medium and Long-term Plan for the Development of Science and Technology (2006–2020)*. The Chinese power structure in the 1980s and 1990s could be described as an alliance between career bureaucrats and technocrats; the bureaucrats needed the technocrats to modernize and develop the economy, whereas the technocrats needed the bureaucrats to advance their political careers. Following Deng's death in 1997, Jiang Zemin became China's 'top technocrat' and instigated a fully-fledged technocracy (Yoon, 2007). Given their training at the nation's top science and engineering schools, China's governing political elite was naturally inclined to favour policies that promoted advances in science and technology (Suttmeier, 2007). Only in its current top leadership did China start to see the rise of social scientists: Xi Jinping holds a PhD in Law from Tsinghua University and Li Keqiang obtained his PhD in Economics from Beijing University. However, the change in educational background of the current leadership does not mean that attitudes towards science and technology have changed among these top leaders.

In July 2013, soon after being made General Secretary of the Chinese Communist Party's (CCP's) Central Committee and State President, Xi Jinping paid a visit to the Chinese Academy of Sciences (CAS), the nation's leading institution for science and research. His articulation of the problems facing the development of science and technology in China was distilled into 'four mismatches' (*sige buxiang shiying*): mismatches between the level of technological development and the requirements of socio-economic development; between the S&T system and the requirements of science and technology for the system to develop rapidly; between the distribution of S&T disciplines and the requirements of science and technology for these disciplines to develop; and between existing S&T personnel and the requirements of the nation in terms of talent. Xi then urged CAS to be 'a pioneer in four areas' (*sige shuaixian*): in leapfrogging to the frontier of scientific research, in enhancing the nation's innovative talent pool, in establishing the nation's high-level think tank in science and technology and in becoming a world-class research institution.

China's political leadership is also enthusiastic about broadening its knowledge. This is illustrated by the fact that, since 2002, the Politburo of the CCP's Central Committee has held frequent group study sessions, to which leading Chinese scholars have been invited to lecture on subjects related to China's socio-economic development, including STI. The Xi–Li duo has pursued this tradition. In September 2013, the Politburo held a group study at Beijing's Zhongguancun Science Park, also known as China's 'Silicon Valley.' During this ninth group study session run by the new leadership – the first ever held outside the Communist Party's Zhongnanhai headquarters – members of the Politburo showed particular interest in new technologies such as three-dimensional printing, big data and cloud computing, nano-materials, biochips and quantum communications. While stressing the importance of science and technology in enhancing the nation's strength, in the speech he gave for the occasion, Xi Jinping indicated that China should focus on integrating innovation with socio-economic development, enhancing the capability for endogenous innovation, nurturing talent, constructing a favourable policy environment for innovation and continuing to open up and engage in international co-operation in science and technology. Calls from the leadership since 2013 for 'positive energy' (*zheng nengliang*) to prevail in all spheres of society, including the university sector, have raised concerns, however, that this new doctrine may inhibit the critical thinking which nurtures creativity and problem-solving research, if the evocation of problems comes to be assimilated with 'negative energy.'

The new leadership is focusing on weaving together the so-called 'two layers of skin' (*liang zhang pi*) of research and the economy, a long-lasting challenge for China's S&T system. The main topic of discussion at the seventh meeting of the Central Leading Group for Financial and Economic Affairs on 18 August 2014, chaired by Xi Jinping, was a draft innovation-driven development strategy which was formally released by the CCP Central Committee and State Council on 13 March 2015. This, in itself, reflects the importance that the leadership attaches to innovation for restructuring China's economic development model.

Enterprises still dependent on foreign core technologies

In fact, the attention being paid to STI at the moment by the political leadership stems from its dissatisfaction with the current performance of the domestic innovation system. There exists a mismatch between input and output (Simon, 2010). Despite a massive injection of funds (Figure 23.3), better-trained researchers and sophisticated equipment, Chinese scientists have yet to produce cutting-edge breakthroughs worthy of a Nobel Prize, including the returnees who are now firmly embedded in domestic research and innovation (Box 23.2). Few research results have been turned into innovative and competitive technology and products. The commercialization of public research results has been rendered difficult, if not impossible, by the fact that these results are considered public goods, thus disincentivizing researchers engaged in technology transfer. With few exceptions, Chinese enterprises still depend on foreign sources for core technologies. According to a World Bank study, China had a US$ 10 billion deficit in 2009 in its intellectual property balance of payments, based on royalties and license fees (Ghafele and Gibert, 2012).

These problems have forced China to put its ambition on hold of embarking on a truly innovation-driven development trajectory. Indeed, China's drive to become a global leader in STI is tied to its capacity to evolve towards a more efficient, effective and robust national innovation system. Upon closer examination, there is a lack of co-ordination between the various actors at the macro level, an unfair distribution of funding at the meso level and an inappropriate performance evaluation of research projects and programmes, individual scientists and institutions at the micro level. It would seem to be both urgent and inevitable to institute reforms across all three levels of the national innovation system (Cao *et al.*, 2013).

Reform has accelerated under the new leadership

The current reform of the country's science and technology system was initiated against such a backdrop. It got under way in early July 2012, when a National Conference on Science, Technology and Innovation was convened shortly before the transition in leadership. One key outcome of the conference was an official document, *Opinions on Deepening the Reform of the Science and Technology System and Accelerating the Construction of the National Innovation System*, released in September. Produced by the CCP's Central Committee and State Council, this document furthered implementation of the *National Medium- and Long-Term Plan for the Development of Science and Technology (2006–2020),* which was released in 2006.

It was also in September 2012 that a new State Leading Group of Science and Technology System Reform and Innovation System Construction convened its first meeting. Made up of representatives from 26 government agencies and headed by Liu Yandong, a member of the Central Committee Politburo and state councillor, the leading group is mandated to guide and co-ordinate the reform and the construction of China's national innovation system, in addition to discussing and approving key regulations. When the country's top leadership changed a few months later, Liu not only kept her party position but was also promoted to vice premier in the state apparatus, thereby ensuring continuity and confirming the importance attached to scientific affairs.

The reform of the S&T system has accelerated since the change in political leadership. In general, the reform conducted by the Xi–Li tandem is characterized by so-called 'top-level design' (*dingceng sheji*), or strategic considerations in formulating the guidelines, so as to ensure that the reform is comprehensive, co-ordinated and sustainable; a balanced and focused approach towards reform which takes into consideration the interests of the CCP and country; and a focus on overcoming institutional and structural barriers, not to mention deep-seated contradictions, while promoting co-ordinated innovation in economic, political, cultural, social and other institutions. Of course, the 'top-level design' has been more broadly exercised in the reforms under the Xi–Li administration. In particular, the reform of the S&T system has strong political backing, with Xi Jinping's aforementioned visit to CAS and the Politburo's Zhongguancun group study setting the course. On several occasions, Xi has taken time off from his busy schedule to preside over the presentation of reports by the relevant government agencies on progress with the reform and the innovation-driven development strategy. He has also been very hands-on when it comes to the reform of China's elite academician (*yuanshi*) system at CAS and the Chinese Academy of Engineering (CAE), the broader reform of CAS and that of funding mechanisms for the centrally financed national science and technology programmes (see p. 633).

A mid-term review of the *Medium- and Long-Term Plan*

In addition to the political leadership's concerns about the mismatch between the soar in R&D input and the relatively modest output in science and technology, coupled with the necessity of harnessing science and technology to restructuring China's economy, the desire for reform may have been spurred by the mid-term review of the *National Medium and Long-term Plan for the Development of Science and Technology (2006–2020)*. As we saw in the *UNESCO Science Report 2010*, the *Medium- and Long-term Plan* set several quantitative goals for China to achieve by 2020, including (Cao *et al.,* 2006):

- raising investment in R&D to 2.5% of GDP;
- raising the contribution of technological advances to economic growth to more than 60%;
- limiting China's dependence on imported technology to no more than 30%;
- becoming one of the top five countries in the world for the number of invention patents granted to its own citizens; and
- ensuring that Chinese-authored scientific papers figure among the world's most cited.

China is well on the way to reaching these quantitative goals. As we have seen, by 2014, GERD had reached 2.09% of GDP. Moreover, technological advances are already contributing more than 50% to economic growth: in 2013, Chinese inventors were granted some 143 000 invention patents and China had risen to fourth place worldwide for the number of citations of Chinese-authored scientific papers. China's dependence on foreign technology should drop to about 35% by 2015. Meanwhile, various government ministries have worked together to initiate policies designed to facilitate implementation of the *Medium- and Long-Term Plan*. These policies include providing innovative enterprises with tax incentives and other forms of financial support, prioritizing domestic high-tech enterprises for government procurement, encouraging assimilation and re-innovation based on imported technology, strengthening the protection of intellectual property rights, nurturing talent, enhancing education and science popularization and establishing the basic platform of S&T innovation (Liu, *et al.,* 2011).

This begs the question: if we look beyond the statistics, what impact has the *Medium- and Long-Term Plan* had on realizing China's ambition of becoming an innovation-oriented nation by 2020? The mid-term review of the *Medium- and Long-Term Plan*'s implementation was approved by the State Council in November 2013. The Ministry of Science and Technology led this effort, assisted by a steering committee set up in conjunction with 22 government agencies, the Chinese Academy of Engineering having been commissioned to organize the review. The same 20 thematic groups which had conducted strategic research at the stage of drafting the *Medium- and Long-Term Plan* now consulted experts from CAS, CAE and the Chinese Academy of Social Sciences. Consultations at CAS alone involved more than 200 experts. Focus groups were constituted with personnel from innovative enterprises, multinational companies operating in China, R&D institutes, universities and other sectors. Attention was paid to measuring the progress made by the 16 mega-engineering programmes (Table 23.2), as well as cutting-edge basic research conducted in a number of key areas through mega-science programmes, the reform of the S&T system, the construction of an enterprise-centered national innovation system, the policies formulated to support implementation of the *Medium- and Long-Term Plan* and so on. Through expert interviews and consultations, as well as questionnaires, the review team also solicited the views of international experts and scholars on China's evolving capability for

Box 23.2: Wooing the Chinese elite back home

Since the introduction of the open-door policy, China has sent more than 3 million students overseas. Of these, about 1.5 million have returned (Figure 23.7). Among the returnees figure a growing number of seasoned entrepreneurs and professionals who have taken advantage of the vast opportunities created by China's rapid economic growth and the preferential policies implemented by the Chinese government to woo them.

Since the mid-1990s, high-profile programmes have been rolled out by the Ministry of Education (Cheung Kong Scholar Programme), the Chinese Academy of Sciences (One Hundred Talents Programme) and other central and local government agencies. These talent-focused programmes have dangled extremely generous incentives, resources and honours before potential recruits. They have targeted scientific pioneers, leaders in key technologies and corporate managers from high-tech industries but also – especially during the global financial crisis – professionals from consulting and the financial and legal worlds. However, these programmes have failed to persuade expatriate Chinese occupying the top jobs to return home.

Unhappy about the overall progress in STI and higher education despite an avalanche of funds, China's political leadership has attributed the problem to the lack of talent of the calibre of the father of China's space technology, Qian Xuesen, or the founder of geomechanics, Li Siguang, or of nuclear physicist Deng Jiaxian. In late 2008, the Department of Organization of the CCP's Central Committee, which appoints and evaluates senior officials at the provincial and ministerial levels, added the title of 'headhunter' to its curriculum vitae by initiating the Thousand Talents Programme *(qianren jihua)*.

In essence, the Thousand Talents Programme aims to spend 5–10 years wooing some 2 000 expatriate Chinese under the age of 55 who hold a foreign doctoral degree and are full professors at well-known institutions of learning, experienced corporate executives and entrepreneurs with patents for core technologies under their belt. The state has agreed to give each recruit RMB 1 million as a start-up subsidy. In parallel, the host institution or enterprise will provide housing of 150–200 m^2 and a salary to match that earned overseas, or almost; a national title is also bestowed upon the recruit.

In late 2010, a new component was added to the Thousand Talents Programme, targeting aspiring young scientists and engineers aged 40 years and under who hold a doctorate from a well-known foreign university, have at least three years of overseas research experience and hold a formal appointment at a well-known foreign university, research institute or company. The recruit is required to work full-time at a Chinese institution for an initial period of five years. In return, he or she receives a subsidy of RMB 500 000 and a research grant worth RMB 1–3 million.

By 2015, the programme had signed up some 4 100 Chinese expatriates and foreign experts with impeccable credentials. Wang Xiaodong, a prestigious Howard Hughes Medical Institute investigator who was elected

Table 23.2: **China's mega-engineering programmes to 2020**

The 16 mega-engineering programmes correspond to about 167 smaller projects. Thirteen have been made public.

Advanced manufacturing technology	Extra large-scale integrated circuit manufacturing technology and associated technology
	Advanced computerized numerical control machinery and basic manufacturing technology
Transportation	Large aircraft
Agriculture	Cultivation of new varieties of genetically modified organisms (Box 23.3)
Environment	Water pollution control and governance (Box 23.4)
Energy	Large-scale oil and gas fields and coal-bed methane development
	Advanced large-scale pressurized water reactors and nuclear power plants with high-temperature, gas-cooled reactors (Box 23.5)
Health	Development of significant new drugs
	Prevention and treatment of AIDS, viral hepatitis and other major infectious diseases
ICTs	Core electronic devices, high-end generic chips and basic software
	Next-generation broadband wireless mobile communication
Space technologies	High-resolution Earth observation system
	Human space flight and the Moon exploration programme

Source: National Medium- and Long-term Plan for the Development of Science and Technology (2006–2020)

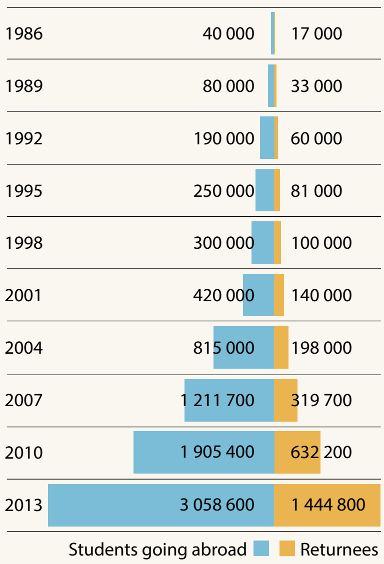
to the US National Academy of Sciences in 2004 at the tender age of 41, and Shi Yigong, a chair professor of structural biology at Princeton University, figure among the prize catches.

The Thousand Talents Programme is not flawless, be it in design or implementation. For one thing, the criteria have changed over time. The programme originally targeted full professors at well-known foreign universities or their equivalents; in practice, the threshold has been lowered to full professors from any institution or even associate professors. Preferential treatment that was originally reserved for new recruits has been extended to qualified earlier returnees with retrospective effect. The evaluation of candidates has paid most attention to academic publications and the required length of full-time employment has been reduced to six months. Given that many, if not most, of the recruits only spend a couple of months in China, even though their contract usually specifies otherwise, the Department of Organization has had to introduce a short-term two-month employment scheme. This not only significantly departs from the programme's original goal but also casts doubt as to whether the programme will encourage the permanent return of outstanding expatriates. This setback suggests that high-flying expatriate Chinese still don't feel the environment is ready for making their move permanent, despite a generous pay package. Among the reasons for this reluctance: personal relationships (*guanxi*) often override considerations of merit in China when it comes to reviewing grant proposals, promotion and awards; rampant misconduct has also tainted the Chinese scientific community; and, in social sciences, some research areas remain taboo.

The Department of Organization has never published the formal list of beneficiaries, for fear that recruits might be frowned upon by their foreign employers or even lose their position through a conflict of interest.

The programme has also alienated domestically trained talent, whose training has been perceived as being of inferior quality, and early returnees, who were treated less generously than more recent recruits. In order to correct these failings, the Department of Organization launched a Ten Thousand Talents Programme, in August 2012 which offers similar perks to a wider range of hopefuls.

Figure 23.7: **Cumulative number of Chinese students going abroad and returnees, 1986–2013**



Source: Author's research

endogenous innovation in a constantly mutating international environment. The mid-term review also included an exercise in which more than 8 000 domestic and foreign experts were invited to assess China's mega-engineering programmes, including through technology foresight studies, to determine where China stood in these technological areas (Table 23.2). Beijing, Jiangsu, Hubei, Sichuan, Liaoning and Qingdao were all selected as sites for the mid-term review at the provincial and municipal levels.

The review was originally due for completion by March 2014 and its preliminary findings were scheduled for distribution to the public by the end of June the same year. However, the second meeting of the steering committee was only held on 11 July 2014. Once the assessment has been completed, the review team will summarize the information collected on the *Medium- and Long-Term Plan's* implementation thus far and the role that science and technology have played since 2006 in driving socio-economic development. Recommendations will then be made for adjusting the implementation plan accordingly. The outcome of the review will also feed into the formulation of the *Thirteenth Five-Year Plan* (2016–2020) and the launch of the S&T systemic reform.

It would nevertheless appear that the review of the *Medium- and Long-Term Plan* will re-affirm the so-called 'whole nation system' (*juguo tizhi*) approach, by which the nation's resources are channelled towards select prioritized areas.[4] This approach is reminiscent of the state-led development of China's strategic weapons programmes (*liangdan yixing*) from the mid-1960s onwards through resource concentration and mobilization. Along with the introduction of 'top-level design' into the formulation of reform initiatives, it may become a hallmark of innovation in China in the years to come.

4. This approach originated from China's state-run sports system, or 'whole nation system' where it was the practice to concentrate the entire nation's resources on the training of athletes who showed promise for winning China medals at the Olympic Games. The success of China's strategic weapons programmes in the 1960s and 1970s and subsequent national defence programmes has been attributed to such a metaphor, which is also used to describe the 16 mega-engineering programmes launched under the *Medium- and Long-Term Plan* to 2020.

Box 23.3: **Cultivating a new variety of GMOs: a mega-engineering programme**

This programme was officially launched on 9 July 2008 when the State Council gave it the go-ahead after debating whether China should commercialize particular genetically modified organisms (GMOs) and, if so, when, as well as how to establish a stringent biosafety and risk assessment mechanism. This is arguably the most controversial of the 16 mega-engineering programmes.

Run by the Ministry of Agriculture, the programme aims to obtain genes with far-reaching applicability and indigenous intellectual property rights and to cultivate major new GMO varieties with traits for disease and insect resistance, stress tolerance and high yields, to promote efficient agricultural production, raise the overall level of agricultural transgenic technology and commercialization and underpin the sustainable development of Chinese agriculture with strong scientific support. Between 2009 and 2013, the central government's appropriation to the programme totalled RMB 5.8 billion.

Current work includes developing GM crops with resistance to viruses, diseases, insects, bacteria and fungi, as well as tolerance to weed-killing herbicides. GM crops such as wheat, maize, soybean, potato, canola, peanut and others are at different stages of laboratory studies, field trials or environmental release but have not yet reached the stage of biosafety certification permitting commercialization.

In the past couple of years, China has witnessed a change in policy towards transgenic technology and especially GM crops, which coincided with the change in the political leadership in late 2012 and early 2013. China's position on the issue of transgenic plants was elaborated in Xi Jinping's speech at the central conference on rural work on 23 December 2013. He said that it is quite normal for there to be doubts and debate, as transgenic plants use a novel technology but that it has broad prospects for development. Xi emphasized the importance of strictly following technical regulations and specifications formulated by the state, proceeding steadily to ensure no mishap and taking safety into account. He also indicated that China should boldly carry out research and innovation, take the commanding heights of transgenic technology and not allow foreign companies to occupy China's market for agricultural GM products.

Soon after the programme's inception, the long-delayed biosafety certification process for GM crops was accelerated to allow biosafety certificates to be issued for two strains of GM rice and phytase maize in 2009. These biosafety certificates expired in August 2014, amid rising contestation from anti-GMO activists. The certificates were nevertheless renewed on 11 December 2014. It remains to be seen whether the GMO mega-engineering programme will proceed smoothly over the next five years.

Source: www.agrogene.cn; author's research

Reform of the Chinese Academy of Sciences

The latest reform of CAS once again raises the question of the academy's place in China's national S&T system, a question which first came up at the academy's inception immediately after the founding of the People's Republic of China in 1949. At the time, research and training were separated at universities and industrial R&D institutes focused on specific problems in their particular sectors. These were the glory days of the academy, when it contributed, in particular, to the success of the strategic weapons programmes through a mission-oriented disciplinary development strategy.

CAS would quickly become a victim of its own success, after its high visibility attracted keen attention from the political leadership and other actors in the S&T system. In the mid-1980s when China began reforming its S&T system, CAS was forced to adopt a 'one academy, two systems' approach. This strategy consisted in concentrating a small number of scientists on basic research and following the global trend in high technology, while encouraging the majority of its staff to engage in the commercialization of research results and projects of direct relevance to the economy. The overall quality of research suffered, as did the academy's ability to tackle fundamental research questions.

In 1998, the president of CAS, Lu Yongxiang, initiated the Knowledge Innovation Programme to improve the academy's vitality (Suttmeier *et al.*, 2006a; 2006b). Initially, CAS hoped to satisfy the Chinese leadership by making the staff of its institutes more nimble and mobile. The academy's very existence was threatened, however, after it was downsized to compensate for the government's efforts to strengthen the research capability of universities and the national defence sector – ironically, the very sector that had historically absorbed CAS personnel or depended upon CAS to take on major research projects. In reaction, CAS not only reversed its early approach but even went to the other extreme by significantly expanding its reach. It established application-focused research institutes in new scientific disciplines and new cities and formed alliances with provincial and local governments and industries. The Suzhou Institute of Nanotech and Nanobionics is one such establishment; it was created jointly by CAS and the Jiangsu provincial and Suzhou municipal governments in 2008. Apparently, some of these new institutes are not fully supported by the public purse; in order to survive, they have to compete with existing institutes and engage in activities that bear little relation to CAS's mission as the national academy. Although CAS hosts the world's largest graduate school in terms of the number of postgraduate degrees awarded each year, which include 5 000 PhDs, CAS has been finding it difficult in recent years to attract the best and brightest students. This has spurred CAS to found two affiliated universities in Beijing and Shanghai, both of which opened their doors to a couple of hundred undergraduates in 2014.

CAS: full of promise but overstretched

Today, CAS employs a staff of 60 000 and counts 104 research institutes. It operates on a budget of roughly RMB 42 billion (*circa* US$ 6.8 billion), just under half of which comes from the government. The academy is struggling with a number of challenges. For one thing, it is in direct competition with other Chinese institutions of learning for funding and talent. Underpaid CAS scientists also have to apply constantly for grants to supplement their income, a widespread phenomenon in the entire research and higher education sector, which may have resulted in underperformance. CAS has also seen its work duplicated on a large scale by its own institutes, which tend not to collaborate with each other. There is also a lack of interest among CAS scientists in seeking opportunities to apply their research to the economy, although this should not be its core mission. Last but not least, the academy is encumbered by the breadth of its mandate, which ranges from research, talent training, strategic high-tech development, commercialization of research results and local engagement to the provision of policy advice as a think tank and through its elite academicians; this makes it extremely difficult for CAS to manage and evaluate institutes and individual scientists. In a word, the academy is big and full of promise, yet so cumbersome, weighed down by the legacy of the past (Cyranoski, 2014a).

Reform or be reformed!

In the past couple of years, CAS has come under enormous pressure from the political leadership to produce visible achievements. The loss of independence of the Russian Academy of Sciences, the successor to the Soviet Academy of Sciences on which CAS was modelled, in a top-down reform in 2013 (see Box 13.2), has sent a chilling signal: if CAS does not reform itself, others will. This realization prompted current CAS President Bai Chunli to take advantage of Xi's call for CAS to become 'a pioneer in four areas' (see p. 628) to propose a sweeping reform of the academy through a new Pioneering Action Initiative (*shuaixian xingdong jihua*). The aim of this initiative is to orient the academy towards the international frontier of science, major national demands and the battleground for the national economy by re-organizing existing institutes into four categories:

- centres of excellence (*zhuoyue chuangxin zhongxin*) focused on basic science, especially in those areas where China has a strong advantage;
- innovation academies (*chuangxin yanjiuyuan*) targeting areas with underdeveloped commercial potential;
- centres of big science (*dakexue yanjiu zhongxin*) built around large-scale facilities to promote domestic and international collaboration; and
- institutes with special characteristics (*tese yanjiusuo*) devoted to initiatives that foster local development and sustainability (Cyranoski, 2014a).

Box 23.4: **Water body pollution control and treatment: a mega-engineering programme**

The mega-engineering programme of water body pollution control and treatment has been designed to address the technology bottleneck in China's efforts to control and treat pollution of water bodies. In particular, the programme aims to achieve a breakthrough in key and generic technologies related to water pollution control and treatment, such as industrial pollution source control and treatment, agricultural non-point source pollution control and treatment, urban sewage treatment and recycling, purification and the ecological restoration of water bodies, drinking water safety and water pollution monitoring and early warning.

The programme focuses on four rivers (Huai, Hai, Liao and Songhua), three lakes (Tai, Chao and Dianchi) and the Three Gorges Reservoir, the largest dam in the world. Projects have been carried out within the six major themes of monitoring and early warning, city water environment, lakes, rivers, drinking water and policies.

The Ministry of Environmental Protection and the Ministry of Housing and Urban and Rural Construction are in charge of the programme, which got under way on 9 February 2009 with a budget of more than RMB 30 billion. The first stage of the programme to early 2014 targeted breakthroughs in key technologies to control source pollution and reduce wastewater discharge. The second stage is currently targeting breakthroughs in key technologies to fix the water bodies. The main goal of the third stage will be to make technological breakthroughs in comprehensive control of the water environment.

The first stage focused on the entire process wastewater treatment technology for heavily polluting industries, comprehensive treatments for heavily polluted rivers and lakes suffering from eutrophication, non-point source pollution control technology, water quality purification technologies, water-related environmental risk assessment and early warning, as well as key remote monitoring technology. Comprehensive demonstration projects were carried out in the Tai Lake basin to improve water quality and eliminate water from rivers running through cities that is of Class-V quality, which means it is only suitable for irrigation and landscaping. The first-stage projects also targeted problems related to drinking water. There have also been some achievements in water resources protection, water purification, safe distribution, monitoring, early warning, emergency treatment and safety management.

Source: http://nwpcp.mep.gov.cn

The reclassification of the CAS institutes and their scientists was still under way in 2015. It must be said that the initiative itself is self-congratulatory, as the academy is still resting on its past achievements, with little consideration for whether this new initiative may be good for the nation as well as for the academy. This explains why some are sceptical about the necessity of maintaining such a gigantic organization, a model not found anywhere else in the world.

The initiative offers the academy a bright future, as long as it can count on sizable government funding – but that is nothing new. Many of the goals that President Bai Chunli proposed for the Pioneering Action Initiative are identical to those of his predecessor, Lu Yongxiang, through his own Knowledge Innovation Programme. Nor is there any guarantee that these goals will be fulfilled through the reform.

The Pioneering Action Initiative is pivoting institutions into a new matrix so as to boost collaboration within the academy and concentrate on tackling key research questions, which has a certain logic. Implementation will be tough, though, since many institutes do not fit easily into any of the four defined categories. Another worry is that the initiative may not necessarily encourage collaboration with scientists external to CAS. The danger is that CAS may actually become even more hermetic and isolated than before.

The timing of the reform may also complicate matters. The reform at CAS coincides with the nationwide reform of public institutions (*shiye danwei*) launched in 2011. In general, the country's 1.26 million public institutions of education, research, culture and health care, which have more than 40 million employees, fall into two types. CAS institutes that fall into Type 1 are to be fully financed from the public purse and will be expected to fulfil only the tasks set by the state. Type II CAS institutes, on the other hand, will be allowed to supplement partial public funding with income earned through other activities, including through government procurement of their research projects, technology transfer and entrepreneurship. The reform will thus have implications both for the institutes and for individual scientists, in terms of the amount of stable funding they receive and the level of salaries, as well as the scope and importance of the executed projects. It is also likely that some CAS institutes will be corporatized, as this is what has happened to China's application-oriented R&D institutes since 1999. Consequently, CAS will need to become a leaner institution, as the state may not always be willing or able to finance such a costly academy.

Box 23.5: **Large-scale advanced nuclear power stations: a mega-engineering programme**

In 2015, China had 23 operable nuclear reactors and a further 26 were under construction. The country's large-scale nuclear power station programme has three components: advanced pressurized water reactors (PWR), special high-temperature reactors (HTR) and used fuel reprocessing. The central government is expected to invest RMB 11.9 billion and RMB 3 billion respectively in the two nuclear reactor sub-programmes.

The PWR sub-programme is being implemented by the State Nuclear Power Technology Corporation (SNPTC). It aims to digest and absorb imported third-generation nuclear power technology, which will then serve as the basis for developing more powerful large-scale advanced PWR technology, and to generate indigenous intellectual property rights.

The programme has three stages. Initially, the Westinghouse Electric Company, now a unit of Japanese engineering and electronics giant Toshiba, is helping SNPTC to build four advanced, passive units with an installed capacity of about 1 000 MW each (AP 1 000 units), through which SNPTC masters the basic design capability for third-generation nuclear power technology. At the second stage, SNPTC will develop a standardized design capability of AP 1 000 units, as well as the ability to build AP 1 000 units in both coastal and inland areas, with support from Westinghouse. By the third stage, SNPTC should be capable of designing advanced, passive third-generation nuclear reactors units of 1400 MW (Chinese AP 1 400); it should also be ready to build a CAP 1 400 demonstration unit and undertake a pre-research programme for the larger CAP 1 700 units.

The programme was launched on 15 February 2008. The construction of the AP 1 000 units in Sanmen in Zhejiang province and Haiyang in Shandong province got under way in 2009. Construction was put on hold, however, after the earthquake-induced nuclear disaster in Japan in March 2011 (see Chapter 24). Construction resumed in October 2012 and four AP 1 000 units are now expected to be online by late 2016.

SNPTC has been co-ordinating domestic nuclear power equipment manufacturers, research institutes and universities, which are in the process of assimilating imported equipment design and manufacturing technology and localizing key equipment used in the AP 1 000. Some key equipment has already been shipped to the Sanmen and Haiyang sites. In 2014, the first reactor pressure vessel for the second AP 1 000 unit in Sanmen was manufactured domestically.

In December 2009, SNPTC and the China Huaneng Group formed a joint venture to start a CAP 1 400 demonstration project in Shidaowan in Shandong province. The conceptual design passed the state's evaluation test at the end of 2010 and a preliminary design was completed in 2011. In January 2014, the National Energy Administration organized the expert review of the project and, in September, the National Nuclear Safety Administration approved the design safety analysis following a 17-month review. Key equipment for CAP 1 400 is currently being manufactured and the related demonstration project, which is due to start soon, is expected to localize 80% of the nuclear island equipment. Safety tests for key components used in CAP 1 400 unit have also gone ahead. The demonstration and standardized units of the CAP 1 400 demonstration project should be operational by 2018 and 2019 respectively.

Meanwhile, also in Shidaowan, a HTR-20 demonstration project is already up and running. The project will develop the world's first fourth-generation demonstration reactor, on the basis of the 100 MW HTR-10 prototype pebble-bed reactor developed by Tsinghua University.

Tsinghua University began building the HTR-10 reactor back in 1995. This fourth-generation nuclear energy technology is modelled on the German HTR-MODUL. The reactor was fully operational by January 2003. HTR-10 is claimed to be fundamentally safer, potentially cheaper and more efficient than other nuclear reactor designs. Operated at high temperatures, it generates hydrogen as a by-product, thus supplying an inexpensive and non-polluting fuel for fuel cell-powered vehicles.

Huaneng, the China Nuclear Energy Construction Company and Tsinghua University have established a joint venture to scale up the HTR experimental design and engineering technology, as well as high-performance fuel cell batch preparation techniques. Postponed after the Fukushima nuclear disaster in March 2011, the project finally got under way in late 2012. When it comes online in 2017, the Shidaowan project will have its first two 250 MW units, which together will drive a steam turbine generating 200 MW.

The third component of this mega-engineering programme concerns the construction of a large commercial spent fuel reprocessing demonstration project to achieve a closed fuel cycle.

Source: www.nmp.gov.cn

Rethinking government funding of research

Another major reform is this time shaking up the way in which the Chinese government funds research. China has seen rising central government expenditure on science and technology over the past decade. With RMB 236 billion (US$ 38.3 billion) in 2013, spending on science and technology accounted for 11.6% of the central government's direct public expenditure. Of this, R&D expenditure has been estimated at about RMB 167 billion (US$ 27 billion) by the National Bureau of Statistics (2014). As new national science and technology programmes had been added over the years, especially the mega-engineering programmes introduced under the *Medium- and Long-Term Plan* after 2006, funding had become decentralized and fragmented, resulting in widespread overlap and an inefficient use of funds. For example, about 30 different agencies administered the central government R&D funding through some 100 competitive programmes up until the launch of the new reform. To compound matters, pervasive corruption and misaligned incentives were seen as weakening the vitality of China's research enterprise (Cyranoski, 2014b). Change seemed inevitable.

Once again, the reform was instigated under the pressure of the political leadership. Initially, the measures proposed by the Ministry of Science and Technology (MoST) and the Ministry of Finance only made small adjustments to the existing system. All the major programmes were to be maintained and linked to one another, with the integration of small programmes, and new procedures for supporting research were to be introduced, along with other measures to avoid repetition and strengthen co-ordination between ministries. The Central Leading Group for Financial and Economic Affairs turned down several drafts of the reform proposal. It was only after the Central Leading Group for Financial and Economic Affairs contributed substantial input of its own that the measure was finally approved by the Central Leading Group for the Deepening of Comprehensive Reform, the Politburo of the CCP's Central Committee and the State Council. The reform re-organizes the nation's R&D programmes into five categories:

- Basic research through the National Natural Science Foundation of China, which currently distributes many of the small-scale competitive grants;
- Major national science and technology programmes, which are presumably the mega-science and mega-engineering programmes under the *Medium- and Long-Term Plan* to 2020;
- Key national research and development programmes, which presumably succeed the State High-Technology R&D Programme, also known as the 863 Programme, and the State Basic Research and Development Programme, also known as the 973 Programme;[5]
- A special fund to guide technological innovation; and
- Special programmes to develop human resources and infrastructure (Cyranoski, 2014b).

These five categories translate into some RMB 100 billion (US$ 16.36 billion), or 60% of the central government's funding for research in 2013, which will be handled by professional organizations specializing in research management by 2017. MoST, which distributed RMB 22 billion (US$ 3.6 billion) in public R&D funding in 2013, will gradually concede its role of administering the funding for programmes under its jurisdiction, most noticeably the 863 and 973 Programmes (Figure 23.8). Some other ministries with a portfolio for science and technology will likewise relinquish their power to distribute public research funds. In return, MoST will survive the reform intact, rather than being dissolved as had been debated for quite some time. The ministry will henceforth be in charge of formulating policy and monitoring the use of funding. In line with the reform, the ministry is restructuring to reorganize relevant departments. For example, its Planning and Development Bureau and Scientific Research Conditions and Finance Bureau have been merged to form the new Resource Allocation and Management Bureau to strengthen operational oversight of the future interministerial conference mechanism. Officials at bureau chief level have also been reshuffled within the ministry.

The interministerial conference mechanism is led by MoST with the participation of the Ministry of Finance, National Development and Reform Commission (NDRC) and others. The interministerial conference is responsible for planning and reviewing strategies for S&T development, determining national S&T programmes and their key tasks and guidelines and overseeing the professional research management organizations that will be formed to review and approve funding for national science and technology programmes. The interministerial conference will be supported by a committee responsible for strategic consulting and comprehensive review, which will be convened by MoST and composed of leading experts from the scientific community, industry and various economic sectors.

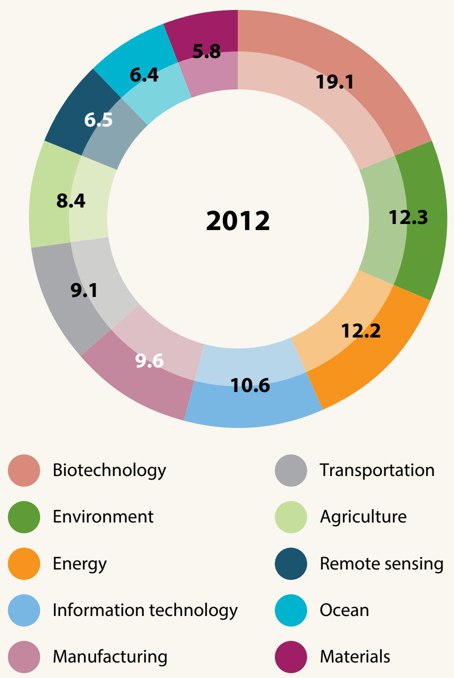
At the operational level, professional research management organizations will be established. Through a 'unified platform' or a national S&T information management system, they will organize project submission, evaluation, management and assessment. MoST and the Ministry of Finance will be responsible for reviewing and supervising the performance evaluation of the funding for national science and technology programmes, evaluating the performance of members of the strategic consulting and comprehensive review committee and the performance of the professional research management organizations. The procedures of programmes and projects will be adjusted as part of the dynamic evaluation and

5. For details of these programmes, see the *UNESCO Science Report 2010*.

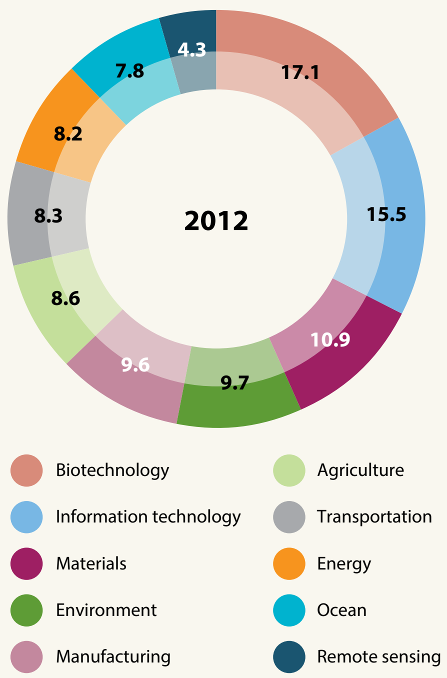
Figure 23.8: **Priorities of China's national research programmes, 2012**

PRIORITIES OF CHINA'S NATIONAL PROGRAMME FOR HIGH-TECH R&D (863 PROGRAMME)

Distribution of new projects by field (%)

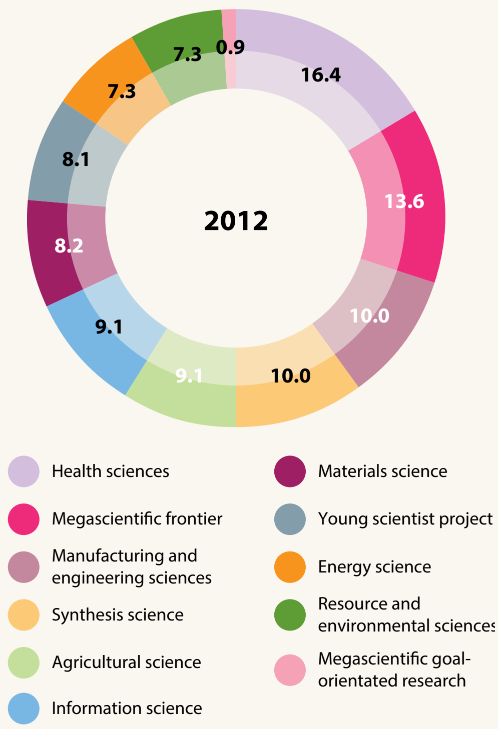


Distribution of budget for new projects by field (%)

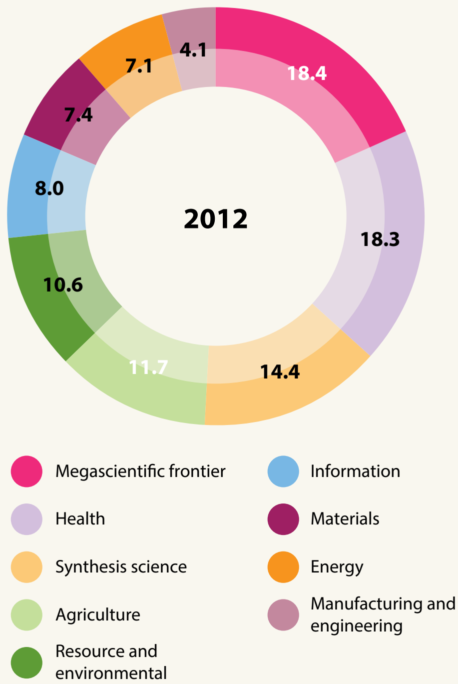


PRIORITIES OF CHINA'S NATIONAL PROGRAMME FOR KEY BASIC R&D (973 PROGRAMME)

Distribution of new projects by field (%)



Distribution of budget by field (%)



Source: Planning Bureau of Ministry of Science and Technology (2013) *Annual Report of the National Programmes of Science and Technology Development.*

monitoring process. The 'unified platform' will also collect and report information on national S&T programmes, including budget, personnel, progress, outcomes and evaluation and assessment, thus subjecting the entire process of research management to public scrutiny.

As yet, it is unclear how the professional research management organizations will be established and, above all, how they will operate. One possibility would be to transform the existing research management organizations, including those under MoST and other government ministries handling similar tasks. The question then becomes how to avoid 'putting new wine into an old bottle,' as opposed to changing fundamentally the way in which the government funds national science and technology programmes. The idea of professional research management organizations has been inspired by the UK model; in the UK, public funds destined for research are distributed through seven research councils for the arts and humanities, biotechnology and biological sciences, engineering and physical sciences, economic and social sciences, medical sciences, the natural environment and science and technology. This begs the question of how to integrate the existing programmes under different ministries according to the logic of scientific research rather than arbitrarily assigning them to the various professional research management organizations. Meanwhile, some government ministries may be reluctant to relinquish their control over funding.

An environmental action plan

China, along with India and other emerging economies, has long insisted on the principle of 'common but differentiated responsibilities' in dealing with global climate change. However, as the world's largest greenhouse gas (GHG) emitter, China is most susceptible to the adverse effects of climate change, mainly in agriculture, forestry, natural ecosystems, water resources (Box 23.4) and coastal areas. Irreversible climate change could throttle China's rise as a great power and cause environmental damage, GHG emissions and rising temperatures could derail China's path to modernity. Indeed, China has been facing the challenge of balancing its multiple development goals, which range from industrialization, urbanization, employment and exports to sustainability and include the target of doubling GDP by 2020. By reducing its GHG emissions and cleaning up the environment, the political leadership is also likely to gain further support from the emerging middle class; this support will be necessary to maintain the legitimacy of the Chinese Communist Party and help overcome other domestic challenges.

These concerns have prompted the Chinese government to come up with policies for energy conservation and GHG emissions reduction. In 2007, NDRC released the National Climate Change Programme, which proposed reducing unit GDP energy consumption by 20% by 2010 from 2005 levels, in order to reduce China's carbon dioxide (CO_2) emissions. Two years later, the government went a step further, establishing a target of reducing unit GDP CO_2 emissions by 40–45% by 2020 from 2005 levels. The reduction in energy consumption became a binding target in the *Eleventh Five-Year Plan* (2006–2010). The *Twelfth Five-Year Plan* (2011–2015) set the targets of reducing unit GDP energy consumption by 16% and CO_2 emissions by 17% by 2015. However, China did not meet the energy target in the *Eleventh Five-Year Plan* (2005–2010) and the *Twelfth Five-Year Plan* was also behind schedule in the first three years for reaching its targets, despite the enormous pressure brought to bear on local officials by the central leadership.

On 19 September 2014, China's State Council unveiled an *Energy Development Strategy Action Plan (2014–2020)* which promised more efficient, self-sufficient, green and innovative energy production and consumption. With the cap of annual primary energy consumption set at 4.8 billion tons of standard coal equivalent until 2020, the plan's long list of targets for building a modern energy structure includes:

- reducing unit GDP CO_2 emissions by 40–50% over 2005 levels;
- increasing the share of non-fossil fuels in the primary energy mix from 9.8% (2013) to 15%;
- capping total annual coal consumption at roughly 4.2 billion tons;
- lowering the share of coal in the national energy mix from the current 66% to less than 62%;
- raising the share of natural gas to above 10%;
- producing 30 billion m^3 of both shale gas and coalbed methane;
- having an installed nuclear power capacity of 58 Gigawatts (GW) and installations with a capacity of more than 30 GW under construction;
- increasing the capacity of hydropower, wind and solar power to 350 GW, 200 GW and 100 GW respectively; and
- boosting energy self-sufficiency to around 85%.

As China burned 3.6 billion tons of coal in 2013, capping total coal consumption at roughly 4.2 billion tons means that China can only increase its coal usage by roughly 17% by 2020 from 2013 levels. The cap also means that annual coal consumption may only grow by 3.5% or less between 2013 and 2020. To compensate for the drop in coal consumption, China plans to expand its nuclear energy production with the construction of new nuclear power stations (Box 23.5) and the development of hydropower, wind and solar energy (Tiezzi, 2014).

There are several reasons for China's emphasis on diversifying its energy mix. In addition to environmental considerations, China is eager to reduce its reliance on foreign energy suppliers. Currently, China receives nearly 60% of its oil and over 30% of its natural gas from foreign sources. For domestic production to make up 85% of total energy consumption by 2020, China will need to increase its production of natural gas, shale gas and coalbed methane. The new energy action plan also calls for deepwater drilling, as well as for the development of oil and gas extraction in its neighbouring seas by undertaking both independent extraction projects and co-operative projects with foreign countries (Tiezzi, 2014).

A week before the announcement of the new energy action plan, President Xi Jinping signed a joint climate change agreement with US President Barack Obama, in which China undertook to raise the share of non-fossil fuel sources to 20% of its energy mix by 2030. China also agreed to slow down then stop the increase in its GHG emissions by 2030; in turn, the USA pledged to reduce its own GHG emissions by up to 28% by 2025 relative to 2005 levels. Both presidents also agreed to co-operate in the fields of clean energy and environmental protection. Whereas China and the USA had blamed one another for the failure of the 2009 summit on climate change in Copenhagen to reach an agreement on setting emissions reduction targets, now there is strong hope that the negotiations might culminate in an agreement at the climate change conference in Paris in late 2015.

Amid all these positive developments, the Standing Committee of the National People's Congress – China's legislature – passed the *Amendment to Environmental Protection Law* on 24 April 2014, marking the end of a three-year revision of China's environmental protection law. The new law, which took effect on 1 January 2015, stipulates harmonizing socio-economic development with environmental protection and, for the first time, establishes clear requirements for building an ecological civilization. Perceived to be the most stringent in China's environmental protection history, the law toughens the penalties for environmental offences with specific articles and provisions for tackling pollution, raising public awareness and protecting whistle-blowers. It also places greater responsibility and accountability on local governments and law enforcement bodies for environmental protection, sets higher environmental protection standards for enterprises and imposes harsher penalties for such acts as tampering with and falsifying data, discharging pollutants deceptively, not operating pollution prevention and control facilities normally and evading supervision, among others (Zhang and Cao, 2015).

CONCLUSION

Realizing the 'China Dream' will not be unconditional

China's new political leadership has placed STI at the core of the reform of its economic system, as innovation can help not only with restructuring and transforming the economy but also with solving other challenges that China faces – from inclusive, harmonious and green development to an ageing society and the 'middle income trap.' The period from now to 2020 seems to be critical for the comprehensive deepening of reform, including the reform of the S&T system. As we have seen, new initiatives have been launched to reform the Chinese Academy of Sciences and the centrally financed national S&T programmes, in order to increase China's chances of becoming an innovation-oriented, modern nation by 2020.

The reform is necessary but it is still too early to predict whether it will lead China in the right direction and, if so, how quickly it will contribute to China's ambition of becoming an innovation-oriented nation. Particular concerns are the extent to which the reform reflects a 'top-level design', at the expense of the consultations with stakeholders and the public, coupled with the integration of bottom-up initiatives that proved crucial for the formulation and implementation of S&T policy in the earlier reform and open-door era. The merit of the 'whole nation system' also needs to be carefully assessed against the trend of globalization, which not only served as the backdrop to China's rise in economic and technological terms during the reform and open-door era but also brought China enormous benefits.

As we have seen, the level of dependence of Chinese enterprises on foreign core technologies is of some concern. The current political leadership has reacted by setting up an expert group under Vice-Premier Ma Kai to identify industrial 'champions' capable of concluding strategic partnerships with foreign multinationals. This resulted in Intel acquiring 20% of the shares in Tsinghua Unigroup, a state company emanating from one of the country's most prestigious universities, in September 2014. At the time of writing in July 2015, the *Wall Street Journal* had just revealed an offer by Tsinghua Unigroup to purchase Micron, a US manufacturer of semiconductors, for € 20.8 billion. Should the deal go ahead, it will be the biggest foreign takeover concluded by a Chinese firm since the China National Offshore Oil Corporation purchased the Canadian oil and gas company Nexen Inc. in 2012 for US$ 15 billion.

Knowledge transfer is evidently embedded in China's foreign direct investment and the efforts of the returnees, who are now active at the forefront of technology and innovation in China. Although the political leadership still calls for globalization to be embraced, recent cases of bribery and anti-monopoly moves targeting multinational companies operating in China, coupled with the restrictions on access to information and the current anti-Western values rhetoric, may lead to an exodus of capital and talent.

The smooth running of China's S&T system and, indeed, the economy as a whole, can be impacted by unstable domestic developments and unexpected external shocks. During the 30-plus-year reform and open-door era from 1978 onwards, scientists and engineers enjoyed a largely stable and favourable working environment which fostered professional satisfaction and career advancement. Chinese science and technology progressed at an impressive pace in an environment that was less politicized, interventionist and disruptive than today. China's scientific community is conscious that its work environment will need to be conducive to creativity and the cross-pollenization of ideas, if it is to contribute effectively to achieving the 'China Dream' envisaged by the country's political leadership.

KEY TARGETS FOR CHINA

- Raise GERD to 2.50% of GDP by 2020;
- Raise the contribution of technological advances to economic growth to more than 60% by 2020;
- Limit China's dependence on imported technology to no more than 30% by 2020;
- Become, by 2020, one of the top five countries in the world for the number of invention patents granted to its own citizens and ensure that Chinese-authored scientific papers figure among the world's most cited;
- Reduce (unit GDP) CO_2 emissions by 40–50% by 2020 from 2005 levels;
- Increase the share of non-fossil fuels in the primary energy mix from 9.8% (2013) to 15% by 2020;
- Cap annual coal consumption at roughly 4.2 billion tons by 2020, compared to 3.6 billion tons in 2013, and lower the share of coal in the national energy mix from 66% at present to less than 62% by 2020;
- Raise the share of natural gas to above 10% by 2020;
- Produce 30 billion m^3 of both shale gas and coalbed methane by 2020;
- Achieve an installed nuclear power capacity of 58 Gigawatts (GW) and installations with a capacity of more than 30 GW under construction by 2020;
- Increase the capacity of hydropower, wind and solar power to 350 GW, 200 GW and 100 GW respectively by 2020;
- Boost energy self-sufficiency to around 85%.

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ACKNOWLEDGMENTS

The author wishes to thank Prof. Richard P. Suttmeier for his comments on the draft chapter and Dr Yutao Sun for providing information on some of the statistics used in the present chapter.

Japan needs to adopt forward-looking policies ... and to pursue the necessary reforms to adapt to the changing global landscape.

Yasushi Sato and **Tateo Arimoto**

ASIMO is the culmination of two decades of humanoid robotics research by Honda engineers. Pictured here in 2007, ASIMO can run, walk on uneven slopes and surfaces, turn smoothly, climb stairs and reach for and grasp objects. ASIMO can also comprehend and respond to simple voice commands. ASIMO has the ability to recognize the face of a select group of individuals. Using its camera eyes, ASIMO can map its environment and register stationary objects. ASIMO can also avoid moving obstacles as it moves through its environment.

Photo: © http://asimo.honda.com

24 · Japan

Yasushi Sato and Tateo Arimoto

INTRODUCTION

Two turning points in Japanese politics

Twice, Japan has experienced a political turning point in the past decade. The first came in August 2009, with the electoral defeat of the Liberal Democratic Party (LDP), which had dominated Japanese politics for over half a century. Frustrated by the LDP's failure to shake Japan out of a two decade-long economic slump, Japanese voters placed their hopes in the Democratic Party of Japan (DPJ). Three prime ministers followed in quick succession, none of whom succeeded in rebooting the economy. Twenty-one months after the Great East Japan Earthquake triggered a tsunami and the Fukushima nuclear disaster in March 2011, disillusioned voters returned the LDP to power in the December 2012 general election.

The new prime minister, Shinzo Abe, put in place a set of extraordinarily active fiscal and economic policies which have been dubbed Abenomics. After news emerged that Japan had officially slipped into recession following an increase in taxation on consumption, the prime minister called a snap election in December 2014 to consult the public on whether or not to pursue Abenomics. His party won a landslide victory.

Long-term challenges: an ageing society and economic stagnation

Although Abenomics has helped Japan to recover from recession in the wake of the global financial crisis of 2008, the nation's underlying problems remain. Japan's population peaked in 2008 before embarking on a gradual decline. As the proportion of seniors in the nation's population has surged, Japan has become the world's most aged society, even if the fertility rate did rise somewhat between 2005 and 2013, from 1.26 to 1.43 children per woman. The combination of a sluggish economy and ageing society has necessitated the mobilization of increasingly massive government expenditure, especially for social security. The share of accumulated total government debt in GDP exceeded 200% in 2011 and has since continued to climb (Table 24.1). To help service this debt, the Japanese government raised the tax on consumption from 5% to 8% in April 2014. The Abe cabinet then decided to postpone raising this tax further to 10% until April 2017, citing Japan's weak economic performance.

The current fiscal situation is clearly unsustainable. Whereas government expenditure on social security rose steadily from 2008 to 2013 at an average annual rate of 6.0%, total national revenue barely progressed. In May 2014, the International Monetary Fund (IMF) recommended that Japan raise its consumption tax rate to at least 15%. This figure is still much lower than in most European nations but it would be very difficult to implement the IMF's recommendation in Japan, as most people, especially seniors, would overwhelmingly vote against any party responsible for such a decision. At the same time, the Japanese would also resist any drop in the current level of public service, which is characterized by cost-efficient, hospitable and universal health care, fair and reliable public education and trusted police and judicial systems. Politicians have thus been able to do little to contrary the rapidly widening gap between revenue and expenditure.

Under such extraordinary fiscal pressure, the government has indeed tried hard to streamline public expenditure. The defence budget remained roughly constant from 2008 to 2013, although it was then moderately augmented as attention focused on changing geopolitical circumstances in Asia. Spending on public works was radically cut back by the DPJ administration but increased again after the Great East Japan Earthquake, especially under the Abe administration. The budget for education shrank constantly from 2008 to 2013, with the notable exception of DPJ's flagship policy of making secondary school education free of charge, introduced in 2010. After expanding constantly for years, the budget for the promotion of science and technology (S&T) went into reverse. Although the government still sees S&T as a key driver of innovation and economic growth, the combination of limited revenue and rising expenditure for social security does not bode well for public support of S&T in Japan.

In the private sector, too, investment in research and development (R&D) has dropped since the global financial

Table 24.1: **Socio-economic indicators for Japan, 2008 and 2013**

Year	GDP growth, volume (%)	Population (millions)	Share of population aged 65 years and above (%)	Government debt as a share of GDP (%)*
2008	-1.0	127.3	21.6	171.1
2013	1.5	127.1	25.1	224.2

*General government gross financial liabilities

Source: OECD (2014) *Economic Outlook No.96;* IMF World Economic Outlook database, October 2014; for population data: UN Department of Economic and Social Affairs crisis of 2008, along with capital investment. Instead of investing their resources, firms have been accumulating profits to constitute an internal reserve which now amounts to roughly 70% of Japan's GDP. This is because they increasingly feel the need to be prepared for momentous socio-economic changes, even though these are hardly predictable. A 4.5% reduction in the corporate tax rate in 2012, in response to similar global trends, helped Japanese firms amass their internal reserve, albeit at the expense of raising their employees' salaries. In fact, Japanese firms have consistently cut operational costs over the past 20 years by replacing permanent employees with contractors, in order to compete in the global market. After peaking in 1997, the average salary in the private sector had dropped by 8% by 2008 and by 11.5% by 2013, enlarging income disparities. Moreover, as in many advanced nations, young people increasingly find themselves occupying temporary jobs or working as contractors. This makes it difficult for them to acquire skills and gives them little say in their career paths.

'Japan is back!'

It was in the midst of such fiscal and economic distress that Prime Minister Abe came to office in December 2012. He vowed to make Japan's economic recovery his top priority by overcoming deflation, which had afflicted the Japanese economy for nearly two decades. Soon after his inauguration, he made a speech in February 2013 entitled *Japan is Back,* during a visit to the USA. Abenomics consists of 'three arrows,' namely monetary easing, fiscal stimulus and a growth strategy. Investors the world over were intrigued and began paying special attention to Japan in 2013, resulting in a rise of stock prices by 57% in a year. At the same time, overappeciation of the yen, a phenomenon which had tormented Japanese manufacturers, came to an end. The prime minister even urged the private sector to raise employees' salaries, which it did.

The full effects of Abenomics on the Japanese economy are yet to be seen, however. Although the depreciation of the yen has helped Japan's export industry, the extent to which Japanese firms will bring their factories and R&D centres abroad back to Japan remains unclear. A weaker yen has also raised the price of imported goods and materials, including oil and other natural resources, worsening Japan's trade balance.

It appears that, in the end, Japan's long-term economic health will depend on the third arrow of Abenomics, namely, its growth strategy, the key elements of which include enhancing the social and economic participation of women, fostering medical and other growing industries and promoting science, technology and innovation (STI). Whether these goals are achieved will fundamentally affect the future of Japanese society.

TRENDS IN STI GOVERNANCE

A radical departure from the past

It was the Basic Law on Science and Technology (1995) which first mandated the Japanese government to formulate the *Basic Plan for Science and Technology,* the most fundamental document in this policy area. The *Basic Plan* has since been revised every five years. The *First Basic Plan* (1996) called for a drastic increase in government expenditure on R&D, a wider range of competitive research funds and proper care for research infrastructure. The *Second* and *Third Basic Plan*s specified life sciences, information and communication technologies (ICTs), environment and nanotechnology/materials science as being the four priority areas for resource allocation, while also emphasizing the importance of basic science. Whereas fostering a competitive research environment and university–industry collaboration continued to be a major policy agenda, communicating science to society gained greater importance. Innovation became a keyword for the first time in the *Third Basic Plan*, published in 2006. A review of implementation of the *Third Basic Plan* by the Council for Science and Technology Policy found growing support for young researchers, a higher proportion of female researchers and greater university–industry collaboration but noted that further efforts were necessary in these areas. The review also emphasized the importance of effective Plan–Do–Check–Act mechanisms.

Just as the Council for Science and Technology Policy was putting the final touches to the *Fourth Basic Plan*, the Great East Japan Earthquake struck on 11 March 2011. The triple catastrophe – the earthquake having triggered a tsunami and the Fukushima nuclear disaster – made a tremendous impact on Japanese society. About 20 000 people died or were reported missing, 400 000 houses and buildings were damaged and properties amounting to hundreds of billions of dollars were destroyed. A wide area encompassing towns and farms had to be evacuated after being contaminated by radioactive materials and six nuclear reactors had to be abandoned; all the remaining reactors were halted across the nation, although a few did temporarily resume operations later. A large-scale plan to save electricity was implemented nationwide over the summer of 2011.

The release of the *Fourth Basic Plan* was postponed until August 2011, in order to take these developments into account. The new *Plan* was a radical departure from its predecessors. It no longer identified priority areas for R&D but rather put forward three key issue areas to be addressed: recovery and reconstruction from the disaster, 'green innovation' and 'life innovation.' The *Plan* also specified other priority issues, such as a safe, affluent and better quality of life for the public, strong industrial competitiveness, Japan's contribution to solving global problems and sustaining the national foundations.

Thus, the *Fourth Basic Plan* made a radical transition from discipline-based to issue-driven STI policy.

In June 2013, just months after the Abe government's pledge to revive the economy rapidly, the government introduced a new type of policy document, the *Comprehensive Strategy on STI*, a combination of a longer-term vision and actions of a one-year duration. The *Comprehensive Strategy* enumerated concrete R&D themes in such fields as energy systems, health, next-generation infrastructure and regional development, while at the same time proposing ways of improving the national innovation system. The plan also identified three key directions for STI policy: 'smartization,[1]' 'systemization' and 'globalization.' In June 2014, the government revised the *Comprehensive Strategy*, specifying the following areas as being important cross-cutting technological fields for realizing the strategy's vision: ICTs, nanotechnology and environmental technology.

Getting universities to play a more active role in innovation

Any general document related to STI policy in Japan in the past decade has consistently laid heavy emphasis on innovation and university–industry collaboration. A rationale often put forward is that Japan is doing fairly well in scientific research and technological development but is losing ground in terms of value creation and competing on the world stage. Politicians, government officials and industrial leaders all believe that innovation is the key to recovery from Japan's chronic economic stagnation. They also agree that universities should play a more active role in this endeavour.

By 2010, there were already major laws in place to foster university–industry collaboration. The Japanese version of the 'Bayh-Dole provision'[2], which accorded intellectual property rights resulting from publicly funded R&D to research institutes rather than the government, was first codified in a specific act passed in 1999 then made permanent by the Industrial Technology Enhancement Act, amended in 2007. Meanwhile, the Intellectual Property Basic Act had come into effect in 2003, the year that an ambitious reform of tax exemptions for private firms' R&D expenses was introduced, in particular those expenses relating to their collaboration with universities and national R&D institutes. In 2006, the Basic Act on Education was officially amended to expand the mission of universities beyond education and research to making a contribution to society, which implicitly encompassed industrial and regional development.

Numerous programmes were launched within these legal frameworks to foster university–industry collaboration. Some aimed at creating large centres for university–industry research collaboration on varied themes, whereas others supported the creation of university start-ups. There were also programmes to strengthen existing intra-university centres for liaising with industry, supporting university research that responded to specific industrial demands and fostering and deploying co-ordinators at universities. The government also created a series of regional clusters in 2000, although many of these were abolished between 2009 and 2012 after the government decided to terminate innumerable programmes in a hasty effort to cut public spending.

Such a broad range of government support has led to persistent growth in university–industry collaboration in Japan in the past five years. Compared with the preceding five years, however, growth has slowed. In particular, the number of new university start-ups has dropped sharply from a peak of 252 in 2004 to just 52 in 2013 (Table 24.2). In part, this trend reflects the maturation of university–industry relationships in Japan but it may also imply a loss of momentum in public policy initiatives in recent years.

Support for high-risk, high-impact R&D

Nonetheless, the Japanese government remains convinced that promoting innovation through university–industry collaboration is vital for the nation's growth strategy. It has thus recently launched a series of new schemes. In 2012, the government decided to invest in four major universities which would then establish their own funds to invest in new university start-ups jointly with financial institutions, private firms or other partners. When such endeavours yield a profit, part of the profit is returned to the national treasury.

1. Smartization is a term underlying such concepts as 'smart grid' and 'smart city.'

2. The Bayh-Dole Act (officially The Patent and Trademark Law Amendments Act) of 1980 authorized US universities and businesses to commercialize their federally funded inventions.

Table 24.2: **Collaboration between universities and industry in Japan, 2008 and 2013**

Year	Number of joint research projects	Amount of money received by universities in joint research projects (¥ millions)	Number of contract research projects	Amount of money received by universities via contract research projects (¥ millions)	Number of new university start-ups
2008	17 638	43 824	19 201	170 019	90
2013	21 336	51 666	22 212	169 071	52

Note: Here, universities include technical colleges and inter-university research institutes.

Source: UNESCO Institute for Statistics, April 2015

In 2014, a new large programme was launched to support high-risk, high-impact R&D, entitled Impulsing Paradigm Change through disruptive Technologies (ImPACT). This scheme is in many ways similar to that of the US Defense Advanced Research Project Agency. Programme managers have been given considerable discretion and flexibility in assembling teams and directing their efforts.

Another major scheme that got under way in 2014 is the Cross-ministerial Strategic Innovation Promotion (SIP) programme. In order to overcome interministerial barriers, the Council for Science, Technology and Innovation[3] directly administers this programme, promoting all stages of R&D which address key socio-economic challenges for Japan, such as infrastructure management, resilient disaster prevention and agriculture.

These new funding schemes reflect the growing recognition among Japanese policy-makers of the need to finance the entire value chain. The Japanese government is hoping that these new schemes will give rise to groundbreaking innovation that will solve social problems and, at the same time, boost the Japanese economy in the way envisioned by the Abe cabinet.

A boost for renewable energy and clean technology

Historically, Japan has made heavy investments in energy and environmental technology. With few natural resources to speak of, it has launched many national projects since the 1970s to develop both renewable and nuclear energy. Japan had the largest share of solar power generation in the world until the mid-2000s, when it was rapidly overtaken by Germany and China.

After the Great East Japan Earthquake of March 2011, Japan decided to place renewed emphasis on the development and use of renewable energy, particularly since the country's entire network of nuclear reactors was at a standstill by May 2012, with no clear prospect of their starting up again. In July 2012, the government introduced a feed-in tariff, a system which mandates utilities to purchase electricity from renewable energy producers at fixed prices. Relevant deregulation, tax reductions and financial assistance have also encouraged private investment in renewable energy. As a result, the market for solar power has quickly expanded, while the cost of solar electricity has steadily dropped. The share of renewable energy (excluding hydroelectric power) in Japan's total electricity generation rose from 1.0% in 2008 to 2.2% in 2013. It is expected that existing government policies will further enlarge the market for renewable energy.

Japanese industry has been a slow-starter in aeronautics but, since 2003, the Ministry of the Economy, Trade and Industry has been subsidizing an undertaking by Mitsubishi Heavy Industries to develop a jet airliner which it hopes will conquer the global market, thanks to its high fuel efficiency, low environmental impact and minimal noise (Box 24.1).

A disaffection for academic careers

As in many other nations, young Japanese PhD-holders have been finding it difficult to obtain permanent positions in universities or research institutes. The number of doctoral students is on the decline, with many master's students not daring to embark on a seemingly unrewarding career in research.

In response, the Japanese government has taken a series of measures since 2006 to diversify the career paths of young researchers. There have been schemes to promote university–industry exchanges, subsidize internships and develop training programmes to give PhD candidates broader prospects and skills. The government has also promoted curricular reform of doctoral programmes to produce graduates who can more readily adapt to the non-academic environment. In 2011, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) initiated a large-scale Programme for Leading Graduate Schools; this programme has funded the ambitious reform of graduate programmes engaged by universities to stimulate creativity and provide broad-based skills, in order to incubate global leaders in industry, academia and government.

At the same time, the government has taken steps to reform universities' personnel systems. In 2006, the government began subsidizing the introduction of a tenure–track system at university, which had traditionally been absent from Japanese academia. The subsidy was expanded in 2011. The concept of university research administrator (URA) was also officially introduced in 2011. URAs perform a wide range of duties, such as analysing their own institution's strengths, formulating strategies to acquire R&D funding, managing R&D funding, handling issues related to intellectual property rights and maintaining external relations. However, in some universities, URAs are still regarded as being no more than support staff for researchers. It may take some time for the specificity of URAs to be duly recognized in Japanese universities.

Falling student rolls may prompt radical reform

A powerful trend in higher education in recent years has been the emphasis on global human resources, or in other words, people who have no difficulty in working transnationally. Traditionally, the Japanese have been conscious that international interaction is not their strong point, largely due to their poor English. At the turn of the

3. Formerly the Council for Science and Technology Policy, it was strengthened and renamed in 2014.

Box 24.1: **The Mitsubishi Regional Jet**

The Mitsubishi Regional Jet is the first jet airliner to be designed and produced in Japan. Its official rollout took place on 18 October 2014 and its maiden flight is scheduled for 2015. The first deliveries should follow in 2017. Hundreds of orders have already been received from domestic and foreign airlines.

The jet's main manufacturers are Mitsubishi Heavy Industries and its subsidiary Mitsubishi Aircraft Corporation, established in 2008. Different models of the jet will carry 70–90 passengers with flight ranges of 1 500–3 400 km.

The Japanese aerospace industry has been a slow-starter in aeronautics. Aircraft production was banned in Japan for seven years after the end of the Second World War. After the ban was lifted, research on aerospace technology gradually took off, thanks to the entrepreneurial efforts of a group of researchers at the University of Tokyo and other academic, industrial and government institutions.

Over the following decades, plans to develop and produce aeroplanes were repeatedly thwarted. A semi-public corporation created in 1959 began developing a medium-sized turboprop airliner YS-11 and actually produced 182 airframes before being disbanded and absorbed into Mitsubishi Heavy Industries in 1982 after accumulating losses. Heavily subsidized and controlled by the Ministry of International Trade and Industry (renamed the Ministry of the Economy, Trade and Industry in 2001), the corporation lacked the requisite flexibility to adapt to the changing international market.

Although the ministry consistently strived to promote the Japanese aerospace industry from the 1970s onwards, it was not easy for Japanese manufacturers to realize their plans to develop new aircraft. For a long time, they remained subcontractors to American and European firms. It was only in 2003 that Mitsubishi Heavy Industries began developing a medium-sized jet airliner, a year after the ministry announced that it would subsidize such an undertaking. The original plan was to make a maiden flight by 2007 but this proved overly optimistic.

The initial budget of ¥ 50 billion has since grown to around ¥ 200 billion but, thanks to the tenacious efforts of Mitsubishi and other manufacturers, the Mitsubish Regional Jet boasts high fuel efficiency, a low environmental impact and little noise. Japan's traditional strength in carbon fibre, which has been widely adopted in aeroplanes all over the world, has also been fully incorporated in the jet. Hopefully, these technological merits will have strong consumer appeal in the global market.

Source: compiled by authors

century, however, virtually all businesses were finding it increasingly difficult to operate within Japan's closed market. In response, MEXT initiated a major project in 2012 for the Promotion of Global Human Resource Development, which was expanded in 2014 into the Top Global University Project. These projects provided universities with generous subsidies to produce specialists who would feel comfortable working transnationally. Such government projects aside, Japanese universities are themselves making it a priority to educate students in today's global context and to enrol international students. By 2013, 15.5% of all graduate students (255 386) were of foreign origin (39 641). The great majority (88%) of international graduates[4] were Asian (34 840), including 22 701 from China and 2 853 from the Republic of Korea.

Arguably the most fundamental challenge facing Japanese universities is the shrinking 18 year-old population. Since peaking at 2 049 471 in 1992, the number of 18 year-olds has almost halved to 1 180 838 (2014). The number of university entrants has nevertheless risen, owing to the surge in the proportion of young Japanese attending university: 26.4% in 1992 and 51.5% in 2014 (Figure 24.1). However, most stakeholders see signs of saturation; they share the view that a radical reform of the nation's university system is imminent.

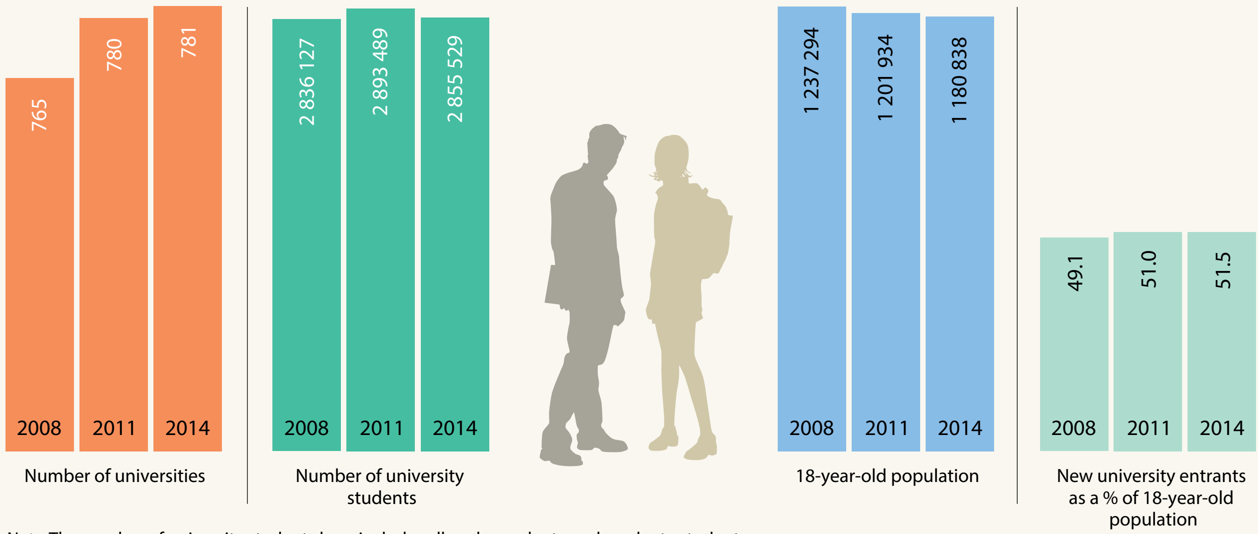
The number of universities in Japan had climbed steadily until recently. As of 2014, there were 86 national universities, 92 other public universities and 603 private universities. This total (781) is quite large by international standards. About half of private universities are now unable to fill their quota, suggesting that a massive consolidation and merger may take place in the near future.

An historic reform which stratifies universities

A government-led structural reform of national universities is already under way. Ever since these were semi-privatized in 2004 and renamed national university corporations, their regular government funding has been cut by roughly 1% each year. National universities were expected to help themselves by obtaining more research grants, more private-sector funding and more donations. Not all of them have managed to adapt well to this new environment, however;

4. Others came from Viet Nam (1 333) and Malaysia (685). Among non-Asian students, 1 959 were European, 872 African, 747 from the Middle East, 649 from Latin America (649) and 424 from North America.

Figure 24.1: **Number of universities and university students in Japan, 2008, 2011 and 2014**



Note: The number of university students here includes all undergraduate and graduate students.

Source: MEXT (2014b, 2014c)

only a handful have remained healthy, the others having suffered from shrinking funding. In light of this situation, the government has been urging universities since 2012 to initiate reforms and to redefine their own missions to make the most of their unique strengths. As an incentive, the government is providing universities willing to engage in reform with a range of subsidies.

The universities' efforts alone have not sufficed, however. In November 2013, MEXT announced the *National University Reform Plan*, in which the ministry suggested that each national university choose one of three directions; it could become a world-class centre for education and research, a national centre for education and research or a core centre for regional revitalization. In July 2014, MEXT made it clear that funding for national universities would also be reformed; under the new scheme, three types of universities would be evaluated according to different criteria and funding options. This is an epoch-making decision because all national universities in Japan have had the same institutional status up until now. From now on, they will be officially stratified.

Publicly funded R&D institutions are also under reform. Previously, institutions such as the Japan Aerospace Exploration Agency, Japan International Cooperation Agency and Urban Renaissance Agency fell under the same category of independent administrative agencies. In June 2014, a bill was passed which attributes a separate status of national R&D agency to 31 out of 98 agencies. National R&D agencies will be evaluated on a relatively long-term basis (every 5–7 years), compared to other agencies (mostly 3–5 years), to maximize their R&D performance.

Although the Institute of Physical and Chemical Research (RIKEN) and the National Institute of Advanced Industrial Science and Technology (AIST) are currently catalogued as independent administrative agencies, the government was intending to make them special national R&D agencies, a status which would have given them considerable latitude in introducing unique evaluation systems and entitled them to pay exceptionally high salaries to outstanding researchers. The plan has been put on hold, however, following a highly publicized case of misconduct by a RIKEN researcher which shall be evoked again below.

Creating spaces where scientists and the public can meet

In 2001, the second *Basic Plan for Science and Technology* recognized the increasing interdependence between science and society. It underlined the need to strengthen bidirectional communication between science and society, urging researchers in social sciences and humanities to play their part. Since then, a great variety of programmes related to science communication, science cafés, science outreach, science literacy and risk communication have been launched. Graduate programmes in science communication and science journalism have been introduced in several universities and the number of science communicators has clearly increased. Since 2006, the Japan Science and Technology Agency has been holding an annual festival called Science Agora to provide a place for scientists and the general public to meet. Science Agora's mandate was expanded in 2014 to include debate on critical social issues related to science and technology.

Scientific advice has come to the fore since the triple catastrophe

The importance of maintaining a dialogue between scientists and policy-makers has been recognized more recently. The issue of scientific advice came to the fore after the Great East Japan Earthquake of March 2011. There was a widespread perception that the government was unable to mobilize scientific knowledge to cope with the triple catastrophe. A series of symposia were held to discuss the role of scientific advice in policy-making and the idea was tabled of appointing science advisors to the prime minister and other ministers, although this idea has not materialized yet. Meanwhile, the Science Council of Japan (the Japanese Academy of Sciences) revised its Code of Conduct for Scientists in January 2013, adding a new section on scientific advice. A stronger commitment to this issue on the part of policy-makers will be necessary for Japan to participate actively in the rapidly evolving international discussion on this topic.

In 2011, the government launched a programme called Science for RE-designing Science, Technology and Innovation Policy (SciREX). The purpose is to establish a system which reflects scientific evidence[5] more robustly in STI policy. The SciREX programme supports several research and education centres within universities, issues grants to researchers in relevant fields, and promote the construction of the relevant evidence base. The many researchers in social sciences and humanities involved in this programme are training specialists in this new field and publishing their findings on such themes as science-based innovation, STI and economic growth, policy-making processes, the social implication of S&T and the evaluation of R&D.

While SciREX is mainly concerned with evidence-based STI policy, science and technology can also inform other policy fields, such as environmental policy and health policy ('science for policy,' as opposed to 'policy for science'). In these fields, policy-makers rely heavily on advice put forward by scientists in various formats because solid policy-making is impossible without specialized knowledge of relevant phenomena.

Despite the obvious virtues of scientific advice for policy-making, the relationship between the two is not always straightforward. Scientific advice can reflect uncertainties and scientists may express divergent opinions. Scientific advisors may be affected by a conflict of interest, or subject to pressure from policy-makers. For their part, policy-makers may select scientific advisors arbitrarily or interpret scientific advice in biased ways. The question of scientific advice has thus become an important topic for discussion in many Western nations and international bodies like the OECD.

5. understood as encompassing not only information and knowledge from natural sciences but also from economics, political science and other social sciences, as well as humanities

Research misconduct has undermined public trust

Research integrity is at the heart of public trust in science. In Japan, the number of publicized cases of research misconduct increased markedly during the 2000s, in parallel with shrinking regular funding for universities and the growth in competitive grants. In 2006, the government and the Science Council of Japan respectively established guidelines on research misconduct but these have not reversed the trend. Since 2010, there has been a spate of reported cases of large-scale research misconduct and misuse of research funds.

In 2014, an extremely serious and highly conspicuous case of research misconduct was exposed in Japan. On 28 January, a 30-year old female researcher and her senior colleagues held a sensational press conference at which they announced that their papers on the creation of Stimulus-Triggered Acquisition of Pluripotent (STAP) cells were being published in *Nature* the next day. This stunning scientific breakthrough received extensive media coverage and the young researcher became a star overnight. Soon after, however, questions were raised in cyberspace about indications of manipulated figures and plagiarized texts in the papers. Her employer, RIKEN, subsequently confirmed her misconduct on 1 April. Although she resisted for a long time and never publicly admitted her misdeeds, she did resign from RIKEN after the institute's investigative committee conclusively rejected the validity of the papers on 26 December, asserting that the STAP cells were in fact another well-known type of pluripotent cell known as embryonic stem cells.

The saga was closely followed by the Japanese population; it seriously undermined public perception of the validity of science in Japan. The case also spurred a wider round of public debate on S&T policy in general. For example, after questions were raised about the young researcher's doctoral thesis, her alma mater, Waseda University, carried out an investigation and decided to cancel her degree with a one-year suspension to give her time to make the necessary corrections. In parallel, the university began investigating other theses originating from her former department. Aside from the problem of quality assurance of degrees, many other issues came to the fore, such as the intense competition among researchers and institutions and the inadequate training of young researchers. In response to this serious, highly publicized case, MEXT revised its guidelines on research misconduct in 2014. These guidelines alone will not suffice, however, to solve the underlying problems.

TRENDS IN R&D

Low government spending on R&D

Japan's gross domestic expenditure on R&D (GERD) had grown consistently until 2007, before plunging suddenly by nearly 10% in the aftermath of the US subprime crisis. Only in 2013 did GERD rebound, mainly due to the recovery of the global economy (Table 24.3). Japan's GERD is closely linked to the nation's GDP, so the drop in GDP in recent years has allowed Japan's GERD/GDP ratio to remain high by international standards.

Government expenditure on R&D increased over the same period but appearances can be deceptive. Japan's R&D budget fluctuates each year owing to the irregular, yet frequent approval of supplementary budgets, especially in the wake of the Great East Japan Earthquake. If we look at the long-term trend, Japan's stagnating government R&D expenditure reflects the extremely tight fiscal situation. By any measurement, though, the ratio of government spending on R&D to GDP has remained low by international standards; the *Fourth Basic Plan* (2011) fixes the target of raising this ratio to 1% or more of GDP by 2015. The *Plan* contains a second ambitious target, that of raising GERD to 4% of GDP by 2020.

The overall structure of Japan's government R&D expenditure has gradually changed. As we said earlier, regular funding of national universities has declined consistently for more than a decade by roughly 1% a year. In parallel, the amount of competitive grants and project funding have increased. In particular, there has been a proliferation recently of multi-purpose, large-scale grants that do not target individual researchers but rather the universities themselves; these grants are not destined purely to fund university research and/or education *per se;* they also mandate universities to conduct systemic reforms, such as the revision of curricula, introduction of tenure–track systems, diversification of researchers' career paths, promotion of female researchers, internationalization of educational and research activities and moves to improve university governance.

As many universities are now in serious want of funding, they spend an extraordinary amount of time and effort applying for these large institutional grants. There is growing recognition, however, of the side-effects of spending so much time on applications, administration and project evaluation: a heavy burden on both academic and administrative staff; short-cycle evaluations can discourage research and education from longer-term viewpoints and; it is often hard to maintain project activities, teams and infrastructure once the projects end. How to strike the best balance between regular and project funding is thus becoming an important policy issue in Japan.

The most remarkable trend in industrial spending on R&D has been the substantial cutback in ICTs (Figure 24.2). Even the Nippon Telegraph and Telephone Corporation, which had historically played a key role as a formerly public organization, was forced to trim its R&D spending. Most other industries maintained more or less the same level of R&D expenditure between 2008 and 2013. Car manufacturers coped relatively well, for instance, Toyota even coming out on top for global car sales between 2012 and 2014. Hardest hit after the global recession of 2008–2009 were Japanese electric manufacturers, including major players such as Panasonic, Sony and NEC, which cut back their R&D spending drastically in the face of severe financial difficulties; compared with manufacturers in other fields, their recovery has been slow and unsteady. It remains to be seen whether the economic stimuli introduced through Abenomics since 2013 will reverse this trend.

Cutbacks in industry have affected research staff

The number of researchers in Japan grew steadily until 2009, when private enterprises began cutting back their research[6] spending. By 2013, there were 892 406 researchers in Japan (by head count), according to the OECD, which translated into 660 489 full-time equivalents (FTE). Despite the drop since 2009, the number of researchers per 10 000 inhabitants remains among the highest in the world (Figure 24.3).

6. Some enterprises stopped hiring, others laid off staff or re-assigned them to non-research positions.

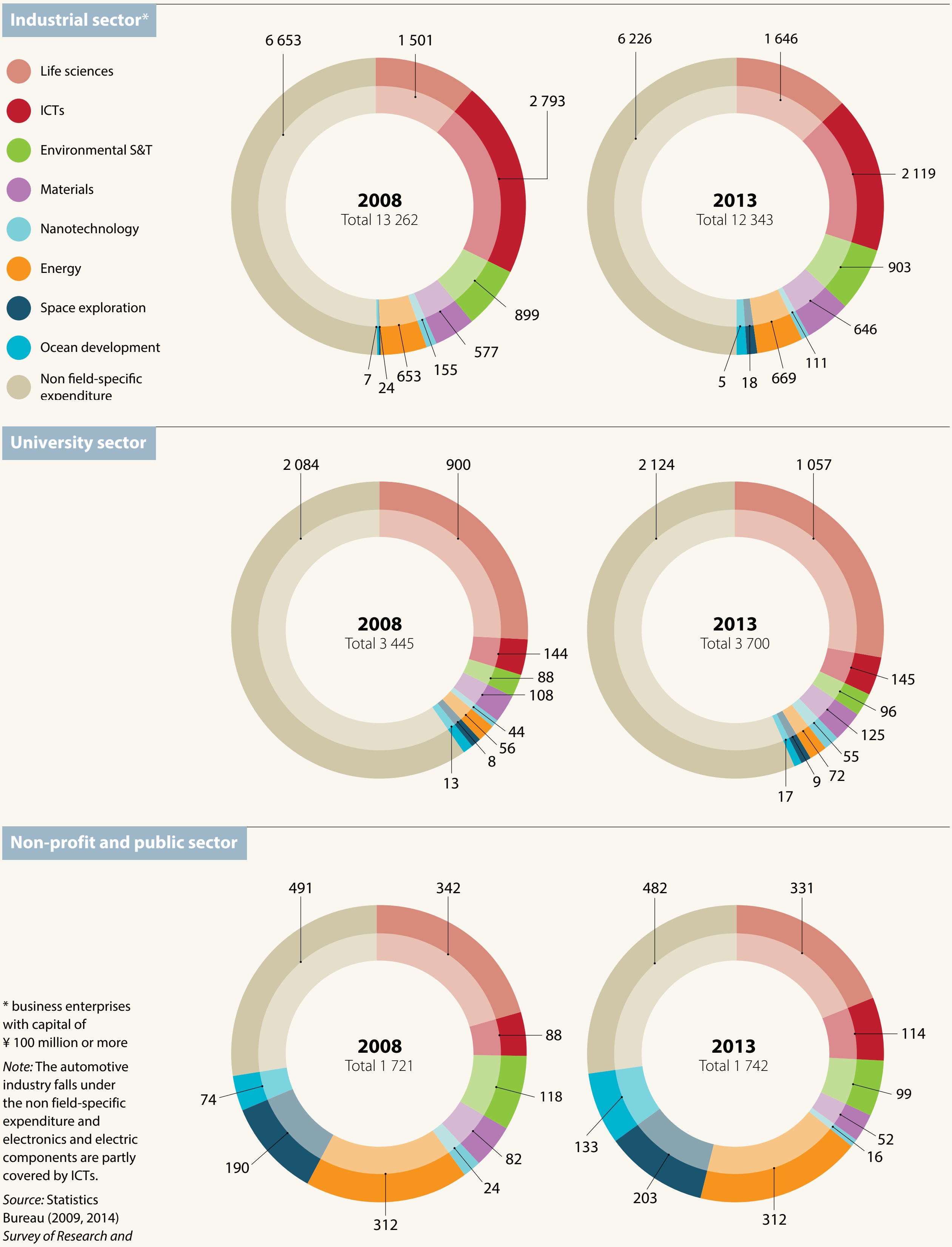
Table 24.3: **Trends in Japanese GERD, 2008–2013**

Year	GERD (¥ billion)	GERD/GDP ratio (%)	Government expenditure on R&D (GOVERD) (¥ billion)	GOVERD/GDP ratio (%)	GOVERD plus higher education expenditure on R&D/ GDP ratio (%)
2008	17 377	3.47	1 447	0.29	0.69
2009	15 818	3.36	1 458	0.31	0.76
2010	15 696	3.25	1 417	0.29	0.71
2011	15 945	3.38	1 335	0.28	0.73
2012	15 884	3.35	1 369	0.29	0.74
2013	16 680	3.49	1 529	0.32	0.79

Source: UNESCO Institute for Statistics, April 2015

Figure 24.2: **R&D expenditure in Japan by field, 2008 and 2013**

In ¥ billions



* business enterprises with capital of ¥ 100 million or more

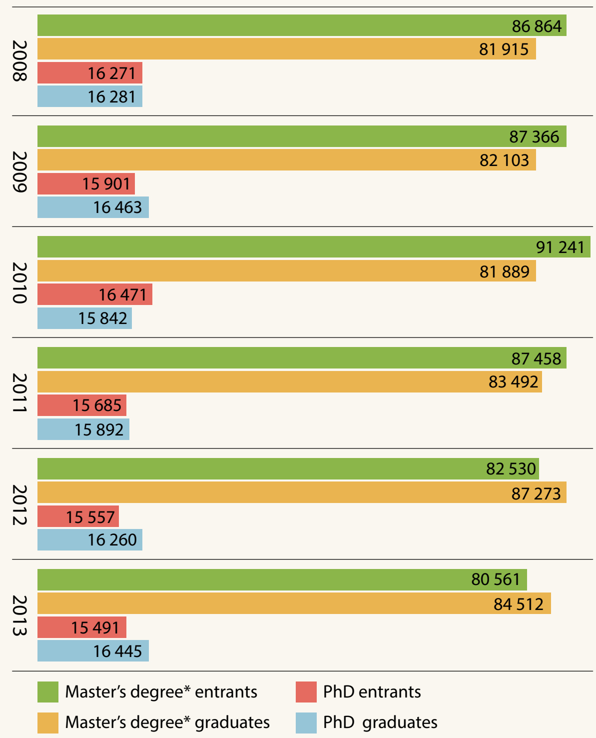
Note: The automotive industry falls under the non field-specific expenditure and electronics and electric components are partly covered by ICTs.

Source: Statistics Bureau (2009, 2014) *Survey of Research and Development*

Figure 24.3: **Number of researchers (HC) in Japan, 2008 and 2013**

Source: Statistics Bureau (2009, 2014) *Survey of Research and Development*

Figure 24.4: **Trends in master's and PhD programmes in Japan, 2008–2013**



* includes professional degree courses

Source: MEXT (2013, 2014c) *Statistical Abstract of Education, Science and Culture*

The number of master's students grew steadily until 2010 when the curve inversed (Figure 24.4). The rise can largely be attributed to the financial crisis from 2008 onwards, when graduates fresh out of university enrolled in graduate schools after giving up hope of finding a job. The drop in enrolment in a master's degree can be partly explained by the growing disappointment in law schools, which were first instituted in 2004 to train a mass of lawyers with diverse backgrounds but have actually produced a mass of jobless lawyers. It might also reflect university students' general scepticism as to the utility of the master's degree. Many master's students also appear to be discouraged from postgraduate study by the prospect of an uncertain career path. The number of new PhD students has also been dropping since peaking at 18 232 in 2003.

Research: more feminine and more international

One in seven Japanese researchers was a woman in 2013 (14.6%). Although this is an improvement on 2008 (13.0%), Japan still has the lowest proportion of women researchers of any member of the Organisation for Economic Co-operation and Development (OECD). The Japanese government is determined to improve this ratio. The *Third* (2006) *and Fourth* (2011) *Basic Plans for Science and Technology* both fixed a goal of a 25% ratio of women: 20% of all researchers in science, 15% in engineering and 30% in agriculture, medicine, dental and pharmaceutical research (Figure 24.5). These percentages are based on the current share of doctoral students in these fields. In 2006, a fellowship scheme was launched for women researchers returning to work after maternity leave. Moreover, given that the ratio of female researchers has been embedded in the assessment criteria of various institutional reviews, many universities now explicitly favour the recruitment of women researchers. As the Abe cabinet strongly advocates a greater social participation by women, it is quite likely that the rise in female researchers will accelerate.

The number of foreign researchers is also gradually rising. In the university sector, there were 5 875 foreign full-time teaching staff (or 3.5% of the total) in 2008, compared to 7 075 (4.0%) in 2013. Since this ratio remains fairly low, the government has been taking measures to internationalize Japanese universities. The selection criteria for most large university grants now take into account the proportion of foreigners and women among teaching staff and researchers.

Scientific productivity a casualty of multitasking

Japan's world share of scientific publications peaked in the late 1990s and has been sliding ever since. The nation was still producing 7.9% of the world's scientific papers in 2007, according to the Web of Science, but its share had receded to

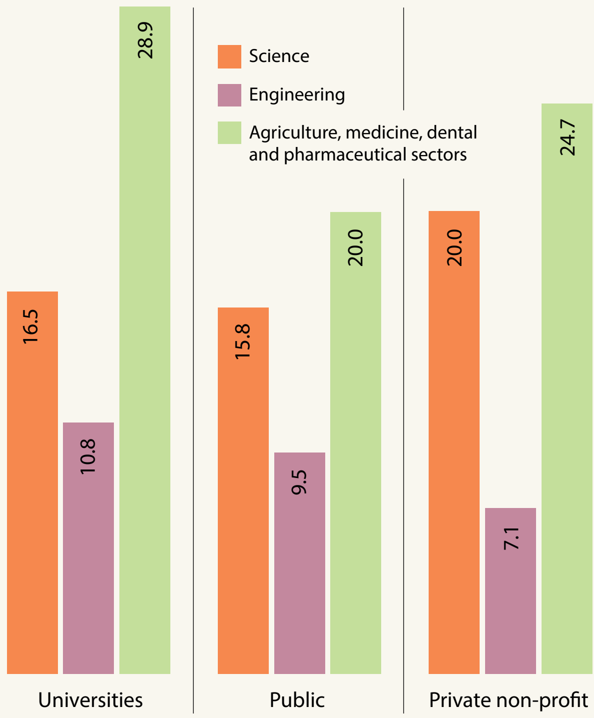
5.8% by 2014. Although this is partly due to China's continuing growth, Japan's poor performance is extraordinary: the world produced 31.6% more papers in 2014 than in 2007 but Japan's production declined by 3.5% over the same period.

One explanation may lie in the meagre growth in Japanese university spending on R&D over the same period, just 1.3% in constant prices, according to the UNESCO Institute for Statistics. The shrinking amount of university researchers' time reserved for research may also be to blame. As we have seen, there has been a modest increase in the number of university researchers in Japan in recent years but the use of their time has changed considerably: each researcher spent an average of 1 142 hours on research in 2008 but only 900 hours in 2013 (Figure 24.6). This worrying 21% drop can be partly accounted for by the decrease in the average number of hours worked by university researchers, which were cut back from 2 920 to 2 573 over the same period. What is certain is that the time allocated to research has been curtailed far more sharply than the time devoted to teaching and other activities; researchers face an array of unavoidable tasks these days: preparing classes in English as well as in Japanese, writing syllabi for all their classes, mentoring students beyond the academic setting, recruiting prospective students, setting up highly diversified and complicated enrollment processes, adapting to increasingly stringent environmental, safety and security requirements, etc..

The decline in publications by Japanese researchers might also be related to changes in the nature of public R&D funding. More and more grants to individual researchers as well as universities are becoming innovation-oriented, and just writing academic papers is no longer regarded as adequate. Whereas innovation-oriented R&D activities also lead to academic papers, Japanese researchers' effort is now possibly less concentrated on producing papers *per se*. At the same time, there are indications that decrease in private R&D funding has brought about a drop of publications by researchers in the private sector.

The downward trend in Japan's publication record is visible in all fields of science (Figure 24.7). Even in chemistry, materials science and physics, fields where Japan used to have a certain presence, its world share has dropped considerably. This is somewhat ironic, considering that a growing number of Japanese scientists have been internationally recognized in recent years for their truly outstanding work. Since the beginning of the century, 15 Japanese scientists (two of whom have become US citizens) have received Nobel prizes (Box 24.2). In point of fact, most of their achievements were made decades ago. This begs the question of whether Japan still retains the institutional and cultural environment that gives rise to such creative work. In the current climate, it will be a real challenge to realize the *Fourth Basic Plan's* target of positioning 100 institutions among the world's top 50 for the citation of research papers in specific fields by 2015.

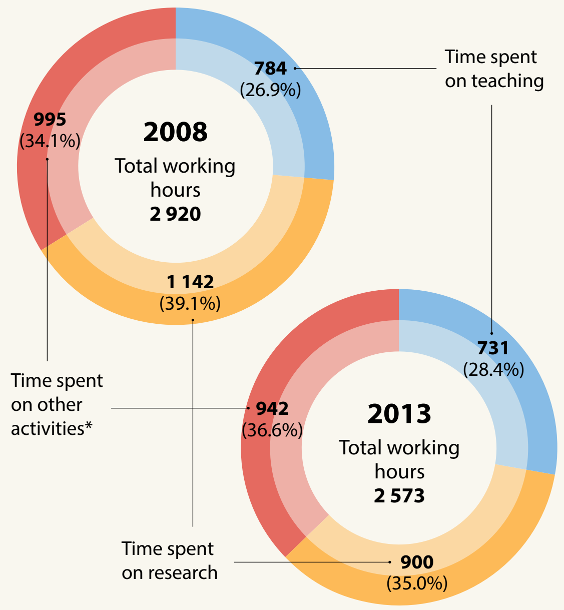
Figure 24.5: **Share of female researchers in Japan by sector and employer, 2013 (%)**



Note: Data are unavailable for the business enterprise sector.

Source: Statistics Bureau (2014) Survey of Research and Development.

Figure 24.6: **Breakdown of working hours of Japanese university researchers, 2008 and 2013**



* Time spent on university administration, services to society such as clinical activities, etc

Source: MEXT (2009, 2014d) *Survey on FTE data for Researchers in Higher Education Institutions*

Figure 24.7: **Scientific publication trends in Japan, 2005–2014**

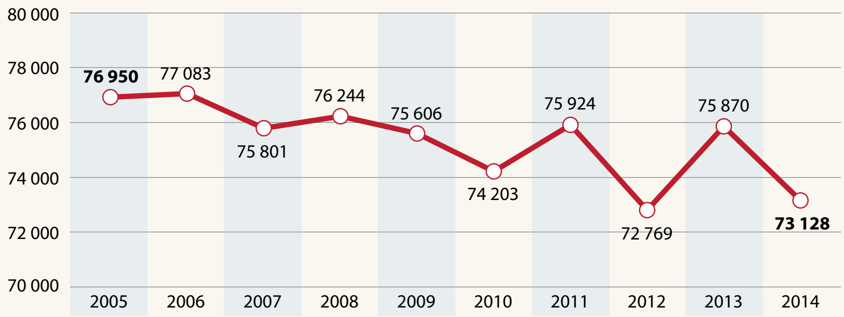
The number of Japanese publications has declined since 2005

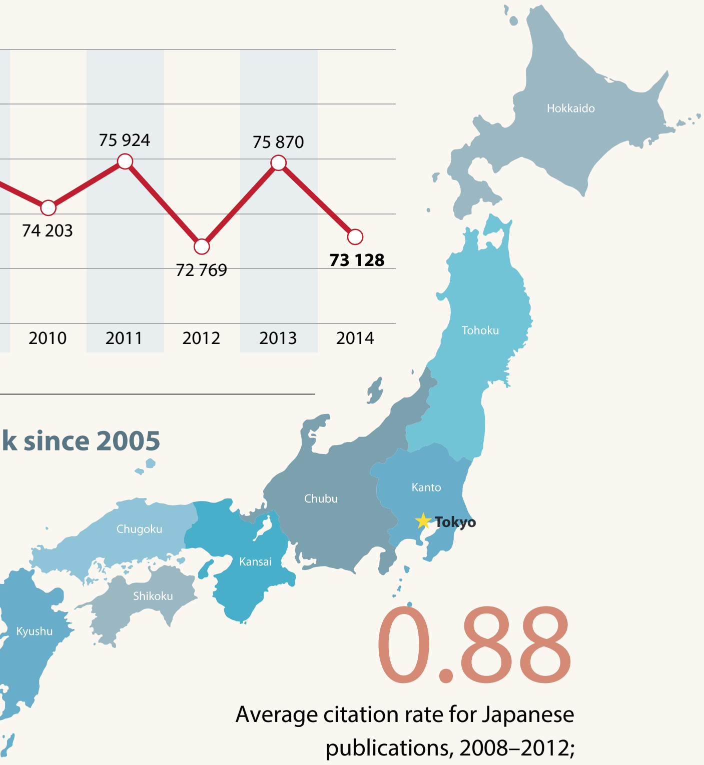
606

Publications per million inhabitants in 2005

576

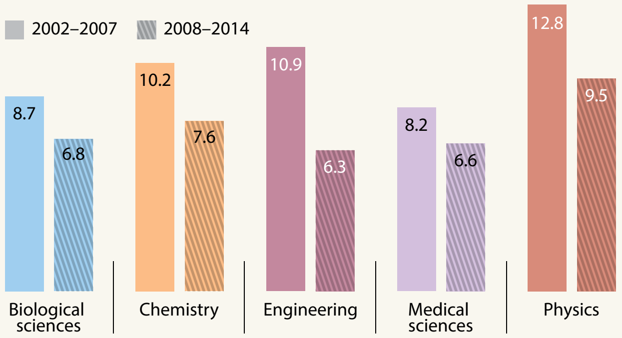
Publications per million inhabitants in 2014





Japan's world share of scientific publications has shrunk since 2005

World share of Japanese articles by field (%)



0.88

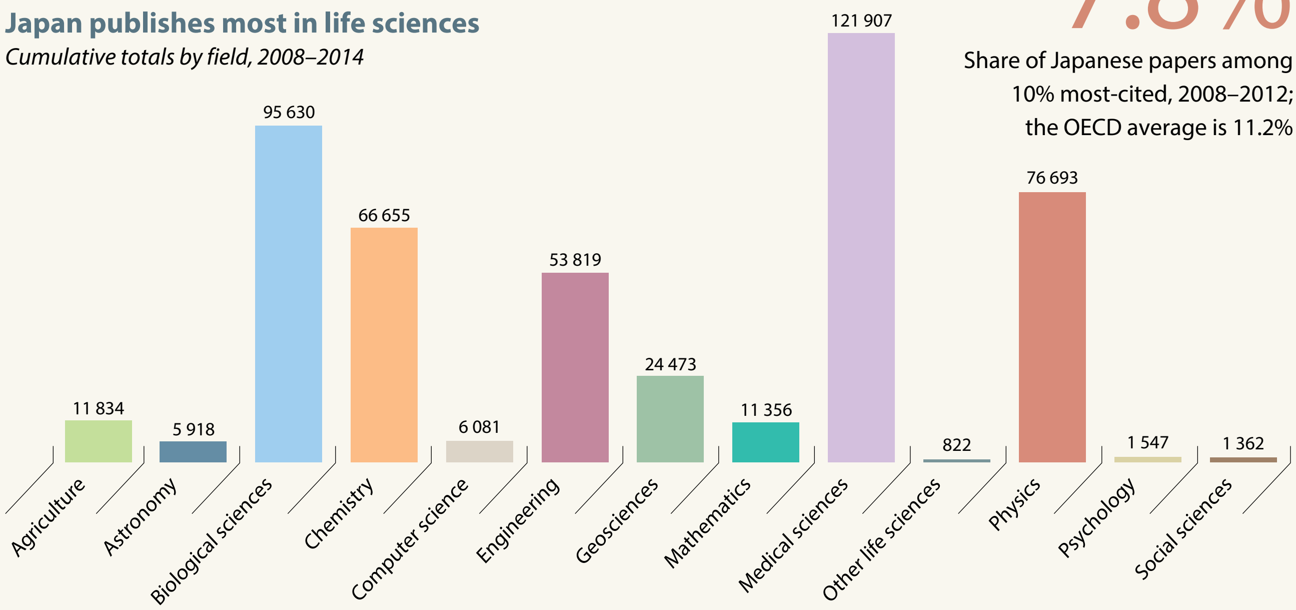
Average citation rate for Japanese publications, 2008–2012; the OECD average is 1.08

7.8%

Share of Japanese papers among 10% most-cited, 2008–2012; the OECD average is 11.2%

Japan publishes most in life sciences

Cumulative totals by field, 2008–2014



Note: Excludes 45 647 unclassified articles

27.1%

Share of Japanese papers with foreign co-authors, 2008–2014; the OECD average is 29.0%

Japan's top partners are the USA and China

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Japan	USA (50 506)	China (26 053)	Germany (15 943)	UK (14 796)	Korea, Rep. (12 108)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix, November 2014; for Japan's world share of publications: NISTEP (2009, 2014) *Indicators of Science and Technology*

Box 24.2: **Why the increase in Japanese Nobel laureates since 2000?**

Every year, Japanese people excitedly await the announcement from Sweden of the year's Nobel laureates. If Japanese scientists are named, great celebration by the media and the public follows.

Between 1901 and 1999, the public would have had to be extremely patient: just five Japanese scientists received the prestigious award over this entire period. Since 2000, on the other hand, 16 Japanese scientists have been distinguished, including two who have become US citizens.

This does not necessarily mean that the research environment in Japan has improved overnight, since much of the laureates' work was done before the 1980s. However, public and private R&D funding did make a difference in some cases. The work of Shinya Yamanaka, for example, received ample funding in the 2000s from the Japan Society for the Promotion of Science and the Japan Science and Technology Agency. Yamanaka was recompensed (Nobel Prize for Physiology or Medicine, 2012) for his discovery of induced pluripotent stem cells. As for Shuji Nakamura (Nobel Prize for Physics, 2014), he invented efficient blue light-emitting diodes (LED) in the 1990s, thanks to the generous support of his company, Nichia Corporation.

What other factors could explain the increase in Japanese Nobel laureates? It would appear that the focus of the prize has changed. Although the selection process is not disclosed, the social impact of research seems to have been carrying more weight in recent years. All eight Nobel prizes awarded to Japanese scientists since 2010 are for discoveries which have had a demonstrable impact on society, even though three Japanese physicists (Yoichiro Nambu, Toshihide Maskawa and Makoto Kobayashi) received the prize in 2008 for their purely theoretical work in particle physics.

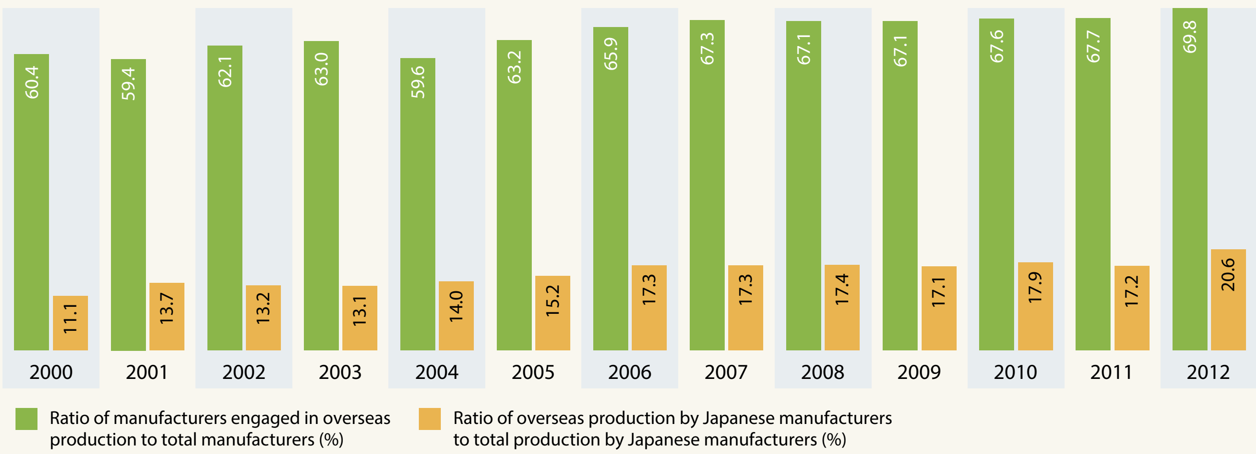
If the Nobel Prize Committee is indeed giving greater recognition to the social impact of research, this could well be a reflection of the changing mindset of the global academic community. The *Declaration on Science and the Use of Scientific Knowledge* and *Science Agenda: Framework for Action* from the World Conference on Science in 1999 may well be the harbinger of this change. Organized in Budapest (Hungary) by UNESCO and the International Council for Science, the World Conference on Science produced documents which explicitly stressed the importance of 'science in society and science for society,' as well as 'science for knowledge.'

Source: compiled by authors

Patents: aiming for quality over quantity

The number of patent applications to the Japan Patent Office (JPO) has been declining since 2001. Many factors seem to have contributed to this phenomenon. In the past decade, many firms have refrained from applying for large quantities of patents, instead focusing their efforts on obtaining high-quality patents. This is partly because of the steep rise in examination fees charged by the JPO since 2004. After the global crisis in particular, Japanese firms could no longer afford to spend as much as before on patent applications. They have also come to lay more emphasis on applying to foreign patent offices, reducing the relative importance of domestic patents. In addition, years of an overappreciated yen and a shrinking Japanese market have spurred many firms to move their R&D and manufacturing centres abroad; as a result, they now feel less inclined to file many of their patents in Japan (Figure 24.8).

Figure 24.8: **Overseas production by Japanese manufacturers, 2000-2012**



Source: Cabinet Office (2008–2013) *Annual Survey of Corporate Behaviour*

Chapter 24

Table 24.4: **Patent activities in Japan, 2008 and 2013**

	Patent applications	Granted patents	Examination time (months)	PCT international applications
2008	391 002	159 961	29	28 027
2013	328 436	260 046	11	43 075

PCT = Patent Cooperation Treaty

Source: Japan Patent Office (2013, 2014) *Annual Report of Patent Administration*

The JPO had actually intended for the number of patent applications in Japan to drop, in order to solve the chronic problem of long waiting times for patent applications to be examined. The first Intellectual Property Promotion Programme had been established in 2004 to reduce the waiting time from 26 months to 11 months by 2013. JPO encouraged private firms to select only their best candidates for patent application; it also raised the number of patent examiners by 50%, mainly through massive hiring of fixed-term officials, and at the same time improved their productivity. In the end, JPO achieved its goal just in time (Table 24.4).

There may be another explanation for the decrease in patent applications: this could be a symptom of Japan's weakening innovative capabilities. Since patent statistics reflect so many different factors, their validity as an indicator of R&D seems less evident than it once did. In today's ever-more globalized world, the very meaning of the national patent system is changing.

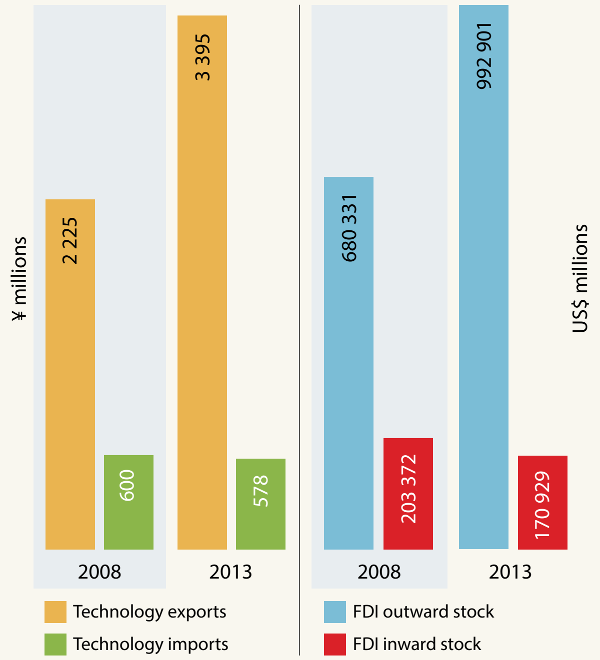
TRENDS IN GLOBAL ENGAGEMENT

Strong on technology but less competitive than before

In recent years, Japan's economic relationship with the world has fundamentally changed. In 2011, the country recorded a trade deficit for the first time since 1980. This was partly due to a decrease in exports, combined with a rise in oil and natural gas imports following the 2011 triple catastrophe in the Tohoku area and the subsequent halting of nuclear power plants. The trade deficit did not turn out to be a temporary phenomenon, however. It has become chronic, fuelled by the weak competitiveness of Japanese manufacturers in the global market, the transfer of their factories overseas and high prices for oil and other natural commodities. Even though Japan's current account is still in the black, its industrial fabric is definitely less competitive than it used to be.

That is not to say that Japan's technological strength has waned. For example, technology exports grew by more than 53% between 2008 and 2013, whereas technology imports remained roughly constant over the same period. Japan's outward FDI stocks swelled by 46%, even as inward FDI stocks shrank by 16%. Japan has thus been increasingly active in transferring technology and investing abroad. The fact that FDI inflows remain low in comparison with other nations has

Figure 24.9: **Japan's technology trade and FDI stock, 2008 and 2013**



Source: Statistics Bureau (2014); UNCTAD (2009, 2014) *World Investment Report*

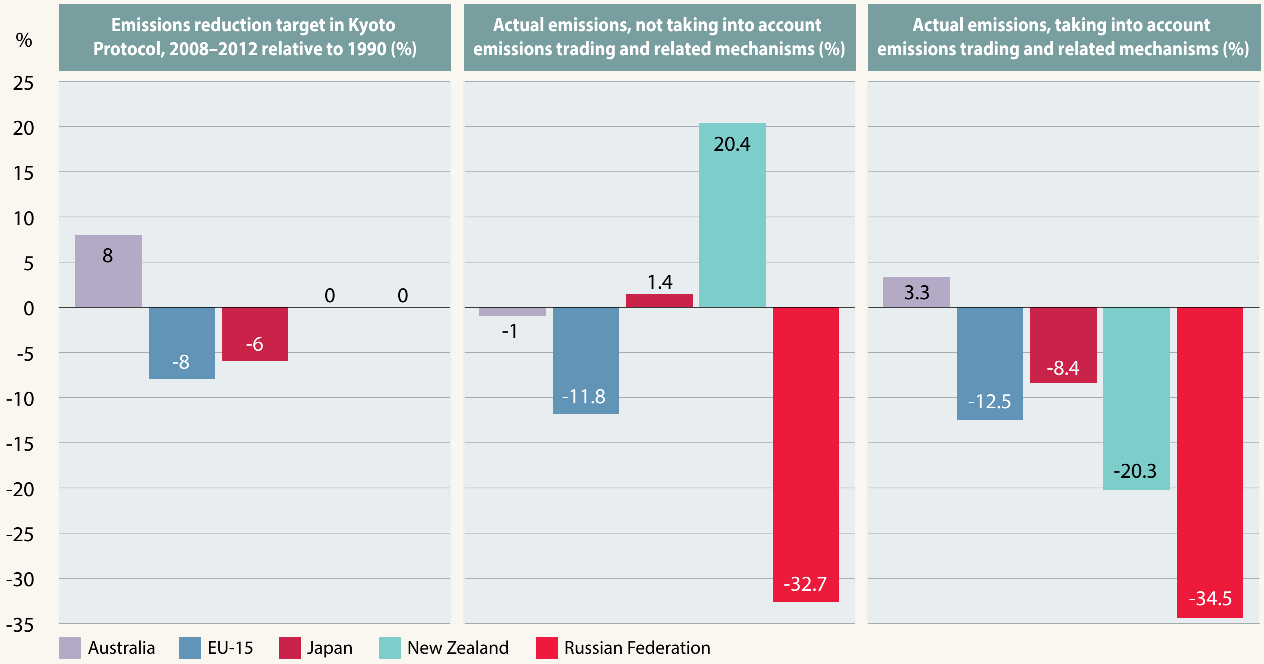
become a source of concern, however, for it means that Japan is failing to attract foreign investors and introduce foreign business resources. The Japanese government regards FDI inflows as being generally beneficial because they create jobs and boost productivity, while at the same time promoting open innovation and revitalizing the regional economy, which has long suffered from depopulation and ageing.

Incentives to attract FDI

The Japanese government has recently taken steps to stimulate FDI inflows (Figure 24.9). A law enacted in November 2012 provides incentives for global corporations to relocate their R&D centres and Asian branches to Japan, such as a reduction in corporate tax and other privileges. Just months later, in June 2013, the Abe Cabinet's *Japan Revitalization Strategy: Japan is Back*, fixed the target of doubling FDI inflows by 2020. To this end, the government designated six National Strategic Special Zones that are expected to become international centres for business and innovation through deregulation. Behind these measures is a sense of crisis that Japan might be losing its attractiveness as a business destination relative to other Asian nations.

Fortunately, there is currently a fertile environment for business. A drastic depreciation of the yen in recent few years has induced many Japanese manufacturers to bring their factories back to Japan, thereby steadily generating jobs. Lower oil prices and corporate tax rates have also fostered this 're-shoring' trend among Japanese firms. Although it is uncertain how long these

Figure 24.10: **Japan's progress towards targets under the Kyoto Protocol, 2012**
Other countries are given for comparison



Source: Greenhouse Gas Inventory Office of Japan, National Institute for Environmental Studies

favourable conditions will last, there are signs that Japanese corporations are also re-evaluating the unique strengths of the business environment in Japan, which include social stability, reliable production infrastructure and a capable labour force.

A commitment to international targets

While aiming for competitiveness, Japan has also been deeply committed to the international agenda for sustainable development. Under the *Kyoto Protocol* of 1997, Japan agreed to reduce its greenhouse gas emissions by 6% over 2008–2012 relative to 1990. Taking into account emissions trading and related mechanisms, Japan has reached this target (Figure 24.10). Ironically, the economic damage caused by the global financial crisis helped Japan to attain this feat. Japan has been reluctant to participate in any new scheme, however, as long as major emitters such as China, the USA and India do not have any substantial duty[7]. In fact, Japanese firms were dissatisfied with the *Kyoto Protocol* because they perceived Japan as already being a low-emitter by the 1990s and felt it would be more difficult for the country to achieve a similar goal than for other countries.

More recently, Japan has eagerly taken part in emerging global frameworks for sustainability. Japan has been an active participant of the Belmont Forum, an association of funding agencies supporting research on earth's environmental changes, ever since its inception in 2009. It has also been one of the drivers behind an ambitious scheme beginning in 2015, Future Earth. This scheme incorporates several global research frameworks for global environmental change and is expected to last for ten years. Japan also hosted the 10th Conference of the Parties to the Convention on Biological Diversity in October 2010. The *Nagoya Protocol* adopted by this conference provides a legal framework for the fair, equitable sharing of benefits arising from the utilization of genetic resources. The conference also adopted 20 *Aichi Biodiversity Targets* for the global community to 2015 and 2020. In accordance with these international agreements, the Japanese government revised its own *National Strategy for Biodiversity* in 2012, specifying detailed targets, action plans and indicators for evaluation[8].

Japan's proactive stance on global engagement is founded on its vision of science diplomacy. Japan considers that its participation in co-operative programmes in science and technology strengthens its diplomatic relations and is therefore in the national interest. In 2008, MEXT and the Ministry of Foreign Affairs launched a joint programme for a Science and Technology Research Partnership for Sustainable Development (SATREPS) with developing countries; collaborative research projects tackle problems in such areas as environment, energy, natural disasters and infectious diseases.

7. China and India did not have specific targets under the *Kyoto Protocol* and the USA was not a signatory.

8. Japan's legal framework in this field consists of the Basic Act on Biodiversity (2008) and the Act on Promotion of Regional Co-operation for Biodiversity (2010).

CONCLUSION

A need for forward-looking policies and a new mindset

Japan has experienced some stark trends since 2010: public and private funding of R&D have barely evolved, fewer students are entering doctoral programmes and the number of scientific publications is declining. These trends have been shaped by the current macro-socioeconomic context: an ageing population, demographic decline, sluggish economic growth and a burgeoning national debt burden.

Over the same period, science and technology in Japan have also been deeply affected by a national tragedy, the Great East Japan Earthquake of 2011. Other milestones will also go down in history: LDP's return to power in December 2012, heralding the launch of Abenomics, and the STAP cells controversy in 2014, which has shaken the scientific establishment and public trust in science.

Recent events and macro-trends have spawned fundamental challenges for the academic, government and industrial sectors. For the academic sector, university reform has clearly been a central challenge for some time. The ongoing reform is a multifaceted exercise involving the consolidation and merger of universities in the face of a declining young population, greater internationalization and the promotion of female researchers, enhanced collaboration with industry, development of a healthy research environment and better career prospects for young researchers. An overarching goal will be to improve the mediocre visibility of Japanese universities in the global landscape. Perhaps hardest of all, Japanese universities will be expected to carry out this array of reforms on a shrinking regular budget. This will demand a highly cost-effective use of public funding for universities; it will be important for the government to work in concert with the academic and industrial sectors to devise the most efficient use of the public purse in funding universities.

In April 2016, the *Fifth Basic Plan for Science and Technology* will become operational simultaneously with the start of the third six-year planning period for national universities. On this occasion, the ongoing reform of the university sector and its funding systems will need to move into higher gear, if it is to improve research productivity and diversify and internationalize university education. The academic community, in turn, will need to share its vision of the university of the future and strengthen internal governance mechanisms.

A major additional challenge for the academic community – and the government – will be to restore public confidence. Official statistics show that the triple catastrophe of 2011 has shaken the public's trust not only in nuclear technology but also in science and technology, in general. Moreover, just as public confidence was recovering, the STAP cells scandal broke. The academic community and the government should not content themselves with taking steps to prevent misconduct in research; they should also re-examine systemic aspects of the problem, such as the excessive concentration of R&D funds in a handful of institutions or laboratories, the vertiginous drop in regular funding and permanent research positions and evaluations of researchers based on short-term performance.

The academic community in Japan will also have to live up to the growing expectations of society. In addition to producing excellent research output, universities will be required to turn out high-quality graduates who can exercise leadership in today's speedy, globalized world fraught with uncertainty. Japanese universities will also be expected to collaborate keenly with industry to create social and economic benefits at the local, national, regional and global levels. In this respect, the role of public R&D institutes such as RIKEN and AIST will be particularly important because they can serve as arenas where academic, industrial and other stakeholders can readily interact. Also offering potential for innovation is the new Japan Agency for Medical Research and Development, established in April 2015 on the model of the US National Institutes of Health to realize Prime Minister Abe's vision of a vehicle to promote the Japanese medical industry.

The industrial sector in Japan has its own share of challenges. By 2014, Abenomics and other factors, including the recovery of foreign economies, had helped major Japanese firms recover from the global crisis but their financial health remains heavily dependent on relatively strong share prices. The effects of the past few years on investor confidence are still visible in the reluctance of Japanese firms to raise R&D spending or staff salaries and in their aversion to the necessary risk-taking to launch a new cycle of growth. Such a stance will not ensure the long-term health of the Japanese economy, since the positive effects of Abenomics cannot last forever.

One possible direction for Japanese industry would be for it to devise macrostrategies around a set of basic concepts suggested by the Japanese government in its *Comprehensive Strategy for STI*: 'smartization', 'systemization' and 'globalization'. It has become difficult for Japanese manufacturers to compete in the global market as far as the production of stand-alone commodities is concerned. However, Japanese industry can use its technological strength to satisfy global demand with system-oriented, network-based innovation supported by ICTs. In such fields as health care, urban development, mobility, energy, agriculture and disaster prevention, there are great opportunities worldwide for innovative firms to supply highly integrated, service-oriented systems. What Japanese industry needs is to combine its traditional strengths with a future-oriented vision. Such an approach could be applied to preparing for the 2020 Olympic/Paralympic Games in Tokyo; to that end, the Japanese government is now promoting STI via grants and other programmes in a broad range of fields, including environment, infrastructure, mobility, ICTs and robotics, using such keywords as 'sustainable,' 'safe and secure,' 'friendly to senior and challenged people,' 'hospitable' and 'exciting.'

Another possibility for Japan will be to promote creative industries in such areas as digital contents, online services, tourism and Japanese cuisine. The Ministry of Economy, Trade and Industry (METI) has been promoting the Cool Japan Initiative for several years now, which culminated in the establishment of the Cool Japan Fund Inc. by law in November 2013 to help Japan's creative industries spread their wings abroad. Such endeavours could be more tightly integrated into Japan's overall STI policy.

Almost a quarter of a century has passed since the Japanese economy entered the doldrums in the early 1990s. During this prolonged economic slump, each of the industrial, academic and governmental sectors in Japan has undergone reforms. Many electric, steel and pharmaceutical firms were merged and restructured, as were financial institutions; national universities and national research institutes were semi-privatized; and government ministries went through a comprehensive reorganization. These reforms have surely strengthened the foundation for R&D in Japan's industrial, academic and government sectors. What is needed now is for Japan to have confidence in its national innovation system. It needs to adopt forward-looking policies and arm itself with the courage to pursue the necessary reforms to adapt to the changing global landscape.

KEY TARGETS FOR JAPAN

- Raise the GERD/GDP ratio to 4% or more by 2020;
- Raise government expenditure on R&D to 1% of GDP or more by 2015;
- Position 100 institutions among the world's top 50 in specific fields for the citation of research papers by 2015;
- Raise the share of women occupying high-level posts in both the public and private sectors to 30% by 2020;
- Raise the proportion of women researchers by 2015 to 20% in science, 15% in engineering and 30% in agriculture, medicine, dental and pharmaceutical research;
- Attract 300 000 international students to Japan by 2020;
- Double the amount of FDI inflows (US$ 171 billion in 2013) by 2020.

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The government has decided to respond to [the] increasingly competitive [global] environment by raising its investment in research and development, strengthening the manufacturing sector and developing new creative industries.

Deok Soon Yim and **Jaewon Lee**

Songdo International Business District is a new smart city erected on 600 ha of reclaimed land on Incheon's waterfront, 65 km from Seoul. It is connected to Incheon International Airport by a 12 km-long bridge and forms part of the Incheon Free Economic Zone.

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25 · Republic of Korea

Deok Soon Yim and Jaewon Lee

INTRODUCTION

Time for a new development model

The Republic of Korea[1] has become a benchmark for successful economic development. Between 1970 and 2013, GDP per capita grew from US$ 255 to US$ 25 976, driven by the strong manufacturing and industrial capabilities that turned it into one of Asia's economic 'tigers'. Among the many factors contributing to this success story is the country's commitment to technological progress and to developing an educated, skilled labour force. Today, the Republic of Korea is the only nation to have transformed itself from a major recipient of foreign aid into a major donor.

However, the government recognizes that this remarkable economic growth is no longer sustainable. Global competition with China and Japan is intense, exports are slipping and the global demand for green growth has altered the balance. In addition, a rapidly ageing population and declining birthrates threaten Korea's long-term economic development (Table 25.1). Middle-income households are straining to make ends meet in the face of stagnating wages and there are signs of evident social distress; the Organisation for Economic Co-operation and Development (OECD) reports that the Korean divorce rate has doubled in recent years and that its suicide rate is the highest of any OECD member. The time has come for an alternative development model.

The new priority: a creative economy

Against this backdrop, the government has been trying to set a new path by developing more competitive technologies. Under the Lee Myung-bak administration (2008–2013), the government embarked on a major campaign for 'low carbon technology and green growth,' as we saw in the *UNESCO Science Report 2010*. Lee's government targeted a 5% investment in research and development (R&D) as a percentage of GDP by 2012 and strengthened the ministry responsible for science and technology by transferring responsibility for the budget and co-ordination to the National Science and Technology Council (NSTC).

The current Park Geun-hye administration is emphasizing the 'creative economy,' in an effort to revitalize the manufacturing sector through the emergence of new creative industries.

TRENDS IN STI GOVERNANCE

Science to converge with culture, culture to fuse with industry

In her inaugural address in February 2013, President Park Geun-hye spoke of 'a new era of hope and happiness.' She identified five administrative goals for her government: a creative economy centred on jobs, tailored employment and welfare, creativity-oriented education and cultural enrichment, a safe and united society and strong security measures for sustainable peace on the Korean Peninsula. She offered a new vision for national development, defining it as 'the convergence of science and technology (S&T) with industry, the fusion of culture with industry and the blossoming of creativity in the very border areas that were once permeated by barriers.'

This new vision seeks to transform the country's economic model by deepening its reliance on science, technology and innovation (STI), which have served the country so well in the past. President Park's vision builds on that of her predecessor, who had managed to raise gross domestic expenditure on R&D (GERD) to 4.15% of GDP by 2013, the second-highest level of commitment in the world after Israel (Figure 25.1). This meteoric rise was made possible thanks largely to the strong progression in industrial R&D.

1. The present chapter covers only the Republic of Korea, so references to the abbreviation of 'Korea' designate solely the Republic of Korea.

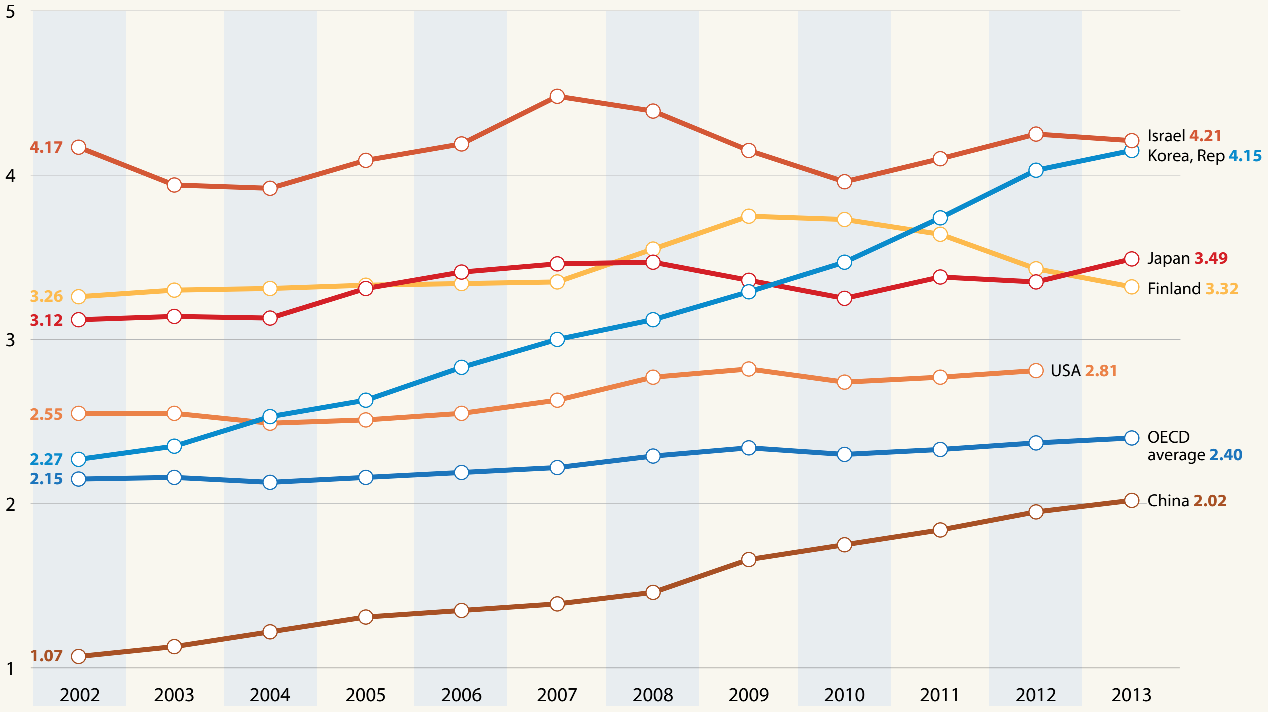
Table 25.1. **Socio-economic trends in the Republic of Korea, 2008–2013**

	2008	2009	2010	2011	2012	2013
Population (thousands)	48 948	49 182	49 410	49 779	50 004	50 219
Population growth rate (%)	0.62	0.62	0.60	0.57	0.55	0.53
GDP (current US$ millions)	1 002 216	901 934	1 094 499	1 202 463	1 222 807	1 304 553
GDP per capita (current US$)	20 474	18 338	22 151	24 155	24 453	25 976
GDP growth rate (%)	2.82	0.70	6.49	3.68	2.29	2.97
Life expectancy at birth (years)	79.8	80.3	80.6	81.0	81.4	–
Inflation, consumer prices (%)	4.67	2.76	2.96	4.00	2.20	1.31
Unemployment rate (% labour force)	3.20	3.60	3.70	3.40	3.20	3.1

Source: World Bank's World Development Indicators, accessed March 2015

Figure 25.1: **Progression in GERD/GDP ratio in Republic of Korea, 2002–2013 (%)**

Other countries and regions are given for comparison



Source: OECD (2015) *Main Science and Technology Indicators*

At the time of fixing the 5% target for the GERD/GDP ratio in 2008, there had been some discordant opinions about the government's strong focus on industrial research and innovation. Some analysts underscored the need to lay greater emphasis on basic research and on upgrading the quality and performance of scientific research, in order to obtain greater global recognition. The previous Lee Myung-bak administration had taken various measures to address these issues, including its *Second Basic Plan for Science and Technology* over 2008–2013 and its Low Carbon, Green Growth policy.

High spending for low carbon, green growth

The *Second Basic Plan for Science and Technology over 2008–2013* came to be known as the 577 Initiative, in reference to the targets it proposed: the number 5 refers to a 5% GERD/GDP ratio by 2012, the first 7 refers to the government's seven priority areas and the second 7 to the associated policy areas (MEST, 2011). The first target had not quite been achieved by 2012.

Between 2008 and 2011, the government invested KRW 23.72 trillion (US$ 28.1 billion) in the following seven priority areas:

- Advancement of key industries, such as the automobile, shipping and semi-conductor industries (KRW 2.06 trillion);
- Core technology for the development of new industries (KRW 3.47 trillion);
- Knowledge-based service industries (KRW 0.64 trillion);
- State-driven technology, such as space, defence and nuclear power (KRW 9.08 trillion);
- Issue-driven areas such as new diseases and nanodevices (KRW 3.53 trillion);
- Global issues such as renewable energy and climate change (KRW 3.78 trillion);
- Basic and convergent technology, such as intelligent robots and biochips (KRW 1.16 trillion).

The seven policy areas are:

- Nurturing talented students and researchers;
- Promotion of basic research;
- Support for SMEs to foster technological innovation;
- Stronger international co-operation in developing strategic technologies;
- Regional technological innovation;
- A stronger national base for S&T[2]; and
- Dissemination of a science culture.

2. This refers to increasing the number of national R&D facilities and developing a system of co-ordination to operate these facilities efficiently, which includes an online database on S&T, along with efforts to facilitate university–industry co-operation.

The 577 Initiative chalked up some impressive achievements (MEST, 2011):

- An increase in the number of publications recorded in international journals from 33 000 in 2009 to 40 000 in 2012, beyond the target of 35 000;
- An increase in the number of students on scholarships from 46 000 in 2007 to 110 000 in 2011;
- An increase in the number of researchers from 236 000 in 2008 to 289 000 by 2011, equivalent to 59 researchers per 10 000 population – this nevertheless supposes that the target of 100 researchers per 10 000 population will not be reached by 2012;
- A meteoric rise in the World Bank ranking of domestic environments for business creation, from 126th place in 2008 to 24th in 2012;
- An increase in GERD from 3.0% to 4.0% of GDP between 2007 and 2012 (Figure 25.1), driven largely by the business enterprise sector;
- A steep progression in the number of subscribers to the National Science and Technology Information Service, an internet-based platform for S&T statistics, from 17 000 in 2008 to 107 000 in 2010 – the government also introduced more transparent ways of evaluating S&T, including better indicators with more focus on quality control.

Within its Low Carbon, Green Growth policy (2008), the government established the Composite Measure for R&D in Green Technology in 2009. This measure proposes a series of development strategies and investment targets, including that of doubling government investment in green technology to KRW 2 trillion between 2008 and 2012. This target had been surpassed by 2011, when investment reached KRW 2.5 trillion. In all, the government invested KRW 9 trillion (*circa* US$ 10.5 billion) in green technology between 2009 and 2012.

The green growth policy has been institutionalized in the new *Five-Year Plans for Green Growth*, the first of which covered 2009–2013. In order to support both basic research and technological development in green technology, the government introduced its *Plan for National Carbon Dioxide Capture Sequestration* (CCS) in 2010. CCS is a technology for capturing carbon emissions on a large scale, such as those from power plants, and storing the carbon underground in disused mines and the like. The government plans to commercialize CCS technology by 2020. Total investment in green technology by the top 30 private companies amounted to KRW 22.4 trillion (US$ 26.2 billion) between 2011 and 2013.

The government also decided to host the Green Climate Fund in 2012 and supported the establishment of the Global Green Growth Institute[3] in 2010, which works with public and private partners in developing countries and emerging economies to put green growth at the heart of economic planning. The Green Climate Fund is based in the city of Incheon. The fund originated at the global climate talks in Copenhagen (Denmark) in 2009, where it was decided to create a fund endowed with US$ 100 billion per year by 2020 to help developing countries adapt to climate change. In November 2014, 30 countries meeting in Berlin (Germany) pledged[4] the first US$ 9.6 billion.

The government also launched the Green Technology Center Korea in 2013. This government-funded think tank co-ordinates and supports national R&D policies related to green technology, in collaboration with Korean ministries and agencies. The centre also serves as the Republic of Korea's gateway to international co-operation in the design and diffusion of green technology, with a focus on creating a new growth engine for developing countries. The Republic of Korea's partners in this endeavour are the United Nations Development Programme, United Nations Economic and Social Commission for Western Asia and the World Bank.

A blueprint for a creative economy

The *Third Basic Plan for Science and Technology, 2013–2017* came into effect in 2013, the year President Park Geun-hye took office. It serves as a blueprint for Korea's 18 ministries for the years to come. The major feature of this third plan is that it suggests, for the first time, that the government should allocate US$ 109 billion (KRW 92.4 trillion) to R&D over five years as seed money to foster the emergence of a creative economy (MSIP, 2014). This is expected to increase the contribution of R&D to economic growth from 35% to 40%. In addition, this third plan undertakes to raise gross national income per capita to US$ 30 000 and to create 640 000 jobs in science and engineering by 2017 (Table 25.2). These figures demonstrate how the current government plans to use science and technology to foster national growth, although some have questioned whether all of these targets can be reached by 2017.

The *Third Basic Plan* outlines five strategies for reaching these targets (NSTC, 2013) :

- Increase government investment in R&D, support private-sector R&D through tax relief and improve the planning of new research projects;

3. The Global Green Growth Institute was originally conceived by the Lee government as an NGO. It became an international body in 2012 after the signing of agreements with 18 governments. See: http://gggi.org

4. The biggest contributions to the Green Climate Fund were pledged by the USA (US $3 billion), Japan (US$ 1.5 billion), Germany, France and the UK (US$ 1 billion each). Some developing countries made pledges of a more modest nature, including Indonesia, Mexico and Mongolia.

Table 25.2: **The Republic of Korea's R&D targets to 2012 and 2017**

		Unit of measure	Situation as of 2007	Situation as of 2012	Target to 2012 of *Second Basic Plan*	Target to 2017 of *Third Basic Plan*
Financial investment	GERD	In KRW trillions	31.3	59.30^{+1}	–	–
		In current PPP$ billions	40.7	68.9^{+1}	–	–
		Percentage of GDP	3.00	4.15^{+1}	5.00	5.00
	Government-financed R&D expenditure	In KRW trillions	7.8	13.2	92.4 (total over 2012–2017)	
		Percentage of GDP	0.74	0.95^{+1}	1.0	–
	Share of basic research in government R&D budget	Percentage share	25.3	35.2	35.0	40.0
	Share of support for SMEs in government R&D budget	Percentage share	–	12.0^{-2}	–	18.0
	Government investment in green technology	In KRW trillions	1	2	2	–
	Government investment in quality of life	Percentage of government expenditure on R&D	–	15.0	–	20.0
Human capital investment	Researchers (FTE)	Total number	222 000	315 589	$490\ 000^{-1}$	–
		Per 10 000 population	47	64	100	–
	PhD-holders in science and engineering	Percentage of total population	–	0.4	–	0.6
	COSTII score	Ranking among 30 OECD countries	–	9th	–	7th
Output	Articles published in Science Citation Index	Total number	29 565	49 374	35 000	–
	Number of patents with international co-applications	Per 1 000 researchers	–	0.39^{-1}	–	0.50
	Technology competitiveness of SMEs	Percentage of total potential	–	74.8^{-1}	–	85.0
	Early-stage entrepreneurial activity	Percentage of enterprise's total activity	–	7.8	–	10.0
	Jobs in science and engineering	Total	–	6 050 000	–	6 690 000
	Gross national income per capita	US$	23 527	25 210	–	30 000
	Contribution of R&D to economic growth	Percentage of GDP	30.4^{-1*}	35.4^{**}	40.0^{***}	40.0^{****}
	Industrial value added per capita	US dollars	–	19 000	–	25 000
	Value of technology exports	US dollars millions	2 178	4 032	–	8 000
	Technology trading	Ratio of technology revenue to expenditure	0.43	0.48	0.70	–

-n/+n = n years before or after reference year.

* average contribution over 1990–2004
** average contribution over 1981–2010
*** average contribution over 2000–2012
**** average contribution over 2013–2017

Note: The Composite Science and Technology Innovation Index (COSTII) was developed by the Korean National Science and Technology Council in 2005. It compares the innovation capacity of 30 OECD countries.

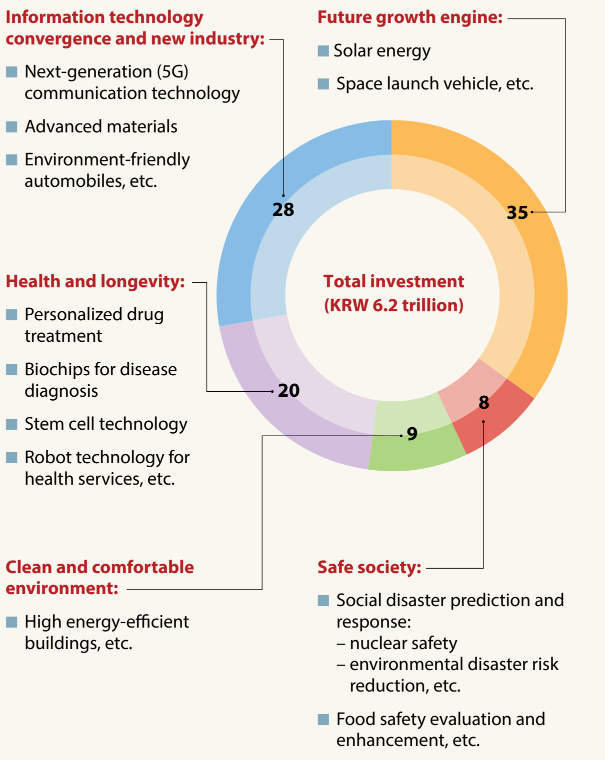
Source: MEST (2008); MSIP (2014b); UNESCO Institute for Statistics; MSIP (2013c)

- Identify five strategic areas for national technological development (Figure 25.2);
- Nurture creative talent by, for example, providing more funding for basic research and inviting 300 eminent foreign scientists to visit and work with national laboratories, etc.;
- Increase support for small and medium-sized enterprises (SMEs) to help them market their research output and technology;
- Create more jobs by enabling 'ecosystems' to support start-ups in science and technology, through funding, consultation services, etc.

Within the five strategic areas mentioned above, a total of 120 strategic technologies have been designated by the government, 30 of which are considered investment priorities over the five years to 2017, by which time the government expects some of these to be technologically feasible. As of mid-2015, the government had not yet announced budgetary targets to 2017. The Ministry of Science, ICTs and Future Planning (MSIP) is in the process of designing a strategic roadmap which will include an implementation plan.

Figure 25.2: **The Republic of Korea's strategic technologies for 2013–2017**

Budget share (%)



Source: NSTC (2013)

A reshuffle of the country's administrative cards

Several government bodies were restructured between 2009 and 2013. In particular, the Park Geun-hye administration established a new Ministry of Science, ICTs and Future Planning (MSIP). MSIP took over responsibility for S&T from the Ministry of Education, Science and Technology (MEST) and recovered some parts of broadcasting and communications from the Korea Communications Commission and some tasks from the Ministry of Knowledge Economy, which was renamed the Ministry of Trade, Industry and Energy.

The National Science and Technology Council (NSTC) was given greater authority in 2011 to meet the demand for greater convergence between science and technology. Its co-ordination function has been reinforced to enable it to prepare the *Basic Plans for Science and Technology* and the *Basic Plans for the Promotion of Regional Science and Technology*, among other documents. The council has also assumed deliberative and legislative power over major plans related to S&T that are suggested by each ministry. It has also recovered responsibility for evaluating national R&D programmes and for fixing the national R&D budget. Moreover, in an effort to streamline co-operation between the government and the private sector, the NSTC is now jointly chaired by the Prime Minister and a person designated by the President from the private sector (NSTC, 2012).

TRENDS IN R&D

The 5% target within reach for 2017

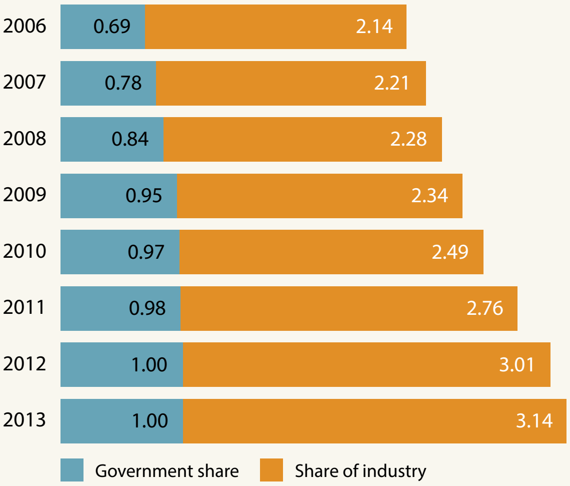
R&D financed by the Government and other national sources has risen almost continually since 1993. By 2008, it was rising by 13.3%[5] per year. The global financial crisis slowed the growth rate somewhat to 11.4% in 2010 and it slipped farther in 2014 to 5.3%. This decline in government funding has been offset by the industrial sector, which funds three-quarters of GERD and managed to increase its own investment in R&D between 2009 and 2013 by an average of 12.4% each year (Figures 25.3–25.5). As a consequence, the GERD/GDP ratio pursued its progression, albeit at a slower pace than that anticipated by the *Second Basic Plan for Science and Technology*. The Republic of Korea may have missed its target of devoting 5% of GDP to GERD by 2012 but the government is determined to see that this target is reached by 2017 (Kim, 2014).

More resources for basic research

Government investment in basic research has changed focus since 2008 by placing greater emphasis on quality. This has also entailed improving the quantity of allocated

5. If other national sources are excluded, government-funded R&D expenditure grew by 12.9% in 2009 and 2010 but only by 2.4% in 2013, according to the UNESCO Institute for Statistics.

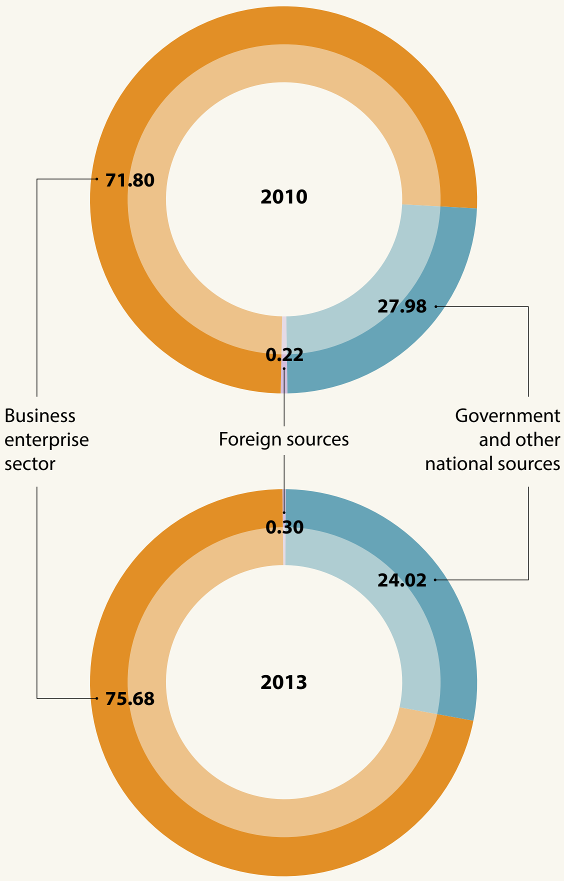
Figure 25.3: **GERD in the Republic of Korea by source of funds and as a share of GDP, 2006–2013** (%)



Note: The government share refers to R&D financed by the government, the higher education sector and other national sources but the contribution of all but the government share is negligible.

Source: MSIP (2014b)

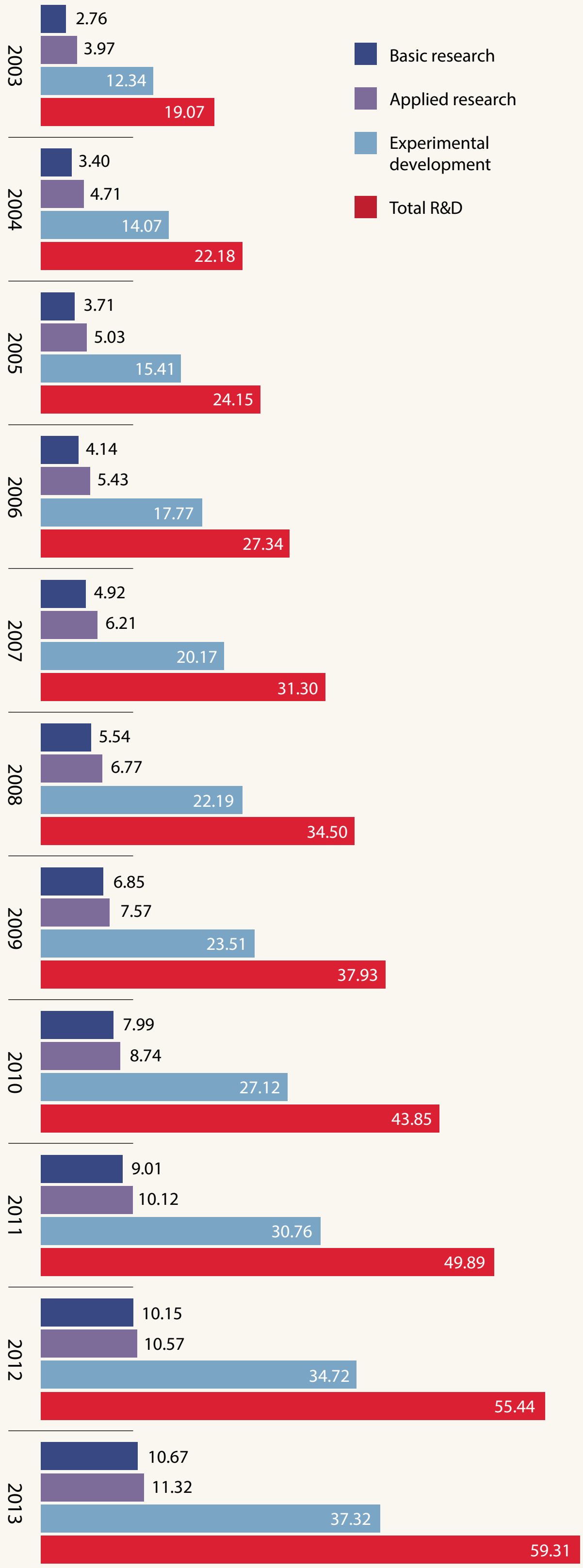
Figure 25.4: **GERD in the Republic of Korea by source of funds, 2010 and 2013** (%)



Source: MSIP (2014b)

Figure 25.5: **GERD in the Republic of Korea by type of research, 2003–2013**

In KRW trillions



Source: MSIP (2014b)

funds. The share of GERD devoted to basic research rose from 15.2% in 2006 to 18.1% in 2009, a share maintained ever since. This was largely thanks to the *Second Basic Research Promotion Plan*, which raised the basic research budget from 25.6% of government spending on R&D (2008) to 35.2% (2012). In parallel, funding allocated to individual basic scientists tripled over the same period from KRW 264 billion to KRW 800 billion (*circa* US$ 936 million) [MSIP, 2014a].

The current government is pursuing this policy. This can be seen in the budget allocated to the International Science Business Belt, currently under construction in the city of Daejeon. This ambitious project was enshrined in the *Basic Plan for an International Science Business Belt,* adopted by the Lee government in 2011. The aim is to correct the impression that the Republic of Korea made the transition from a poor agricultural country to an industrial giant through imitation alone, without developing an endogenous capacity in basic sciences. A National Institute for Basic Science opened on the site in 2011 and a heavy ion accelerator is currently under construction to support basic research and provide linkages to the business world (Box 25.1). Between 2013 and 2014, the Park government doubled the 'business belt's' budget to KRW 210 billion (*circa* US$ 246 million) [Kim, 2014].

The heavy ion accelerator should enable Korean scientists to improve their productivity in physics, which has evolved little since 2008, contrary to biological sciences (Figure 25.6).

Efforts to develop regional autonomy in R&D

The third *National Plan for the Regional Development of Science and Technology 2008–2012* was awarded a much greater share of investment than its two predecessors. The R&D budget for the regions was multiplied by 15 between 2008 and 2013, soaring from KRW 4 689 billion (*circa* US$ 5.9 billion) to KRW 76 194 billion (*circa* US$ 89.2 billion). This budget excludes Seoul and the city of Daejeon, where Daedeok Innopolis is located, the heart of the country's high-tech research community. Much of the funding went on building R&D infrastructure (MSIP, 2013a). This rise should be qualified, however; the share of regional R&D investment in relation to GERD actually remained constant at about 45% of the total over this period. Despite the massive injection of funds, a government evaluation of the third plan's implementation concluded that regional governments remained excessively reliant on central government funding for R&D and that regional R&D remained highly inefficient (MSIP, 2014a). Consequently, the fourth *National Plan for the Regional Development of Science and Technology 2013–2017* has fixed the objective of strengthening regional autonomy and responsibility for R&D. It is reviewing the feasibility of decentralizing inclusive R&D budgets to regional authorities and of improving R&D planning and management capabilities at regional level (MSIP, 2014a).

Industrial production and technology still dominate R&D

Despite the new focus on basic research, 'industrial production and technology' still represented two-thirds of GERD in 2013 (Figure 25.7). Of note is that R&D investment in health and environment rose by more than 40% between 2009 and 2012.

The number of private R&D centres increased by 50% between 2010 and 2012, from 20 863 to 30 589. Since 2004, more than 90% of corporate research institutes have been operated by SMEs and venture companies, although large

Box 25.1: **The Republic of Korea's Silicon Valley**

Moving away from its earlier focus on catch-up technology, the Republic of Korea has invested in a dedicated world-class science and business cluster in and around the city of Daejeon, less than an hour's journey from Seoul in a high-speed train. The International Science Business Belt dates from 2011. It is the country's biggest research complex, home to 18 universities, several science parks and dozens of research centres, both private and public.

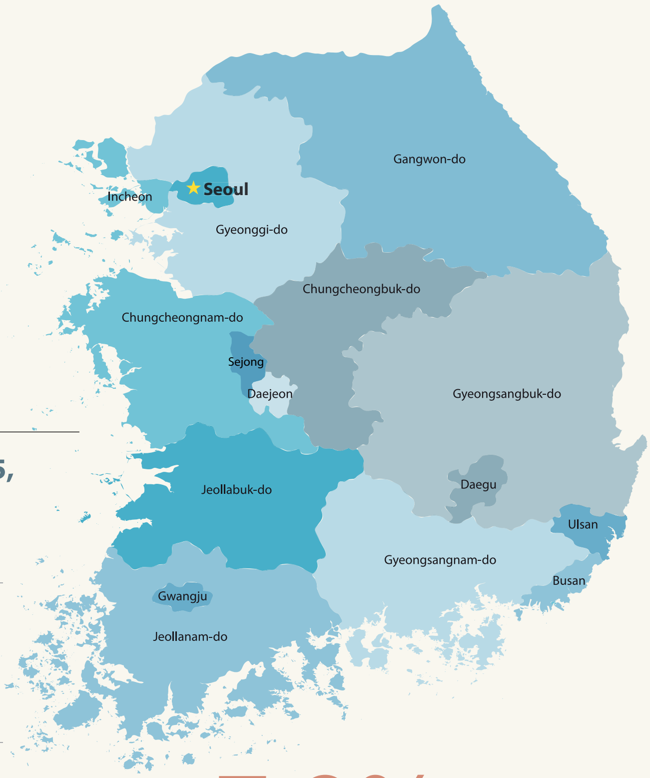
The jewel in the crown will be a heavy ion accelerator, due for completion by 2021. It will form part of the multi-functional research facility now called RAON. Here, researchers will be able to carry out groundbreaking research in basic science and look forward to discovering rare isotopes. RAON will be hosted by the Institute for Basic Science, which is itself under construction. It should open its doors in 2016. The institute plans to attract world-renowned scientists and to cultivate an environment that maximizes the researcher's autonomy; it intends to make its mark among the top 10 world-class research institutes in basic science with a measurable impact on society by 2030.

In order to foster synergies and convergence between basic science and business, high-tech companies and leading enterprises are being invited to group themselves around hubs such as the Korea Basic Science Institute.

The ultimate aim is to build a global city combining science, education, culture and art, where creativity, research and innovation can flourish, as they do in Silicon Valley in the USA or in the cities of Boston (USA), Cambridge (UK) or Munich (Germany).

Source: NTSC (2013), www.isbb.or.kr/index_en.jsp, http://ibs.re.k

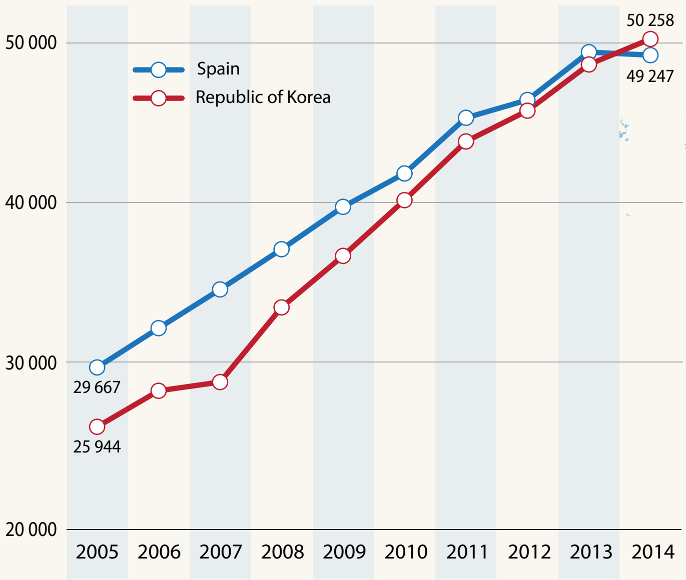
Figure 25.6: **Scientific publication trends in the Republic of Korea, 2005–2014**



0.89

Average citation rate for Korean publications, 2008–2012; the OECD average is 1.08; the G20 average is 1.02

Korean publications have nearly doubled since 2005, overtaking those of similarly populated Spain



7.9%

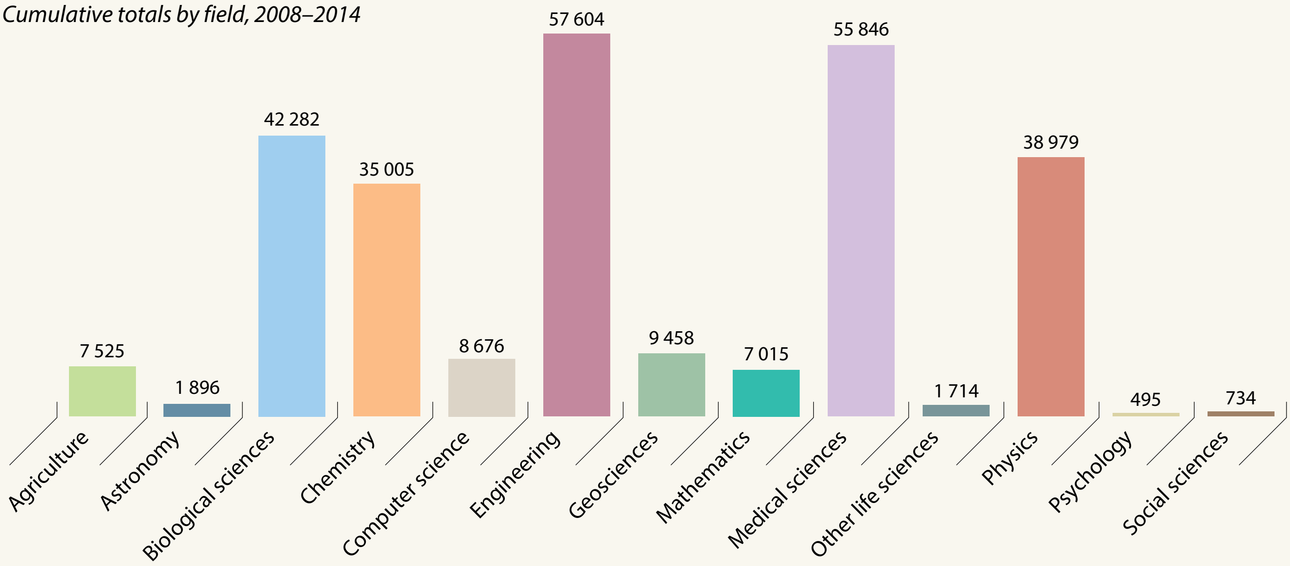
Share of Korean papers among 10% most-cited, 2008–2012; the OECD average is 11.1%; the G20 average is 10.2%

27.6%

Share of Korean papers with foreign co-authors, 2008–2014; the OECD average is 29.4%; the G20 average is 24.6%.

Korean scientists publish most in engineering, physics, chemistry and life sciences

Cumulative totals by field, 2008–2014



The USA remains the Republic of Korea's main partner, followed by Japan and China

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Rep. of Korea	USA (42 004)	Japan (12 108)	China (11 993)	India (6 477)	Germany (6 341)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

conglomerates accounted for 71 % of all private investment in R&D in 2009 and 74% in 2012. This shows that just a handful of major companies are the principal investors in Korean R&D, even though SMEs and venture companies play a key role by establishing and operating R&D centres.

Strong growth in domestic and international patents

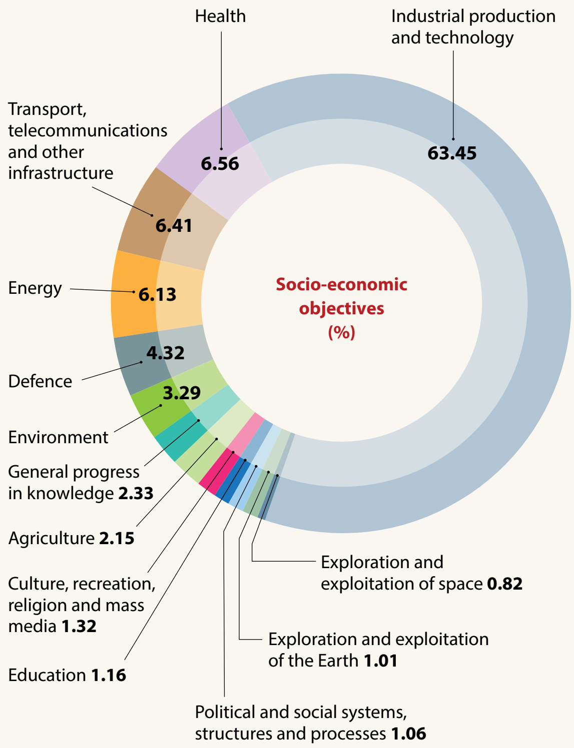
The number of domestic patents registered more than doubled between 2009 and 2013 from 56 732 to 127 330 (KIPO, 2013). This is quite a feat, especially coming as it does in the wake of the global financial crisis. In 2013, Koreans took third place (14 548) for the number of patents registered in the USA, behind Japan (51 919) and Germany (15 498).

The country also recorded a rise within triadic patent families – an aggregate of registrations with patent offices in Europe, Japan and the USA – even though the ratio per billion KRW of research budget slipped (Figure 25.8). This didn't prevent Korean inventors from ranking fourth in 2012.

Technology trade has doubled

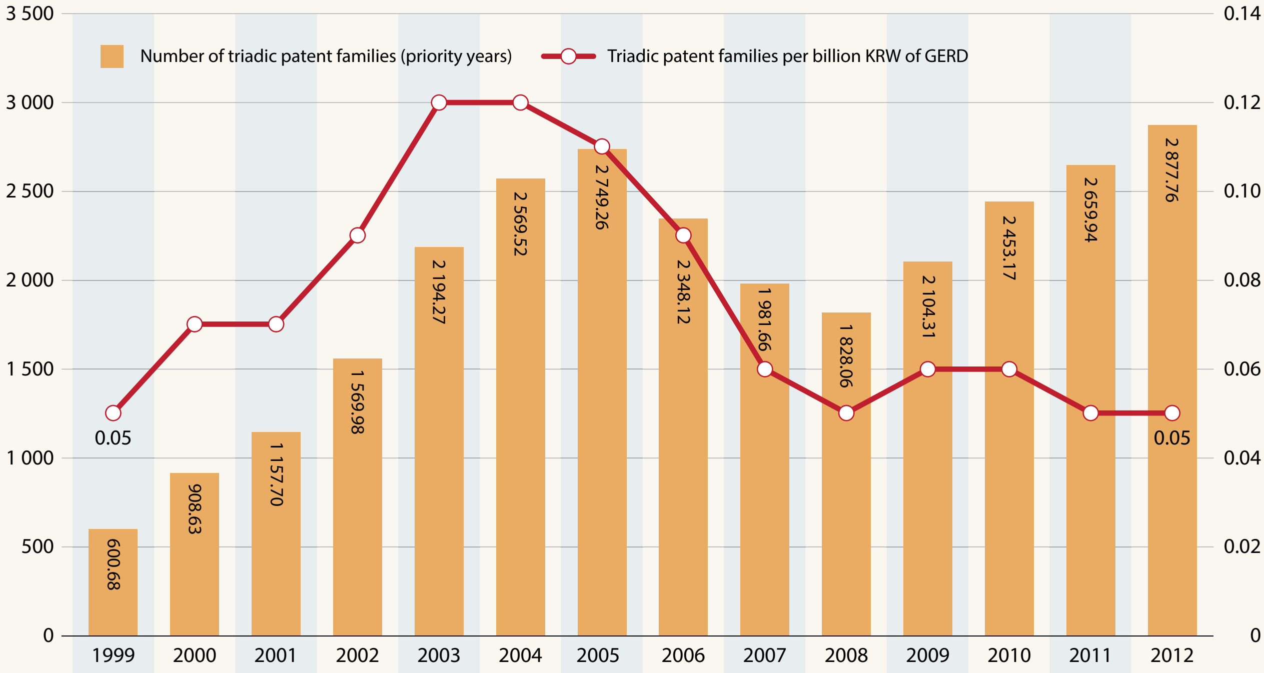
The volume of technology trade doubled between 2008 and 2012 from US$ 8.2 billion to US$ 16.4 billion. The trade balance, which can be calculated as a ratio of technology exports to technology imports, improved from 0.45 in 2008 to 0.48 in 2012 (MSIP, 2013b). Although this increasing volume of technology trade implies that the country is actively engaging in global innovation, it continues to record a large deficit in the global technology marketplace that it is striving to remedy.

Figure 25.7: **GERD in the Republic of Korea by socio-economic objective, 2013** (%)



Source: MSIP (2014b)

Figure 25.8: **Triadic patent family registrations in the Republic of Korea, 1999–2012**



Source: MSIP (2014b)

The volume of Korean high-tech exports (US$ 143 billion) is comparable to that of Singapore (US$ 141 billion) and higher than that of Japan (US$ 110 billion). Six out of ten high-tech exports fall into the category of electronics and telecommunications; exports in this sector even increased from US$ 66.8 billion in 2008 to US$ 87.6 billion by 2013.

Most countries experienced a dip in high-tech exports in 2009 after the global financial crisis hit but, whereas the Republic of Korea and Singapore rapidly recovered, the volume of high-tech exports stagnated in Japan and has not yet recovered in the USA, where high-tech exports earned US$ 237 billion in 2008 but just US$ 164 billion five years later.

Great strides in technological competitiveness

In 2014, the Republic of Korea ranked 6th for scientific competitiveness and 8th for technological competitiveness, according to the Institute of Management Development, based in Switzerland. The rankings for both science and technology have improved hugely since the turn of the century but it is in technological competitiveness that Korea has made the biggest strides in the past five years. The country is particularly efficient in communication technologies. For example, it ranked 14th in 2014 for mobile telecommunication costs per minute, compared with 33rd a year earlier. Other indicators surveyed remained sluggish, however. For example, in terms of technological co-operation among corporations, Korea it ranked 39th, whereas its rank on cybersecurity issues was downgraded from 38th to 58th over the same period. This correlates with the drop in scientific productivity in computer sciences observed in recent years.

TRENDS IN HUMAN RESOURCES

Korea now ranks sixth for the number of researchers

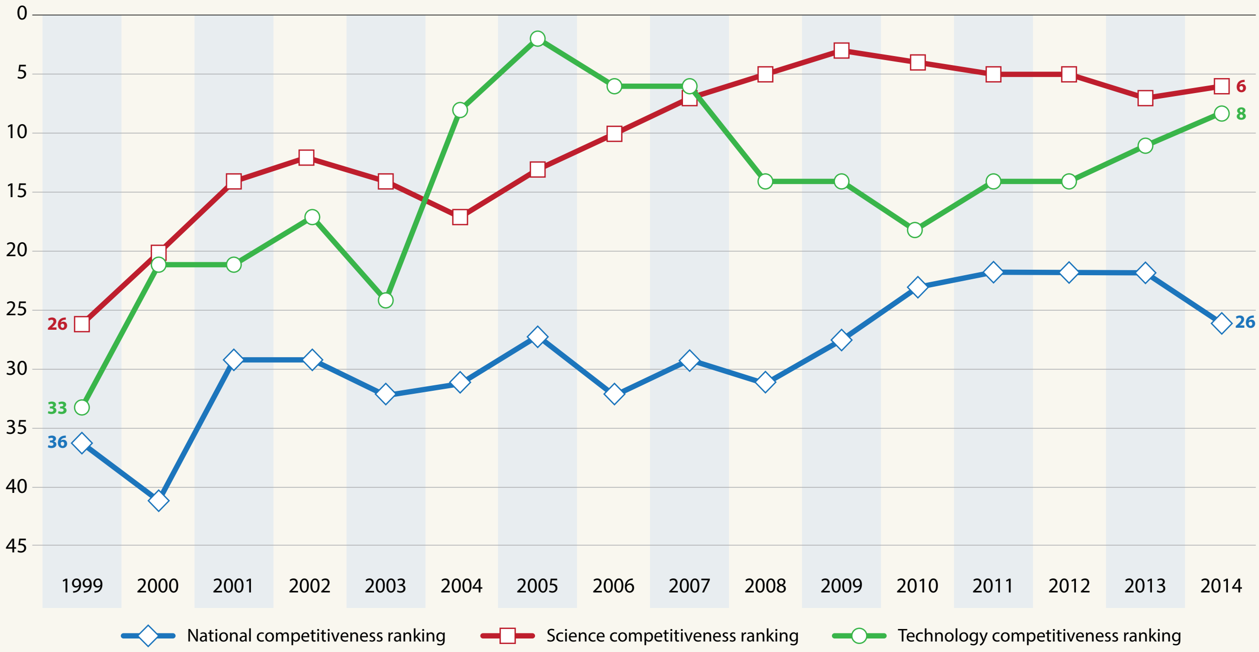
The number of full-time equivalent (FTE) researchers grew steeply between 2008 and 2013 from 236 137 to 321 842 (Figure 25.10). As a result, the Republic of Korea now ranks sixth for this indicator after China, the USA, Japan, the Russian Federation and Germany. More importantly, the Republic of Korea has more researchers per million population than any of these countries: 6 533 in 2013. In terms of researcher density, it is surpassed only by Israel and some Scandinavian countries. Moreover, thanks to the steady rise in the country's GERD/GDP ratio, the investment available to each researcher has managed to keep pace with the burgeoning numbers of personnel, even climbing slightly from PPP$ 186 000 to PPP$ 214 000 between 2008 and 2013 (Figure 25.10).

Women remain a minority in Korean science

In 2008, only one in six researchers (15.6%) was a woman. The situation has improved somewhat since (18.2% in 2013) but the Republic of Korea still lags far behind the beacons for this indicator, Central Asia and Latin America, where about 45% of researchers are women, even if it performs better than Japan (14.6% in 2013). When it comes to remuneration, there is a yawning gap between men and women researchers in the Republic of Korea (39%), the widest of any OECD country. Japan has the next-biggest gap in remuneration (29%).

The government is cognizant of the problem. In 2011, it introduced a *Second Basic Plan for Women Scientists and*

Figure 25.9: **Changes in Republic of Korea's competitiveness ranking in science and technology, 1999–2014**

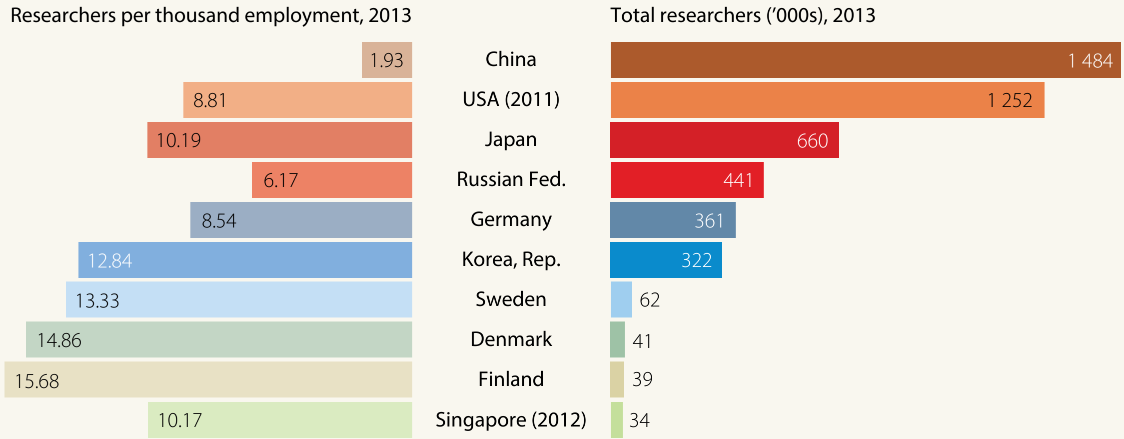


Source: IMD (2014) *World Competitiveness Yearbook*. Institute of Management Development: Lausanne (Switzerland)

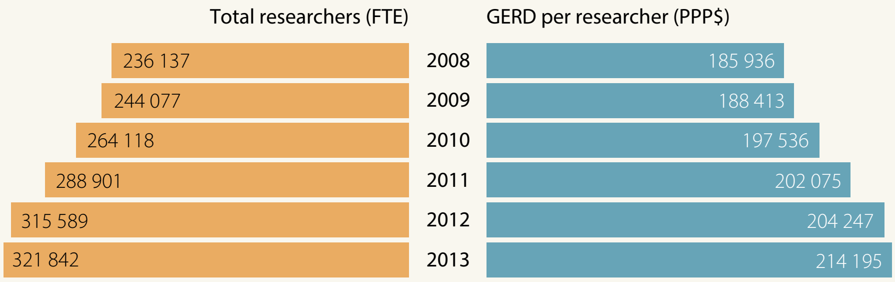
Figure 25.10: **Trends among Korean researchers (FTE), 2008–2013**

The Republic of Korea has one of the world’s greatest researcher intensities

Other countries are given for comparison



The budget per researcher has risen since 2008



Source: OECD (2015) *Main Science and Technology Indicators*

Engineers (2009–2013), which outlines measures for fostering career development and making the working environment more women-friendly. In 2011, centres for women in science and technology lodged within several universities merged to form the Centre for Women in Science, Engineering and Technology (WISET). WISET develops policies to mainstream women in science, engineering and technology. The centre held a Gendered Innovation Forum in March 2014 to bring Korean experts together with science attachés from embassies in Seoul. The centre is also hosting the next Gender Summit in Seoul in late 2015. The first gender summits have been held in Europe and the USA since 2011. This will be the first such event in Asia.

Measures to nurture creative talents

The Korean government has come to realize that developing national capabilities for innovation will require nurturing creativity among the young (MSIP, 2013b). To this end, it has outlined several strategies for the ‘renaissance of the natural sciences and engineering’. Ministries have jointly introduced ‘measures to nurture creative talents’, in order to attenuate the focus on academic backgrounds and promote a new culture whereby people encourage and respect the creativity of individuals. One example of these measures is the Da Vinci Project being experimented in selected primary and secondary schools to develop a new type of class which encourages students to exercise their imagination and which revitalizes hands-on research and experience-based education.

The government is also promoting the Open Academy Project with the Korea Advanced Institute of Science and Technology and other universities to establish an online platform where students can study and enter into discussion with professors. There are plans to make online courses accessible to anyone with an interest in studying and to link these courses to an academic credit banking system to ensure that the credits obtained by students enrolled in these online courses are recognized.

The *Second Basic Plan for Nurturing Human Resources in Science and Engineering* (2011–2015) aims to foster human resources in science and technology by focusing on the development of creativity, the scope of which is to be expanded to include elementary and secondary education. The government is promoting education for science, technology, engineering, arts and mathematics (STEAM) to promote the convergence of these fields and help students grasp economic and social challenges in the future. Brain Korea 21 plus has been implemented within the scope of the plan (Box 25.2). The government has also expanded its financial support to young researchers: the number of projects qualifying for government support rose from 178 (KRW 10.8 billion) in 2013 to 570 (KRW 28.7 billion) in 2014.

Based on the *Medium-and Long-term Supply and Demand Forecast for Human Resources in Science and Technology* (2013–2022), the country will face an excess of 197 000 graduates and 36 000 postgraduates with a master's degree by 2022, whereas there will be shortage of 12 000 PhD-holders.

As industry needs a greater number of employees with training in science and technology than in the past, policy measures will need to correct this misalignment. For example, the government plans to conduct a foresight exercise with a focus on human resource needs in emerging technologies to make up for the projected shortfall in these fields.

A creative economy town

The Creative Economy Town[6] is one example of a series of offline and online platforms set up by the Park government to allow individuals to share and commercialize their ideas. Professionals from relevant fields act as mentors, providing legal advice on intellectual property rights and other issues and connecting budding innovators with companies which have the potential to market their ideas.

A second example is the Innovation Center for the Creative Economy. This government centre is located in Daejeon and Daegu and serves as a business incubator.

These initiatives are not without controversy, however, as some feel that the government is intervening too much. The main question hinges on whether or not entrepreneurship can be better fostered with government support or by leaving entrepreneurs to fend for themselves in the marketplace.

A survey conducted by the Korea Federation of Small and Medium-Sized Enterprises in 2014 revealed that the federation's members judged the level of entrepreneurship in the Republic of Korea to be quite low.[7] It is still too early at this point to analyse whether or not the government's efforts have succeeded in fostering innovation.

A more systemic approach to co-operation

Korean scientists have been participating in international projects and exchanges for years. Some 118 scientists collaborated with the European Organization for Nuclear Research (CERN) in 2013, for instance. The Republic of Korea is also a partner in the project which is currently building an International Thermonuclear Experimental Reactor in France and invested around KRW 278 billion in this project from 2012 to 2014. The government also contributed KRW 20 million (*circa* US$ 23 000) to support the participation of more than 40 individual Korean researchers in the European Union's Seventh Framework Programme for Research and Technological Development from 2007–2013 (MSIP, 2012).

6. https://www.creativekorea.or.kr

7. http://economy.hankooki.com/lpage/industry/201410/e20141028102131120170.htm

Box 25.2: **Brain Korea 21 Plus: the sequel**

The *UNESCO Science Report 2010* followed the fortunes of the Brain Korea project, which had been renewed in 2006 for another six years. Within this project, universities and graduate schools wishing to qualify for government funding were obliged to organize themselves into research consortia. The aim was to encourage world-class research.

This approach seems to have worked, for the performance and output of both participating graduates and faculties effectively improved. For example, the number of articles produced by university staff and graduates increased between 2006 and 2013 from 9 486 to 16 428. Importantly, the impact factor per article also progressed: from 2.08 in 2006 to 2.97 in 2012 (NSTC, 2013).

Encouraged by this success, the project was extended for another six years in 2013, under the name of Brain Korea 21 Plus. In its first year, the project received an allocation of KRW 252 billion (*circa* US$ 295 million).

Whereas the initial project focused on increasing the quantity of R&D performed, Brain Korea 21 Plus is focusing on improving the quality of both teaching and research at local universities, along with their ability to manage projects. By 2019, the project hopes to have enrolled a great deal more students in accredited master's and PhD programmes than in the past, in order to nurture some of the talent that will be needed to develop a more creative economy.

Source: https://bkplus.nrf.re.kr

The government is also encouraging Korean collaboration with world-class laboratories through a home-grown scheme, the Global Research Laboratory Programme, which was launched in 2006. Each year, the Ministry of Science, ICTs and Future Planning and the National Research Foundation invite Korean research institutions to answer their call for project proposals. These proposals may concern basic sciences or technological fields, as long as the research topic necessitates collaboration with laboratories abroad. Successful joint projects may be awarded annual funding of KRW 500 million (*circa* US$ 585 000) for up to six years. The number of Global Research Laboratory projects has increased from 7 in 2006 to 48 in 2013 (MSIP, 2014a).

The current government is particularly keen to see the private sector develop core technologies by investing in foreign companies. The *National Plan for International Co-operation in Science, Technology and ICTs* (2014) sets out to do just that. A key element of the plan is the establishment of the Korea Innovation Centre, which will play a supporting role for Korean researchers and entrepreneurs eager to invest abroad while attempting to woo foreign investors to Korean shores (Box 25.3).

Some forms of international assistance also incorporate science and technology, such as the Techno Peace Corps programme, which funds postdoctoral students. Another example is the project being implemented by the government in Viet Nam to establish the Viet Nam–Korea Institute of Science and Technology. The government also plans to establish 'centres for appropriate science and technology' in developing countries, in order to provide post-management of projects, including consultancies and education; for example, the government has established an innovative Water Centre (iWc) in Cambodia to boost Cambodian R&D oriented towards providing a clean water supply and serve as a base for the Republic of Korea's international assistance in science and technology. The government's overall budget for this type of international assistance is expected to increase from KRW 8.2 billion in 2009 to KRW 28.1 billion (*circa* US$ 32.9 million) in 2015 (Kim, 2011).

CONCLUSION

A new orientation towards entrepreneurship and creativity

The Republic of Korea has come through the global financial crisis since 2008 remarkably unscathed. However, this should not mask the fact that the country has outgrown its catch-up model. China and Japan are competing with Korean technology in global markets and exports are slipping as global demand evolves towards green growth.

The government has decided to respond to this increasingly competitive global market by raising its investment in R&D, strengthening the manufacturing sector and developing new creative industries. The country's investment in R&D has already risen quite substantially but there is now some doubt as to whether this has produced the desired result. It may be that investment in R&D has reached a point where marginal growth in the performance of R&D is close to zero. The Republic of Korea thus now needs to optimize the management of its national innovation system to take full advantage of this rising investment.

Without a corresponding restructuring of industry and its accompanying innovation system, the injection of R&D funding

Box 25.3: The Korea Innovation Centre

Established in May 2014 as part of the new 'creative economy,' the Korea Innovation Centre promotes Korean exports and the internationalization of national researchers.

It also incites venture companies and SMEs to enter the world market. In order to encourage networking and common platforms for co-operation, it is opening up offices in the European Union (Brussels), the USA (Silicon Valley and Washington, DC), China and the Russian Federation, as well as at home.

The Korea Innovation Centre is operated jointly by the National Research Foundation, which provides the secretariat, and the National Information Technology Industry Promotion Agency. Its mission is aligned with the five strategies designated under the 2014 *National Plan for International Co-operation in Science, Technology and ICTs:*

- Establish systemic linkages to support international co-operation and overseas business;
- Enhance support for SMEs to launch overseas ventures;
- Strengthen innovation capacities by developing world-class human resources in STI;
- Strengthen international co-operation and partnerships in science, technology and ICTs;
- Create more efficient management systems to respond to international demand.

Source: www.msip.go.kr

may not be able to produce better output. As posited by the theory of innovation systems, the total productivity of a national innovation system is a key factor for change but it is also quite difficult to transform the national innovation system, as it tends to be an 'ecosystem' that is most concerned with linking the various actors through relationships and processes.

The country is now striving to become more entrepreneurial and creative, a process that will entail changing the very structure of the economy. Up until now, it has relied on large conglomerates such as Hyundai (vehicles) and Samsung and LG (electronics) to drive growth and export earnings. In 2012, these conglomerates still represented three-quarters of private investment in R&D – an even higher share than three years previously (KISTEP, 2013). The challenge will be for the country to produce its own high-tech start-ups and to foster a creative culture in SMEs. Another challenge will be to turn the regions into hubs for creative industries by providing the right financial infrastructure and management to improve their autonomy.

KEY TARGETS FOR THE REPUBLIC OF KOREA

- Raise GERD from 4.03% to 5.0% of GDP between 2012 and 2017;
- Ensure that SMEs achieve 85% of their potential technological competitiveness by 2017, compared to 75% in 2011;
- Raise support for SMEs from 12% of the government R&D budget in 2012 to 18% by 2017;
- Raise the share of basic research in the government budget from 32% in 2012 to 40% by 2017;
- Raise the share of government investment in improving the quality of life through R&D from 15% in 2012 to 20% in 2017;
- Increase the number of jobs in S&T from 6.05 million to 6.69 million by 2017;
- Increase the share of early-stage entrepreneurial activity in enterprises from 7.8% in 2012 to 10% in 2017;
- Increase the number of PhD-holders from 0.4% to 0.6% of the population between 2012 and 2017;
- Raise industrial added value per capita from US$ 19 000 in 2012 to US$ 25 000 by 2017;
- Commercialize the technology for carbon dioxide capture sequestration by 2020;
- Double the value of technology exports from US$ 4 032 million to US$ 8 000 million between 2012 and 2017.

In sum, the government's agenda for a creative economy reflects a growing consensus that the country's future growth and prosperity will depend on its ability to become a global leader in developing and commercializing innovative new products, services and business models.

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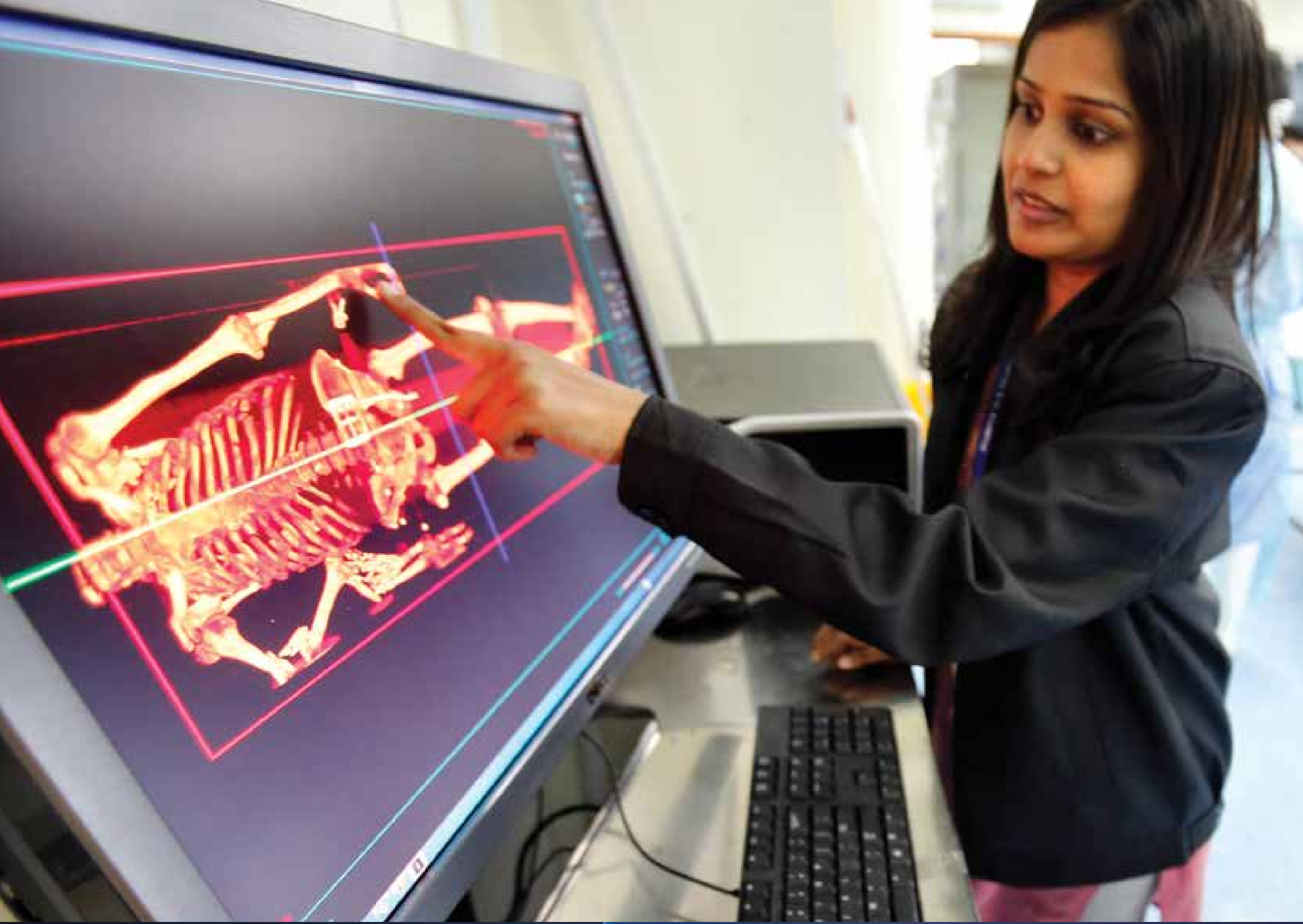


Accountability and effective monitoring [of innovation] is a must to ensure that investment yields a desirable rate of return.

Rajah Rasiah and **V.G.R. Chandran**

Dr Kastoori Karupanan demonstrates the Digital Autopsy at a mortuary in Kuala Lumpur Hospital. This forensic application creates a three-dimensional image that enables a virtual body to be viewed and dissected in high definition.

Photo: © Bazuki Muhammad/Reuters

26 · Malaysia

Rajah Rasiah and V.G.R. Chandran

INTRODUCTION

Stable economic growth but challenges lie ahead

The Malaysian economy grew by 4.1% per year on average between 2002 and 2013, pausing only briefly in 2009 at the height of the global financial crisis (Figure 26.1). The rapid return to positive growth in 2010 can be at least partly attributed to the two stimulus packages adopted by the government in November 2008 and March 2009.

Malaysia was an early convert to globalization. Since the launch of export-oriented industrialization in 1971, multinational corporations have relocated to Malaysia, fuelling a rapid expansion in manufactured exports that has helped turn the country into one of the world's leading exporters of electrical and electronic goods. In 2013 alone, Malaysia accounted for 6.6% of world exports of integrated circuits and other electronic components (WTO, 2014).

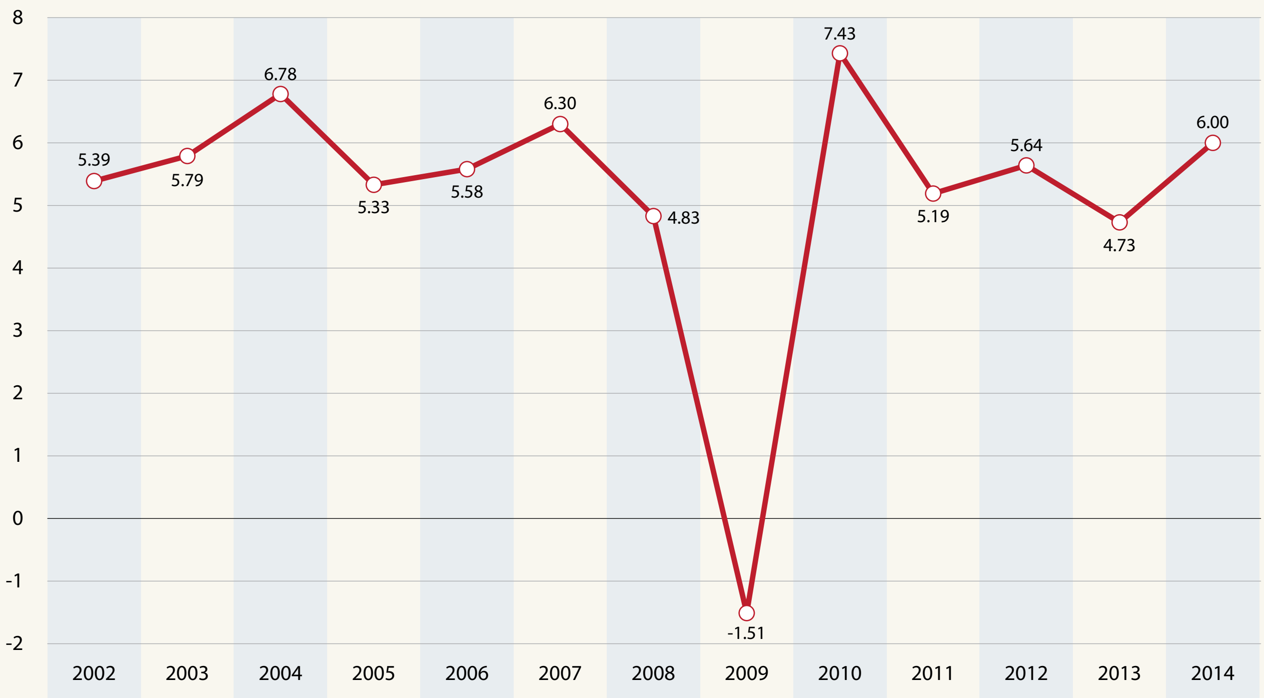
Rapid growth and the consequential tightening of the labour market led the Malaysian government to focus from the 1990s onwards on a shift from a labour-intensive economy to an innovation-intensive one. This goal is encapsulated in *The Way Forward* (1991), which fixes a target of achieving high-income status by 2020. Whereas Malaysia has done remarkably well over the past two years in terms of structural reform, several areas still require attention if the country is to achieve its goal. We shall now examine these areas one by one.

The rapid expansion of exports in electronics from the 1970s onwards has turned Malaysia into a major hub for the production of high-tech goods. Today, Malaysia is highly integrated in global trade, with manufacturing contributing over 60% of its exports. Half of these exports (49%) were destined for the East Asian market[1] in 2010, compared to just 29% in 1980. Over the past 15 years or so, the share of manufacturing in GDP has gradually declined as a natural consequence of the concomitant growth in services as a corollary of greater development. Modern manufacturing and services are deeply intertwined, as high-tech industries often have a massive services component. The development of the services sector is thus not, in itself, a cause for concern.

More worrying is the fact that the shift towards services has neglected the development of high-tech services. Moreover, although the volume of manufacturing has not declined, less value is being added to manufactured goods than before. As a consequence, Malaysia's trade surplus declined from

1. essentially China, Indonesia, Republic of Korea, the Philippines, Singapore, and Thailand

Figure 26.1: **GDP growth in Malaysia, 2002–2014 (%)**



Source: World Bank's World Development Indicators, June 2015

144 529 ringgits (MYR) in 2009 to MYR 91 539 in 2013 and Malaysia has been losing ground in high-tech exports. High-tech manufacturing has stagnated in absolute terms in recent years and its share of global added value has slipped from 0.8% in 2007 to 0.6% in 2013. Over the same period, Malaysia's global share of high-tech exports (goods and services) has contracted from 4.6% to 3.5% (WTO, 2014). The contribution of high-tech industries to national GDP has likewise dropped.

Malaysia also needs to reduce its reliance on oil and gas extraction. In 2014, oil and gas contributed nearly 32% of government revenue. Although natural gas represented about 40% of Malaysia's energy consumption in 2008, there have been gas shortages since 2009, owing to the combination of a declining domestic gas supply and rising demand. To compound matters, the sharp drop in global oil prices between July and December 2014 forced the government to cut expenditure in January 2015 to maintain its budget deficit at 3%. A recent budget review indicates that Malaysia will not be able to rely on its natural resources to propel itself towards high-income status by 2020.

Rising inequality is a growing concern in Malaysia, with the disparity between the top 20% income-earners and the bottom 40% widening. The government's Subsidy Rationalization Programme, which had first been rolled out in 2010 with little effect, moved into high gear in 2014 with three consecutive increases in natural gas prices in a single year. The removal of energy subsidies, coupled with the introduction of a general sales tax on consumer goods in April 2015, is expected to increase the cost of living. The four out of ten Malaysians in the lowest income bracket are also increasingly exposed to social and environmental risks. The incidence of dengue increased by 90% in 2013 over the previous year, for instance, with 39 222 recorded cases, in a trend which may be linked to deforestation and/or climate change. The rising crime rate is another concern.

Although Malaysia remains committed to reducing its carbon emissions by 40% by 2020 over 2012 levels, as pledged by the Malaysian prime minister at the climate summit in Warsaw in 2013, it faces growing sustainability challenges. In January 2014, Selangor, the most developed of Malaysia's federated states, experienced water shortages. These were not caused by lack of rainfall – Malaysia lies in the tropics – but by high pollution levels and the drying of reservoirs as a consequence of overuse. Land clearing and deforestation remain major concerns, causing landslides and population displacements. Malaysia is the world's second-biggest producer of palm oil after Indonesia, the two countries contributing about 86% of all palm oil in 2013, according to the World Wildlife Fund's 2013 Palm Oil Buyer's Scoreboard. Since the 1990s, palm oil exports have represented the third-largest category of Malaysian exports after fossil fuels (petroleum and gas) and electronics. About 58% of Malaysia remained forested in 2010. With the government having committed to preserving at least half of all land as primary forest, Malaysia has little latitude to expand the extent of land already under cultivation. Rather, it will need to focus on improving productivity (Morales, 2010).

Avoiding the middle-income trap

The Najib Razak coalition government came to power in 2009 before being re-elected in 2013. The government estimates that 6% annual growth is necessary to reach high-income status by 2020, which is somewhat higher than the average for the previous decade. A greater focus on innovation will be necessary to reach this goal.

One of the first schemes introduced by the current administration was the Economic Transformation Programme (ETP) in 2010, which contributes to the National Transformation Programme (2009). The ETP laid the foundations for the introduction of the *Tenth Malaysia Plan* (2011–2015) in 2010. The ETP seeks to strengthen industrial competitiveness, raise investment and improve governance, including public-sector efficiency. As much as 92% of this programme is to be financed by the private sector. The programme focuses on 12 growth areas:

- Oil, gas and energy;
- Palm oil and rubber;
- Financial services;
- Tourism;
- Business services;
- Electronics and electrical goods;
- Wholesale and retail;
- Education;
- Health care;
- Communications, content and infrastructure;
- Agriculture; and
- Greater Kuala Lumpur/Kelang Valley.

The programme identifies six Strategic Reform Initiatives to drive competitiveness and create a business-friendly environment: competition, standards and liberalization; public finance reform; public service delivery; narrowing disparities; the government's role in business; and human capital development. The education component of the *Economic Transformation Programme* focuses on four main areas: Islamic finance and business; health sciences; advanced engineering; and hospitality and tourism.

ISSUES IN STI GOVERNANCE

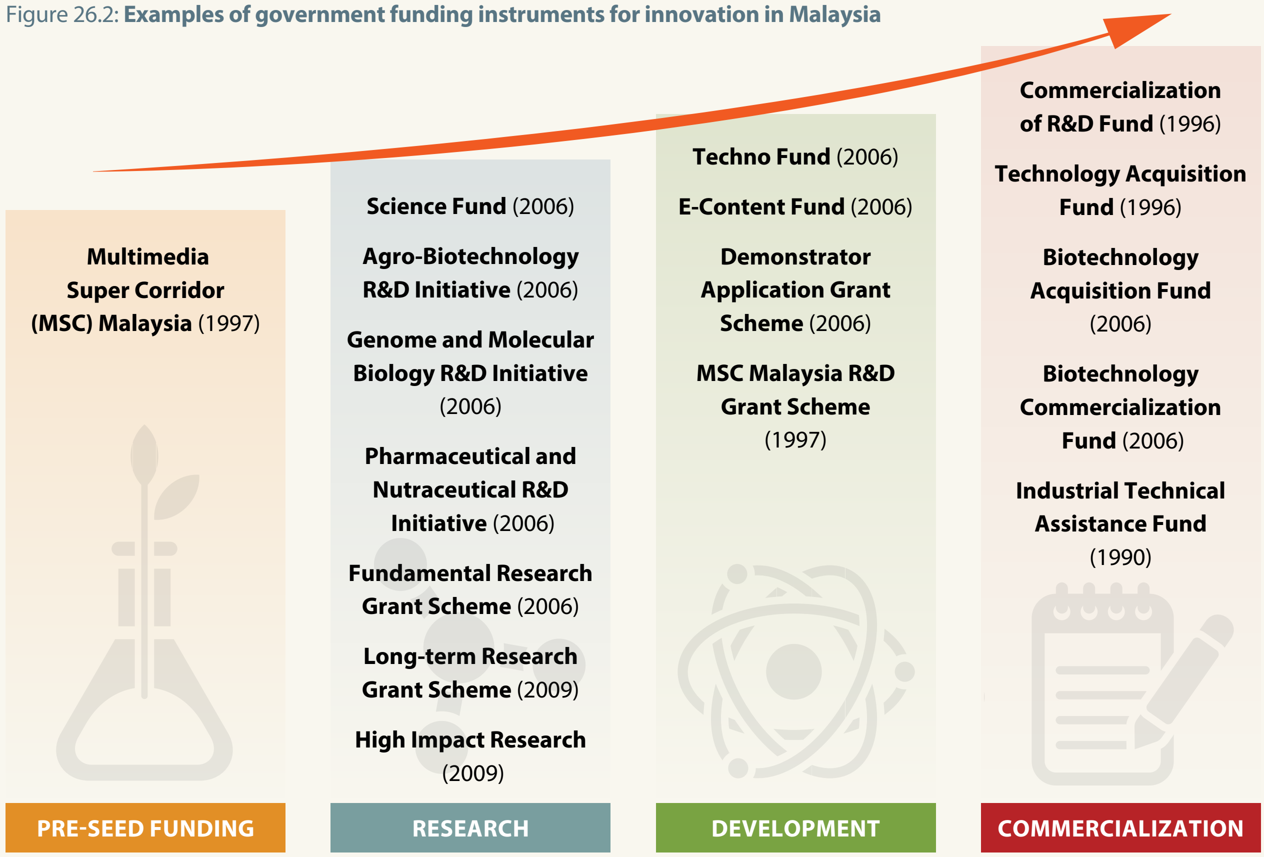
Growing expectations of S&T for inclusive development
Despite significant progress since the 1970s, Malaysia is not yet in the same league as dynamic Asian economies such as the Republic of Korea, with which it is often compared. Governance issues and weak institutional capabilities in STI figure at the top of the list of current shortcomings. In addition, budget deficits have recently started putting pressure on public investment levels, including research and development (R&D). In particular, recurrent crises have pushed the government to shift expenditure towards addressing socio-economic problems.

Innovation for inclusive development has risen in the public policy agenda and is currently being widely discussed in Malaysia, in a context of low farm productivity, increasing health-related problems, natural disasters, environmental problems and even monetary inflation. In 2014, the government launched transdisciplinary research grants with the objective of including societal benefits among the performance criteria at Malaysia's research universities and providing incentives to promote science in support of poverty alleviation and sustainable development.

Effective inter-agency co-ordination across policy boundaries will obviously be necessary to develop innovative solutions to the problems outlined above. The Ministry of Science, Technology and Innovation (MoSTI) and the Ministry of Education are the principal drivers of Malaysia's national innovation system. There seems to be some agreement that applied research is the purview of MoSTI, whereas basic research falls under the Ministry of Education, but there is no mechanism for co-ordinating basic and applied research. Also, MoSTI monitors innovation through surveys, the provision of grants and evaluations but it lacks the industrial exposure to co-ordinate industrial grants effectively, a failing which is evident from the absence of an effective performance criterion for some government grant programmes, including the TechnoFund (Figure 26.2). It is important that a body closer to industry, such as the Ministry of International Trade and Industry (MoITI) or its sub-organ, the Malaysian Industrial Development Authority (MIDA), be entrusted with this role. Accountability and effective monitoring is a must to ensure that investment yields a desirable rate of return.

Despite the long-standing role of government in funding R&D programmes, there is currently no systematic approach to R&D programme appraisal and monitoring. Remedying this

Figure 26.2: **Examples of government funding instruments for innovation in Malaysia**



Note: The year of the fund's creation is given in brackets

Source: Adapted from MoSTI (2013)

oversight would require introducing a legal framework and engaging the stakeholders in the early stages of designing performance monitoring and assessment criteria. Indeed, an independent monitoring body could provide greater accountability and transparency over the disbursement and collection of R&D funds and reduce duplication.

There has been some recognition of the need to co-ordinate STI better, in particular as concerns research and commercialization of the results. For example, the National Science Research Council presented a proposal in 2014 to establish a central independent agency to co-ordinate R&D. The agency's mandate would incorporate technology foresight, among other tasks, as well the monitoring, evaluation and management of R&D.

Many issues have resurfaced in current policy

The government's focus on STI dates back to the launch of the *First Science and Technology Policy* in 1986. This was followed by an *Action Plan for Industrial Technology Development* in 1991 to stimulate the development of strategic and knowledge-intensive industries, as well as by the creation of intermediary organizations such as training centres, universities and research laboratories to propel this development. It is the *Second Science and Technology Policy* (2002–2010), however, which is considered the first comprehensive formal national policy with specific strategies and action plans to set the STI agenda.

The current *Third National Science and Technology Policy* (2013–2020) emphasizes the generation and utilization of knowledge; talent development; energizing innovation in industry; and improving the governance framework for STI to support innovation. Nevertheless, many of the issues targeted in the first two policies have resurfaced in the third policy, implying that the objectives fixed in the previous policies have not been achieved; these issues include the diffusion of technology, the private sector's contribution to R&D and innovation, commercialization, monitoring and evaluation.

Without business R&D, 2020 target will not be reached

Without a doubt, R&D is contributing far more to the country's development than even a decade ago. Between 2008 and 2012, gross domestic expenditure on R&D (GERD) rose from 0.79% to 1.13% of GDP (Figure 26.3). This is all the more remarkable in that GDP grew steadily over the same period. Despite this progress, Malaysia still lags behind Singapore or the Republic of Korea for this indicator; the gap is particularly wide when it comes to business expenditure on R&D (BERD). In 2012, Malaysia's BERD/GDP ratio stood at 0.73%, compared to 1.2% in Singapore and 3.1% in the Republic of Korea. Malaysia is targeting a 2.0% GERD/GDP ratio by 2020; whether or not it reaches this target will depend largely upon the dynamism of the business enterprise sector.

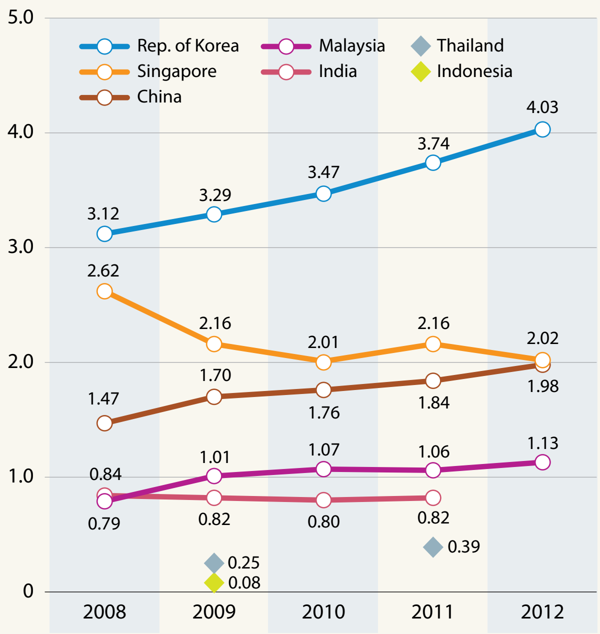
While private sector participation in R&D has risen considerably since 2005, in particular, its share is still quite low in comparison with dynamic Asian economies. For example, between 2006 and 2011, a total of 25 423 ICT patents were filed in the USA by Koreans, compared to a meagre 273 by Malaysians (Rasiah *et al.*, 2015a, 2015b).

R&D spillovers have not been significant, despite the strong presence of multinational corporations in Malaysia. This is due to the lack of a critical mass of R&D infrastructure, especially as concerns human capital and laboratories specializing in frontier R&D at research universities and government-owned institutions (OECD, 2013; Rasiah, 2014).

The involvement of multinational corporations in frontier R&D is still limited in Malaysia, so pro-active measures will be required to develop this activity (Rasiah *et al.*, 2015a). R&D conducted by both national and foreign firms is largely confined to product proliferation and problem-solving. For example, in the ICT industry, no firm is engaged in R&D targeted at miniaturizing ICT nodes or in expanding wafer diameters. Innovative activity tends to be limited to the transfer and diffusion of technology through intra-industry trade, particularly in the country's free trade zones. This constant focus on production-type operations will only be able to contribute to incremental innovation (Rasiah, 2010). In 2012, a group of multinationals established a platform to promote collaborative R&D; although this is a step in the right direction, it is too early at this stage to assess its success (Box 26.1).

Figure 26.3: **GERD/GDP ratio in Malaysia, 2008–2012**

Other countries are given for comparison



Source: UNESCO Institute for Statistics, May 2015

Box 26.1: A multinational platform to drive innovation in electrical goods and electronics

To address the shortcomings of the local innovation ecosystem, a group of multinational corporations have created their own platform for Collaborative Research in Engineering, Science and Technology (CREST). Established in 2012, this trilateral partnership involving industry, academia and the government strives to satisfy the research needs of electrical and electronics industries, which employ nearly 5 000 research scientists and engineers.

This platform was initiated by ten leading electrical and electronic companies: Advanced Micro Devices, Agilent Technologies, Altera, Avago Technologies, Clarion, Intel, Motorola Solutions, National Instruments, OSRAM and Silterra. These companies generate close to MYR 25 billion (*circa* US$ 6.9 billion) in annual revenue and spend nearly MYR 1.4 billion on R&D. Government grants have been utilized extensively by these multinational firms since 2005 (Rasiah *et al*, 2015a).

The Northern Corridor Implementation Authority, Khazanah Nasional, University of Malaya and University of Science Malaysia work closely with CREST. Besides R&D, the focus is on talent development, the ultimate aim being to help the industry add greater value to its products.

Source: www.crest.my

The current gaps in knowledge, capability and financing also make it harder for small and medium-sized enterprises (SMEs) to undertake R&D. Most of the SMEs that work as subcontractors for multinational firms have remained confined to the role of original equipment manufacturers. This prevents them from participating in original design and original brand manufacturing. SMEs thus need greater support in accessing the requisite knowledge, capability and financing. One key strategy is to connect SMEs to the incubation facilities in the country's science and technology parks.

Losing ground in high-tech exports

While discovery and patenting are crucial for Malaysia's export-oriented competitiveness and growth strategy, there still seems to be little return on investment in R&D (Chandran and Wong, 2011). Although patent applications with the Malaysian patent office have increased steadily over the years (7 205 in 2013), they lag far behind those of competitors such as the Republic of Korea (204 589 in 2013), according to the World Intellectual Property Organization. Moreover, domestic applications seem to be of lower quality in Malaysia, with a cumulative grants-to-application ratio of 18% between 1989 and 2014, against 53% for foreign applicants over the same period. In addition, academic or public research organizations in Malaysia appear to have a limited ability to translate research into intellectual property rights. The Malaysian Institute of Micro-electronic Systems (MIMOS),[2] Malaysia's forefront public R&D institute, which was corporatized in 1992, contributed 45–50% of Malaysia's patents filed in 2010 (Figures 26.4 and 26.5) but the low citations that have emerged from those patents suggest that the commercialization rate is low.

Of some concern is that Malaysia's global share of high-tech density has declined over the years and that the contribution of high-tech industries to manufacturing exports has dropped considerably since 2000 (Table 26.1).

Table 26.1: **Intensity of high-tech industries in Malaysia, 2000, 2010 and 2012**

Other countries are given for comparison

	World share, 2000 (%)	World share, 2010 (%)	World share, 2012 (%)	Share of manufacturing exports, 2000 (%)	Share of manufacturing exports, 2010 (%)	Share of manufacturing exports, 2012 (%)
Malaysia	4.05	3.33	3.08	59.57	44.52	43.72
Thailand	1.49	1.92	1.70	33.36	24.02	20.54
Indonesia	0.50	0.32	0.25	16.37	9.78	7.30
India	0.18	0.57	0.62	6.26	7.18	6.63
Korea, Rep.	4.68	6.83	6.10	35.07	29.47	26.17
Brazil	0.52	0.46	0.44	18.73	11.21	10.49
Japan	11.10	6.86	6.20	28.69	17.97	17.41
Singapore	6.37	7.14	6.44	62.79	49.91	45.29
China	3.59	22.82	25.41	18.98	27.51	26.27
United States	17.01	8.18	7.48	33.79	19.93	17.83
European Union	33.82	32.31	32.00	21.40	15.37	15.47

Source: World Bank's World Development Indicators, April 2015

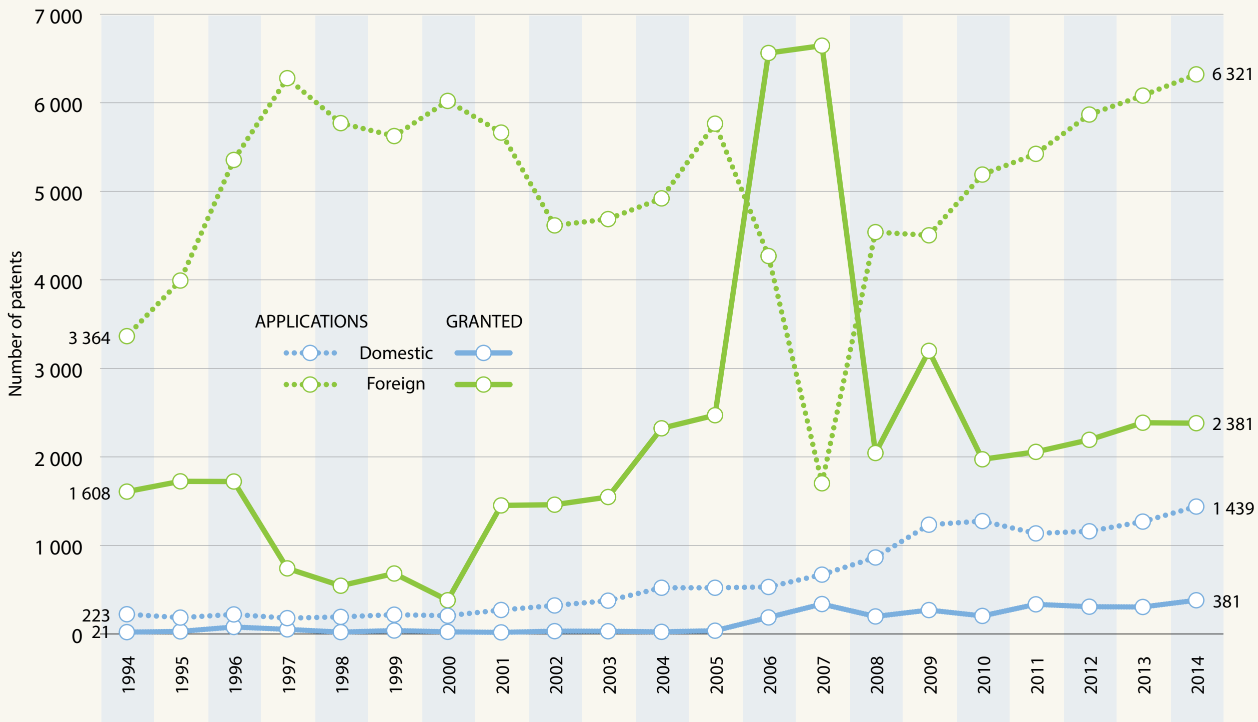
A need to increase the rate of return on R&D

As argued by Thiruchelvam *et al.* (2011), there is still little return on investment in R&D, despite the added emphasis on pre-commercialization and commercialization in the *Ninth Malaysia Plan* (2006–2010). This low commercialization rate can largely be attributed to a lack of university–industry collaboration, rigidities in research organizations and problems with co-ordinating policies. Universities seem to confine the commercialization of their research results to specific areas, such as health and ICTs.

In 2010, the government established the Malaysian Innovation Agency to spur the commercialization of research.

2. This institute was attached to the Office of the Prime Minister until its corporatization.

Figure 26.4: **Patent applications and granted patents in Malaysia, 1994–2014**

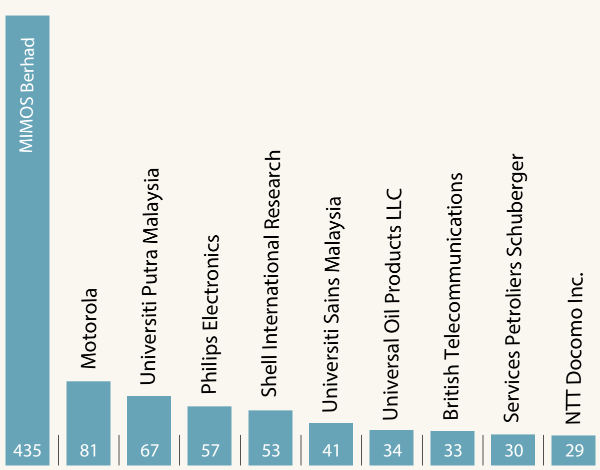


Note: The data for 2014 are for January–November.

Source: Malaysian Patent Office, March 2014

The Malaysian Technology Development Corporation has also made a concerted effort to help companies translate commercialization grants into viable products. On the whole, however, the results have not been encouraging. Success in commercialization has been limited to a handful of organizations, namely, the Malaysian Palm Oil Board (Box 26.2), Rubber Research Institute of Malaysia, Universiti Putra Malaysia and Universiti Sains Malaysia.

Figure 26.5: **Top patent assignees in Malaysia, 2010**



Source: Compiled from PCT database

Five years after its inception, the Malaysian Innovation Agency has made a limited impact on commercialization thus far, owing to the unclear delineation of its role in relation to MoSTI and its limited resources. Nevertheless, there is some evidence to suggest that the agency is beginning to play a catalytic role in driving commercialization and an innovative culture, especially as regards innovation beyond the hardware industry, which is where firms[3] offering services, such as airline services, are active. The agency still needs to strengthen its ties with other agencies and ministries, however, to ensure the effective implementation of government strategies and plans. Some consolidation of the various agencies and ministries involved in STI would also be desirable, in order to facilitate effective collective action while preserving competition within the system.

The numerous science and technology parks in Malaysia benefit from government incentives designed to stimulate commercialization. These include the Long Research Grants Scheme, Fundamental Research Grants Scheme, the TechnoFund and E-science Fund (Figure 26.2). Although the first two grant schemes focus largely on basic research,

3. A survey by the Malaysian Science and Technology Information Centre in 2012 found that the great majority of firms reporting product innovation had recourse to in-house R&D – 82% in manufacturing and 80% in services – whereas most of the remainder (17% and 15% respectively) conducted R&D jointly with other firms (MASTIC, 2012).

applicants are also encouraged to commercialize their findings. The TechnoFund and E-science Fund, on the other hand, focus exclusively on commercialization. There is a serious need to assess their role and success rate in promoting commercialization. There is also a need to strengthen institutional capabilities in technoparks and to ensure that these public goods effectively target the commercialization of knowledge, with a minimum rate of failure in translating these grants into products and services worth commercializing, which is known as a minimum dissipation of rents (Rasiah *et al*., 2015a). Most multinational corporations established in Malaysia specialize in ICTs and are located in the Kulim High Tech Park (Kedah) and Penang (Table 26.2).

In 2005, MoSTI extended the research grants it had been offering to domestic firms since 1992 to multinationals (Rasiah *et al*., 2015b). As a consequence, the number of patents filed in the USA by foreign firms specializing in integrated circuits rose from 39 over the 2000–2005 period to 270 over 2006–2011. As in Singapore, the focus of these research grants is on both basic and applied research (Figure 26.2). However, whereas, in the case of Singapore, university–industry linkages and science parks have largely determined the success of such schemes, these relays are still evolving in Malaysia (Subramoniam and Rasiah, forthcoming).

Box 26.2: **The Malaysian palm oil industry**

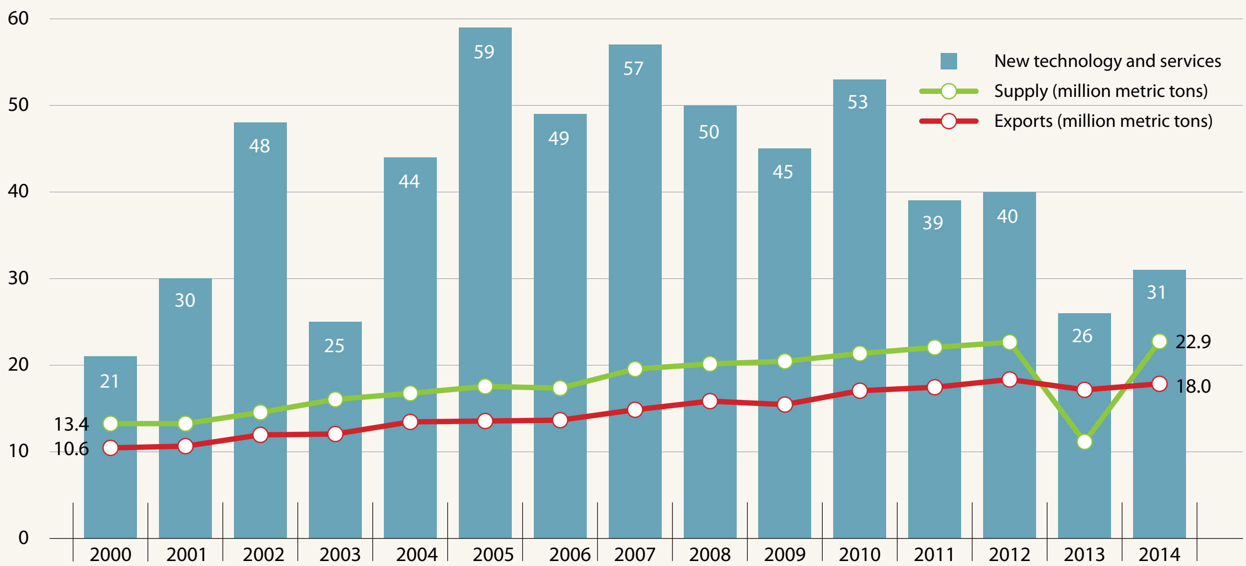
The oil palm industry contributes to R&D through a cess fund managed by the Malaysian Palm Oil Board (Figure 26.6). This entity derives its funding mainly from the cess (or tax) imposed on the industry for every tonne of palm oil and palm kernel oil produced. In addition, the Malaysian Palm Oil Board receives budget allocations from the government to fund development projects and for research projects approved by the Long-term Research Grants scheme. Through the cess, the palm oil industry thus contributes strongly to funding the research grants provided by the Malaysian Palm Oil Board; these grants amounted to MYR 2.04 billion (*circa* US$ 565 million) over the 2000–2010 period.

The Malaysian Palm Oil Board publishes several journals, including the *Journal of Oil Palm Research*, and oversees the Tropical Peat Research Institute, which conducts research into the effects of planting palm oil on peat land and on the transformation of peat into a greenhouse gas once it reaches the atmosphere.

The Malaysian Palm Oil Board supports innovation in areas such as biodiesel and alternate uses for palm biomass and organic waste. Its research into biomass has led to the development of wood and paper products, fertilizers, bio-energy sources, polyethylene sheeting for use in vehicles and other products made of palm biomass. Between 2013 and 2014, the Malaysian Palm Oil Board recorded a rise in the number of new technologies commercialized from 16 to 20.

The Malaysian Palm Oil Board resulted from the merger of the Palm Oil Research Institute of Malaysia and the Palm Oil Registration and Licensing Authority in 2000 by act of parliament.

Figure 26.6: **Key indicators for Malaysia's oil palm industry, 2000–2014**



Source: Malaysian Palm Oil Board (2015); United Nations' Comtrade database

Source: www.mpob.gov.my

Table 26.2: **Semiconductor firms in Penang and Kedah with R&D and/or chip design, 2014**

	Origin	Year	Structure	Main activity	Upgrading
Advanced Micro Devices	USA	1972	Integrated device manufacturing	Assembly and testing	Has in-house R&D to support assembly and testing
Altera	USA	1994	Integrated device manufacturing	Design centre	Has in-house R&D to support design
Avago Technology	Singapore	1995	Integrated device manufacturing	Assembly and testing	Has in-house R&D to support assembly and testing of analogue, mixed-signal and opto-electronic components
Fairchild	USA	1971	Integrated device manufacturing	Assembly and testing	Started as national Semiconductor; has in-house R&D to support assembly and testing
Globetronics	Malaysia	1991	Fabless	Die sawing, sorting, plating and assembly of LEDs	Has R&D to support production
Infineon	Germany	2005	Integrated device manufacturing	Wafer fabrication	Engaged in '8' powerchip fabrication; has in-house R&D to support wafer fabrication
Intel	USA	1972	Integrated device manufacturing	Assembly and testing	Has in-house R&D to support assembly and testing
Intel	USA	1991	Integrated device manufacturing	Design centre	Integrated circuit design; site was previously used by Intel Technology from 1979 onwards; Has in-house support R&D
Marvell Technology	USA	2006	Fabless	Design centre	Has in-house support R&D
Osram	Germany	1972	Integrated device manufacturing	Wafer fabrication	Established first as Litronix in 1972; acquired by Siemens Litronix in 1981; changed to Osram Opto-electronics in 1992; upgraded from assembly and testing to include wafer fabrication in 2005; has in-house support R&D
Renesas Semiconductor Design	Japan	2008	Integrated device manufacturing	Design centre	Specializes in design; has in-house support R&D
Renesas Semiconductor Malaysia	Japan	1972	Integrated device manufacturing	Assembly and testing	Upgraded to include R&D support since 1980 and has expanded R&D since 2005
Silterra	Malaysia	1995	Foundry	Wafer fabrication	Founded as Wafer Technology Malaysia but renamed Silterra in 1999; has in-house R&D to support wafer fabrication

Note: Fabless refers to the design and sale of hardware devices and semiconductor chips while outsourcing the fabrication of these devices to a semiconductor foundry.

Source: Rasiah *et al.* (2015a)

University reform has boosted productivity

In 2006, the government introduced a *Higher Education Strategic Plan Beyond 2020* which established five research universities over the next three years and raised government funding for higher education. For more than a decade, public expenditure on higher education has accounted for about one-third of the education budget (Thiruchelvam *et al.*, 2011). Malaysia spends more on higher education than any of its Southeast Asian neighbours but the level of commitment had slipped somewhat between 2003 and 2007 from 2.6% to 1.4% of GDP. The government has since restored higher education spending to earlier levels, as it accounted for 2.2% of GDP in 2011 (see Figure 27.5).

The meteoric rise in scientific publications since 2009 (Figure 26.7) is a direct consequence of the government's decision to promote excellence at the five research universities, namely: Universiti Malaya, Universiti Sains Malaysia, Universiti Kebangsaan Malaysia, Universiti Putra Malaysia and Universiti Teknologi Malaysia. In 2006, the government decided to provide grants for university research. Between 2008 and 2009, these five universities received an increase of about 71% in government funding (UIS, 2014).

Along with this targeted R&D funding, key performance indicators were changed for the teaching staff, such as by making the publication record of staff an important criterion for promotion. In parallel, the Ministry of Higher Education (MoHE) designed and implemented a performance measurement and reporting system for universities in 2009, which were also entitled to conduct self-assessments and self-monitoring.

One spin-off from the increase in R&D funding by MoHE was that the share of basic research rose from 11% of GERD in 2006 to 34% in 2012. The bulk of the budget still goes towards applied research, which represented 50% of GERD in 2012. Between 2008 and 2011, the lion's share of scientific publications focused on engineering (30.3%), followed by biological sciences (15.6%), chemistry (13.4%), medical sciences (12.0%) and physics (8.7%).

At the same time, Malaysia still has some way to go to improve the impact of its scientific production. At 0.8 citations per paper in 2010, Malaysia trails the OECD (1.08) and G20 (1.02) averages, as well as neighbours such as Singapore, the Republic of Korea or Thailand (see Figure 27.8). It is close to the bottom of the league in Southeast Asia and Oceania for the citation rate and share of its scientific production among the 10% most cited papers between 2008 and 2012 (Figure 27.8).

Although more objective performance measures have been introduced into the university system to assess the outcome of research funding and its impact on socio-economic and sustainable development, a similar system is still missing for public research institutes. In 2013, the government launched an outcome-based approach to assessing public investment in R&D which includes funding for projects on sustainability and ethical issues. The University of Malaya Research Grant, among others, has since absorbed this criterion by including humanities and ethics, social and behavioural sciences and sustainability sciences among its priority areas for research funding.

TRENDS IN HUMAN RESOURCES

Strong growth in researcher intensity

The number of full-time equivalent (FTE) researchers in Malaysia tripled between 2008 and 2012 from 16 345 to 52 052, resulting in a researcher intensity of 1 780 per million population in 2012 (Figure 26.8). Although this intensity is well above the global average, it cannot match that of the Republic of Korea or Singapore.

The government is eager to develop endogenous research capabilities in order to reduce the country's reliance on industrial research undertaken by foreign multinational companies. The *Higher Education Strategic Plan Beyond 2020* fixed the target of producing 100 000 PhD-holders by 2020, as well as increasing the participation rate in tertiary education from the current 40% to 50%. The 100 000 PhD-holders are to be trained locally, overseas and through split programmes with foreign universities (UIS, 2014). As part of this effort, the government has allocated MYR 500 million (*circa* US$ 160 million) to financing graduate students, a measure which helped to double enrolment in PhD programmes between 2007 and 2010 (Table 26.3).

Table 26.3: **University enrolment in Malaysia, 2007 and 2010**

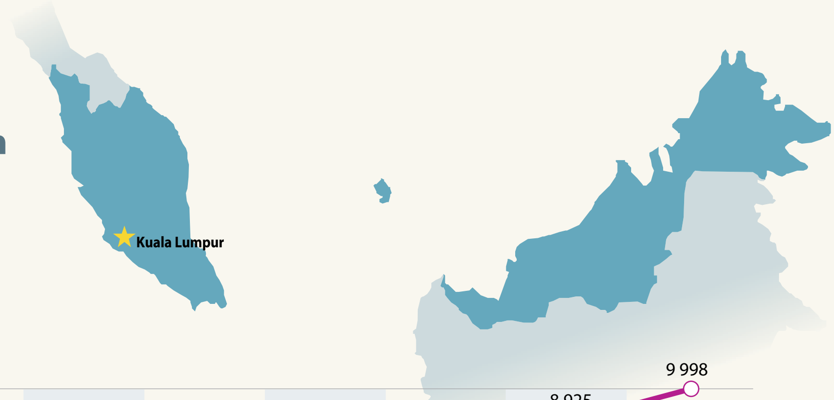
	Total enrolment ('000s) 2007	Private (%) 2007	Total enrolment ('000s) 2010	Private (%) 2010
Bachelor's degree	389	36	495	45
Master's degree	35	13	64	22
PhD	11	9	22	18

Source: UIS (2014)

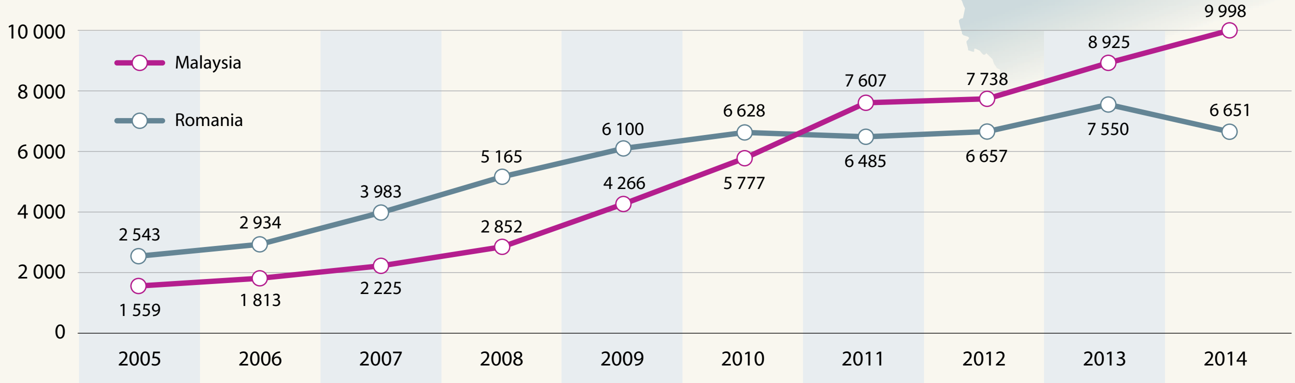
Singapore snaps up much of the diaspora

Despite the rise in tertiary students since 2007, brain drain remains a worry. Singapore alone absorbs 57% of the diaspora, the remainder opting for Australia, Brunei, the UK and USA. There is evidence to show that the skilled diaspora is now three times bigger than two decades ago, a factor which has reduced the human resource pool – and, no doubt, slowed progress in STI. In order to address this issue, the government has launched Talent Corp and a targeted Returning Expert Programme (MoSTI, 2009). Although 2 500 returnees have been approved for the incentive scheme since 2011, the programme is yet to make a big impact.

Figure 26.7: **Scientific publication trends in Malaysia, 2005–2014**



Malaysian publications have grown rapidly since 2005, overtaking those of similarly populated Romania



0.83

Average citation rate for Malaysian publications, 2008–2012; the OECD average is 1.08; the G20 average is 1.02

8.4%

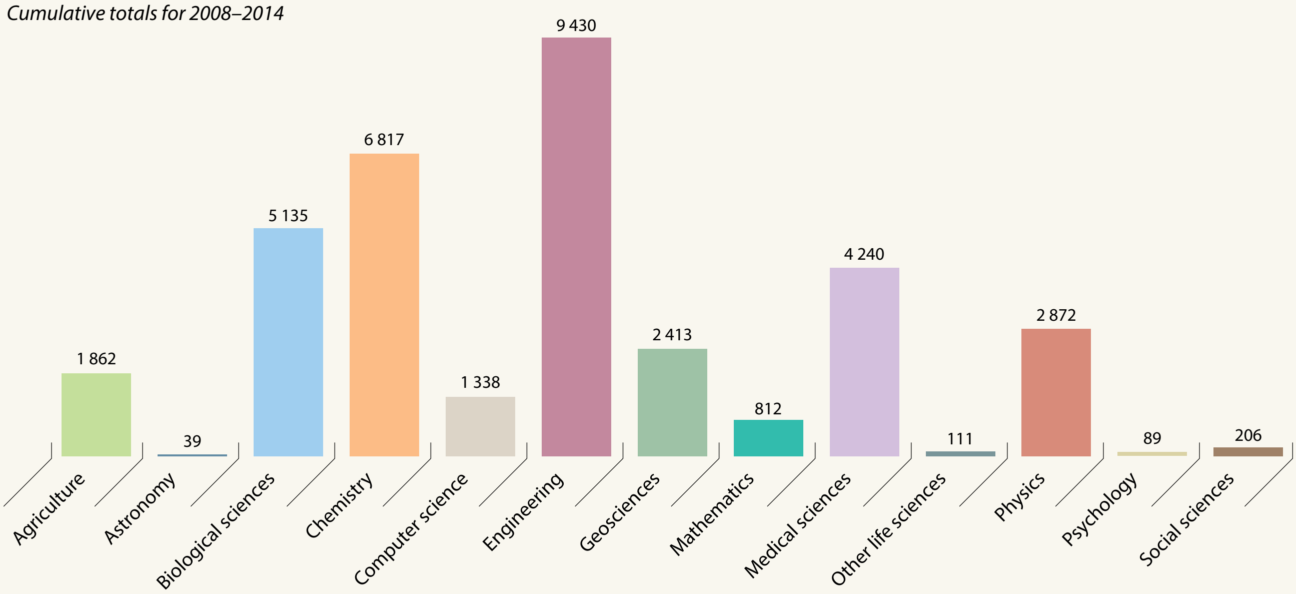
Share of Malaysian papers among 10% most-cited, 2008–2012; the OECD average is 11.1%; the G20 average is 10.2%

46.4%

Share of Malaysian papers with foreign co-authors 2008–2014; the OECD average is 29.4%; the G20 average is 24.6%

Nearly half of Malaysian publications are in engineering or chemistry

Cumulative totals for 2008–2014



Note: The total by field excludes unclassified publications (11 799) between 2008 and 2014.

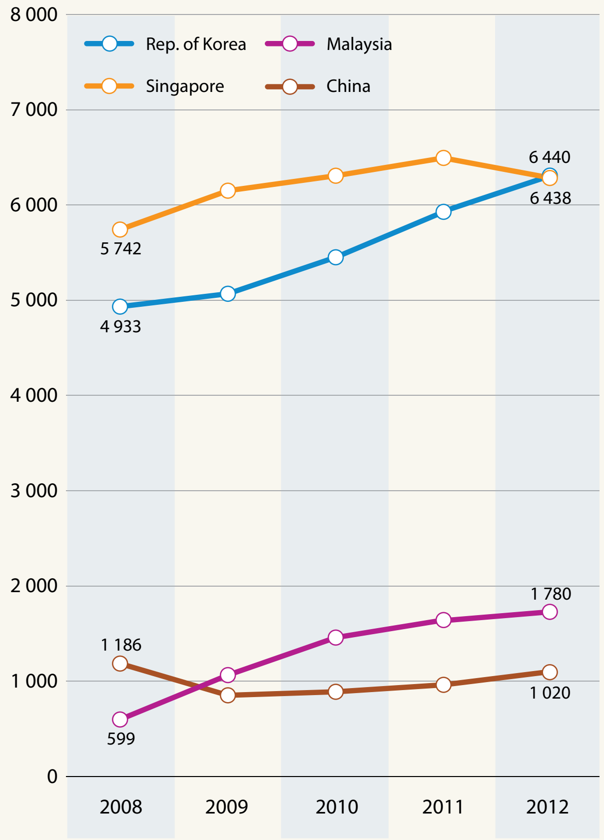
Malaysia's key scientific partner countries span four continents

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Malaysia	UK (3 076)	India (2 611)	Australia (2 425)	Iran (2 402)	USA (2 308)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

Figure 26.8: **Researchers (FTE) per million population in Malaysia, 2008–2012**
Other countries are given for comparison



Source: UNESCO Institute for Statistics, May 2015

Strong growth in private and foreign students

Meanwhile, private universities are increasingly absorbing more undergraduate students than their public counterparts. Between 2007 and 2010, the share of students enrolled in a bachelor's programme at a private university rose from 37% to 45%. This is a consequence of the five leading research universities' growing focus on graduate education since 2009, accompanied by more competitive intake requirements, as well as the preference of some students for private universities where the use of English as a medium of communication is more common. Of note is that a much larger proportion of academic staff hold a master's or doctoral degree at public institutions (84%) than at private ones (52%) [UIS, 2014].

The government is increasing the number of international schools at primary and secondary levels to accommodate the needs of returnees and earn foreign exchange from non-Malaysian pupils. The target outlined in the *Economic Transformation Programme* (2010) is for there to be 87 international schools by 2020. Although there were 81 such schools by 2012, most of these establishments have small rolls: there were a total of 33 688 pupils in 2012, less than half the government target of 75 000 pupils by 2020. To close the gap, the government has embarked on an international promotional campaign.

In 2005, Malaysia adopted the target[4] of becoming the sixth-largest global destination for international university students by 2020. Between 2007 and 2012, the number of international students almost doubled to more than 56 000, the target being to attract 200 000 by 2020. Among member states of the Association of Southeast Asian Nations (ASEAN), Indonesian students were most numerous, followed by Thais. By 2012, Malaysia was one of the top ten destinations for Arab students; the upheaval caused by the Arab Spring has incited a growing number of Egyptians and Libyans to try their luck in Malaysia but there has also been a sharp rise in the number of Iraqis and Saudis. Particularly strong growth has also been observed among Nigerian and Iranian students (Figure 26.9).

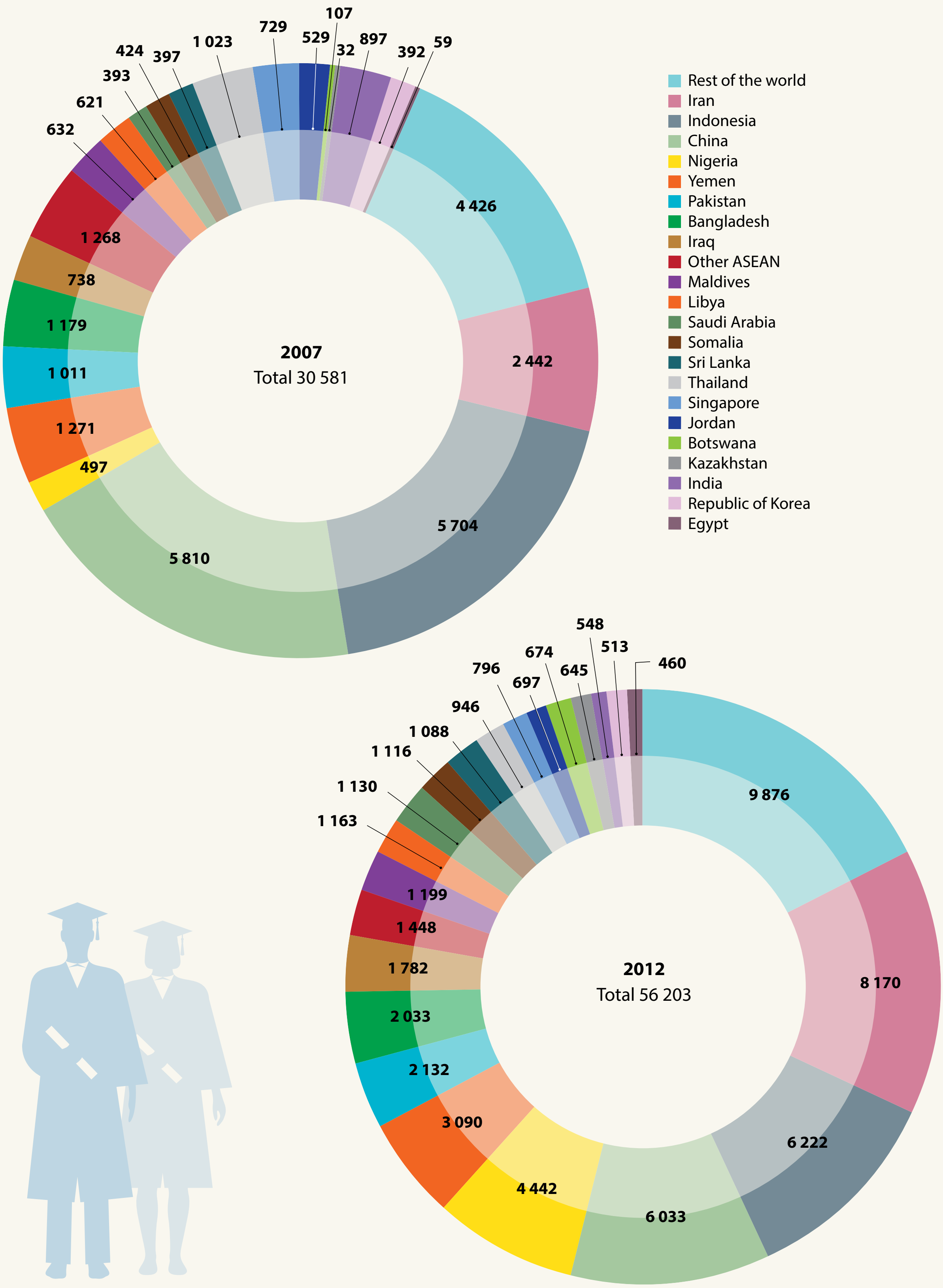
Concerns about the declining quality of education

The ratio between university students enrolled in fields related to science, technology, engineering and mathematics (STEM) and those enrolled in non-STEM disciplines has grown since 2000 from 25:75 to 42:58 (2013) and may soon reach the government's target of 60:40. There is evidence, however, that the quality of education has declined in recent years, including the quality of teaching. The results of the Programme for International Student Assessment (PISA) in 2012 show that Malaysian 15 year-olds perform below average in mathematics and scientific literacy. Indeed, Malaysia's score has declined significantly in some fields, with only one out of 100 Malaysian 15 year-olds being able to solve complex problems, in comparison to one out of five in Singapore, the Republic of Korea and Japan. In 2012, Malaysians also scored lower in knowledge acquisition (29.1) and utilization of knowledge (29.3) than teenagers in Singapore (62.0 and 55.4 respectively) or the average for all PISA participants (45.5 and 46.4 respectively).

A number of the education reforms implemented since 1996 have faced resistance from teachers. The most recent national education blueprint (2013–2025), adopted in 2012, aims to provide equal access to quality education, develop proficiency in the English and Malay languages and to transform teaching into a profession of choice. In particular, it seeks to leverage ICTs to scale up quality learning across Malaysia and improve the delivery capabilities of the Ministry of Education through partnerships with the private sector, in addition to raising transparency and accountability. A central goal will be to promote a learning environment that promotes creativity, risk-taking and problem-solving by both teachers and their pupils (OECD, 2013). As it takes time for education reforms to deliver results, consistent monitoring of these reforms will be the key to their success.

4. *See:* http://monitor.icef.com/2012/05/malaysia-aims-to-be-sixth-largest-education-exporter-by-2020

Figure 26.9: **Number of degree-seeking international students in Malaysia, 2007 and 2012**
By country of origin



Source: UNESCO Institute for Statistics, June 2015

TRENDS IN INTERNATIONAL CO-OPERATION

A Malaysian centre for South–South co-operation

When *ASEAN Vision 2020* was adopted in 1997, its stated goal was for the region to be technologically competitive by 2020. Although the focus of ASEAN has always been on the creation of a single market along the lines of the European model, leaders have long acknowledged that successful economic integration will hinge on how well member states manage to assimilate science and technology. The ASEAN Committee on Science and Technology was established in 1978, just eleven years after ASEAN was founded by[5] Indonesia, Malaysia, the Philippines, Singapore and Thailand. Since 1978, a series of action plans have been developed to foster co-operation among member states, in order to create a more even playing field in STI. These action plans cover nine programme areas: food science and technology; biotechnology; meteorology and geophysics; marine science and technology; non-conventional energy research; micro-electronics and information technology; materials science and technology; space technology and applications; and S&T infrastructure and the development of resources. Once the ASEAN Economic Community comes into effect in late 2015, the planned removal of restrictions to the cross-border movement of people and services should spur co-operation in science and technology and enhance the role of the ASEAN University Network (see Chapter 27).

In 2008, the Malaysian government established the International Centre for South–South Cooperation in Science, Technology and Innovation, under the auspices of UNESCO. The centre focuses on institution-building in countries of the South. Most recently, it ran a training course on the maintenance of infrastructure from 10 March to 2 April 2015, in collaboration with the Malaysian Highway Authority, Construction Industry Development Board, the Institution of Engineers Malaysia and the Master Builders Association Malaysia.

As far as bilateral co-operation is concerned, the Malaysian Industry–Government Group for High Technology (MIGHT) and the British government established the Newton-Ungku Omar Fund in 2015, which is being endowed with £ 4 million annually for the next five years by each government. In 2014, MIGHT also signed an agreement with Asian Energy Investment Pte Ltd, based in Japan, to create a fund management company called Putra Eco Ventures which would invest in efficient and renewable energy assets and businesses. Potential targets for funding are smart-grid and energy-saving technologies, as well as smart buildings.

5. Brunei Darussalam joined in 1984, Viet Nam in 1995, Lao PDR and Myanmar in 1997 and Cambodia in 1999.

CONCLUSION

To become an Asian Tiger, Malaysia will need endogenous research

Malaysia's chances of emulating the success of the 'Asian Tigers' and reaching its goal of becoming a high-income country by 2020 will depend upon how well it succeeds in stimulating the commercialization of technology and innovation. Foreign multinational firms are generally engaged in more sophisticated R&D than national firms. However, even the R&D conducted by foreign firms tends to be confined to product proliferation and problem-solving, rather than pushing back the international technology frontier.

R&D is conducted predominantly in large-scale enterprises in the electronics, automotive and chemical industries, where it mainly involves process and product improvements. SMEs make little contribution to R&D, even though they make up 97% of all private firms.

Even the foreign multinationals which dominate private sector R&D are heavily dependent on their parent and subsidiary firms based outside Malaysia for personnel, owing to the lack of qualified human capital and research universities within Malaysia to call upon.

The weak collaboration between the principal actors of innovation, namely universities, firms and research institutions, is another shortcoming of the national innovation system. It will be critical to nurture the research capabilities of universities and their ties with domestic firms, in order to foster innovation and improve the commercialization rate of intellectual property. Although applied research has expanded at Malaysian universities in recent years following a government drive to promote research excellence, this trend has yet to translate into sufficient numbers of patent applications. Similarly, the low absorptive capacity of domestic firms has made technological upgrading difficult. Intermediary organizations will play an important role in bridging this gap by facilitating effective knowledge transfer.

The following measures would help to remedy some of these problems:

- The role of public research organizations would be strengthened by training a greater number of researchers and technicians and ensuring that the Long-term Research Grant Scheme and E-science Fund effectively target the production of industry-related innovation. There is also a need to correct market failures that have stifled the expansion of vocational and technical education in the country.
- Collaboration between public research institutes, universities and industry should be strengthened through long-term plans, including in-depth technology foresight

exercises targeting specific sectors. In this context, there should be an attempt to integrate basic research with commercialization.

- Public research institutes and universities should be encouraged to act as facilitators in improving the local industrial R&D landscape, by providing domestic firms with critical knowledge and know-how through consulting services and other means. The success of the Malaysian Palm Oil Board in transferring know-how and knowledge can serve as a model in this respect.

In addition, in order to overcome shortages in human capital, the government should:

- encourage Malaysians to pursue tertiary education at the world's leading research-based universities, especially those abroad that have a reputation for undertaking frontier R&D, such as in semiconductors at Stanford University (USA) or in molecular biology at the University of Cambridge (UK); one way of doing this is to offer bonded scholarships to students who gain admission to prestigious universities renowned for exposing students to frontier R&D;
- assist national universities in upgrading the qualifications of their academic personnel, so that tenure is given only on the basis of proven participation in world-class research and publications. There is a need for better linkages between universities and industrial firms, in order to make academic research more relevant to the needs of industry;
- promote stronger scientific links between Malaysian universities and proven international experts in key research areas and facilitate two-way 'brain circulation';
- turn science and technology parks into a major launch pad for new innovative start-ups by encouraging universities to set up technology transfer offices and encouraging parks to become the nodes linking universities with industry; this will require evaluating candidate universities and firms seeking incubation facilities prior to granting them space in science and technology parks, as well as regular reviews to assess the progress made by start-up companies.

KEY TARGETS FOR MALAYSIA

- Attain high-income economy status by 2020;
- Raise the GERD/GDP ratio to 2% by 2020;
- Raise the participation rate in higher education from 40% to 50% by 2020;
- Produce 100 000 PhD-holders by 2020;
- Raise the share of science, technology and mathematics students at university level to 60% of the total by 2020;
- Develop 87 international primary and secondary schools by 2020 with a roll of 75 000 pupils;
- Increase the number of international students to 200 000 by 2020 to make Malaysia the world's sixth-largest destination;
- Reduce carbon emissions by 40% by 2020 over 2012 levels;
- Preserve at least 50% of land as primary forest, as compared to 58% in 2010.

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A major challenge for the region will be to draw on its scientific knowledge base to maintain and expand the range of high-tech exports in increasingly competitive global markets.

Tim Turpin, Jing A. Zhang, Bessie M. Burgos and **Wasantha Amaradasa**

A worker harvests fresh produce from a three-storey greenhouse at the Sky Greens vertical farm in Singapore in 2014. As part of a government drive to increase self-reliance in the production of leafy vegetables, Sky Greens has received some research support.
Photo: © Edgar Su/Reuters

27 · Southeast Asia and Oceania

Australia, Cambodia, Cook Islands, Fiji, Indonesia, Kiribati, Lao People's Democratic Republic, Federated States of Micronesia, Malaysia, Myanmar, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, Viet Nam

Tim Turpin, Jing A. Zhang, Bessie M. Burgos and Wasantha Amaradasa

INTRODUCTION

The region has largely withstood the global crisis

The countries covered by the present chapter[1] together account for over 9% of the world's population. Taken as a group, they produced 6.5% of the world's scientific publications (2013) but only 1.4% of global patents (2012). GDP per capita at current prices ranges from just under PPP$ 2 000 in Kiribati to PPP$ 78 763 in Singapore (Figure 27.1). Australia and Singapore together produce four-fifths of the region's patents and publications.

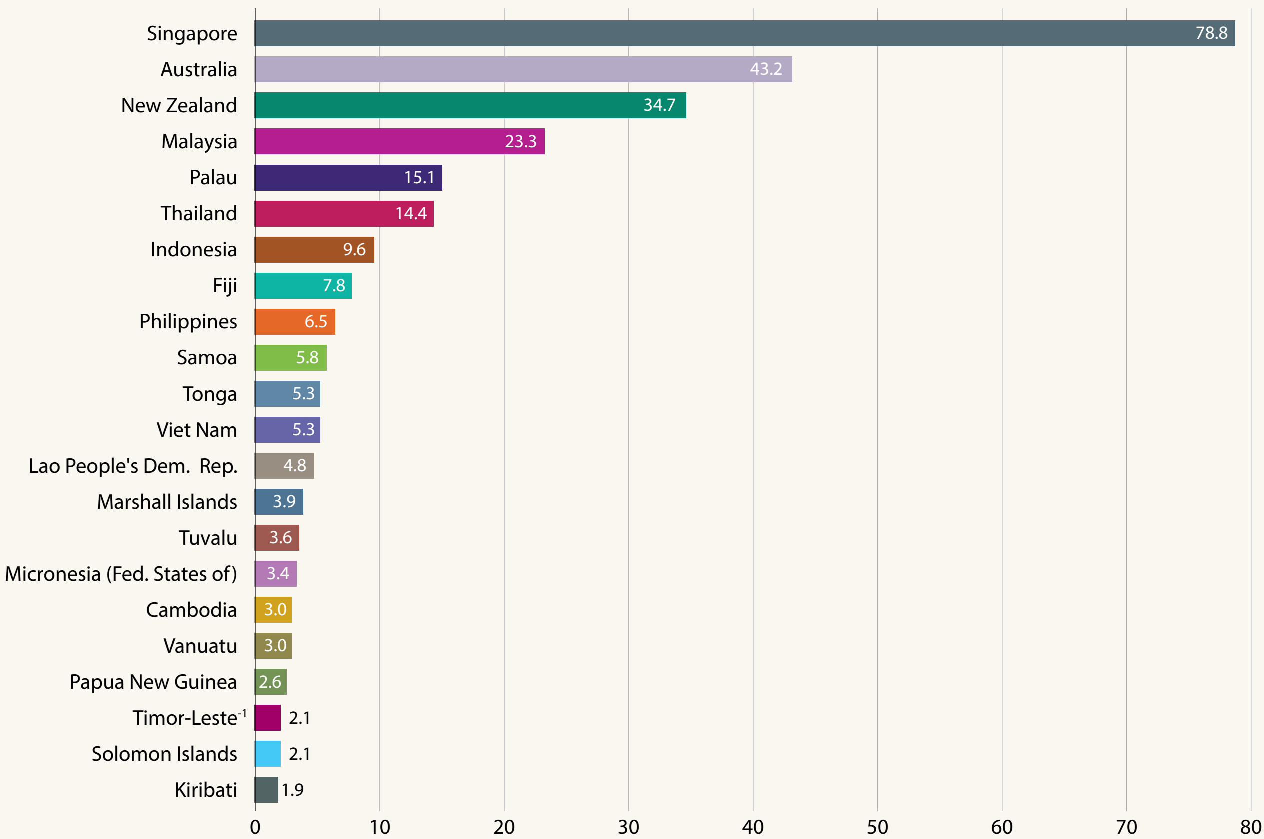
Economically, the region fared comparatively well through the global financial crisis of 2008–2009. Although growth rates dipped in 2008 or 2009, a number of countries avoided recession altogether, including Australia (Figure 27.2).

As a consequence, pressures on budgets for science and technology (S&T) have not been as severe as predicted back in 2010. Timor-Leste even recorded insolent growth rates up until 2012, buoyed by foreign direct investment (FDI) that peaked at 6% of GDP in 2009 before falling back to just over 1.6% in 2012.

According to the World Bank's Knowledge Economy Index, there has been a general slip in overall rankings in Southeast Asia since 2009. New Zealand and Viet Nam are the only ones to have improved their position. Some, such as Fiji, the Philippines and Cambodia, even slipped considerably over this period. Singapore continues to lead the region for the innovation component of the same index and Australia and New Zealand that for education. The Global Innovation Index tends to rank countries in a similar order.

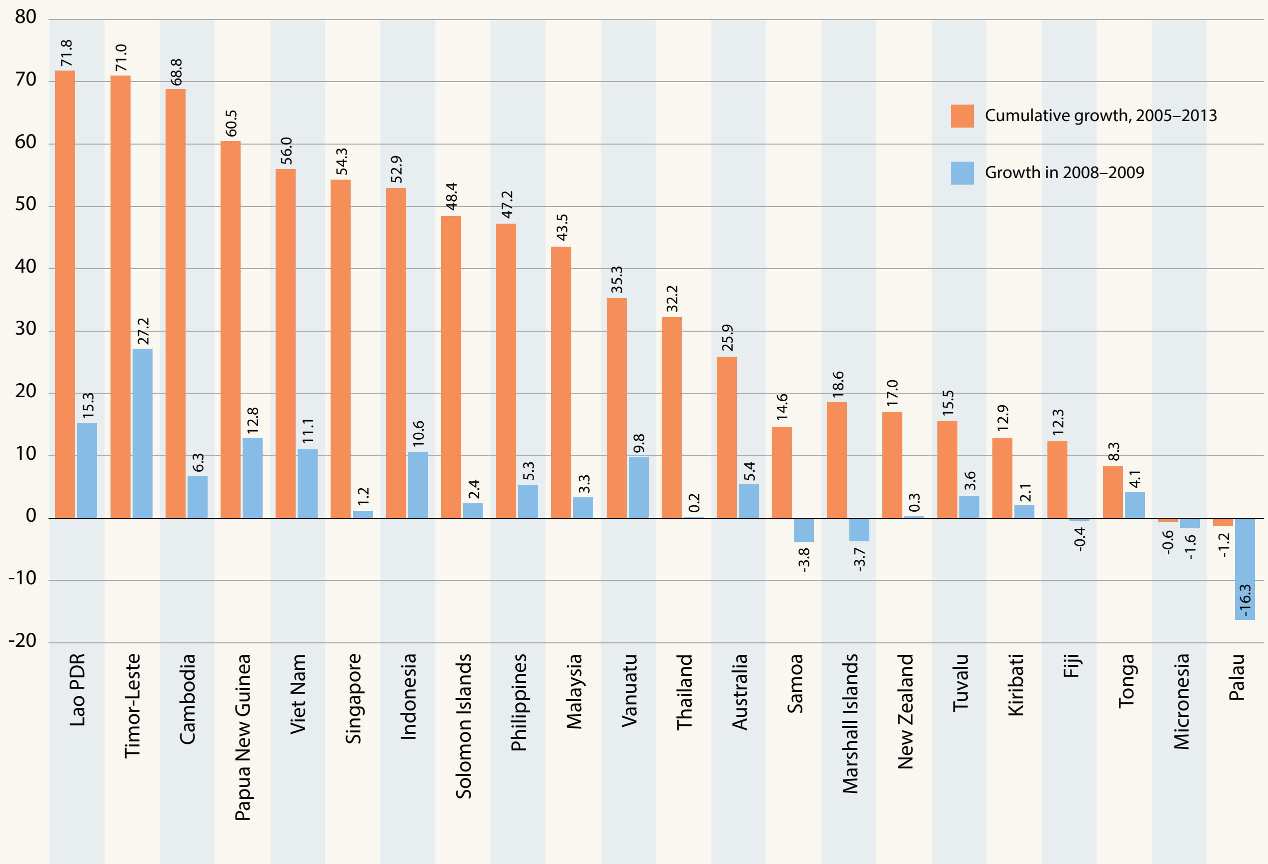
1. Malaysia is covered in greater detail in Chapter 26.

Figure 27.1: **GDP per capita in Southeast Asia and Oceania, 2013**
In thousands of current PPP$



-n = data are for *n* years before reference year
Source: World Bank's World Development Indicators, April 2015

Figure 27.2: **Trends in GDP growth in Southeast Asia and Oceania, 2005–2013**



Note: For Timor-Leste, the most recent data are for 2012, not 2013.
Source: World Bank's World Development Indicators, April 2015

Strong growth in internet access since 2010 has levelled out the disparity between countries to some extent, although connectivity remained extremely low in the Solomon Islands (8%), Cambodia (6%), Papua New Guinea (6.5%), Myanmar (1.2%) and Timor-Leste (1.1%) in 2013 (Figure 27.3). Advances in mobile phone technology have clearly been a factor in the provision of internet access to remote areas. The flow of knowledge and information through internet is likely to play an important role in the more effective dissemination and application of knowledge across the vast Pacific Island nations and least developed countries of Southeast Asia.

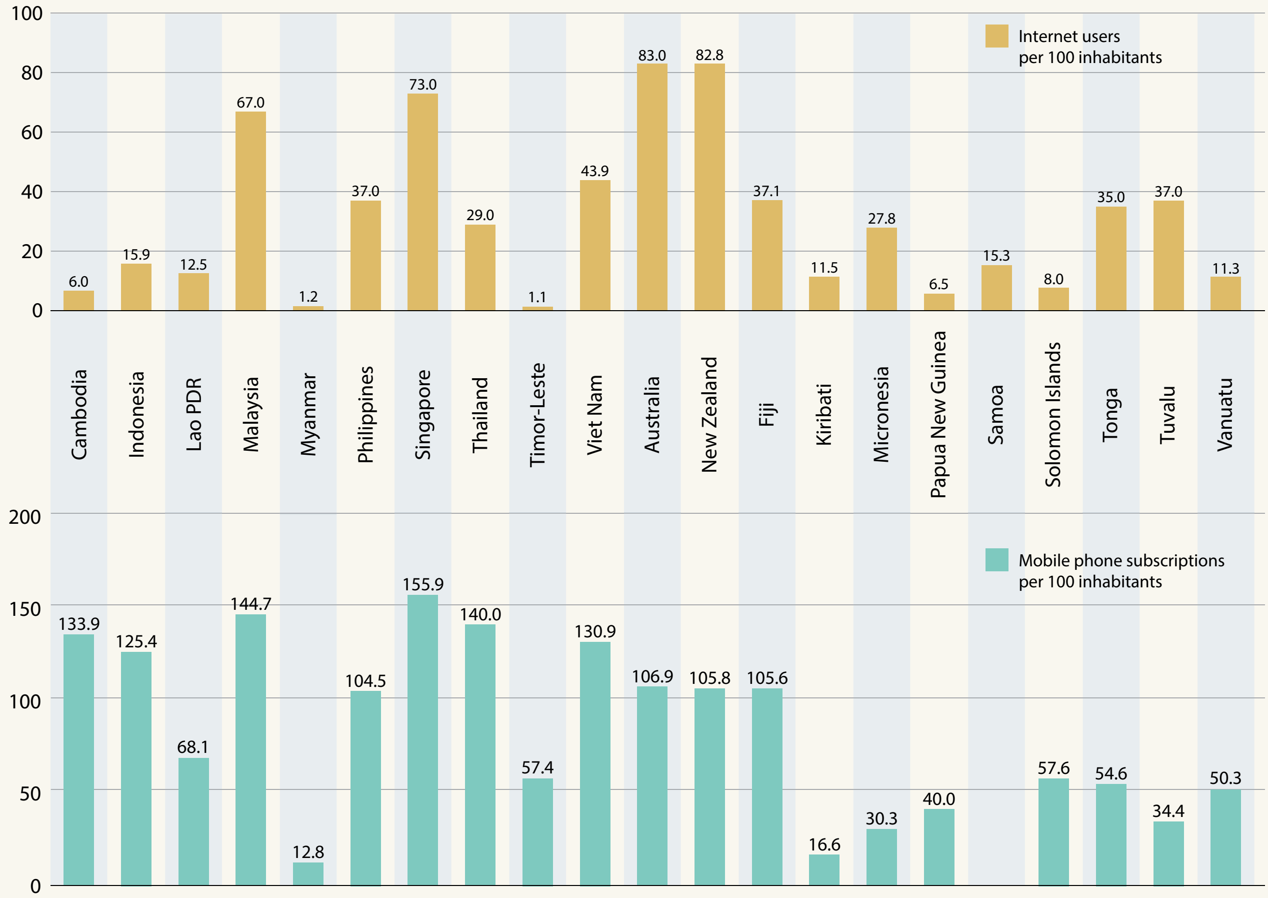
Political change at national and regional levels

Thailand has been experiencing political instability for the past five years, culminating in a military coup in 2014 and erratic economic growth. Indonesia, by contrast, has enjoyed a period of comparative stability with economic growth of about 4% on average since 2010; the government elected in 2014 has introduced a number of fiscal and structural reforms designed to encourage investment (World Bank, 2014). These reforms should help accelerate business R&D, which was already showing solid growth in 2010.

Myanmar has been undergoing a period of democratic reform since 2011, which has prompted the easing of international sanctions. The return of US and European Union (EU) trade privileges has already generated significant investment growth across many sectors. A foreign investment law passed in 2012, followed in January 2014 by a Special Economic Zone Law, provides incentives for export-oriented industries. Myanmar's geostrategic location between India and China, coupled with the creation of the Association of Southeast Asian Nations (ASEAN) Economic Community in 2015, has led the Asian Development Bank to predict an 8% growth rate per year for Myanmar through the next decade.

Australia's incoming government in September 2013 coincided with a steep decline in the value of its natural resources, as demand for minerals eased in China and elsewhere. As a consequence, the new government sought to reduce public spending, in order to balance its 2014–2015 budget. Science and technology were among the many casualties of this cost-cutting exercise. On 17 June 2015, Australia signed a free trade agreement with China which removes almost all import duties. 'It is the highest degree

Figure 27.3: **Internet and mobile phone access in Southeast Asia and Oceania, 2013 (%)**



Source: International Telecommunications Union

of liberalization of all the free trade agreements China has so far signed with any economy', commented China's commerce minister Gao Hucheng at the signing (Hurst, 2015).

A common market by the end of the year

The ASEAN countries intend to transform their region into a common market and production base with the creation of the ASEAN Economic Community by the end of 2015. The planned removal of restrictions to the cross-border movement of people and services is expected to spur co-operation in science and technology. Moreover, the increased mobility of skilled personnel within the region should be a boon for the development of skills, job placement and research capabilities within ASEAN member states and enhance the role of the ASEAN University Network (Sugiyarto and Agunias, 2014). As part of the negotiating process, each member state may express its preference for a specific research focus. The Laotian government, for instance, hopes to prioritize agriculture and renewable energy. More contentious are proposals to develop hydropower on the Mekong River, given the drawbacks of this energy option (Pearse-Smith, 2012).

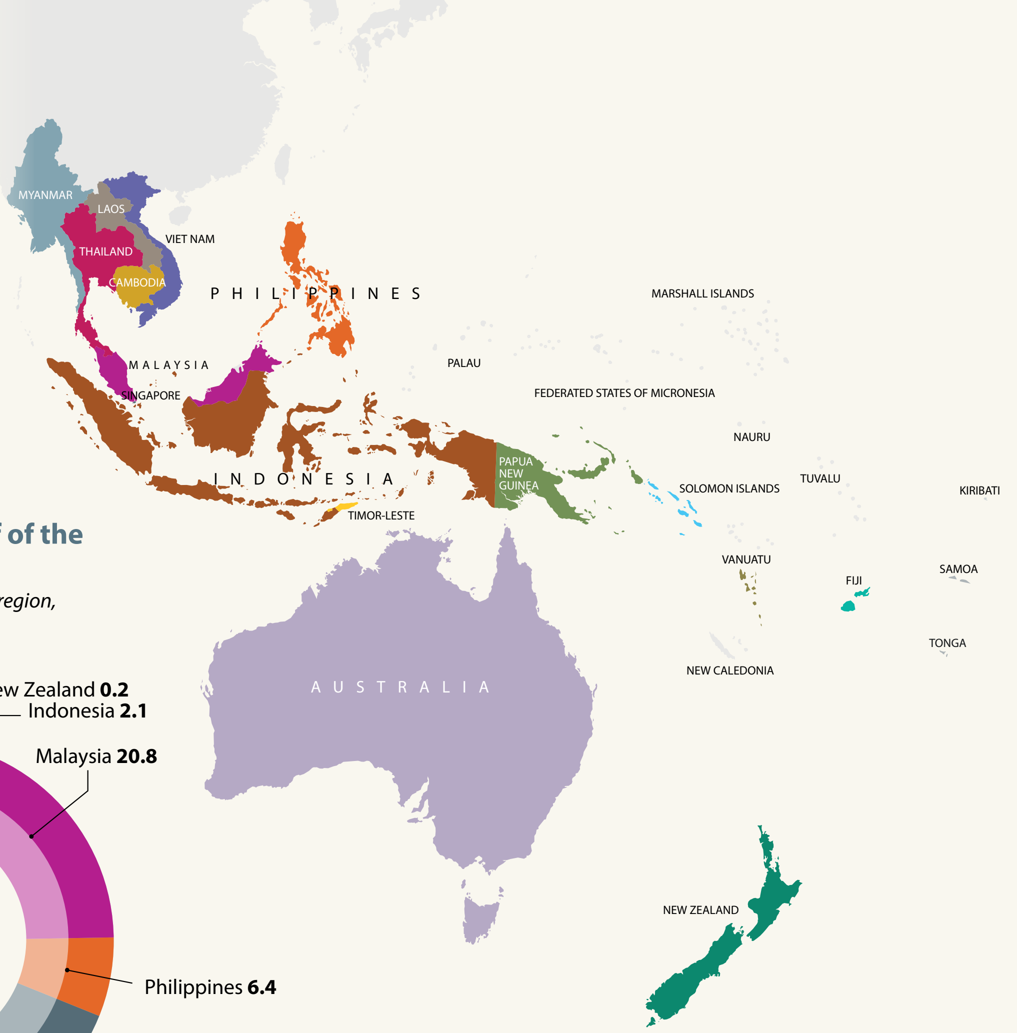
TRENDS IN STI GOVERNANCE

High-tech exports have defied predictions

In spite of pessimistic predictions, high-tech exports across the region have performed well since 2008. Overall, high-tech exports from all countries in the region increased by 28%. However, the situation has not been uniform. Between 2008 and 2013, almost all countries increased the value of their exports. For Malaysia and Viet Nam, the increase was significant: high-tech exports from Viet Nam increased almost tenfold. The Philippines, by contrast, recorded a reduction of nearly 27% over the same period.

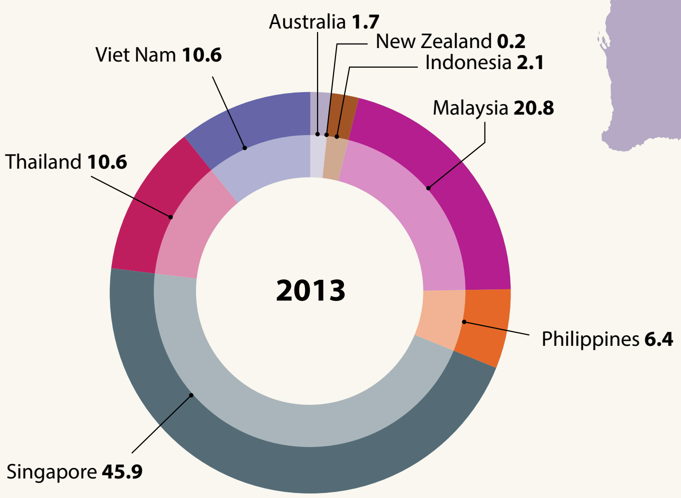
Four countries dominate the export of high-tech products from the region. Singapore accounts for nearly 46% and Malaysia just under 21% (Figure 27.4). Malaysia, Singapore, Thailand and Viet Nam together account for 90% of high-tech exports from the region. Two product categories dominate these exports: computers/office machines (19.3%) and, above all, electronic communications: (67.1%). It is likely that these export products included a considerable proportion of re-exported components, so these data should be interpreted accordingly. Although Singapore and Malaysia record a

Figure 27.4:
Trends in high-tech exports from Southeast Asia and Oceania, 2008 and 2013



Singapore exports almost half of the region's high tech goods

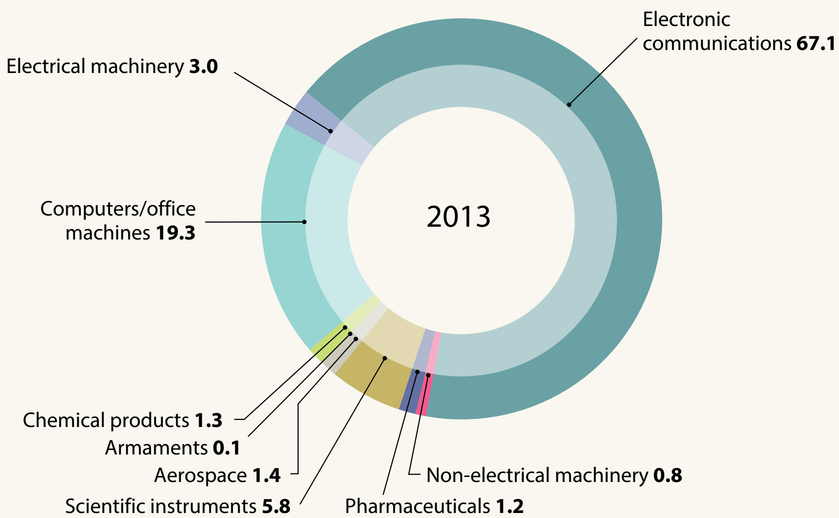
National shares of high-tech exports from the region, 2013 (%)



Note: The regional shares of Cambodia, Fiji, Kiribati, Myanmar, Palau, Papua New Guinea, Samoa, the Solomon Isalnds, Timor-Leste, Tonga and Vanuatu are close to zero.

Share of electronic communications in the region's high-tech exports (%)

Total exports from the region by type, 2013



45.9%

Singapore's share of the region's high-tech exports in 2013

20.8%

Malaysia's share of the region's high-tech exports in 2013

10.6%

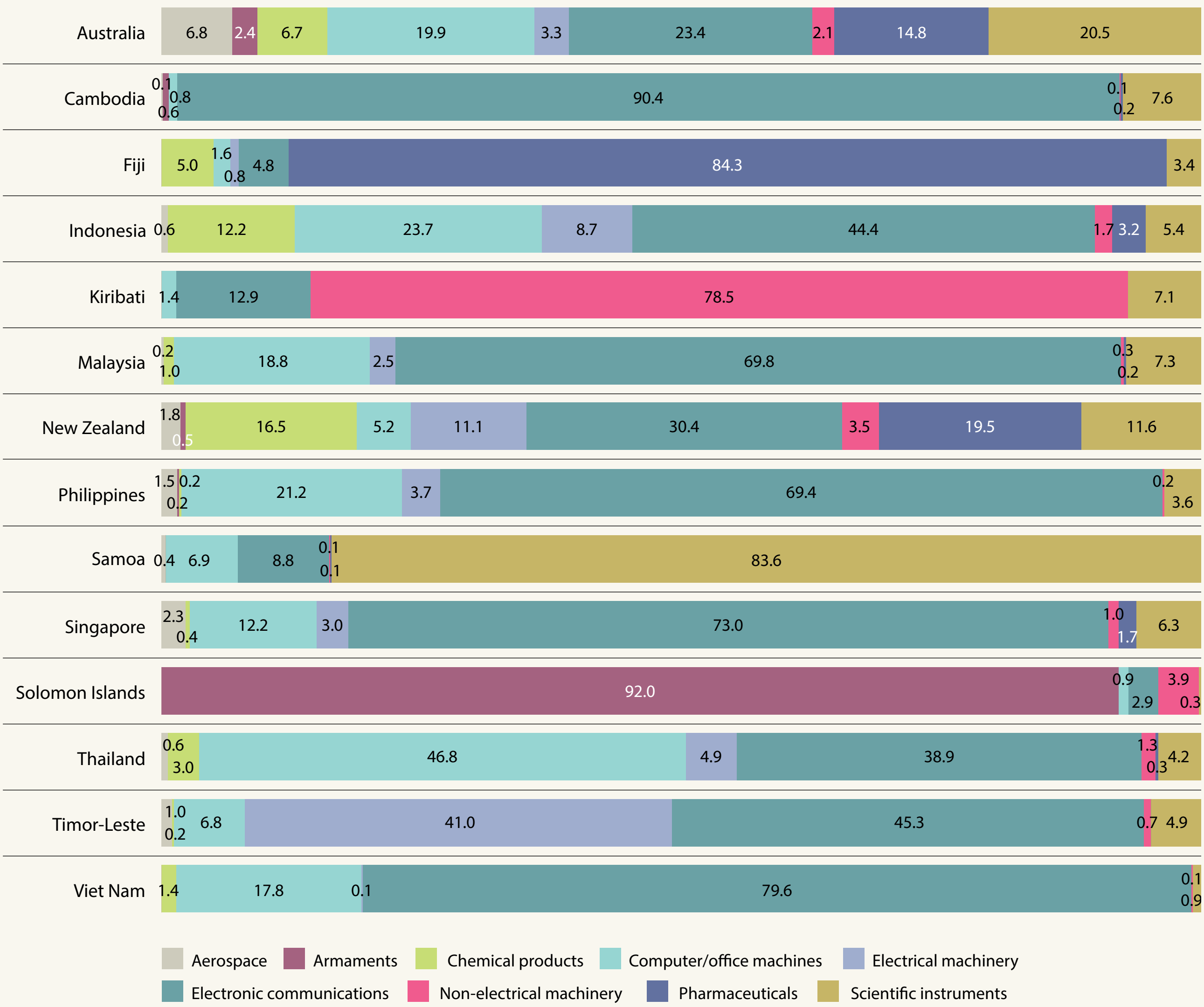
Respective shares of Thailand and Viet Nam in the region's high-tech exports in 2013

1.7%

Australia's share of the region's high-tech exports in 2013

Electronic communications dominate high-tech exports

National high-tech exports by type, 2013 (%)



Growth in high-tech exports has been fastest in Cambodia and Viet Nam, exports have receded in the Philippines and Fiji

US$ millions

	High-tech exports (US$ millions)		Change (US$ millions)	Change (%)
	2008	2013		
Australia	4 340.3	5 193.2	852.9	19.7
Cambodia	3.8	76.5	72.7	1 913.6
Fiji	5.0	2.7	-2.3	-45.7
Indonesia	5 851.7	6 390.3	538.6	9.2
Malaysia	43 156.7	63 778.6	20 622.0	47.8
New Zealand	624.3	759.2	134.9	21.6
Philippines	26 910.2	19 711.4	-7 198.8	-26.8
Samoa	0.3	0.2	-0.1	-40.6
Singapore	123 070.8	140 790.8	17 719.9	14.4
Thailand	33 257.9	37 286.4	4 028.5	12.1
Viet Nam	2 960.6	32 489.1	29 528.5	997.4
Total	240 181.9	306 482.5	66 300.7	27.6

Source: United Nations' Comtrade database comparatively high proportion of business sector R&D, it is likely that much of the research associated with computers/ office machines and electronic communications could be undertaken globally, rather than locally. Both countries host numerous large multinational companies. Australia also has a high proportion of business sector funding but, in Australia's case, this is largely a product of R&D undertaken in, and on behalf of, the mining and minerals sector.

Although scientific output has increased in global terms, there has been no overall rise in the level of patenting across the region. The region has even receded for this metric: Southeast Asia and Oceania produced 1.4% of the world's patents in 2012, compared to 1.6% in 2010, largely owing to the drop in patents registered from Australia. Four countries accounted for 95% of the patents obtained by the region: Australia, Singapore, Malaysia and New Zealand. The significant rise in high-tech exports across some countries in the region is at odds with the comparatively small global proportion of patenting activity. A major challenge for the region will be to draw on its scientific knowledge base to maintain and expand the range of high-tech exports in increasingly competitive global markets.

Squaring science policy with sustainable development still a challenge

A tension between the competing objectives of scientific excellence and scientific practice characterizes much of the region. In most countries, there is a clear desire to link S&T policies to innovation and development strategies. In the industrialized economies of Australia, New Zealand and Singapore, investment in science is viewed, in policy terms, as a component of national innovation strategies. Making science subservient to economic objectives at the policy level nevertheless carries a danger of underserving the many ways in which science can underpin socio-economic and cultural development, such as in health, education or in addressing global sustainability challenges.

Among developing economies, science policy is generally linked to development strategies yet, in this context too, there is a tension between assessments of scientific capacity through measures such as citation and development priorities. Among the poorer countries such as Cambodia, Lao PDR and Timor-Leste, or transition economies such as Myanmar, the development imperative is evident in recent policy documents which focus on harnessing human capital to serve basic development needs. International projects can be a way of reconciling limited national means with sustainable development goals. For instance, the Asian Development Bank funded a project to develop the use of biomass in three of the six countries located[2] in the Greater Mekong Subregion between 2011 and 2014: Cambodia, Lao People's Democratic Republic (PDR) and Viet Nam.

2. the other three being China, Myanmar and Thailand

Many of the less economically developed countries are struggling to steer their own scientific efforts toward sustainable development, at a time when the United Nations' Sustainable Development Goals are about to take over from the Millennium Development Goals in late 2015. They could begin by encouraging their scientists to focus more on attaining local goals for sustainable development, rather than on publishing in high-profile international journals on topics that may be of lesser local relevance. The difficulty with this course of action is that the key metrics for recognizing scientific quality are publications and citation data. The answer to this dilemma most likely lies in the need to recognize the global nature of many local development problems. As pointed out by Perkins (2012):

> We are dealing with problems without boundaries and we underestimate the scale and nature of their consequences at our collective peril. As global citizens, the research and policy communities have an obligation to collaborate and deliver, so arguing for national priorities seems irrelevant.

TRENDS IN R&D

Developing research personnel high on the agenda

Across the region, human resources for S&T are primarily concentrated in Australia, Malaysia, Singapore and Thailand. The strongest concentration of researchers is to be found in Singapore, which, with 6 438 full-time equivalent (FTE) researchers per million inhabitants in 2012, is well ahead of all G7 countries (Table 27.1). Technicians across the region are most concentrated in Australia and New Zealand, reflecting a pattern found in other mature economies, but Singapore has a much lower concentration. One of the driving forces for the freer flow of skills across ASEAN member States has been the demand from Malaysia and Singapore for ready access to technical personnel from elsewhere in the region. Malaysia and Thailand are both suppliers and recruiters of skilled personnel, as are the Philippines in some specialist fields. The freer flow of skilled personnel across ASEAN after 2015 should benefit both supplier and recruiter nations.

In terms of research training, Malaysia and Singapore stand out for their significant investment in tertiary education. Over the past decade, the share of their education budget devoted to tertiary education has risen from 20% to over 35% in Singapore and 37% in Malaysia (Figure 27.5). These two countries also happen to have the greatest share of PhD candidates among university students. In most countries, new institutions have sprung up to accommodate the growing demand for higher education.

Table 27.1: **Research personnel in Southeast Asia and Oceania, 2012 or closest year**

	Population ('000s)	Total researchers (FTE)	Researchers per million inhabitants (FTE)	Technicians per million inhabitants (FTE)
Australia (2008)	21 645	92 649	4 280	1 120
Indonesia (2009)	237 487	21 349	90	–
Malaysia (2012)	29 240	52 052	1 780	162
New Zealand (2011)	4 414	16 300	3 693	1 020
Philippines (2007)	88 876	6 957	78	11
Singapore (2012)	5 303	34 141	6 438	462
Thailand (2011)	66 576	36 360	546	170

Source: UNESCO Institute for Statistics, June 2015

There is also a growing pattern of subregional university collaboration. The ASEAN University Network established in the late 1990s now consists of 30 universities across the ten ASEAN countries. It has served as a model for more recent spin-offs, such as the Pacific Island Network constituted in 2011, which consists of ten Pacific universities operating across five countries. In parallel, many Australian and New Zealand universities have established campuses at universities across the region.

Four countries have a high proportion of tertiary students enrolled in science degrees: Myanmar (23%), New Zealand and Singapore (each with 14%) and Malaysia (13%). Myanmar also has the highest proportion of women enrolled in tertiary education, in general. It will be interesting to see if Myanmar manages to maintain this high proportion of women among students as it pursues its transition.

Women constitute half of researchers in Malaysia, the Philippines and Thailand but remain an unknown quantity in Australia and New Zealand, for which there are no recent data (Figure 27.6). More than half of researchers are employed by the higher education sector in most countries (Figure 27.7). Academics even make up eight out of ten researchers in Malaysia, suggesting that the multinational companies on its soil either do not count a majority of Malaysians on their research staff or do not conduct in-house R&D. The notable exception is Singapore, where half of researchers are employed by industry, compared to between 30% and 39% elsewhere in the region. In Indonesia and Viet Nam, the government is a major employer of researchers.

Better R&D data as vital as greater investment

Although data on gross domestic expenditure on R&D (GERD) are rather sketchy and date back several years in many cases – or are even non-existent for the smallest Pacific Island states – they still illustrate the blend of scientific capacity across Southeast Asia and Oceania. Singapore has conceded its regional lead for R&D intensity, which shrank from 2.3% to 2.0% of GDP between 2007 and 2012, having been overtaken by Australia, which has maintained a steady investment level of 2.3% of GDP in R&D (Table 27.2). Australia's dominant position may be short-lived, however, as Singapore plans to increase its GERD/GDP ratio to 3.5% by 2015.

A comparatively high share of R&D is performed by the business sector in four countries: Singapore, Australia, the Philippines and Malaysia (see Chapter 26). In the case of the latter two, this is most likely a product of the strong presence of multinational companies in these countries. Since 2008, many countries have boosted their R&D effort, including in the business enterprise sector. However, in some cases, business expenditure on R&D is highly concentrated in the natural resource sector, such as mining and minerals in Australia. The challenge for many countries will be to deepen and diversify business sector involvement across a wider range of industrial sectors.

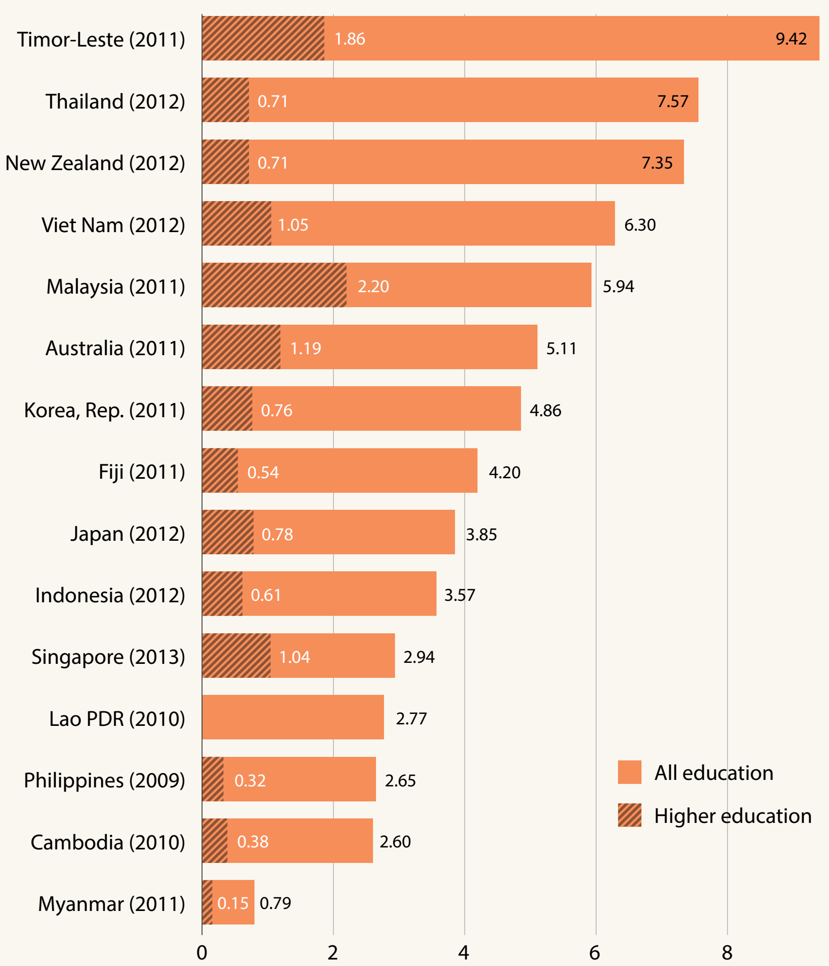
An emerging Asia–Pacific knowledge hub

The number of scientific publications catalogued in the Web of Science by the countries under study showed healthy growth between 2005 and 2014, some Asian countries even recording annual growth of 30% or more (Figure 27.8). Fiji and Papua New Guinea were the main contributors to publications from the Pacific Island states. Whereas Australia and New Zealand publish more in life sciences, the Pacific Islands tend to focus on geosciences. Southeast Asian countries specialize in both.

Figure 27.5: **Trends in higher education in Southeast Asia and Oceania, 2013 or closest year**

Five countries devote more than 1% of GDP to higher education

As a share of GDP, 2013 (%)



2.20%
Share of GDP devoted to higher education by Malaysia in 2011

0.15%
Share of GDP devoted to higher education by Myanmar in 2011

19.9%
Average share of spending on higher education in Southeast Asia and Oceania within education expenditure (%)

3.3%
Average share of the population enrolled in higher education in Southeast Asia and Oceania (among countries listed in the table below)

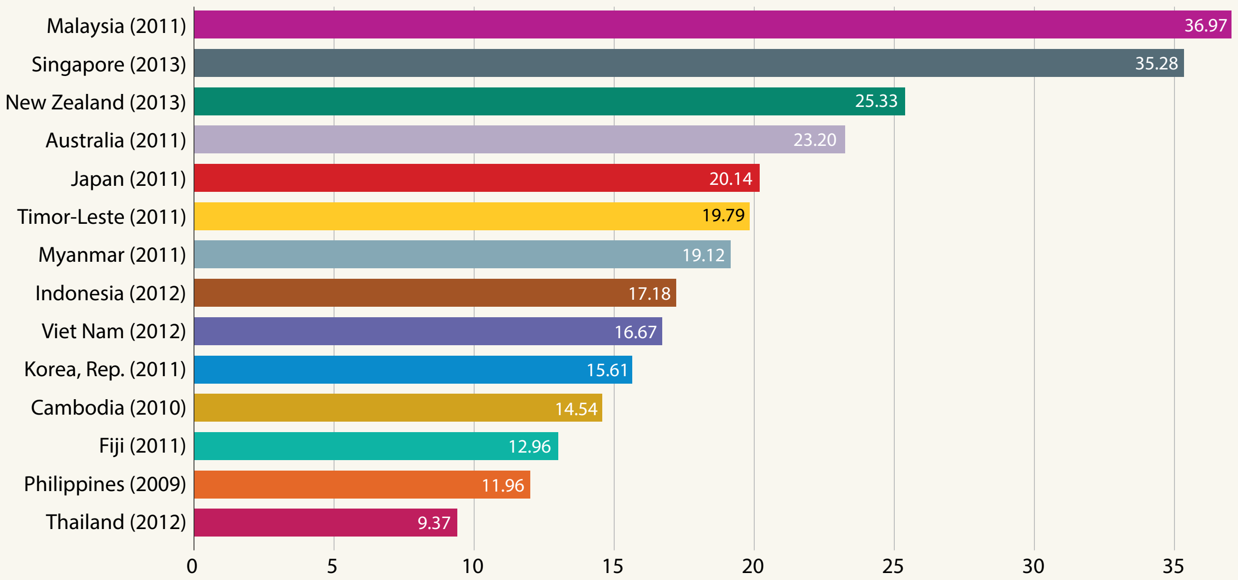
Australia and New Zealand count the greatest share of tertiary students among the total population

	Year	Tertiary enrolment, all fields	Share of total pop. (%).	Tertiary enrolment in scientific disciplines	Share of science in tertiary enrolment (%)
Australia	2012	1 364 203	5.9	122 085	8.9
New Zealand	2012	259 588	5.8	36 960	14.2
Singapore	2013	255 348	4.7	36 069	14.1
Malaysia	2012	1 076 675	3.7	139 064	12.9
Thailand	2013	2 405 109	3.6	205 897	8.2[-2]
Philippines	2009	2 625 385	2.9	–	–
Indonesia	2012	6 233 984	2.5	433 473[-1]	8.1
Viet Nam	2013	2 250 030	2.5	–	–
Lao PDR	2013	137 092	2.0	6 804[-1]	5.4[-1]
Cambodia	2011	223 222	1.5	–	–
Myanmar	2012	634 306	1.2	148 461	23.4

-n = data are for *n* years before reference year

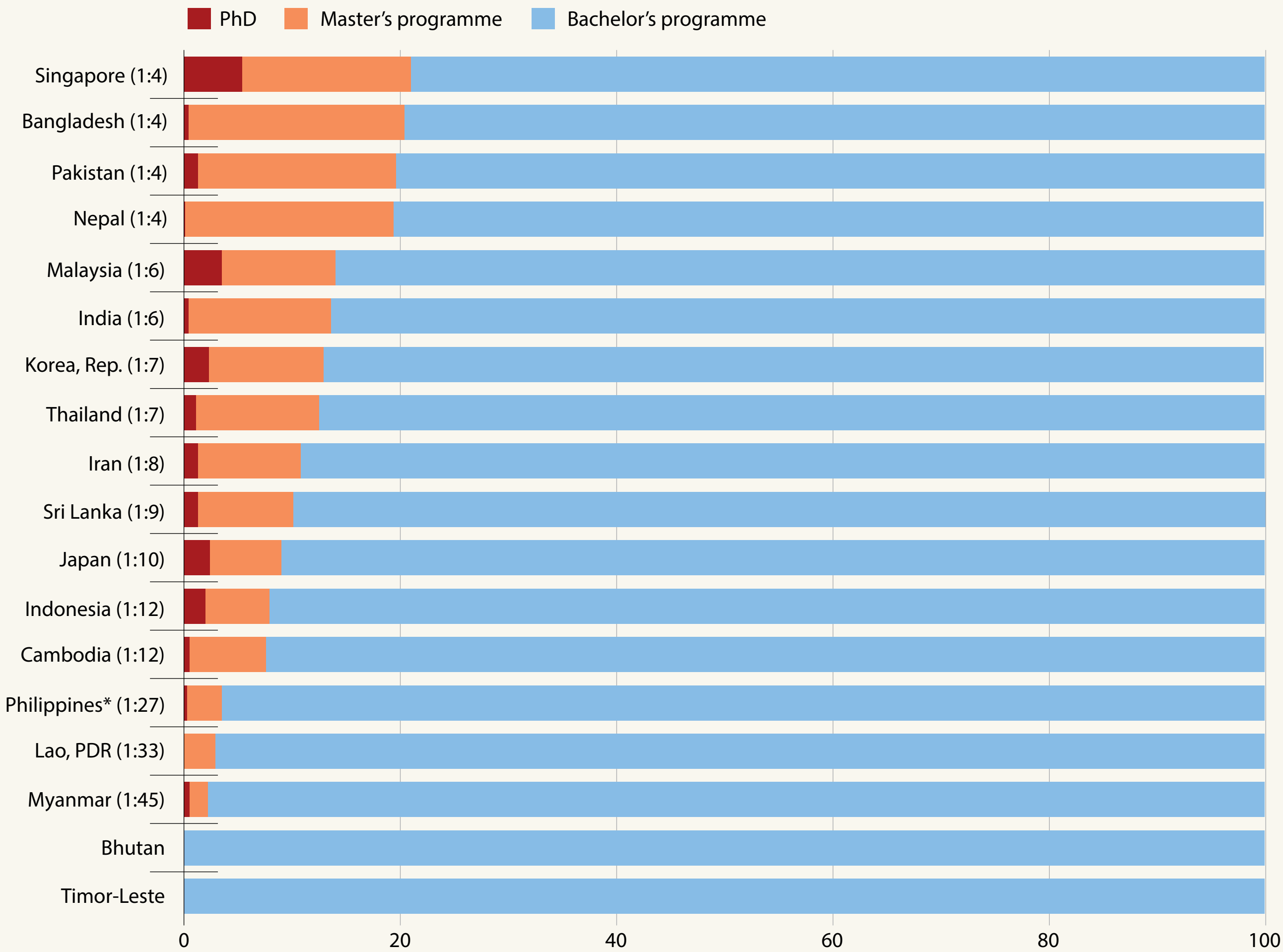
More than one-third of education spending goes on higher education in Malaysia and Singapore

As a share of total public expenditure on education, 2013 or nearest year (%)



Singapore and Malaysia have the greatest share of PhD students among university students

University enrolment in Asia by level of study, 2011, selected countries



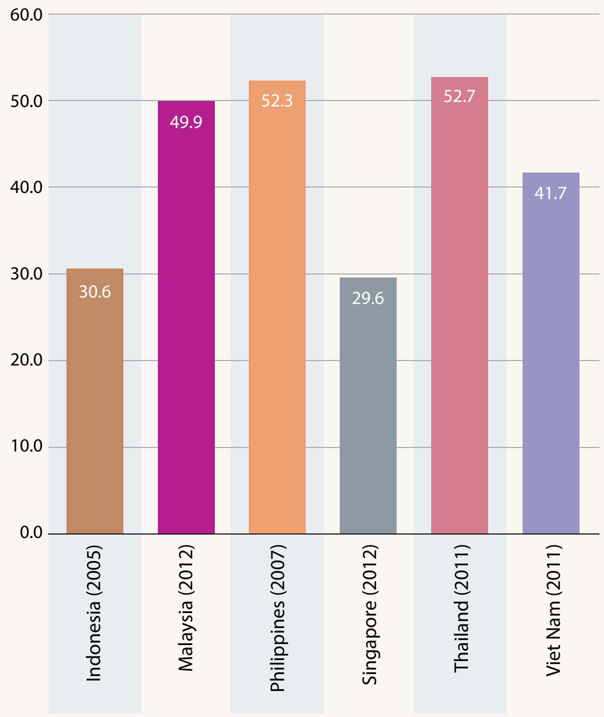
* Data for the Philippines are for 2008.

Note: Between brackets is the ratio of enrolment in master's/PhD programmes to bachelor's programmes.

Source: UNESCO Institute for Statistics, June 2015; for university enrolment in Asia: UIS (2014)

Figure 27.6: **Women researchers (HC) in Southeast Asia, 2012 or closest year (%)**

Head counts



Source: UNESCO Institute for Statistics, June 2015

Countries around the Pacific Rim are seeking ways to link their national knowledge base to regional and global advances in science. One motivation for this greater interconnectedness is the region's vulnerability to geohazards such as earthquakes and tsunamis – the Pacific Rim is not known as the Ring of Fire for nothing. The need for greater disaster resilience is inciting countries to develop collaboration in the geosciences. Climate change is a parallel concern, as the Pacific Rim is also one of the most vulnerable regions to rising sea levels and increasingly capricious weather patterns. In March 2015, much of Vanuatu was flattened by Cyclone Pam. Partly to ensure the viability of its agriculture, Cambodia has adopted a *Climate Change Strategic Plan* covering 2014 –2023, with financial support from the European Union and others.

The citation rate for papers published across the region is growing. Between 2008 and 2012, countries from Southeast Asia and Oceania surpassed the OECD average for the number of papers among the 10% most-cited. In some cases, the growth in international co-authorship may be a factor in this positive outcome, as in Cambodia. All but Viet Nam and Thailand have increased their share of internationally co-authored scientific papers over the past decade. For the smaller or transition economies, international collaboration even represents more than 90% of the total, as in Papua New Guinea, Cambodia, Myanmar and some Pacific Island states.

Although collaboration is strongly linked to global knowledge hubs such as the USA, UK, China, India, Japan and France, there is evidence of an emerging Asia–Pacific 'knowledge hub.' Australia, for instance, is one of the top five collaborators for 17 of the 20 countries in Figure 27.8.

The Asia–Pacific Economic Cooperation (APEC) intends to accompany the development of an Asia–Pacific knowledge hub. APEC completed a study[3] in 2014 of skills shortages in the region, with a view to setting up a monitoring system to address training needs before these shortages become critical.

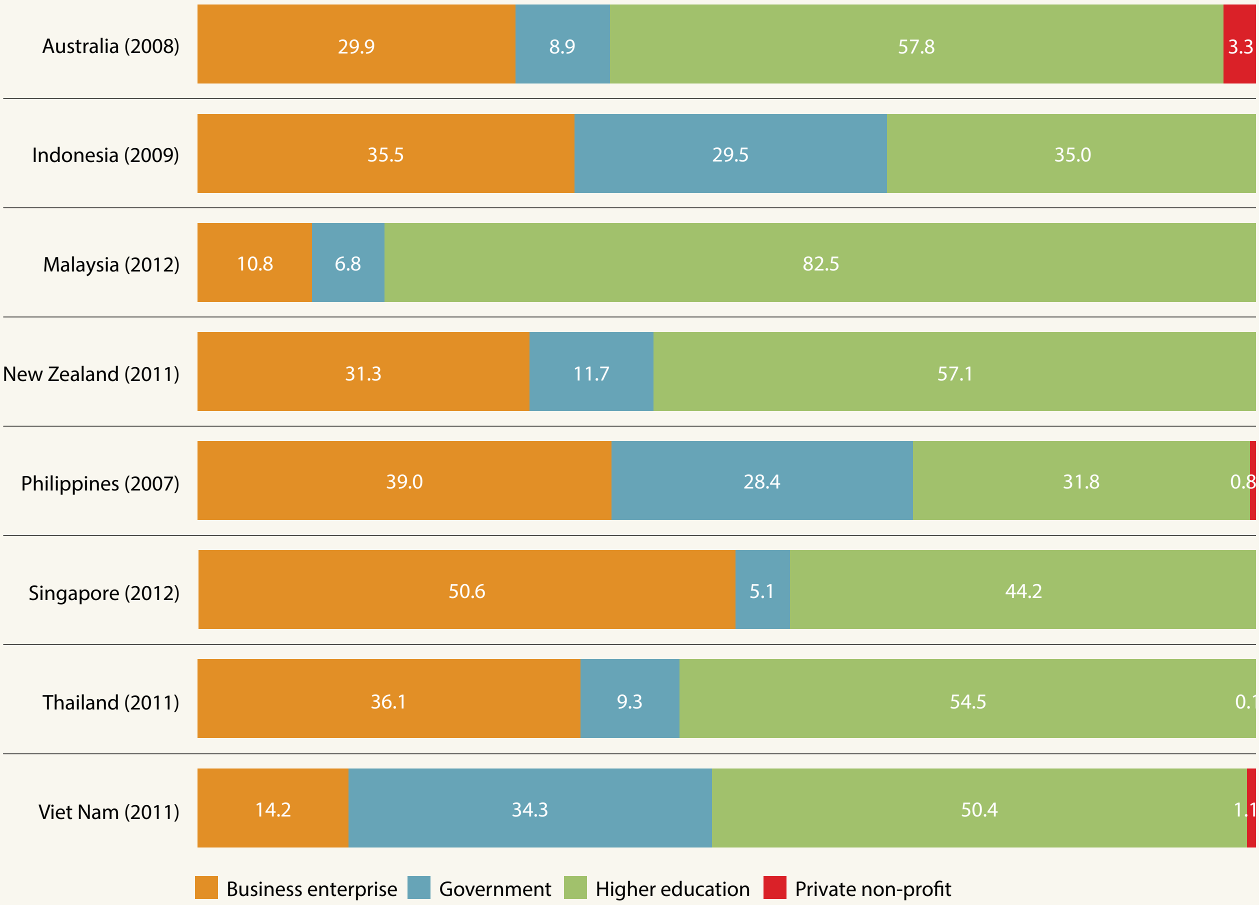
The ASEAN Committee on Science and Technology launched the ASEAN Krabi initiative in 2010, which has since developed the *ASEAN Plan of Action on Science, Technology and Innovation* (APASTI) covering the period 2016–2020. The interesting feature of APASTI is its integrated approach to science, technology and innovation (STI); it seeks to raise competitiveness across the region by contributing to both social inclusion and sustainable development. APASTI is scheduled to be adopted by ASEAN member states by the end of 2015; it identifies eight thematic areas:

- Focusing on global markets;
- Digital communication and social media;
- Green technology;
- Energy;
- Water resources;
- Biodiversity;
- Science; and
- 'Innovation for life'.

In parallel, schemes such as the annual ASEAN–European Union Science, Technology and Innovation Days are reinforcing dialogue and co-operation between these two regional bodies. The second of these days took place in France in March 2015 and the third is scheduled to take place in Viet Nam in 2016. In 2015, the theme was Excellent Science in ASEAN. Some 24 exhibitors presented research from their institution or enterprise. There were also sessions on scientific topics and two policy sessions, one on the evolution of the ASEAN Economic Community and the second on the importance of intellectual property rights for the Pacific region. This annual forum was launched within the Southeast Asia–EU Network for Biregional Co-operation project (SEA–EU NET II) funded by the EU's Seventh Framework Programme for Research and Innovation. A network to foster policy dialogue between the EU and the Pacific region has been launched within the same framework programme (see p. 725).

3. See: http://hrd.apec.org/index.php/APEC_Skills_Mapping_Project

Figure 27.7: **Researchers (FTE) in Southeast Asia and Oceania by sector of employment, 2012 or closest year (%)**



Note: The data for Viet Nam are by head count.

Source: UNESCO Institute for Statistics, June 2015

Table 27.2: **GERD in Southeast Asia and Oceania, 2013 or closest year**

	As % of GDP	Per capita PPP$	Share performed by business (%)	Share funded by business (%)
Australia (2011)	2.25	921.5	57.9	61.9-3
New Zealand (2009)	1.27	400.2	45.4	40.0
Indonesia (2013*)	0.09	6.2	25.7	–
Malaysia (2011)	1.13	251.4	64.4	60.2
Philippines (2007)	0.11	5.4	56.9	62.0
Singapore (2012)	2.02	1 537.3	60.9	53.4
Thailand (2011)	0.39	49.6	50.6	51.7
Viet Nam (2011)	0.19	8.8	26.0	28.4

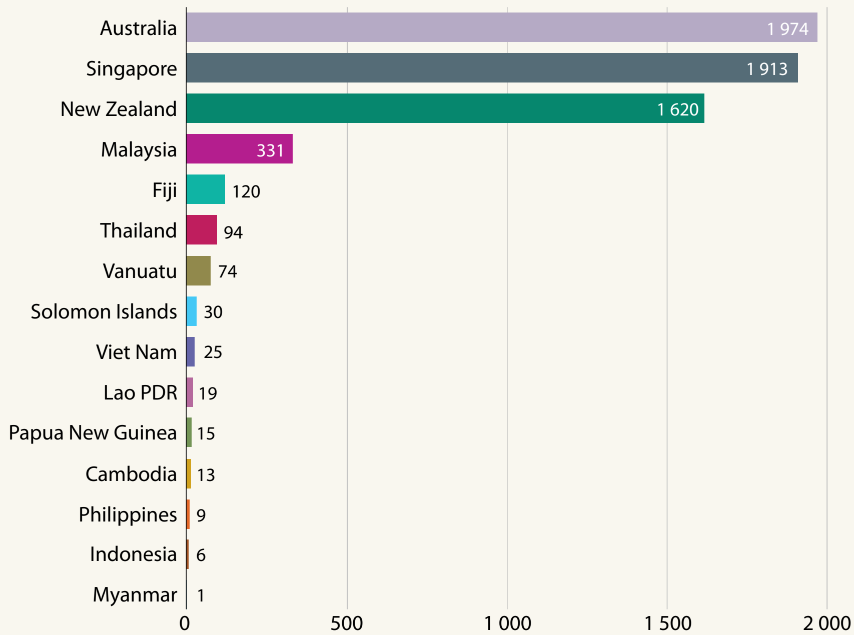
* national estimate

Source: UNESCO Institute for Statistics, June 2015

Figure 27.8: **Scientific publication trends in Southeast Asia and Oceania, 2005–2014**

Scientists from Australia, Singapore and New Zealand are the most prolific

Publications per million inhabitants in 2014



60.1%

Malaysia's annual growth rate for the number of publications, 2005–2014

31.2%

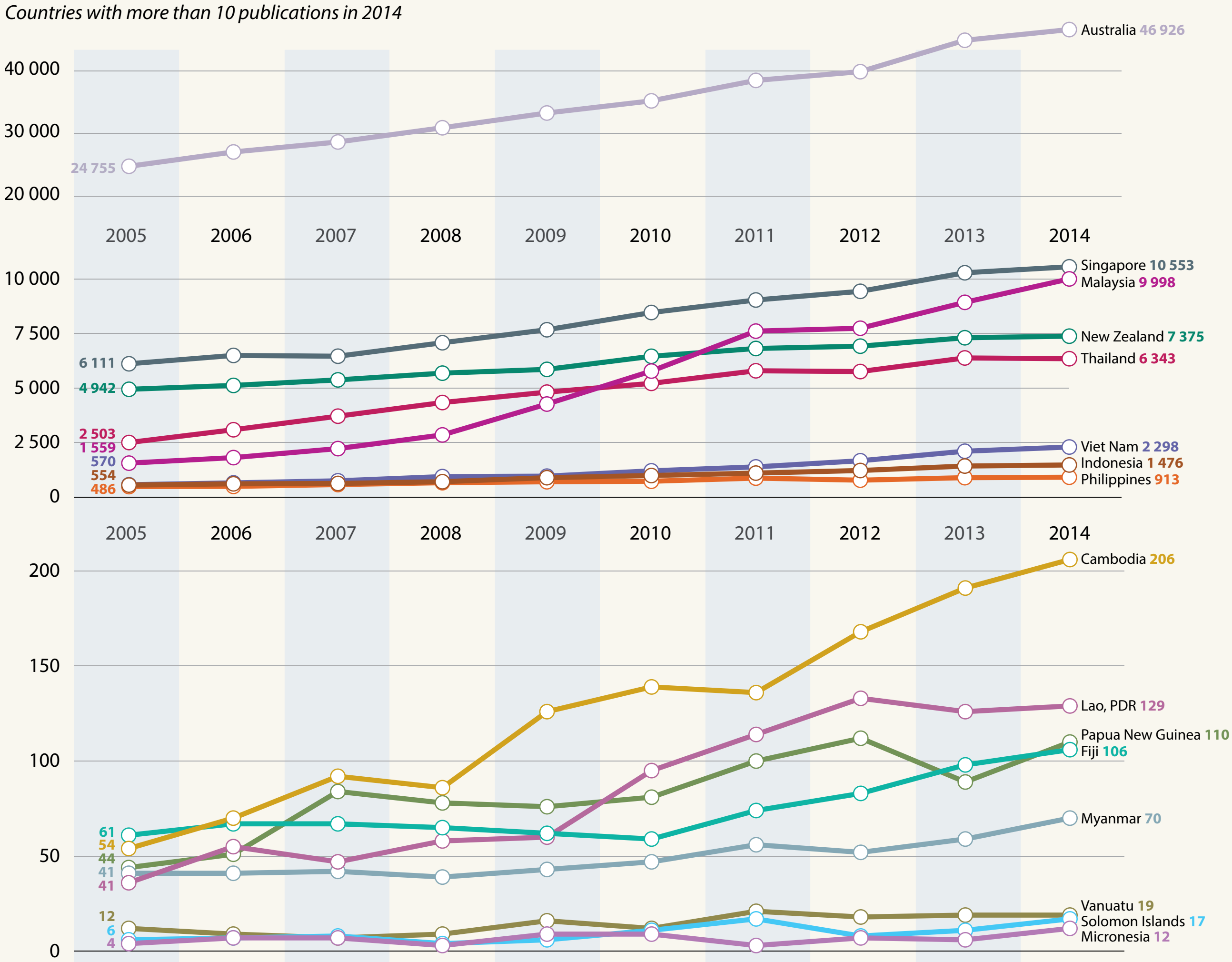
Average annual growth in publications from Viet Nam, Cambodia and Lao PDR, 2005–2014

7.8%

Average annual growth in publications from Australia, New Zealand and Singapore, 2005–2014

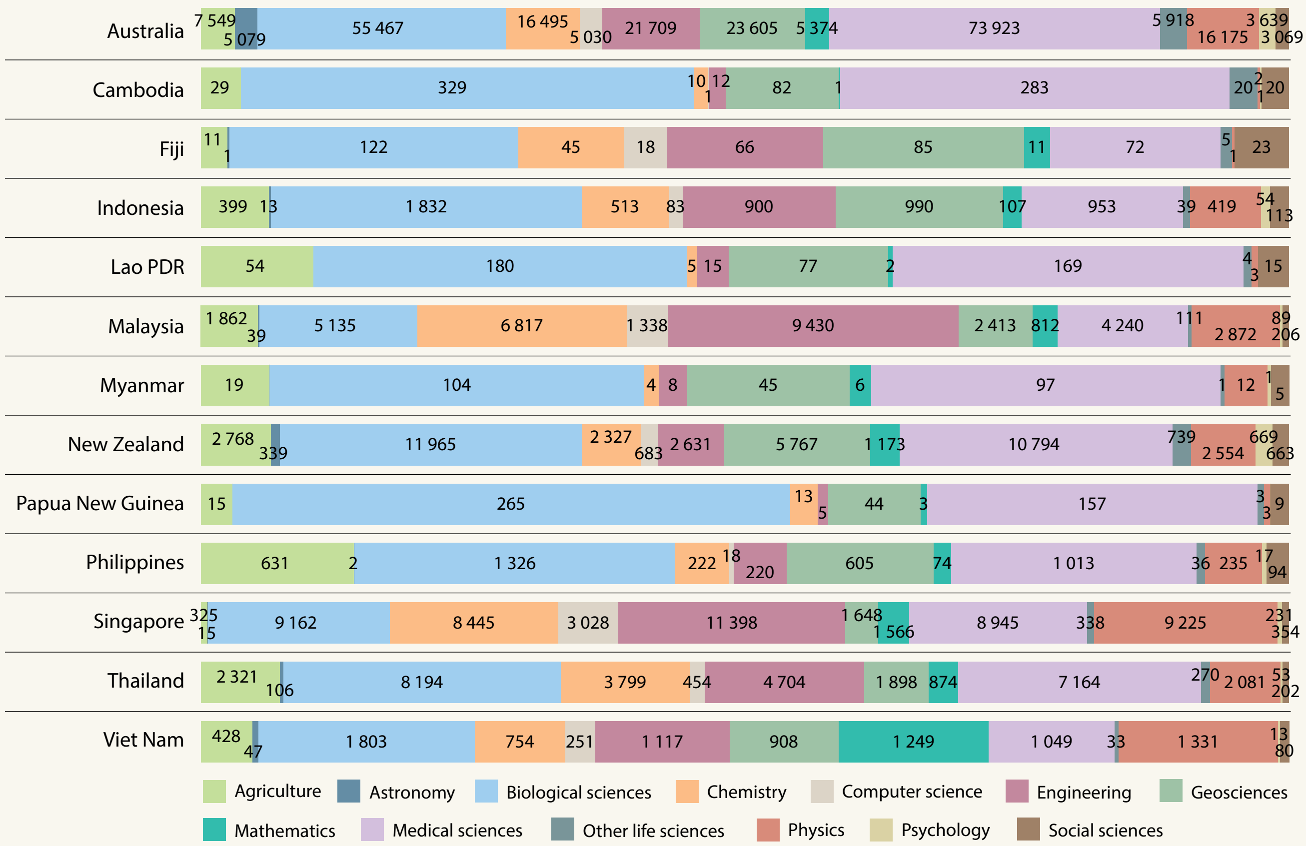
Steady growth in the most prolific countries

Countries with more than 10 publications in 2014



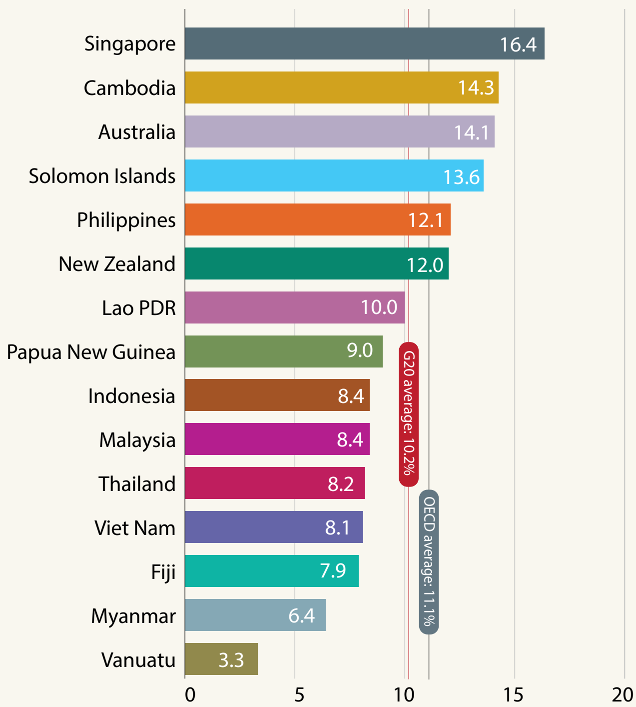
Engineering dominates in Malaysia and Singapore, life sciences and geosciences elsewhere

Countries with more than 20 publications in 2014; cumulative totals by field, 2008–2014



Note: Unclassified articles are excluded.

Six countries topped the OECD average for the share of papers among the 10% most cited between 2008 and 2012



Five countries topped the OECD average for the average citation rate between 2008 and 2012

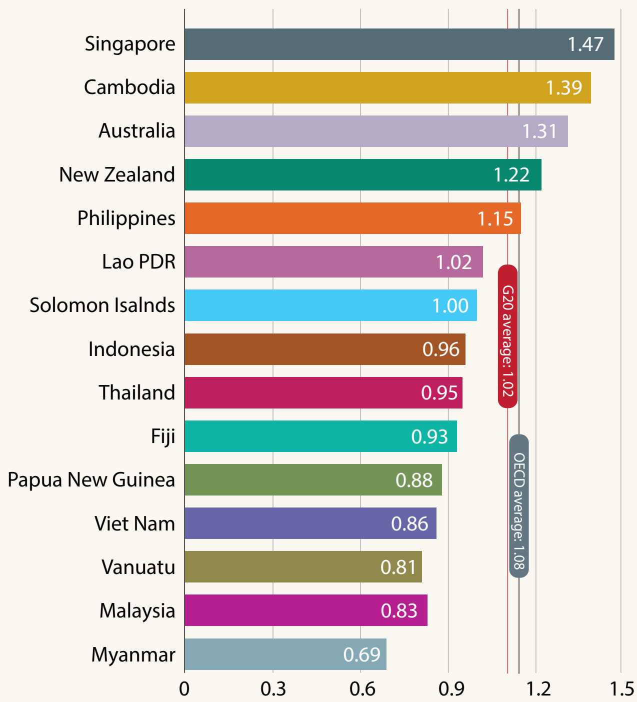


Figure 27.8 *(continued)*

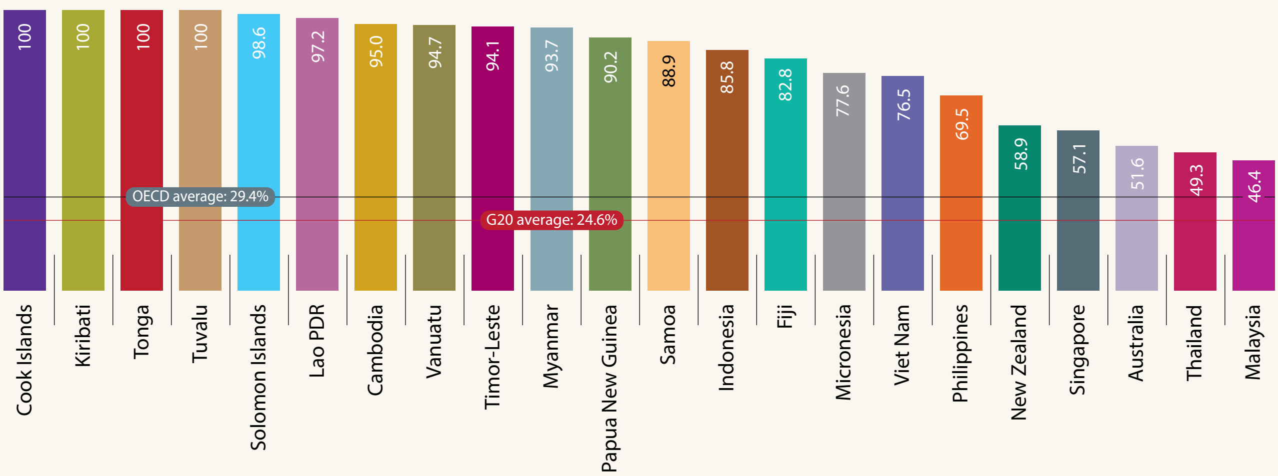
Countries collaborate with a wide range of partners

Main foreign partners, 2008 –2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Australia	USA (43 225)	UK (29 324)	China (21 058)	Germany (15 493)	Canada (12 964)
Cambodia	USA (307)	Thailand (233)	France (230)	UK (188)	Japan (136)
Cook Islands	USA (17)	Australia/ New Zealand (11)		France (4)	Brazil/Japan (3)
Fiji	Australia (229)	USA (110)	New Zealand (94)	UK (81)	India (66)
Indonesia	Japan (1 848)	USA (1 147)	Australia (1 098)	Malaysia (950)	Netherlands (801)
Kiribati	Australia (7)	New Zealand (6)	USA/Fiji (5)		Papua New Guinea (4)
Lao PDR	Thailand (191)	UK (161)	USA (136)	France (125)	Australia (117)
Malaysia	UK (3 076)	India (2 611)	Australia (2 425)	Iran (2 402)	USA (2 308)
Micronesia	USA (26)	Australia (9)	Fiji (8)	Marshall Islands (6)	New Zealand/ Palau (5)
Myanmar	Japan (102)	Thailand (91)	USA (75)	Australia (46)	UK (43)
New Zealand	USA (8 853)	Australia (7 861)	UK (6 385)	Germany (3 021)	Canada (2 500)
Papua New Guinea	Australia (375)	USA (197)	UK (103)	Spain (91)	Switzerland (70)
Philippines	USA (1 298)	Japan (909)	Australia (538)	China (500)	UK (410)
Samoa	USA (5)	Australia (4)	Ecuador/Spain/ New Zealand/France/ China/Costa Rica/Fiji/ Chile/Japan/Cook Islands (1)		
Singapore	China (11 179)	USA (10 680)	Australia (4 166)	UK (4 055)	Japan (2 098)
Solomon Islands	Australia (48)	USA (15)	Vanuatu (10)	UK (9)	Fiji (8)
Thailand	USA (6 329)	Japan (4 108)	UK (2 749)	Australia (2 072)	China (1 668)
Tonga	Australia (17)	Fiji (13)	New Zealand (11)	USA (9)	France (3)
Vanuatu	France (49)	Australia (45)	USA (24)	Solomon Islands/ New Zealand/ Japan (10)	
Viet Nam	USA (1 401)	Japan (1 384)	Korea, Rep. (1 289)	France (1 126)	UK (906)

Small or fledgling science systems have very high rates of foreign collaboration

Share of papers with foreign co-authors, 2008–2014



Note: Data are unavailable for some indicators for the Cook Islands, Kiribati, Micronesia, Niue, Samoa, Tonga and Vanuatu.

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

AUSTRALIA

End of commodities boom squeezing S&T budgets

Australia continues to play a significant role in STI across the region. Its universities remain a draw for aspiring scientists and engineers from the region and it counts the highest absolute number of FTE researchers and technicians, as well as the highest GERD/GDP ratio (2.25%) and a dynamic business sector which contributes almost two-thirds of GERD (Table 27.2). In 2014, Australia accounted for 54% of the region's papers in the Web of Science (Figure 27.8).

The national innovation system is not without its weaknesses, however. As Australia's Chief Scientist Ian Chubb recently noted, although Australia ranked 17th out of 143 countries in the Global Innovation Index in 2014, it ranked 81st as a converter of raw innovation capability into the output that business needs, namely new knowledge, better products, creative industries and growing wealth. In 2013, Australia's high-tech exports contributed just 1.7% of the total from Southeast Asia and Oceania, ahead of only New Zealand, Cambodia and the Pacific Island states (Figure 27.4). In contrast to many of the ASEAN countries, Australia is not very engaged in product assembly in the global electronics value chain; this illustrates why comparisons of high-tech exports by countries in the region need to take into account the position of each economy in global high-tech production and export.

Australia's economic success in recent decades has been driven largely by the resources boom, primarily in iron ore and coal. Importantly, this has also driven much of R&D investment: 22% of business expenditure on R&D in 2011 concerned the mining sector, which also contributed 13.0% of GERD. The mining sector accounted for 59% of Australian exports in 2013, nearly two-fifths of which consisted in iron ore. Since 2011, the global price for iron ore has dropped from US$ 177 to less than US$ 45 per tonne (July 2015). A major factor behind the fall has been the reduced demand from China and India. Although prices are predicted to stabilize or even rise through 2015, the impact on Australian foreign earnings from this major export sector has been substantial. As a consequence, science in Australia has been hit both by cuts made to R&D expenditure in the mining and minerals sector and by cuts in public funding for science overall.

A new policy direction

Between 2010 and 2013, the majority of policy reports focused on innovation. This has not changed with the current government. The review of the Australian Co-operative Research Centre programme announced in 2014, for instance, has been mandated to explore ways of boosting Australia's productivity and national competitiveness.

The coalition government headed by Tony Abbott has nevertheless introduced changes in the overall direction of STI policy since coming to power in September 2013. In a context of reduced government revenue since the end of the commodities boom, the government's 2014–2015 budget made severe cuts to the country's flagship science institutions. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) faces a reduction of AU$ 111 million (3.6%) over four years and a loss of 400 jobs (9%). The Cooperative Research Centres programme survives but its funding has been frozen at current levels and will be reduced further by 2017–2018. In addition, a number of programmes fostering innovation and commercialization have been abolished. These include some long-running initiatives such as Enterprise Connect, the Industry Innovation Councils and Industry Innovation Precincts. The current government has replaced these incentive schemes with five industry-specific growth centres. The creation of these centres was announced in the government's 2014–2015 budget. Each is to be endowed with a budget of AU$ 3.5 million over four years with a focus on:

- Food and agriculture;
- Mining equipment and services;
- Oil, gas and energy reserves;
- Medical technologies and pharmaceuticals; and
- Advanced manufacturing.

The success of the centres will be measured by business-focused metrics such as increased investment, employment, productivity and sales, reduction in bureaucratic red-tape, improved industry–research linkages and a greater number of businesses integrated into international value chains, in line with the new approach established by the Minister of Industry and Science, Ian Macfarlane, in 2014.

There has been a decisive shift in the present government's approach away from renewable energy and carbon reduction strategies. The Australian carbon tax introduced by the previous Labour government has been abolished and, in the 2014–2015 budget, the government announced plans to abolish the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation. ARENA was established in July 2012 to promote the development, commercialization and dissemination of renewable energy and enabling technologies; it incorporated the Australian Centre for Renewable Energy, which had opened in 2009. However, both ARENA and the Clean Energy Finance Corporation were established by acts of parliament and, although the minister responsible advised parliament in October 2014 that the government was committed to abolishing both agencies, the present government has been unable to obtain majority support from the upper house to repeal the relevant acts.

Not all government research programmes lost out in the 2014–2015 budget. The Antarctic programme was one of its beneficiaries, with provision for a brand new AU$ 500 million icebreaker. This move supports the government strategy of turning the island of Tasmania into a regional hub for Antarctic research and services.

There has also been a shift in priorities in favour of medical research, with the planned establishment of an AU$ 20 billion medical research fund. The fund's creation hinged on a government proposal to abolish free medical treatment under the Medicare system for low-income households, a system that has been in place for two decades, and to replace Medicare with a 'co-payment' levy. The controversial new levy was ultimately defeated in parliament. The proposal is revealing of the current government's philosophy that science is a cost to be recovered from users, rather than a strategic national investment.

The approach to science in the 2014–2015 budget attracted concern from key stakeholder groups. The budget has been described as 'short-sighted' and 'destructive' by the CSIRO and as 'worse than we even imagined' by the Cooperative Research Centres Association. One of Australia's leading professors, Jonathan Borwein, has observed that 'there is more to science than medical research'. In May 2015, the government announced an additional AU$ 300 million in funding for the National Collaborative Research Infrastructure Strategy and committed further financial means in the federal budget for the medical research fund proposed in the 2014–2015 budget.

Another policy development has emerged from a May 2015 review of the Cooperative Research Centres programme. The review recommended a sharper commercial focus and the introduction of shorter-term (three years) co-operative research projects within the overall programme. These recommendations have all been accepted by the current government. Given that no additional funding has been announced for the programme, the sharper commercial focus in future may well come at the expense of the public good at those co-operative research centres oriented towards areas such as climate change and health.

One recent initiative that has drawn support from the scientific community is the creation of a National Science Council to be chaired by the prime minister. Although the Chief Scientist proposed that this would 'help provide strategic thinking for science', the Academy of Science argued that the new council would not compensate for the lack of a science minister. This was a reference to the decision made in December 2014 to entrust the Minister for Industry with the portfolio for science.

Announced in October 2014, the government's *Industry Innovation and Competitiveness Agenda* introduces initiatives to enhance science, engineering and mathematics education but only in the context of how this can contribute to the nation's industrial and economic prospects. There is currently little policy discussion about the importance of science for enhancing the nation's knowledge base or tackling pressing health and environmental problems of both national and global dimensions.

Universities have come to dominate public research

Australian science has historically been built around a strong government research system with four main pillars: the CSIRO, Australian Institute of Marine Science, Australian Nuclear Science and Technology Organisation and the Defence Science and Technology Organisation. State agriculture departments have historically also played a role in agricultural research.

In recent years, however, the university system has become the main focus for government-funded research. Over 70% of the value of public sector research in Australia is now performed by universities, equivalent to 30% of GERD. University research is dominated by medical and health sciences (29%), engineering (10%) and biological sciences (8%). The government research sector, which now performs only 11% of GERD, focuses primarily on the same fields, with the notable addition of agricultural research (19%). The other shares are medical and health sciences (15%), engineering (15%) and biological sciences (11%). This research focus is reflected in the statistics (Figure 27.8).

The government's role has shifted away from supporting public research institutions to becoming a major funder, regulator of standards and assessor of research quality. Many R&D functions formerly carried out by government research agencies have been transferred to the private sector or to universities. This has changed the nature of public funding away from direct appropriations towards a grant system operated through agencies such as the Australian Research Council and the National Health and Medical Research Council, the Cooperative Research Centres Programme and the Rural R&D corporations. The latter corporations, which have been in place now for over 70 years, are a unique Australian mechanism combining public funding with matching producer levies. Government policy emphasizes relevance to industry when allocating competitive research grants, research block grants, doctoral scholarships and university admissions (Australian Government, 2014).

As a consequence, much contemporary policy debate is focusing on how to direct the expanding university research capabilities towards the business sector.

A report commissioned by the Chief Scientist reveals that 11% of Australia's economy relies directly on advanced physical and mathematical sciences, contributing AU$ 145 billion to annual economic activity (AAS, 2015). As we have seen, the strengths of the university and government sectors lie elsewhere and, although the current government intends to foster research of relevance to industry, its focus is on ocean and medical sciences.

The Chief Scientist has also drawn attention to some underlying structural issues in the Australian innovation system, such as the cultural barriers that inhibit both risk-taking behaviour and the flow of people, ideas and funding between the public and private sectors. Laying better pathways between science and its applications will be an urgent challenge for the next decade, if Australia is to emulate more innovative economies.

An academic sector with a regional focus

There are currently 39 Australian universities, three of which are private. In 2013, they had a collective roll of 1.2 million students, 5% of whom (62 471) were enrolled in a master's or PhD programme. This is a much lower percentage than elsewhere in Asia, including Singapore, Malaysia, the Republic of Korea, Pakistan and Bangladesh (Figure 27.5). Moreover, more than 30% of postgraduate students come from overseas and more than half of them (53%) are enrolled in science and engineering fields. This suggests that Australia is producing only a modest number of home-grown scientists and engineers, a trend which may be ringing alarm bells in some policy circles but also underscores Australia's role as a regional hub for the training of scientists.

The growing regional centrality of the Australian higher education system is also reflected in co-authorship trends for scientific publications. Australian authors figure among the top five collaborating countries with all Pacific countries covered in the present chapter and seven out of the nine Southeast Asian countries. The overwhelming international evidence is that collaboration is essential for solving industrial and social problems. Australia is thus uniquely well placed, thanks to its globally recognized public research system and high level of international collaboration (52%). There are sound underlying reasons for seeking to maintain this national leading edge.

In parallel, the Asian region is rapidly gaining scientific strength. An interesting debate has emerged recently, in which some argue that funding priorities should be directed towards supporting regional research strengths relative to Asian universities. From this perspective, a more nuanced set of priorities emerge, led by ecology, the environment, plant and animal science, clinical medicine, immunology and neuroscience.

A twin challenge for STI

The challenge for STI in Australia is twofold. First, in order to realize the imperative of moving the economy towards more value-added production, there is a need to align public investment in R&D with emerging opportunities for innovative products and services. For example, the declining pre-eminence of coal as the main source of energy for driving global production opens up new scientific opportunities for alternative energies. A decade ago, Australian R&D was well-placed to be at the forefront of this frontier field. Since then, other countries have overtaken Australia but the potential for it to be a leader in this field remains. The proposed industry growth centres and the long-running Cooperative Research Centres programme offer the structure and scientific capacity to underpin such development but the government will also need to utilize policy better to minimize the business-sector risk, in order to capitalize on the science sector's strength in these areas.

An associated challenge will be to ensure that science does not become the hand-maiden of industrial and commercial development. It is Australia's strengths in science and the solidity of its institutions that have enabled the country to become a key regional knowledge hub.

CAMBODIA

A growth strategy that is working

Since 2010, Cambodia has pursued its impressive transformation from a post-conflict state into a market economy. Growth averaged 6.4% per year between 2007 and 2012 and the poverty rate shrank from 48% to 19% of the population, according to the Asian Development Bank's *Country Partnership Strategy 2014–2018*.

Cambodia exports mainly garments and products from agriculture and fisheries but is striving to diversify the economy. There is some evidence of expansion in value-added exports from a low starting point, largely thanks to the manufacture of electrical goods and telecommunications by foreign multinationals implanted in the country.

Higher spending on education, little on R&D

Public expenditure on education accounted for 2.6% of GDP (2010), compared to 1.6% in 2007. The share going to tertiary education remains modest, at 0.38% of GDP or 15% of total expenditure, but it is growing. Despite this, Cambodia still ranks lowest in the region for the education dimension of the World Bank's Knowledge Economy Index.

According to the UNESCO Institute for Statistics, GERD accounts for approximately 0.05% of GDP. As in many of the world's least developed economies, there is a strong reliance on international aid. The regulatory environment in which non-governmental organizations (NGOs) operate is currently a focus of parliamentary debate in Cambodia. It will be interesting to see if any potential legislative change to the regulations reduces R&D investment from the not-for-profit sector.

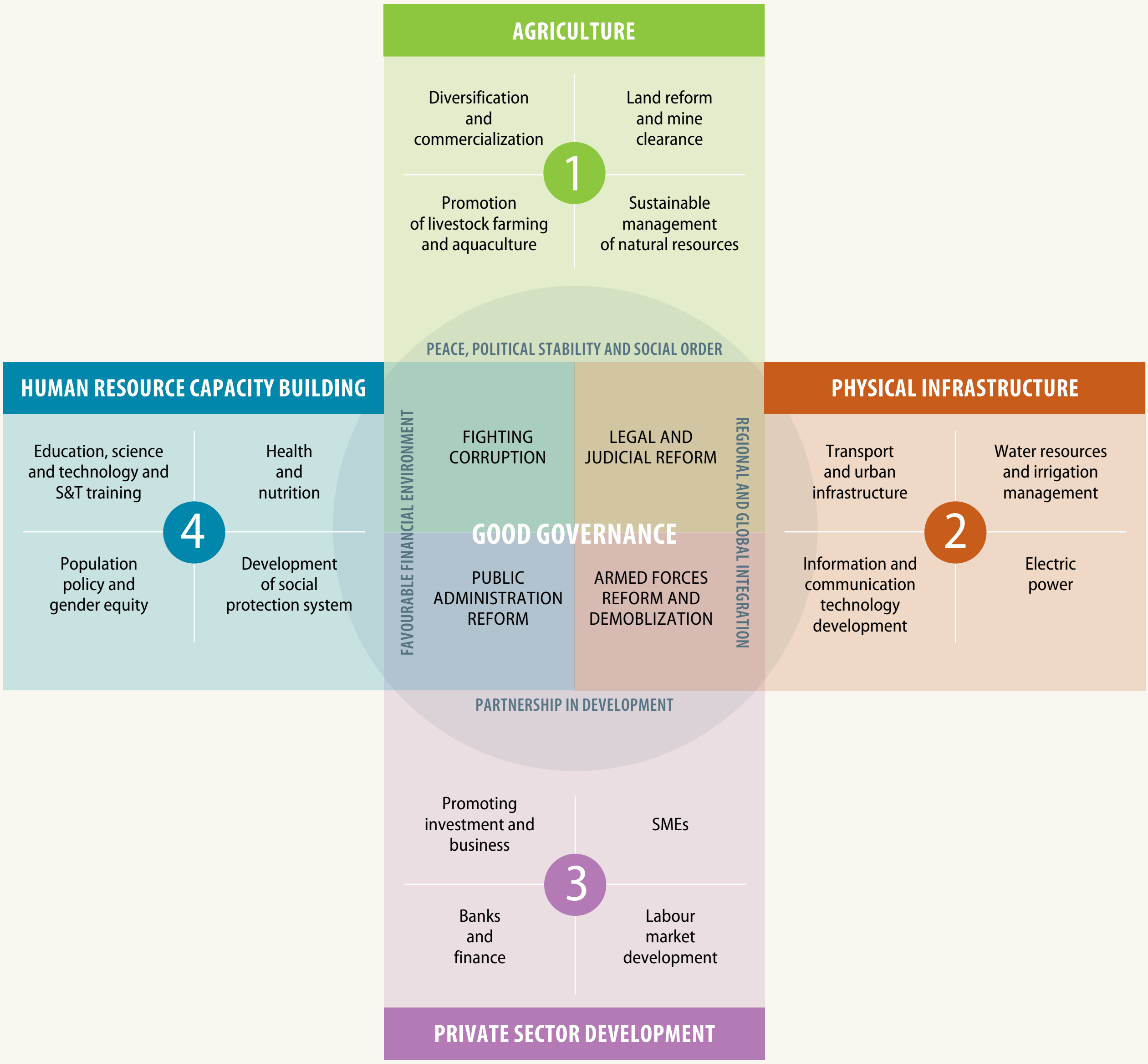
Scientific publications grew by 17% on average between 2005 and 2014, a rate surpassed only by Malaysia, Singapore and Viet Nam (Figure 27.8). They came from a low starting point, however, and had a narrow focus: the majority focused on biological and medical sciences in 2014.

A first national strategy for S&T

Like many low-income countries, Cambodia has been held back by the limited co-ordination of S&T across ministries and the absence of any overarching national strategy for science and development. In 2010, the Ministry of Education, Youth and Support[4] approved a *Policy on Research Development in the Education Sector*. This move represented a first step towards a national approach to R&D across the university sector and the application of research for the purposes of national development.

4. A National Committee for Science and Technology representing 11 ministries has been in place since 1999. Although seven ministries are responsible for the country's 33 public universities, the majority of these institutions come under the umbrella of the Ministry of Education, Youth and Support.

Figure 27.9: **Cambodia's rectangular development strategy, 2013**



Source: Royal Government of Cambodia (2013) *Rectangular Strategy for Growth, Employment, Equity and Efficiency: Phase III.* September, Phnom Penh

This policy was followed by the country's first *National Science and Technology Master Plan 2014–2020*. It was officially launched by the Ministry of Planning in December 2014, as the culmination of a two-year process supported by the Korea International Cooperation Agency (KOICA, 2014). The plan makes provision for establishing a science and technology foundation to promote industrial innovation, with a particular focus on agriculture, primary industry and ICTs.

Another indication that Cambodia is taking a more co-ordinated approach to S&T policy and its integration into the country's wider development plans is Phase III of the government's *Rectangular Development Strategy*, which got under way in 2014. Phase III is intended to serve as a policy instrument for attaining the objectives of the new *Cambodia Vision 2030,* which aims to turn Cambodia into an upper-middle economy by 2030, and the country's *Industrial Development Policy 2015–2025*. The latter were both foreshadowed in the *Rectangular Development Strategy* of 2013, which is significant for having identified specific roles for science (Figure 27.9). The *Industrial Development Policy 2014–2025* was launched in March 2015 and complemented related medium-term strategies, such as the *National Sustainable Development Strategy for Cambodia*, published in 2009 with support from the United Nations Environment Programme and Asian Development Bank, and the *Climate Change Strategic Plan 2014–2023,* published with support from European international development agencies.

A need for a stronger human resource base

The *Rectangular Development Strategy* sets out four strategic objectives: agriculture; physical infrastructure; private sector development; and human capacity-building. Each of these objectives is accompanied by four priority areas for action (Royal Government of Cambodia, 2013). A role for science and technology has been defined in one or more of the priority areas for each 'rectangle' (Figure 27.9). Although science and technology are clearly identified as a cross-cutting strategy for promoting innovation for development, it will be important to co-ordinate and monitor the implementation of priority activities and assess the outcome. The key challenge here will be to build a sufficient human resource base in science and engineering to support the 'rectangular' targets.

Cambodia is likely to remain reliant on international research collaboration and NGO support for some time. Between 2008 and 2013, 96% of Cambodian articles involved at least one international co-author, a trend which may explain the high citation rate. Of note is that Cambodians count both Asian (Thailand and Japan) and Western scientists (USA, UK and France) among their closest collaborators (Figure 27.8). One strategic policy issue will be how to align NGO research support on national strategic plans for development.

Another pressing challenge for Cambodia will be to diffuse human capacity beyond the university sector. The country's narrow economic and scientific base offers some opportunity for growth tied to food production. However, the diffused responsibility for science and technology across 11 key ministries presents challenges for effective policy development and governance. Although there is evidence of growing collaboration across some key agricultural institutions, such as the Cambodian Agricultural Research and Development Institute and the Royal University of Agriculture, difficulties persist in extending this type of collaboration to a broader range of institutions.

One difficulty will be to enhance the technological capacity of the many SMEs active in agriculture, engineering and the natural sciences. Whereas the large foreign firms in Cambodia that are the main source of value-added exports tend to specialize in electrical machinery and telecommunications, the principal task for S&T policy will be to facilitate spillovers in terms of skills and innovation capability from these large operators towards smaller firms and across other sectors (De la Pena and Taruno, 2012).

There is little evidence that the Law on Patents, Utility Model Certificates and Industrial Designs (2006) has been of practical use, thus far, to any but the larger foreign firms operating in Cambodia. By 2012, 27 patent applications had been filed, all by foreigners. Of the 42 applications for industrial design received up to 2012, 40 had been filed by foreigners. Nevertheless, the law has no doubt encouraged foreign firms to introduce technological improvements to their on-shore production systems, which can only be beneficial.

INDONESIA

Ambitious targets for this emerging market economy

By far the most populous country in Southeast Asia, Indonesia is emerging as a middle-income economy with appreciable levels of growth but it has not developed a technology-intensive industrial structure and lags behind comparable economies for productivity growth (OECD, 2013). Since 2012, economic growth has slowed (to 5.1% in 2014) and remains well below the East Asian average. Since taking office in October 2014, President Joko Widodo has inherited the ambitious growth targets enshrined in the *Master Plan for Acceleration and Expansion of Indonesia's Economic Development 2011–2025*: 12.7% growth on average from 2010 to 2025, in order to make Indonesia one of the world's ten largest economies by 2025.

According to World Bank projections, economic growth will accelerate somewhat through 2015– 2017. In the meantime, the volume of high-tech exports remains well below the level of Viet Nam or the Philippines. The same goes for internet access. Although investment in tertiary education has risen since 2007 and Indonesia has no lack of university graduates, enrolment in science remains comparatively low.

Moves to develop industrial research

Much of Indonesia's scientific capacity is concentrated in public research institutions, which employed one in four (27%) researchers by head count in 2009, according to the UNESCO Institute for Statistics. Nine institutions come under the umbrella of the Ministry of Research and a further 18 under other ministries. The majority of researchers (55% by head count) are employed by the country's 400 universities, however, four of which figure in the top 1 000, according to the World Ranking Web of Universities. Researchers publish mainly in life sciences (41%) and geosciences (16%), according to the Web of Science (Figure 27.8). The publication rate has grown since 2010 but at a slower pace than for Southeast Asia overall. Almost nine out of ten articles (86%) have at least one international co-author.

One-third of researchers were employed by industry in 2009, including state-owned enterprises (Figure 27.7). A World Bank loan was announced in 2013 to 'strengthen the bridge' between research and development goals by helping research centres to 'define their strategic priorities and upgrade their human resources to match these priorities' (World Bank, 2014). The big challenge will be to nurture the private sector and encourage S&T personnel to migrate towards it.

The government has put incentive schemes in place to strengthen the linkages between R&D institutes, universities and firms but these focus primarily on the public sector supply side. The co-ordination of research activities by different players may be influenced by the National Research Council (*Dewan Riset Nasional*) chaired by the Ministry of Research and Technology, which groups representatives of ten other ministries and has reported to the president since 1999. However, the National Research Council has a modest budget, equivalent to less than 1% that of the Indonesian Institute of Sciences (Oey-Gardiner and Sejahtera, 2011). Moreover, although it continues to advise the Ministry of Research and Technology, it also advises the Regional Research Councils (*Dewan Riset Daerah*) that have assumed greater significance through the Indonesian decentralization process.

Indonesia's innovation effort is weak on two counts. In addition to the very modest role played by the private sector, the GERD/GDP ratio is negligible: 0.08% in 2009. In 2012, as part of the *Master Plan* to 2025's key strategy for 'strengthening human resource capacity and national science and technology,' the Ministry for Research and Technology released a plan to foster innovation in six economic corridors; this plan still places emphasis primarily on the public sector, despite the government's desire to transfer S&T capacity to industrial enterprises. The plan aims to decentralize innovation policy by establishing regional priorities, which nevertheless remain focused on resource-based industries:

- Sumatra: steel, shipping, palm oil and coal;
- Java: food and beverages, textiles, transport equipment, shipping, ICTs and defence;
- Kalimantan: steel, bauxite, palm oil, coal, oil, gas and timber;
- Sulawesi: nickel, food and agriculture (including cocoa), oil, gas and fisheries;
- Bali – Nussa Tengarra (Lesser Sunda Islands): tourism, animal husbandry and fisheries; and
- Papua – Maluku Islands: nickel, copper, agriculture, oil and gas and fisheries.

The predicted additional economic activity in these six corridors has already inspired a policy recommendation for over US$ 300 million to be directed towards new infrastructure development, to improve power generation and transportation. The government has committed 10% of this amount, the remainder having been provided by state-owned enterprises, the private sector and through public–private partnerships.

Since taking office, the Joko Widodo government has been focusing on fiscal reform to improve the business environment. His government has not changed the general direction of S&T policies and thus still plans to transfer part of public investment in R&D to the business sector. Recent regulations have sought to increase the level of value-added production in sectors such as the mobile phone industry. A new initiative intended to promote development at the value-added end of the market is a proposal in the 2015 budget to establish a body which would oversee the development of creative industries such as fashion and design. The overall national structure for managing science policy and public sector investment in science remains largely unchanged.

The multi-donor Programme for Eastern Indonesia SME Assistance (PENSA) is currently being evaluated. PENSA was launched in 2003 with the general objective of expanding opportunities for SMEs in Eastern Indonesia. More recently, the emphasis has shifted towards enhancing the financial capacity of SMEs and reforming the business environment. Consequently, by the time PENSA 2 was launched in 2008, it had become a five-year technical assistance programme with a focus on training commercial bank employees in outreach services and improving the regulatory environment and corporate governance among firms in

Eastern Indonesia. The Business Incubator Technology (BIT) programme for SMEs has taken a more direct approach; by 2010, there were up to 20 BIT units at public universities.

The recent policy shift towards creating six economic corridors and linking S&T to development goals is part of an overall strategy to reduce economic dependence on the nation's natural resources. The current trend towards lower global prices for raw materials instils an added urgency.

LAO PEOPLE'S DEMOCRATIC REPUBLIC

Sustainability of rapid resource-based growth in doubt

Lao PDR is one of the poorest countries in Southeast Asia but, thanks to its rich endowment in natural resources (forestry, hydropower, minerals), its strategic location in the midst of a fast-growing region and policies that exploit these advantages, it has been experiencing rapid economic expansion. In 2013, Lao PDR was rewarded for its efforts to liberalize the economy by being admitted to the World Trade Organization; membership should enable the country to become increasingly integrated in the world economy. Thanks to average annual real growth of close to 7.5% for the past 15 years, the poverty rate has halved to 23% in the past two decades. Concerns have nonetheless been raised as to the sustainability of this resource-based growth (Pearse-Smith, 2012).

Recent data are unavailable for Lao PDR on R&D expenditure and personnel but the number of scientific publications did increase between 2005 and 2014 by 18% a year, albeit from a very low base (Figure 27.8). Almost all publications throughout this period had international co-authors, mostly from Thailand. As with other countries highly dependent on foreign aid and international scientific collaboration, the current focus on local priorities for development may yet be challenged by broader global interests. At present, Lao PDR has the lowest proportion of researchers among ASEAN member states; ASEAN economic integration scheduled for 2015 onwards is likely to provide the country with more opportunities for regional scientific co-operation. The shortage of highly skilled personnel will be less of a challenge for Lao PDR than managing the balancing act of raising the level of skills while simultaneously creating local employment opportunities for the influx of skilled job-seekers.

The premises of an S&T policy framework

As a small economy with a limited capacity in science and engineering, Lao PDR has been actively seeking to build on regional strengths and foster collaboration among Laotian scientists. In 2011, a Ministry of Science and Technology was established. In parallel, representatives of relevant various ministries sit on the National Science Council; the latter was established in 2002 as an advisory board for S&T policy. In 2014, an event was held to improve dialogue between scientists and policy-makers from different sectors of the economy.

Strategies for achieving sustainable development underpin most of the challenges facing Lao PDR. Currently, hydropower and mining account for a large part of the nation's economic output. Balancing the environmental cost with the economic benefit to be gained from these activities will be a challenge.

MYANMAR

A lack of infrastructure to develop markets

Since 2011, Myanmar has been in transition towards a market-based economy. The country is rich in resources such as natural gas (39% of commodity exports), precious stones (14%) and vegetables (12%). Market development is hampered, however, by the lack of infrastructure: telecommunications and internet access remain a luxury and three out of four citizens lack access to electricity.

Geosciences represented 11% of scientific articles between 2008 and 2013, reflecting the importance of fossil fuels for the economy. Two-thirds of Myanmar's modest output nevertheless focused on the biological and medical sciences (Figure 27.8). Nearly 94% of publications had at least one foreign co-author.

There have been some interesting international joint ventures recently involving public and private partners. For example, infrastructure development for the first international standard special economic zone (Thilawa) commenced in 2013 on the outskirts of Yangon. This multi-billion dollar joint venture involves a Japanese consortium (39%), the Japanese government (10%), the Sumitomo corporation and local Myanmar firms (41%), as well as the Myanmar government (10%). Companies in manufacturing, garments, processed foods and electronics industries are among those which plan to establish factories there. Thilawa is expected to be commercially operational by the end of 2015 and should serve as a focal point for future S&T-based collaboration between the public and private sectors.

Pressure on a traditionally solid education system

Historically, Myanmar has enjoyed a solid education sector and comparatively high literacy rates. In recent years, education appears to have suffered, though, from funding shortages and the limited access to international collaboration as a corollary of the sanctions. Overall expenditure on education as a share of GDP fell by about 30% and spending on tertiary education was halved between 2001 and 2011.

There are 161 universities managed by 12 different ministries but researchers claim to have either little or no access to research funding (Ives, 2012). Myanmar nevertheless has the highest proportion of students enrolled in tertiary science degrees (nearly 23%) and the highest proportion of women in science: 87% of all doctoral graduates were women in 2011, including in the sciences.

A need to rationalize the institutional structure of science

The Ministry of Science and Technology has been in place since 1996 but is responsible for only one-third of the country's universities. The Ministry of Education is responsible for a further 64 institutions and the Ministry of Health for another 15. The remaining 21 institutions are the responsibility of nine other ministries. It is very difficult to generate a comprehensive overview of national S&T capability, as there is no single agency responsible for collecting R&D data. The Ministry of Science and Technology has its own database but it reports GERD as accounting for an unrealistic 1.5% of GDP (De la Pena and Taruno, 2012).

One of the biggest challenges facing Myanmar will be to maintain current funding levels for institutional structures that have been in place for some time. It will also be a challenge to reduce the number of ministries responsible for funding and managing the public scientific effort. At present, there appears to be no co-ordinating structure that could serve to align scientific investment with key socio-economic objectives.

NEW ZEALAND

An increasingly Asian–Pacific economy

New Zealand's economy relies heavily on international trade, especially that with Australia, China, the USA and Japan. Exports are dominated by food and beverages (38% in 2013), including some knowledge-intensive products. The main destination for dairy products used to be the UK but, upon integrating the European Economic Community in 1973, the UK also signed up to its common agricultural policy, which effectively excluded external producers from the European market. This forced New Zealand to shift its focus from northern hemisphere markets towards supplying the Asia–Pacific region, which was taking 62% of New Zealand's exports by 2013.

New Zealand is not only one of the few agrarian economies among OECD members. It also has a lower GERD/GDP ratio than many other OECD economies: 1.27% in 2011. Business sector R&D increased slightly between 2009 and 2011 from 0.53% to 0.58% of GDP and thus now contributes just under half of national investment in R&D.

Despite a fairly low R&D intensity, New Zealand scientists are very productive; they authored 7 375 publications in 2014, up by 80% from 2002, with a good citation rate. Globally, New Zealand has the sixth-highest number of scientific articles in relation to GDP, making it the regional leader for this indicator.

International engagement has had a significant impact on New Zealand's national innovation system. Nearly two-thirds of internationalized New Zealand firms undertake at least some type of innovation, such as innovation in goods or services or innovation in marketing methods, whereas only one-third of non-internationalized firms indulge in the same, according to a Business Operations Survey conducted in 2013 by Statistics New Zealand. In the past six years, New Zealand has also upscaled its efforts in science diplomacy (Box 27.1).

Aligning research priorities with national challenges

New Zealand's eight universities play a key role in the country's science system. They account for 32% of GERD, or 0.4% of GDP and employ more than half (57% in FTE) of the country's researchers (2011). In 2010, the government strengthened its own role in the national innovation system by creating a Ministry of Science and Innovation to drive policy-making. In 2012, the ministry was merged with three other agencies, the Ministry of Economic Development, the Department of Labour and the Department of Building and Housing to create what is now the Ministry of Business, Innovation and Employment (MoBIE).

The government established a taskforce in 2010 to reform the country's Crown Research Institutes (CRI), in order to ensure that 'CRIs can best deliver on national priorities and respond to the needs of research users, particularly industry and business' (CRI, 2010). The Crown Research Institutes are the largest dedicated providers of scientific research in New Zealand. Created in 1992, these state enterprises provide core services which earn them operating income. The taskforce's recommendations led to a reform in 2011 which changed the focus of the CRIs from profitability to driving growth and made their priorities more relevant to New Zealand's needs. The CRIs are now responsible for identifying infrastructure needs and formulating policies to provide greater support for innovation, such as through skills development, incentives for business investment in R&D, stronger international linkages and the design of strategies to increase the impact of public research.

Historically, the CRI's priorities have focused on high-value manufacturing services, biological industries, energy and minerals, hazards and infrastructure, environment, health and society. In 2013, the government announced a series of National Science Challenges to identify government priorities for investment in research and provide a more strategic approach to implementing related goals. The first National

Science Challenge in 2010 identified the following ten priority areas for research (MoBIE, 2013):

- Ageing well;
- A better start – improving the potential of young New Zealanders to have a healthy and successful life;
- Healthier lives;
- High value nutrition;
- New Zealand's biological heritage: biodiversity, biosecurity, etc.;
- Our land and water – research to enhance primary sector production and productivity while maintaining and improving the quality of land and water quality for future generations;
- Life in a changing ocean – understanding how to exploit our marine resources within environmental and biological constraints;
- The deep south – understanding the role of the Antarctic and the Southern Ocean in determining our climate and our future environment;
- Science for technological innovation; and
- Resilience to nature's challenges – research into enhancing our resilience to natural disasters.

Box 27.1: **New Zealand: using science diplomacy to make a small voice heard**

Science diplomacy is often viewed as the domain of great powers and associated with megascience projects like the International Space Station. Beneath these high-visibility projects, however, science plays a key role in more discreet and mundane ways in the functioning of the international system.

Under the leadership of Sir Peter Gluckman, Chief Science Advisor to the Prime Minister, New Zealand has been quietly building a number of networks since 2009 that combine science and diplomacy to advance the interests and presence of smaller powers in the international arena. In an era where international economic governance is increasingly seen as the purview of groupings of populous countries like the G8 or the G20, New Zealand's approach acts as a 'canary in the mine' for larger countries, says Prof. Gluckman, alerting them to the particularities of smaller powers which have not always been reflected in the traditional rules-based international architecture.

Science for diplomacy

New Zealand has formed an informal 'coalition of the willing' with other advanced economies of less than 10 million inhabitants. This is a select group: the International Monetary Fund includes just three countries outside Europe in this category: Israel, New Zealand and Singapore. With the addition of the smaller European powers of Denmark, Finland and Ireland, the 'coalition of the willing' currently counts six members.

New Zealand hosts and funds the secretariat of its Small Advanced Economies Initiative. The coalition shares data, analysis, discourse and projects in three areas: public science and higher education; innovation; and economics. A fourth area of co-operation involves 'conversations' between members on how to strengthen national branding and the voice of smaller nations within a broader diplomatic agenda.

Diplomacy for science

As the world's highest emitter of methane per capita, owing to its large population of livestock, New Zealand is particularly keen to promote a science-based international dialogue at the nexus between food security and greenhouse gas emissions from agriculture – agriculture accounting for about 20% of global emissions.

At the climate summit in Copenhagen (Denmark) in 2009, New Zealand proposed creating a Global Research Alliance to Reduce Agricultural Greenhouse Gases. One motivation was also the 'existential concern regarding future market resistance to our farm products'. This alliance currently has 45 members. It is unique in that it is led by scientists, rather than government administrators, in recognition of the fact that countries prefer to spend their research funds within their own border. In Prof. Gluckman's own words, 'here, the diplomatic interests of New Zealand demanded that science be done but, for that science to be done, the diplomats had to create the vehicle then get out of the way.'

Science as aid

In its aid policy, New Zealand makes a special effort to take into account the interests of smaller countries; it focuses on issues such as energy and food security or non-communicable diseases, where the small size of countries is a particular handicap. For instance, New Zealand's priority aid activities in Africa, such as solar-powered electric fence technology, heat-resistant livestock and enhanced forage plant species, all rely on science and its local adaptation.

'I have tried to show how a small country can use science within the diplomatic sphere to protect and advance its interests', says Prof. Gluckman. That argument seems to have borne fruit. New Zealand gained enough support for it to be elected to a non-permanent seat on the United Nations Security Council for the 2015–2016 term.

Source: Based on a lecture given by Prof. Gluckman in June 2015, as part of a summer course on science diplomacy at the World Academy of Sciences.

Read the full speech: www.pmcsa.org.nz/wp-content/uploads/Speech_Science-Diplomacy_Trieste-June-2015-final.pdf

The National Science Challenges fundamentally change New Zealand's research agenda by emphasizing collaboration. Each priority area involves a broad portfolio of multidisciplinary research activities, relying on strong collaboration between researchers and intended end-users, as well as ties to international research.

Challenge funding identified in the 2013 budget provides for an investment of NZ$ 73.5 million (*circa* US$ 57 million) over four years and NZ$ 30.5 million per year thereafter, in addition to the NZ$ 60 million allocated in the 2012 budget. The 2014 budget expanded the Centres of Research Excellence programme and increased the budget for competitive science funding, in order to compensate for the shift in funding to the National Science Challenges. Health and environmental issues remain a key focus for increases through 2015.

Although the government's approach to science policy in the 2014 budget was generally well-received, there is growing concern about an apparent absence of a coherent national strategy for science. Critics have pointed to the need for effective R&D tax credits, for example.

How to make the most of a clean, green brand?

Government investment in science has traditionally been weighted heavily towards primary industries, with the largest sectorial priority, agriculture, receiving 20% of the total. It is thus hardly surprising that scientific publications are concentrated in life sciences (48% of the total in 2014, followed by environmental sciences (14%). A future challenge will be to diversify scientific capacity towards priority areas identified for future growth, such as ICTs, high-value manufacturing and processed primary products, as well as environmental innovation.

As an agricultural trading nation, New Zealand has a great opportunity to embrace 'greener' growth. The government has asked the Green Growth Advisory Group to come up with policy advice on three particularly important topics: how to make the most of a clean, green brand; how to make smarter use of technology and innovation; and how to move businesses towards a lower-carbon economy. The 2012 report by the New Zealand Green Growth Research Trust on *Green Growth: Opportunities for New Zealand* identified no fewer than 21 specific green-growth opportunities in sectors that could enhance New Zealand's competitive advantage in this area, including biotechnology and sustainable agricultural products and services, geothermal energy, forestry and water efficiency.

PHILIPPINES

A desire to reduce disaster risk

Despite a rash of natural disasters in recent years, GDP has pursued moderate growth in the Philippines (Figure 27.2). This growth has been driven largely by consumption that has itself been fuelled by remittances from workers abroad and IT-enabled services, shielding the economy from the lingering weakness of the global economy (World Bank, 2014). Higher economic growth has not substantially reduced poverty, however, which still affects 25% of the population.

The Philippines is one of the world's most vulnerable countries to natural disasters. Every year, between six and nine tropical cyclones make landfall, alongside other extreme events such as floods and landslides. In 2013, the Philippines had the misfortune to lie in the path of Cyclone Haiyan (known as Yolanda in the Philippines), possibly the strongest tropical cyclone ever to hit land, with winds that were clocked at up to 380 kph.

To address disaster risk, the Philippines has been investing heavily in critical infrastructure and enabling tools such as Doppler radars, generating 3D disaster-simulation models from Light Detection and Ranging (LiDAR) technology and the wide-scale installation of locally developed sensors for accurate and timely disaster information nationwide. In parallel, it has been building local capability to apply, replicate and produce many of these technologies.

The decision to promote technological self-reliance to reduce disaster risk is also a feature of the government's approach to inclusive, sustained growth. The revised *Philippine Development Plan 2011–2016* enunciates strategies for using S&T and innovation to boost productivity and competitiveness in agriculture and small businesses, in particular, in sectors and geographical areas dominated by the poor, vulnerable and marginalized.

Building self-reliance in technology

The Department of Science and Technology is the key government institution for science and technology, with policy development being co-ordinated by a series of sectorial councils. Within the framework of the current *National Science and Technology Plan, 2002–2020* (NSTP), the strategic focus is on building technological self-reliance. The *Harmonized Agenda for Science and Technology, 2002–2020* reflects this focus in its approach to problem-solving related to inclusive growth and disaster risk reduction. The *Harmonized Agenda* was presented to the President in August 2014. Although S&T are guided by the NSTP, the *Harmonized Agenda* attempts to provide more detail of how the country can become technologically self-reliant to sustain science and technology beyond the mandate of the current Aquino administration.

The *Harmonized Agenda* focuses on the development of critical technologies such as remote sensing, LiDAR processing, testing and metrology facilities, advanced climate change and weather modelling, advanced manufacturing and high-performance computing. Five centres of excellence are to be established or upgraded by 2020 in biotechnology, nanotechnology, genomics, semiconductors and electronic[5] design.

The five centres of excellence are all government-funded:

- the Centre for Nanotechnology Application in Agriculture, Forestry and Industry (est. 2014) is based at the University of the Philippines Los Baños;
- the Biotech Pilot Plant (est. 2012 and since upgraded) is housed at the University of the Philippines Los Baños;
- the Philippine Genome Centre (est. 2009) is hosted by the University of the Philippines Diliman; it operates two core facilities in DNA sequencing and bioinformatics;
- the Advanced Device and Materials Testing Laboratory is located in the Department of Science and Technology's compound in Bicutan in Taguig City and has been operational since 2013; it houses three laboratories in surface analysis, thermal, chemical and metallurgical analysis;
- the Electronic Product Development Centre will also be located in the Department of Science and Technology's compound in Bicutan in Taguig City; it will provide state-of-the-art design, prototyping and testing facilities for printed circuit boards.

5. Electronic products accounted for 40% of export revenue in April 2013, according to the Semiconductor and Electronics Industry in the Philippines, Inc., which groups 250 Filipino and foreign companies, including Intel.

The Technology Transfer Act (2010) is expected to enhance innovation by providing a framework and support system for the ownership, management, use and commercialization of intellectual property arising from government-funded R&D. To better address needs in terms of human capital, the Fast-Tracked Science and Technology Scholarship Act of 2013 expands the coverage of existing scholarship programmes and strengthens the teaching of science and mathematics in secondary schools. The Philippine National Health Research System Act (2013), meanwhile, has formed a network of national and regional research consortia to boost domestic capacity.

A need to scale up the R&D effort

The Philippines trails its more dynamic ASEAN peers for investment in both education and research. The country invested 0.3% of GDP in higher education in 2009, one of the lowest ratios among ASEAN countries (Figure 27.5). After stagnating for the first half of the century, tertiary enrolment leapt from 2.6 million to 3.2 million between 2009 and 2013. The rise in PhD graduates has been even more spectacular, their number having doubled over the same five-year period from 1 622 to 3 305, according to the UNESCO Institute for Statistics.

Concomitantly, the number of FTE researchers per million inhabitants (just 78 in 2007) and the level of national investment in R&D (0.11% of GDP in 2007) remain low by any standards. Bringing science to underpin future innovation and development is likely to remain a challenge until the level of investment rises. This will include leveraging FDI in areas like electronics, in order to move closer to the higher end of the scale for value-added goods in the global value chain.

Box 27.2: **'Scuba' rice for the Philippines**

The Philippines is one of the most vulnerable countries to the impact of climate change and extreme weather patterns. In 2006, damage caused by cyclones and floods cost the rice industry more than US$ 65 million.

Researchers from the Philippine-based International Rice Research Institute (IRRI) and the University of California in the USA have developed flood-tolerant rice varieties known as 'scuba rice' which can withstand up to two weeks of complete submergence in water. Through marker-assisted backcrossing, researchers transferred the flood-tolerant gene SUB1 into valued local rice varieties. This led to the official release of flood-tolerant local rice varieties across Asia, including the Philippines, in 2009 and 2010.

In 2009, the Philippine National Seed Industry Council approved the release of 'scuba' rice, known locally as 'Submarino rice', with the Philippine Rice Research Institute (PhilRice) acting as distributor.

Since its release, Submarino rice has been distributed by the Department of Agriculture to flood-prone areas across the country, in partnership with IRRI and PhilRice. In pilot farms in the Philippines, this variety has been observed to survive floods with a good yield and less fertilizer use than before, since farmlands receive nutrients from the silt brought by floods.

Critics contest this point. They argue that Submarino rice requires 'a high input of chemical fertilizer and pesticides' and that it is therefore 'not affordable by the majority of poor farmers.' They prefer to endorse alternative growing methods, such as the System of Rice Intensification (see Box 22.2).

Source: Renz (2014); Asia Rice Foundation (2011); IRRI–DFID (2010)

The government's current policy of directing STI towards pressing national problems is laudable. Such an approach also reinforces the economic rationale for government intervention in the science system to address market failures and make markets work within the purview of good governance. A key challenge will be to build sufficiently solid infrastructure to sustain current efforts to solve pressing problems. The idea here has been to promote the thinking that the government has to lay down a set of S&T infrastructure for 'core technologies' that it should fund. There is no better example of the virtues of sustained support for research than the International Rice Research Institute based in the city of Los Baños (Box 27.2 on previous page).

SINGAPORE

From emerging to knowledge economy

Singapore is a small country with no natural resources. In the space of a few decades, it has become by far the wealthiest country in Southeast Asia and Oceania, with GDP per capita of PPP$ 78 763 in 2013, double that of New Zealand, the Republic of Korea or Japan.

The economy receded briefly (-0.6% growth) in 2009, after the global financial crisis reduced international demand for exports and tourism, prompting the government to cut corporate taxes and to dig into its reserves to shore up businesses and save jobs. The economy has since been expanding at a somewhat erratic rate, with 15% growth in 2010 but less than 4% annually since 2012.

Although Singapore's R&D intensity is surpassed only by that of Australia among the countries profiled in the present chapter – and then only by a whisker – its R&D effort appears to have been a casualty of the global financial crisis. In 2006, when GERD represented 2.13% of GDP, the government fixed the target of raising this ratio to 3% by 2010. It was approaching this target in 2008 (2.62%) but GERD has since fallen back to 2.02% in 2012. The contraction in business expenditure on R&D (BERD) since 2008 would seem to be largely responsible for this failure (Figure 27.10). Singapore nevertheless remains an international hub for R&D in the Asia–Pacific region. Moreover, it plans to raise GERD to 3.5% of GDP by 2015.

Scientific publications seem to have been less affected by the recession, even if they have progressed at a more pedestrian pace since 2005 than some other Southeast Asian countries (Figure 27.8). Singapore's scientific output emphasizes engineer-ing research (17% of the total) and physics (11%). This is atypical for the region, where life sciences and geosciences tend to dominate. It is also well above the global average for the share of articles devoted to engineering research (13%) and physics (11%).

Since 2010, Singapore's major universities have gained an international reputation. In 2011, the National University of Singapore and Nanyang University were ranked 40th and 169th respectively in the Times Higher Education World University Rankings. By 2014, they had risen to the 26th and 76th positions respectively.

One cause for concern has been the declining density of technicians (Table 27.1). Whereas the proportion of technicians in Thailand and Malaysia has been rising, it receded by 8% in Singapore between 2007 and 2012. Singapore may benefit from the freer flow of skilled personnel to redress this trend, once the ASEAN Economic Community comes into play in late 2015.

Strengthening domestic innovation to complement FDI

Singapore's economic development is strongly dependent on FDI inflows: inward FDI stock stood at 280% of GDP in 2013, according to UNCTAD. This reflects Singapore's success over the past two decades in persuading multinational corporations to invest in high-tech and knowledge-intensive industries.

Over the past two decades, Singapore has adopted a cluster-based approach to developing its research ecosystem, which now combines both innovative foreign multinationals and endogenous enterprises. Singapore's success rests to a large extent on the alignment of policies designed to leverage national development from a strong multinational presence with policies promoting local innovation. Over the past decade, Singapore has invested heavily in state-of-the-art facilities and equipment and offered attractive salary packages to world-renowned scientists and engineers, driving up Singapore's researcher intensity to one of the highest levels in the world: 6 438 per million inhabitants in 2012 (Table 27.1). In parallel, the government has launched vigorous higher education policies endowed with a generous budget – consistently more than 1% of GDP between 2009 and 2013 – to develop intellectual capital and provide research personnel for both foreign and domestic companies.

Government policies have also focused on developing endogenous capabilities for innovation. Several national research institutions have been grouped into hubs and encouraged to establish ties with renowned knowledge hubs abroad, in order to create centres of excellence in two niche areas: Biopolis (for biomedical research) opened in 2003 and Fusionopolis (for ICTs) in 2008.

It was also in 2008 that Singapore's Research, Innovation and Enterprise Council approved the establishment of a National Framework for Innovation and Enterprise (NFIE). NFIE has two core goals: to commercialize cutting-edge technologies developed by R&D laboratories through the creation of start-up companies; and to encourage universities and polytechnics to pursue academic entrepreneurship and transform the results of their R&D into commercial products. Between 2008 and 2012, S$ 4.4 billion (*circa* US$ 3.2 billion) was allocated under NFIE to fund:

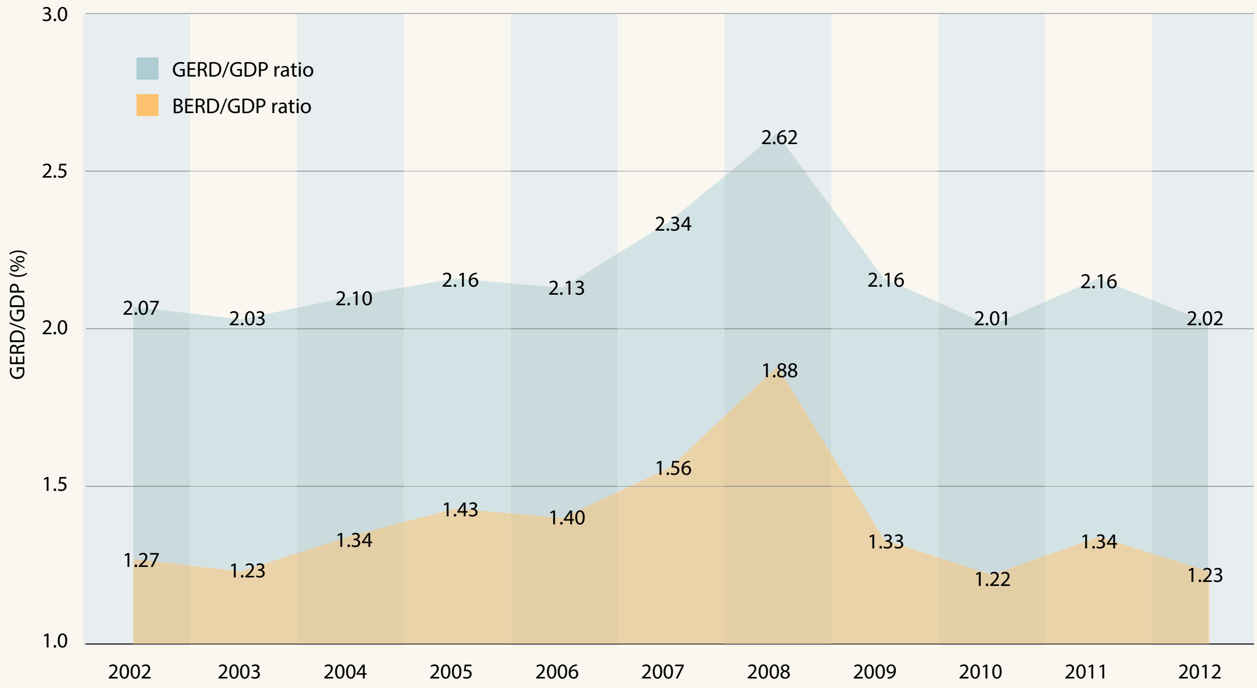
- the establishment of university enterprise boards;
- an innovation and capability vouchers scheme (Box 27.3);
- early-stage venture funding (Box 27.3);
- proof-of-concept grants (Box 27.3);
- a disruptive innovation incubator (Box 27.3);
- a technology incubation scheme (Box 27.3);
- incentives for global entrepreneurial executives to move to Singapore (Box 27.3);
- translational R&D grants for polytechnics to help take research to market;
- national intellectual property principles for publicly funded R&D; and
- the creation of innovation and enterprise institutes.

The National Research Foundation works in tandem with NFIE to provide funding for collaborative innovation (Box 27.3). In parallel, innovation and enterprise institutes have been established to provide an organizational context in which to nurture partnerships and develop funding proposals; that hosted by Singapore Management University, for instance, provides a forum where academics and commercial enterprises can meet. Potential partners can receive guidance from the institute when seeking grants from the National Research Foundation to develop business concepts and seed grants for early-stage development.

The government agency A*STAR has been sponsoring a new initiative for a Smart Nation since November 2014. The aim is to develop new partnerships across the public and private sectors, with a view to strengthening Singapore's capabilities in cybersecurity, energy and transport, in order to 'green' the country and improve public services. In 2015, A*STAR's Institute for Infocomm Research signed an agreement with IBM for the creation of innovative solutions in the areas of big data and analytics, cybersecurity and urban mobility as a contribution to the Smart Nation initiative. In December 2014, the minister in charge of the Smart Nation initiative, Vivian Balakrishnan, had explained[6] the rationale behind the scheme at the opening of the Singapore Maker Festival. The current shift from mass production to mass customization of technology such as mobile phones, combined with lower prices for hardware, the generalization of sensors and easy connectivity, had placed data and innovation at an individual's fingertips, she said. The minister undertook to

6. See: www.mewr.gov.sg/news

Figure 27.10: **Trends in GERD in Singapore, 2002–2012**



Source: UNESCO Institute for Statistics, June 2015

Box 27.3: Innovative ways of financing innovation in Singapore

The National Research Foundation offers enterprises financial support through the following schemes to encourage them to engage in collaborative innovation.

The Incubator for Disruptive Enterprises and Start-ups (IDEAS)
IDEAS was launched jointly by the National Research Foundation and Innosight Ventures Pte Ltd, a Singapore-based venture capital firm. The idea behind IDEAS was to build on the Technology Incubation Scheme established in 2009. Through IDEAS, start-ups with disruptive innovation potential are identified and offered guidance during their early stages. They receive an investment of up to S$ 600 000, 85% of which is provided by the National Research Foundation and the remainder by the incubator. An investment committee evaluates the start-ups. In 2013, the government announced that it would be providing up to S$ 50 million, in order to stimulate the early-stage investment ecosystem.

Innovation and Capability Voucher
Introduced in 2009, the Innovation and Capability Voucher is intended to facilitate the transfer of know-how from knowledge institutions to SMEs. The scheme provides SMEs with funding grants of up to S$ 5 000 to enable them to procure R&D or other services from universities or research institutes.

The scope of the scheme was extended in 2012 to allow the vouchers to be applied in human resource or financial management. The policy expectation is that projects or services purchased from research institutions will lead to upgrades in technology and new products or processes, enhancing knowledge and skills in the process.

Early Stage Venture Fund
Through this fund, the National Research Foundation invests S$ 10 million on a 1:1 ratio in seed venture capital funds that invest in Singapore-based, early-stage high-tech companies.

Proof of Concept Grants
The National Research Foundation administers this scheme, which provides researchers from universities and polytechnics with grants of up to S$ 250 000 for technological projects at the proof-of-concept stage. The government runs a parallel scheme for private enterprises (Spring Singapore).

Technology Incubation Scheme
The National Research Foundation co-invests up to 85% (capped at S$ 500 000) in Singapore-based start-up companies that are being incubated by seeded technology incubators that themselves provide investee companies with physical space, mentorship and guidance.

Global Entrepreneur Executives
This co-investment scheme has been designed to attract high-growth and high-tech venture-backed companies. It targets ICTs, medical technology and clean technology. The objective is to encourage companies to relocate to Singapore. The National Research Foundation invests up to US$ 3 million in matching funding in eligible companies.

Innovation Cluster Programme
This scheme provides funding to strengthen partnerships across businesses, research performers and government in technological areas with potentially large markets. Four plans to develop innovation clusters were funded under this programme in 2013, in diagnostics; speech and language technologies; membranes; and additive manufacturing. Grants for collaborative projects focused on establishing shared infrastructure, capacity-building and on bridging gaps along the value chain.

Source: http://iie.smu.edu.sg; www.spring.gov.sg; www.guidemesingapore.com

make 'as much data as possible' available to the public and promised that, in return, 'if you have got a product or a service that will make life better, pitch it to us'. A Smart Nation Programme Office is being set up in the Prime Minister's Office to bring citizens, the government and industrial players together to identify issues, co-develop prototypes and deploy these effectively.

According to the National Research Foundation, Singapore's long-term goal is to become 'one of the most research-intensive, innovative and entrepreneurial economies in the world, in order to create high-value jobs and prosperity for Singaporeans'. The main challenge for the immediate future will be to expand the role of business enterprises in research and innovation. Singapore's business expenditure on R&D (BERD) is lower than that of R&D-intensive nations with a similarly small population, such as Finland, Sweden or the Netherlands. What distinguishes the latter is the presence of large home-grown multinationals which fund the bulk of BERD. Singapore's BERD, on the other hand, is spread over a far larger number of companies, meaning that a broader segment of industry must be engaged in R&D to increase BERD.

Another challenge will be to sustain the country's advantages and further accelerate collaborative research to internationalize innovation to an even greater extent. One of Singapore's strengths is its capacity to forge influential public–private and public–public partnerships within a compact and integrated research system. Singapore is about to embark upon the next five-year funding tranche for R&D, entitled *Research, Innovation and Enterprise 2020*. This programme will continue to place heavy emphasis on collaborative partnerships within the open innovation paradigm that has worked so well for Singapore up until now, in pursuit of its vision of becoming Asia's innovation capital.

THAILAND

Private sector invests most in value-added chemical goods

Thailand experienced growth of just 27% between 2005 and 2012. Socio-political unrest through the latter part of 2013 and a military *coup d'état* in May 2014 placed the economy at a crossroads. The World Bank (2014) expects consumer and investor confidence to recover once the situation stabilizes. The Thai economy is, nevertheless, likely to remain one of the slowest-growing in Southeast Asia until at least 2016, according to the IMF.

Recent governments have considered it a top priority to promote high-tech manufacturing, in order to stimulate demand. There is certainly evidence of growth in services. However, raising R&D capacity in Thailand will depend very much on private-sector investment, which has accounted for about 40% of GERD in recent years. Given the country's GERD/GDP ratio of 0.39% in 2011, industrial R&D remains low key but this picture could be changing: the Minister of Science and Technology issued a statement in May 2015 claiming a 100% increase in GERD to 0.47% of GDP in 2013 that had been largely driven by private-sector investment.[7]

In light of these statistics, the comparatively high proportion of high-tech exports from Thailand, which account for 10.6% of the total from Southeast Asia and Oceania (Figure 27.4), suggests that high-tech goods may be designed elsewhere and assembled in Thailand, rather than being the fruit of in-house R&D, such as Thai exports of hard disc drives, computers and aeroplane engines. Thailand is the region's biggest exporter of chemical goods: 28% of the total. At present, value-added chemical products are the main focus of private-sector investment in R&D. Clearly, there is a need to develop a business environment that encourages multinational corporations to invest in R&D, as Singapore and Malaysia have done. Thai governments have wrestled with this dilemma but, thus far, have been reticent to offer financial incentives to foreign firms, unlike Malaysia (see Chapter 26).

A major challenge will be to achieve a stable socio-economic environment that is conducive to maintaining FDI, in order to fuel investment in industrial R&D, and to developing higher education of quality. Thailand is still one of the world's largest producers of hard disc drives and light pick-up trucks but maintaining this global edge will require considerable investment in higher education to overcome the skills shortage.

The shortage of both skilled and unskilled labour has remained a chronic problem for Thai businesses (EIU, 2012). Investment in tertiary education was quite high in 2002 (1.1% of GDP) but had fallen to 0.7% of GDP by 2012. Although expenditure on higher education has been slipping as a percentage of GDP, there is a commitment to raising the proportion of students enrolling in science, technology, engineering and mathematics. A pilot programme was initiated in 2008 to establish science-based schools for gifted pupils with a creative streak and a bent for technology (Pichet, 2014). Teaching and learning are project-based, the long-term aim being to help pupils specialize in different fields of technology. Five schools have since been established within this programme:

- the Science-based Technology Vocational College (Chonburi) in central Thailand;
- Lamphun College of Agriculture and Technology in the north (agricultural biotechnology);
- Suranaree College in the northeast (science-based industrial technology);
- Singburi Vocational College (food technology); and
- Phang-nga Technical College in the south (innovation in tourism).

The number of FTE researchers and technicians per million inhabitants increased by 7% and 42% respectively between 2005 and 2009. Researcher density nevertheless remains low, with the great majority of researchers being employed by public research institutes or universities. The National Science and Technology Development Agency (NSTDA) alone employs over 7% of the country's full-time researchers in four institutions: the National Centre for Genetic Engineering and Biotechnology; the National Electronics and Computer Technology Centre; the National Metal and Materials Technology Centre; and the National Nanotechnology Centre.

7. see www.thaiembassy.org/permanentmission.geneva/contents/files/news-20150508-203416-400557.pdf

Ambitious policy targets

Although the *Ten-Year Action Plan for Science and Technology* (2004–2013) introduced the concept of a national innovation system, it did not clearly indicate how to integrate innovation in science and technology. This omission has been remedied by the *National Science, Technology and Innovation Policy and Plan* (2012–2021) adopted in 2012, which identifies avenues for achieving this goal, such as infrastructure development, capacity-building, regional science parks, industrial technology assistance and tax incentives for R&D. Central to the new plan is a commitment to strengthening collaboration between public research agencies and the private sector. The plan also perceives regional development as a potential remedy to the socio-economic disparities which have fuelled social unrest. It fixes a target of raising GERD to 1% of GDP by 2021, with a private-public sector ratio of 70:30.

A complex array of financial incentives target the private sector, including grants or matching grants with innovation coupons, assistance with industrial technology, low-interest loans for innovation and tax incentives to promote the upgrading of skills and technology. The 200% tax reduction for R&D introduced in 2002 to enable companies having invested in R&D to claim a double deduction for their expenses incurred during the same fiscal year has recently been increased to 300%. The statement issued by the Minister of Science and Technology in May 2015 drew attention to the Industrial Technology Assistance Programme for SMEs that includes innovation coupons, loan guarantees and access to ministry-run testing labs. Moreover, a new talent mobility programme allows researchers in universities or government laboratories to be seconded to private firms; under this latter initiative, the firm reimburses the university or research laboratory for the person's salary for the duration of the secondment but importantly, SMEs are exempt from this clause, thanks to a ministerial subsidy which reimburses the laboratory on their behalf. Recent legislative changes now allow for the transfer of ownership of intellectual property from funding agencies to grantees and a new law allows government agencies to set up funds for the commercialization of technology. Collectively, these initiatives are intended to reform the incentive system for R&D.

On the administrative side, there are plans to establish an STI Advisory Committee which will report directly to the Prime Minister. This development should coincide with the transfer of the National STI Policy Office from the Ministry of Science and Technology to the Office of the Prime Minister.

One tambon, one product

Another challenge will be to transfer the knowledge and skills currently concentrated in research institutions and science parks to productive units situated in rural areas, including farms and SMEs.

The One Tambon, One Product programme is being pursued in rural Thailand. Inspired by the One Village, One Product programme in Japan in the 1980s, which sought to combat depopulation, the Thai government introduced the One Tambon, One Product programme (a tambon being a subdistrict) between 2001 and 2006 to stimulate local entrepreneurship and innovative, quality products. A superior product is selected from each tambon for formal branding with one to five stars to indicate the standard of quality before undergoing nationwide promotion. Tambon products include garments and fashion accessories, household goods, foodstuffs and traditional handicrafts. The spread of mobile phone technology into rural areas is opening up opportunities for access to market-based information, as well as product development and modern production processes. The challenge here will be to orient product development towards higher value-added output.

TIMOR-LESTE

Oil-fuelled growth

Since gaining independence in 2002, Timor-Leste has shown healthy economic growth which is largely attributable to the extraction of natural resources: crude petroleum accounted for 92% of exports in 2014. GDP expanded by 71% between 2005 and 2013, the second-highest rate in the region (Figure 27.2). This has made the young country increasingly independent economically, with overseas development assistance falling steadily from 22.2% of gross national income in 2005 to 6.0% in 2012.

The region's third-biggest spender on higher education

The longer-term objective, set out in the country's *Strategic Development Plan 2011–2030*, is to progress from a low-income to an upper middle-income economy by 2030, like Cambodia. The *Development Plan* emphasizes higher education and training, infrastructure development and the need to reduce dependence on oil. Local capacity-building in science and technology and international scientific collaboration will be key factors in achieving the ambitious targets set out in the plan. These targets are based on the assumption that annual economic growth will maintain a cruising speed of 11.3% through to 2020 and 8.3% through to 2030, thanks largely to a burgeoning private sector. By 2030, there are plans to have at least one hospital in all 13 districts and a specialist hospital in Dili and for at least half of the nation's energy needs to be met by renewable sources.

At present, scientific capacity and R&D output are low but the government's massive investment in education is likely to change this picture over the next decade. Between 2009 and 2011, Timor-Leste invested 10.4% of GDP in education, on average, and raised the level of investment in higher education from 0.92% to 1.86% of GDP. It has become the second-biggest spender on higher education in the region, after Malaysia (Figure 27.5).

A review of science education in 2010 drew attention to the need to improve its quality and relevance. Three key sectors have been identified as priorities for future education and training: health and medicine; agriculture; and technology and engineering (Gabrielson *et al.*, 2010). Science, technology, engineering and mathematics have all been targeted as priorities for development across all levels of education, with particular emphasis on higher education.

The main research university in Timor-Leste is the Universidade Nacional de Timor-Lorosae (UNTL) but three smaller universities have opened in recent years and seven institutes also conduct research. At the start of 2011, there was a combined enrolment of 27 010 students across UNTL's 11 campuses, representing an increase of more than 100% since 2004. Enrolment of women increased by 70% from 2009 to 2011. In 2010, UNTL joined the School on Internet Asia Project, which allows under-resourced universities in the region to link up with one other and to benefit from distance learning using low-cost satellite-based internet access.

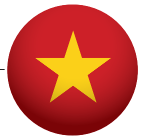
A need for greater co-ordination and inclusiveness

NGOs play a vital role in Timor-Leste's development but their presence does create problems when it comes to co-ordinating programmes across different government sectors. Whereas the Ministry of Education holds the primary responsibility for higher education, many other agencies are also involved. The *Development Plan* to 2030 cites the objective of 'developing an efficient management system to co-ordinate government interventions in higher education and set priority targets and budgets'. It also cites the establishment of a National Qualifications Framework.

Timor-Leste has one of the lowest levels of connectivity to internet in the world (1.1% in 2013) but mobile phone subscriptions have taken off in the past five years. In 2013, 57.4% of the population had a subscription, compared to 11.9% five years earlier. This suggests that the country's potential for accessing the global information system is growing.

Perhaps Timor-Leste's biggest challenge for the future will be to develop its scientific human capital, so that the country can capitalize on innovation in agriculture and industry to effect its economic transformation. In the meantime, Timor-Leste will need to overcome what has been described as 'Dili-centric' development, in reference to the capital city, and to demonstrate that it has the capacity to make use of new knowledge and information.

VIET NAM



Productivity gains needed to compensate for other losses

Viet Nam has become increasingly integrated into the world economy, particularly since its efforts to liberalize the economy enabled it to join the World Trade Organization in 2007. The manufacturing and service sectors each account for 40% of GDP. However, almost half the labour force (48%) is still employed in agriculture. One million workers a year, out of a total of 51.3 million in 2010, are projected to continue leaving agriculture for the other economic sectors in the foreseeable future (EIU, 2012).

In manufacturing, Viet Nam is expected to lose some of its current comparative advantage in low wages in the near future. It will need to compensate for this loss with productivity gains, if it is to sustain high growth rates: GDP per capita has almost doubled since 2008. High-tech exports from Viet Nam grew dramatically during 2008–2013, particularly with respect to office computers and electronic communications equipment – only Singapore and Malaysia exported more of the latter. A big challenge will be to implement strategies that increase the potential for enhancing technology and skills currently present in large multinational firms to smaller-scale domestic firms. This will require strategies to enhance technical capacity and skills among local firms that are, as yet, only weakly integrated with global production chains.

Since 1995, enrolment in higher education has grown tenfold to well over 2 million in 2012. By 2014, there were 419 institutions of higher education (Brown, 2014). A number of foreign universities operate private campuses in Viet Nam, including Harvard University (USA) and the Royal Melbourne Institute of Technology (Australia).

The government's strong commitment to education, in general, and higher education, in particular (respectively 6.3% and 1.05% of GDP in 2012), has fostered significant growth in higher education but this will need to be sustained to retain academics. Reform is under way. A law passed in 2012 gives university administrators greater autonomy, although the Ministry of Education retains responsibility for quality assurance. The large number of universities and even larger pool of research institutions in Viet Nam presents a serious challenge for governance, particularly with respect to co-ordination among ministries. To some extent, market forces are likely to eliminate the smaller and financially weaker units.

There are no recent data available on R&D expenditure but the number of Vietnamese publications in the Web of Science has increased at a rate well above the average for Southeast Asia. Publications focus mainly on life sciences

(22%), physics (13%) and engineering (13%), which is consistent with recent advances in the production of diagnostic equipment and shipbuilding. Almost 77% of all papers published between 2008 and 2014 had at least one international co-author.

Public–private partnerships key in S&T strategy

The autonomy which Vietnamese research centres have enjoyed since the mid-1990s has enabled many of them to operate as quasi-private organizations, providing services such as consulting and technology development. Some have 'spun off' from the larger institutions to form their own semi-private enterprises, fostering the transfer of public sector S&T personnel to these semi-private establishments. One comparatively new university, Ton Duc Thang (est. 1997), has already set up 13 centres for technology transfer and services that together produce 15% of university revenue. Many of these research centres serve as valuable intermediaries bridging public research institutions, universities and firms. In addition, Viet Nam's most recent Law on Higher Education, passed in June 2012, offers university administrators greater autonomy and there are reports that growing numbers of academic staff are also serving as advisors to NGOs and private firms.

The *Strategy for Science and Technology Development for 2011–2020,* adopted in 2012, builds upon this trend by promoting public–private partnerships and seeking to transform 'public S&T organisations into self-managed and accountable mechanisms as stipulated by law' (MoST, 2012). The main emphasis is on overall planning and priority-setting, with a view to enhancing innovation capability, particularly in industrial sectors. Although the *Strategy* omits to fix any targets for funding, it nevertheless sets broad policy directions and priority areas for investment, including:

- research in mathematics and physics;
- investigation of climate change and natural disasters;
- development of operating systems for computers, tablets and mobile devices;
- biotechnology applied particularly to agriculture, forestry, fisheries and medicine; and
- environmental protection.

The new *Strategy* foresees the development of a network of organizations to support consultancy services in the field of innovation and the development of intellectual property. The *Strategy* also seeks to promote greater international scientific co-operation, with a plan to establish a network of Vietnamese scientists overseas and to initiate a network of 'outstanding research centres' linking key national science institutions with partners abroad.

Viet Nam has also developed a set of national development strategies for selected sectors of the economy, many of which involve S&T. Examples are the *Sustainable Development Strategy* (April 2012) and the *Mechanical Engineering Industry Development Strategy* (2006), together with *Vision 2020* (2006). Spanning the period 2011–2020, these dual strategies call for a highly skilled human resource base, a strong R&D investment policy, fiscal policies to encourage technological upgrading in the private sector and private-sector investment and regulations to steer investment towards sustainable development.

PACIFIC ISLAND COUNTRIES

Small states with big development needs

Pacific Island economies are mostly dependent on natural resources, with a tiny manufacturing sector and no heavy industry. The trade balance is more skewed towards imports than exports, with the exception of Papua New Guinea, which has a mining industry. There is growing evidence that Fiji is becoming a re-export hub in the Pacific; between 2009 and 2013, its re-exports grew threefold, accounting for more than half of all exports by Pacific Island states. Now that it has joined the World Trade Organization (in 2012), Samoa can also expect to become more integrated in global markets.

The wider cultural and social context heavily influences science and technology in the Pacific Island countries. Furthermore, limited freedom of expression and, in some cases, religious conservatism discourage research in certain areas. This said, the experience of these countries shows that sustainable development and a green economy can benefit from the inclusion of traditional knowledge in formal science and technology, as underlined by the *Sustainable Development Brief* prepared by the Secretariat of the Pacific Community in 2013.

The *UNESCO Science Report 2010* observed that the lack of national and regional policy frameworks was a major stumbling block for developing integrated national STI agendas. Pacific Island states have since moved forward in this regard by establishing a number of regional bodies to address technological issues for sectorial development.

Examples are the:

- Secretariat of the Pacific Community for climate change, fisheries and agriculture;
- Pacific Forum Secretariat for transport and telecommunications; and
- Secretariat of the Pacific Region Environmental Programme for related issues.

Unfortunately, none of these agencies has a specific mandate for S&T policy. The recent establishment of the Pacific–Europe Network for Science, Technology and Innovation (PACE-Net Plus) goes some way towards filling this void, at least temporarily. Funded by the European Commission within its Seventh Framework Programme for Research and Innovation (2007–2013), this project spans the period 2013–2016 and thus overlaps with the European Union's Horizon 2020 programme (see Chapter 9). Its objectives are to reinforce the dialogue between the Pacific region and Europe in STI; to support biregional research and innovation through calls for research proposals and to promote scientific excellence and industrial and economic competition. Ten of its 16 members[8] come from the Pacific region.

PACE-Net Plus focuses on three societal challenges:

- Health, demographic change and well-being;
- Food security, sustainable agriculture, marine and maritime research and the bio-economy; and
- Climate action, resource efficiency and raw materials.

PACE–Net Plus has organized a series of high-level policy dialogue platforms alternately in the Pacific region and in Brussels, the headquarters of the European Commission. These platforms bring together key government and institutional stakeholders in both regions, around STI issues.

A conference held in Suva (Fiji) in 2012 under the umbrella of PACE–Net Plus produced recommendations for a strategic plan[9] on research, innovation and development in the Pacific. The conference report published in 2013 identified R&D needs in the Pacific in seven areas: health; agriculture and forestry; fisheries and aquaculture; biodiversity and ecosystem management; freshwater; natural hazards; and energy. Noting the general absence of regional and national STI policies and plans in the Pacific, the conference also established the Pacific Islands University Research Network to support intra- and inter- regional knowledge creation and sharing and to prepare succinct recommendations for the development of a regional STI policy framework. This policy framework was supposed to be informed by evidence gleaned from measuring STI capability but the absence of data presents a formidable barrier. This formal research network will complement the Fiji-based University of the South Pacific, which has campuses in other Pacific Island countries.

8. The ten are the: Australian National University, Montroix Pty Ltd (Australia), University of the South Pacific, Institut Malardé in French Caledonia, National Centre for Technological Research into Nickel and its Environment in New Caledonia, South Pacific Community, Landcare Research Ltd in New Zealand, University of Papua New Guinea, Samoa National University and the Vanuatu Cultural Centre.

9. See: http://pacenet.eu/news/pacenet-outcomes-2013

In 2009, Papua New Guinea articulated its *National Vision 2050*, which led to the establishment of a Research, Science and Technology Council. *Vision 2050*'s medium-term priorities include:

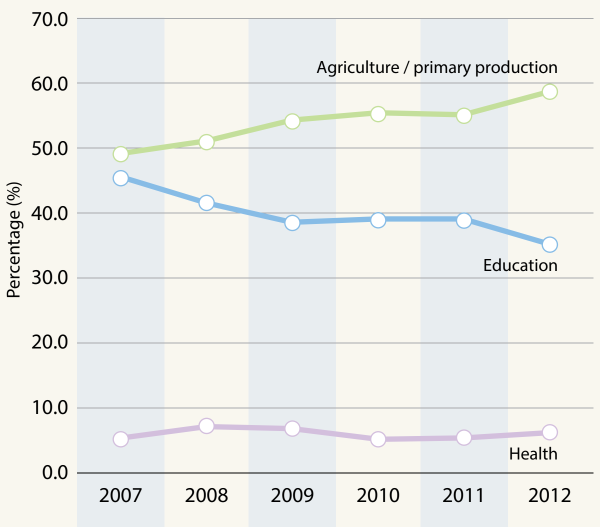
- emerging industrial technology for downstream processing;
- infrastructure technology for the economic corridors;
- knowledge-based technology;
- S&T education; and
- the ambitious target of investing 5% of GDP in R&D by 2050.

At its gathering in November 2014, the Research, Science and Technology Council re-emphasized the need to focus on sustainable development through science and technology. Moreover, in its *Higher Education Plan III 2014–2023*, Papua New Guinea sets out a strategy for transforming tertiary education and R&D through the introduction of a quality assurance system and a programme to overcome the limited R&D capacity.

Like Papua New Guinea, Fiji and Samoa consider education to be one of the key policy tools for driving STI and modernization. Fiji, in particular, has made a supreme effort to re-visit existing policies, rules and regulations in this sector. The Fijian government allocates a larger portion of its national budget to education than any other Pacific Island country (4% of GDP in 2011), although this is down from 6% of GDP in 2000. The proportion of the education budget allocated to higher education has fallen slightly, from 14% to 13%, but scholarship schemes like National Toppers, introduced in 2014, and the availability of student loans have made higher education attractive and rewarding in Fiji. Many Pacific Island countries take Fiji as a benchmark: the country draws education leaders from other Pacific Island countries for training and, according to the Ministry of Education, teachers from Fiji are in great demand in these countries.

According to an internal investigation into the choice of disciplines in school-leaving examinations (year 13), Fijian students have shown a greater interest in science since 2011. A similar trend can be observed in enrolment figures at all three Fijian universities. One important initiative has been the creation of the Higher Education Commission (FHEC) in 2010, the regulatory body in charge of tertiary education in Fiji. FHEC has embarked on registration and accreditation processes for tertiary-level education providers to improve the quality of higher education in Fiji. In 2014, FHEC allocated research grants to universities with a view to enhancing the research culture among faculty.

Figure 27.11: **Government expenditure on R&D in Fiji by socio-economic objective, 2007–2012**



Source: Fiji Bureau of Statistics, 2014

Fiji is the only Pacific Island country with recent data for GERD. The national Bureau of Statistics cites a GERD/GDP ratio of 0.15% in 2012. Private-sector R&D is negligible. Between 2007 and 2012, government investment in R&D tended to favour agriculture (Figure 27.11). Scientists publish much more in geosciences and medical sciences than in agricultural sciences, however (Figure 27.8).

According to the Web of Science, Papua New Guinea had the largest number of publications (110) among Pacific Island states[10] in 2014, followed by Fiji (106). These publications concerned mainly life sciences and geosciences. A noticeable feature of scientific publications from French Polynesia and New Caledonia is the emphasis on the geosciences: six to eight times the world average for this field. Conversely, nine out of ten scientific publications from Papua New Guinea concentrate on immunology, genetics, biotechnology and microbiology.

Fijian research collaboration with North American partners exceeded that with India between 2008 and 2014 – a large proportion of Fijians are of Indian origin – and was concentrated in a handful of scientific disciplines, such as medical sciences, environmental sciences and biology. International co-authorship was higher for Papua New Guinea and Fiji (90% and 83% respectively) than for New Caledonia and French Polynesia (63% and 56% respectively). Research partnerships also involved countries in Southeast Asia and Oceania, as well as the USA and Europe. Surprisingly, there was little co-authorship with authors based in France, with the notable exception of Vanuatu (Figure 27.8).

Having 100% foreign co-authors has its drawbacks

A near-100% rate of international co-authoring can be a double-edged sword. According to the Fijian Ministry of Health, research collaboration often results in an article being published in a reputed journal but gives very little back in terms of strengthening health in Fiji. A new set of guidelines are now in place in Fiji to help build endogenous capacity in health research through training and access to new technology. The new policy guidelines require that all research projects initiated in Fiji with external bodies demonstrate how the project will contribute to local capacity-building in health research. The Ministry of Health itself is seeking to develop endogenous research capacity through the *Fiji Journal of Public Health*, which it launched in 2012. In parallel, the Ministry of Agriculture revived Fiji's *Agricultural Journal* in 2013, which had been dormant for 17 years. In addition, two regional journals were launched in 2009 as a focus for Pacific scientific research, the *Samoan Medical Journal* and the *Papua New Guinea Journal of Research, Science and Technology*.

Fiji leading growth in ICTs

Access to the internet and mobile phone technologies has increased considerably across the Pacific Island countries in the past few years. Fiji shows substantial growth in this field, supported by its geographical location, service culture, pro-business policies, English-speaking population and well-connected e-society. Relative to many other South Pacific Islands, Fiji has a fairly reliable and efficient telecommunications system with access to the Southern Cross submarine cable linking New Zealand, Australia and North America. A recent move to establish the University of the South Pacific Stathan ICT Park, the Kalabo ICT economic zone and the ATH technology park in Fiji should boost the ICT support service sector in the Pacific region.

Tokelau first to generate all electricity from renewable sources

On average, 10% of the GDP of Pacific Island countries funds imports of petroleum products but in some cases this figure can exceed 30%. In addition to high fuel transport costs, this reliance on fossil fuels leaves Pacific economies vulnerable to volatile global fuel prices and potential spills[11] by oil tankers. Consequently, many Pacific Island countries are convinced that renewable energy will play a role in their countries' socio-economic development. In Fiji, Papua New Guinea, Samoa and Vanuatu, renewable energy sources already represent significant shares of the total electricity supply: 60%, 66%, 37% and 15% respectively. Tokelau has even become the first country in the world to generate 100% of its electricity using renewable sources.

10. They are not covered in the present chapter but the French territories of New Caledonia and French Polynesia had 116 and 58 publications catalogued in the Web of Science in 2013.

11. See: www.pacificenergysummit2013.com/about/energy-needs-in-the-pacific

Targets for developing sustainable energy

New targets for many Pacific Island countries were established between 2010 and 2012 (Tables 27.3 and 27.4) and efforts are under way to improve countries' capacity to produce, conserve and use renewable energy. For example, the EU has funded the Renewable Energy in Pacific Island Countries Developing Skills and Capacity programme (EPIC). Since its inception in 2013, EPIC has developed two master's programmes in renewable energy management and helped to establish two Centres of Renewable Energy, one at the University of Papua New Guinea and the other at the University of Fiji. Both centres became operational in 2014 and aim to create a regional knowledge hub for the development of renewable energy. In February 2014, the EU and the Pacific Islands Forum Secretariat signed an agreement for a programme on Adapting to Climate Change and Sustainable Energy worth € 37.26 million which will benefit 15 Pacific Island[12] states.

12. Cook Islands, Fiji, Kiribati , Marshall Islands, Federated States of Micronesia, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu and Vanuatu

Climate change a common concern

In the Pacific region, climate change mostly concerns marine issues, such as rising sea levels and the increased salinity of soils and groundwater, whereas, in Southeast Asia, carbon reduction strategies are a major focus. Disaster resilience, on the other hand, resonates with both regions.

Climate change seems to be the most pressing environmental issue for Pacific Island countries, as it is already affecting almost all socio-economic sectors. The consequences of climate change can be seen in agriculture, food security, forestry and even in the spread of communicable diseases. The Secretariat of the Pacific Community has initiated several activities to tackle problems associated with climate change. These cover a great variety of areas, such as fisheries, freshwater, agriculture, coastal zone management, disaster management, energy, traditional knowledge, education, forestry, communication, tourism, culture, health, weather,

Table 27.3: **National renewable energy targets for selected Pacific Island states, 2013–2020**

Country	Energy Target	Timeframe
Cook Islands	50% of energy demand provided by renewable energy by 2015 and 100% by 2020	2015 and 2020
Fiji	90% renewable	2015
Nauru	50% renewable	2015
Palau	20% renewable and a 30% reduction in energy consumption	2020
Samoa	10% renewable	2016
Tonga	50% renewable and the overall energy cost reduced by 50%	2015
Vanuatu	33% renewable, target fixed by UNELCO (a private company)	2013

Source: Secretariat of the Pacific Community (2013) *Sustainable Development Brief*

Table 27.4: **Fiji's Green Growth Framework, 2014**

Focus area	Strategy
Support research and innovation in green technologies and services	■ support existing green industries by subsidizing firms that use green technologies throughout the production value chain; ■ increase public research funding for refining and improving existing technologies, such as the Ocean Centre for Sustainable Transport; ■ develop a national framework for promoting innovation and research into environmentally sustainable technologies by the end of 2017.
Promote the use of green technologies	■ increase public awareness of green technologies; ■ measure the success of public school environmental education; ■ examine the potential for tariffs on non-green technology imports; ■ reduce import duties on low carbon technologies; ■ introduce incentives for large-scale FDI in industries that develop environmentally sustainable technology in areas such as transport, energy, manufacturing and agriculture.
Develop national innovative capabilities	■ develop a strategy for science and technology, innovation and R&D that is integrated in an overall sustainable development strategy across all thematic areas by the end of 2017; ■ ensure that at least 50% of secondary school teachers are trained to implement the revised Fiji National Curriculum Framework by 2020.

Source: Ministry of Strategic Planning and National Development and Statistics (2014) *A Green Growth Framework for Fiji: Restoring the Balance in Development that is Sustainable for our Future.* Suva gender implications and biodiversity. Almost all Pacific Island countries are involved in one or more of these activities.

Several projects related to climate change are also being co-ordinated by UNEP, within the Secretariat of the Pacific Region Environmental Programme (SPREP). The aim of SPREP is to help all members improve their 'capacity to respond to climate change through policy improvement, implementation of practical adaptation measures, enhancing ecosystem resilience to the impacts of climate change and implementing initiatives aimed at achieving low-carbon development'.

The first major scheme focusing on adaptation to climate change and climate variability dates back to 2009. Pacific Adaptation to Climate Change involves 13 Pacific Island nations, with international funding from the Global Environment Facility, as well as from the US and Australian governments.

Using S&T to foster value-added production in Fiji

The desire to ensure that fisheries remain sustainable is fuelling the drive to use S&T to make the transition to value-added production. The fisheries sector in Fiji is currently dominated by the catch of tuna for the Japanese market. The Fijian government plans to diversify this sector through aquaculture, inshore fisheries and offshore fish products such as sunfish and deep-water snapper. Accordingly, many incentives and concessions are being offered to encourage the private sector to invest in these areas.

Another priority area in the Pacific is agriculture and food security. The *Fiji 2020–Agriculture Sector Policy Agenda* (MoAF, 2014) draws attention to the need to build a sustainable community and gives high priority in the development agenda to ensuring food security. Strategies outlined in *Fiji 2020* include:

- modernizing agriculture in Fiji;
- developing integrated systems for agriculture;
- improving delivery of agricultural support systems;
- enhancing innovative agricultural business models; and
- strengthening the capacity for policy formulation.

Fiji has taken the initiative of shifting away from subsistence agriculture towards commercial agriculture and agro-processing of root crops, tropical fruits, vegetables, spices, horticulture and livestock.

Little use of technology in forestry

Forestry is an important economic resource for Fiji and Papua New Guinea. However, forestry in both countries uses low- and semi-intensive technological inputs. As a result, product ranges are limited to sawed timber, veneer, plywood, block board, moulding, poles and posts and wood chips. Only a few limited finished products are exported. Lack of automated machinery, coupled with inadequately trained local technical personnel, are some of the obstacles to introducing automated machinery and design. Policy-makers need to turn their attention to eliminating these barriers, in order for forestry to make a more efficient and sustainable contribution to national economic development.

The blueprint for the subregion's sustainable development over the coming decade is the *Samoa Pathway*, the action plan adopted by countries at the third United Nations Conference on Small Island Developing States in Apia (Samoa) in September 2014. The *Samoa Pathway* focuses on, *inter alia*, sustainable consumption and production; sustainable energy, tourism and transportation; climate change; disaster risk reduction; forests; water and sanitation, food security and nutrition; chemical and waste management; oceans and seas; biodiversity; desertification, land degradation and drought; and health and non-communicable diseases.

CONCLUSION

A need to find a balance between local and global engagement in problem-solving

Leaving aside for the moment the region's four leaders for R&D intensity – Australia, Malaysia, New Zealand and Singapore – most countries covered in the present chapter are small both economically and in terms of their scientific production. It is thus not surprising to find an extremely high proportion of researchers in these countries who collaborate more or less systematically with the more scientifically prolific countries in the region and with scientists from knowledge hubs in North America, Europe and elsewhere in Asia. For the less developed economies in the Southeast Pacific and Oceania, co-authorship is in the range of 90–100% and such collaboration appears to be growing. This trend can be of benefit not only for the low income countries but also for global science when it comes to tackling regional problems associated with food production, health, medicine and geo-technical issues. However, the issue for the smaller economies is whether output dominated by international scientific collaboration is steering research in the direction envisaged by national S&T policies or whether research in these less developed countries is being driven by the particular interests of foreign scientists.

We have seen that multinational corporations have gravitated towards Cambodia and Viet Nam in recent years. Despite this, the number of patents granted for these two countries is negligible: four and 47 patents respectively over the period from 2002–2013. Even though 11% of the region's high-tech exports came from Viet Nam in 2013, according to the

Comtrade database, the majority of high-tech exports from Viet Nam (and no doubt Cambodia, too, but data are lacking) were designed elsewhere and simply assembled in the host country. Even if foreign firms *do* intensify their in-house R&D in the low income country that hosts them, this will not necessarily boost capacity for science and technology in the host country. Unless there is a sufficient number of trained personnel and strong institutional capabilities, R&D will continue to take place elsewhere. The rapid growth of FDI in R&D in India and China, where there has been parallel growth in the availability of local skills, is the outcome of strategic business decisions. The alternative for developing economies such as Viet Nam and Cambodia is to draw on the knowledge and skills embedded in the activities of large foreign firms, in order to develop the same level of professionalism among local suppliers and firms. By encouraging foreign high-tech manufacturers to run training programmes in the host country, governments will also be drawing manufacturers into national training strategies, with positive spin-offs for both producers and suppliers. A more technically advanced supply chain that is capable of absorbing new skills and knowledge should, in turn, encourage foreign firms to invest in R&D, with a flow-on benefit to local firms.

Regional blocs are playing an important role in science and technology across the region. We have seen that ASEAN is monitoring and co-ordinating developments in science and moving towards the free flow of skilled personnel across its member states. APEC has recently completed a study of skills shortages in the region with a view to setting up a monitoring system to address training needs before shortages become critical. Pacific Island countries have initiated a number of networks to foster research collaboration and solutions to deal with climate change.

The end of the commodities boom since 2013 has led resource-rich economies to devise S&T policies that can reinvigorate economic alternatives in areas in which countries show strengths, such as life sciences for Australia and New Zealand or engineering for some Asian countries. There is a growing tendency for policy to integrate innovation into S&T policies and STI strategies into longer-term development plans.

To some extent, this trend has created a dilemma for science and, in particular, for scientists. On the one hand, there is a strong imperative to produce quality scientific research and the metric for measuring quality is essentially scientific output in peer-reviewed journals. The careers of academic researchers and those in public research institutions depend upon it, yet many national development plans are also seeking research relevance. Clearly, both imperatives are important for fostering development and international competitiveness. The richer countries have the economic opportunity to pursue advances in basic research and to build a deeper and broader science base. Lower-income economies, however, face accrued pressure to favour relevance. Maintaining career paths for scientists that allow them to pursue both quality and relevance will remain a challenge.

Today, most policies across Southeast Asia and Oceania are oriented towards sustainable development and managing the consequences of climate change. The most notable exception is Australia. To some extent, the focus on sustainable development is probably driven by global concerns and the imminent adoption of the United Nations' Sustainable Development Goals in September 2015. Global engagement is far from the only motivation, however. Rising sea levels and increasingly frequent and virulent hurricanes are threatening agricultural production and freshwater quality and are thus of direct concern to most countries in the region. In turn, global collaboration will remain an important strategy for resolving these local issues.

KEY TARGETS FOR SOUTHEAST ASIA AND OCEANIA

- Attain economic growth of 12.7% on average in Indonesia from 2010 to 2025, in order to become one of the world's ten largest economies by 2025;
- Raise GERD to 1% of GDP in Thailand by 2021, with the private sector contributing 70% of GERD;
- Raise GERD to 3.5% of GDP in Singapore by 2015 (2.1% in 2012);
- By 2030, ensure that all 13 districts in Timor-Leste have at least one hospital and that there is a specialist hospital in Dili, with at least half of the nation's energy needs to be met by renewable energy sources;
- Raise the share of renewable energy by 2015–2016 in the following Pacific Island nations to: Cook Islands, Nauru and Tonga (50%), Fiji (90%) and Samoa (10%).

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ACKNOWLEDGMENTS

The authors wish to thank the following people for their assistance in compiling information and data on the Philippines: Bernie S. Justimbaste, Director of the Planning and Evaluation Service within the Department of Science and Technology (DOST), and Anita G. Tidon, Senior Science Research Specialist and Unit Head of the Socio-Economics Research Division within the DOST–Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development.

Annexes

Annex 1: Composition of regions and sub-regions

Groupings mentioned in Chapter 1

COUNTRIES BY INCOME LEVELS[1]

High-income economies

Antigua and Barbuda; Australia; Austria; Bahamas; Bahrain; Barbados; Belgium; Brunei Darussalam; Canada; Chile; China, Hong Kong SAR; China, Macao SAR; Croatia; Cyprus; Czech Rep.; Denmark; Equatorial Guinea; Estonia; Finland; France; Germany; Greece; Iceland; Ireland; Israel; Italy; Japan; Kuwait; Latvia; Liechtenstein; Lithuania; Luxembourg; Malta; Netherlands; New Zealand; Norway; Oman; Poland; Portugal; Qatar; Korea, Rep. of; Russian Federation; St Kitts and Nevis; Saudi Arabia; Singapore; Slovakia; Slovenia; Spain; Sweden; Switzerland; Trinidad and Tobago; United Arab Emirates; United Kingdom; United States of America; Uruguay

Upper-middle-income economies

Albania; Algeria; Angola; Argentina; Azerbaijan; Belarus; Belize; Bosnia and Herzegovina; Botswana; Brazil; Bulgaria; China; Colombia; Costa Rica; Cuba; Dominica; Dominican Rep.; Ecuador; Fiji; Gabon; Grenada; Hungary; Iran, Islamic Rep. of; Iraq; Jamaica; Jordan; Kazakhstan; Lebanon; Libya; Malaysia; Maldives; Marshall Islands; Mauritius; Mexico; Montenegro; Namibia; Palau; Panama; Peru; Romania; St Lucia; St Vincent and the Grenadines; Serbia; Seychelles; South Africa; Suriname; Thailand; FYR Macedonia; Tonga; Tunisia; Turkey; Turkmenistan; Tuvalu; Venezuela

Lower-middle-income economies

Armenia; Bhutan; Bolivia; Cabo Verde; Cameroon; Congo; Côte d'Ivoire; Djibouti; Egypt; El Salvador; Georgia; Ghana; Guatemala; Guyana; Honduras; India; Indonesia; Kiribati; Kyrgyzstan; Lao PDR; Lesotho; Mauritania; Micronesia; Mongolia; Morocco; Nicaragua; Nigeria; Pakistan; Palestine; Papua New Guinea; Paraguay; Philippines; Moldova, Rep. of; Samoa; Sao Tome and Principe; Senegal; Solomon Islands; South Sudan; Sri Lanka; Sudan; Swaziland; Syrian Arab Rep.; Timor-Leste; Ukraine; Uzbekistan; Vanuatu; Viet Nam; Yemen; Zambia

Low-income economies

Afghanistan; Bangladesh; Benin; Burkina Faso; Burundi; Cambodia; Central African Rep.; Chad; Comoros; Korea, DPR; Congo, Dem. Rep. of; Eritrea; Ethiopia; Gambia; Guinea; Guinea-Bissau; Haiti; Kenya; Liberia; Madagascar; Malawi; Mali; Mozambique; Myanmar; Nepal; Niger; Rwanda; Sierra Leone; Somalia; Tajikistan; Togo; Uganda; Tanzania; Zimbabwe

1. Grouping by income level are based on '2013 gross national income (GNI) per capita', calculated using the World Bank Atlas method, as of 1 May 2015.

AMERICAS

North America

Canada; United States of America

Latin America

Argentina; Belize; Bolivia; Brazil; Chile; Colombia; Costa Rica; Ecuador; El Salvador; Guatemala; Guyana; Honduras; Mexico; Nicaragua; Panama; Paraguay; Peru; Suriname; Uruguay; Venezuela

Caribbean

Antigua and Barbuda; Bahamas; Barbados; Cuba; Dominica; Dominican Rep.; Grenada; Haiti; Jamaica; St Kitts and Nevis; St Lucia; St Vincent and the Grenadines; Trinidad and Tobago

EUROPE

European Union

Austria; Belgium; Bulgaria; Croatia; Cyprus; Czech Rep.; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Luxembourg; Malta; Netherlands; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Sweden; United Kingdom

South-East Europe

Albania; Bosnia and Herzegovina; Montenegro; Serbia; FYR Macedonia

European Free Trade Association

Iceland; Liechtenstein; Norway; Switzerland

Other Europe

Belarus; Moldova, Rep. of; Russian Federation; Turkey; Ukraine

AFRICA

Sub-Saharan Africa

Angola; Benin; Botswana; Burkina Faso; Burundi; Cameroon; Cabo Verde; Central African Rep.; Chad; Comoros; Congo; Côte d'Ivoire; Congo, Dem. Rep. of; Djibouti; Equatorial Guinea; Eritrea; Ethiopia; Gabon; Gambia; Ghana; Guinea; Guinea-Bissau; Kenya; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritius; Mozambique; Namibia; Niger; Nigeria; Rwanda; Sao Tome and Principe; Senegal; Seychelles; Sierra Leone; Somalia; South Africa; South Sudan; Swaziland; Togo; Uganda; Tanzania; Zambia; Zimbabwe

Arab States in Africa

Algeria; Egypt; Libya; Mauritania; Morocco; Sudan; Tunisia

Annex 1: Composition of regions and sub-regions

ASIA

Central Asia
Kazakhstan; Kyrgyzstan; Mongolia; Tajikistan; Turkmenistan; Uzbekistan

Arab States in Asia
Bahrain; Iraq; Jordan; Kuwait; Lebanon; Oman; Palestine; Qatar; Saudi Arabia; Syrian Arab Rep.; United Arab Emirates; Yemen

West Asia
Armenia; Azerbaijan; Georgia; Iran, Islamic Rep. of; Israel

South Asia
Afghanistan; Bangladesh; Bhutan; India; Maldives; Nepal; Pakistan; Sri Lanka

South-East Asia
Brunei Darussalam; Cambodia; China; China, Hong Kong SAR; China, Macao SAR; Korea, DPR; Indonesia; Japan; Lao PDR; Malaysia; Myanmar; Philippines; Korea, Rep. of; Singapore; Thailand; Timor-Leste; Viet Nam

OCEANIA

Australia; New Zealand; Cook Islands; Fiji; Kiribati; Marshall Islands; Micronesia; Nauru; Niue; Palau; Papua New Guinea; Samoa; Solomon Islands; Tonga; Tuvalu; Vanuatu

Least developed countries[2]
Afghanistan; Angola; Bangladesh; Benin; Bhutan; Burkina Faso; Burundi; Cambodia; Central African Rep.; Chad; Comoros; Congo, Dem. Rep. of; Djibouti; Equatorial Guinea; Eritrea; Ethiopia; Gambia; Guinea; Guinea-Bissau; Haiti; Kiribati; Lao PDR; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritania; Mozambique; Myanmar; Nepal; Niger; Rwanda; Sao Tome and Principe; Senegal; Sierra Leone; Solomon Islands; Somalia; South Sudan; Sudan; Timor-Leste; Togo; Tuvalu; Uganda; Tanzania; Vanuatu; Yemen; Zambia

Arab States
Algeria; Bahrain; Egypt; Iraq; Jordan; Kuwait; Lebanon; Libya; Mauritania; Morocco; Oman; Palestine; Qatar; Saudi Arabia; Sudan; Syrian Arab Rep.; Tunisia; United Arab Emirates; Yemen

2. based on the standard classification of the United Nations Statistics Division, as of May 2015: http://unstats.un.org/unsd/methods/m49/m49regin.htm

OECD

Australia; Austria; Belgium; Canada; Chile; Czech Rep.; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Iceland; Ireland; Israel; Italy; Japan; Luxembourg; Mexico; Netherlands; New Zealand; Norway; Poland; Portugal; Korea, Rep. of; Slovakia; Slovenia; Spain; Sweden; Switzerland; Turkey; United Kingdom; United States of America

G20

Argentina; Australia; Brazil; Canada; China; France; Germany; India; Indonesia; Italy; Japan; Korea, Rep. of; Mexico; Russian Federation; Saudi Arabia; South Africa; Turkey; United Kingdom; United States of America; European Union

Groupings mentioned elsewhere in the report *(in alphabetical order)*

Arab Maghreb Union
Algeria; Libya; Mauritania; Morocco; Tunisia

Common Market for Eastern and Southern Africa (COMESA)
Burundi; Comoros; Democratic Republic of Congo; Djibouti; Egypt; Eritrea; Ethiopia; Kenya; Libya; Seychelles; Swaziland; Madagascar; Malawi; Mauritius; Rwanda; Seychelles; Sudan; Uganda; Zambia; Zimbabwe

Asia–Pacific Economic Cooperation (APEC)
Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong (China); Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; The Philippines; Russian Federation; Singapore; Taiwan, China; Thailand; United States of America; Viet Nam

Asian Tigers *(authors' grouping in Chapter 2)*
Indonesia; Malaysia; Philippines; Republic of Korea; Singapore; Taiwan, China; Hong Kong (China); Thailand; Viet Nam

Association of Southeast Asian Nations (ASEAN)
Brunei Darussalam; Cambodia; Indonesia; Lao PDR; Malaysia; Myanmar; Philippines; Singapore; Thailand; Viet Nam

Caribbean Common Market (CARICOM)
Antigua and Barbuda; Bahamas; Barbados; Belize; Dominica; Dominican Republic; Grenada; Guyana; Haiti; Jamaica; Montserrat; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Suriname; Trinidad and Tobago

Central Asia Regional Economic Cooperation
Afghanistan; Azerbaijan; China; Kazakhstan; Kyrgyzstan; Mongolia; Pakistan Tajikistan; Turkmenistan; Uzbekistan

East African Community
Burundi; Kenya; Rwanda; Tanzania; Uganda

Economic Community of Central African States
Angola; Burundi; Cameroon; Central African Republic; Chad; Republic of Congo; Democratic Republic of Congo; Equatorial Guinea; Gabon; Sao Tomé and Principe

Economic Community of West African States
Benin; Burkina Faso; Cape Verde; Côte d'Ivoire; Gambia; Ghana; Guinea; Guinea-Bissau; Liberia; Mali; Niger; Nigeria; Senegal; Sierra Leone; Togo

Economic Cooperation Organization
Afghanistan; Azerbaijan; Iran; Kazakhstan; Kyrgyzstan; Pakistan; Tajikistan; Turkey; Turkmenistan; Uzbekistan

Economic and Monetary Community of Central Africa
Cameroon; Central African Republic; Chad; Republic of Congo; Equatorial Guinea; Gabon

Eurasian Economic Union
Armenia, Belarus, Kazakhstan, Russian Federation; Kyrgyzstan's accession expected to come into force in May 2015.

Greater Mekong Subregion
Cambodia; People's Republic of China; Lao People's Democratic Republic; Myanmar; Thailand; Viet Nam

Indian Ocean Rim Association for Regional Cooperation
Australia; Bangladesh; India; Indonesia; Iran; Kenya; Madagascar; Malaysia; Mauritius, Mozambique; Oman; Singapore; South Africa; Sri Lanka; Tanzania; Thailand, United Arab Emirates; Yemen

Intergovernmental Authority on Development
Djibouti ; Eritrea; Ethiopia; Kenya; Somalia; South Sudan; Sudan; Uganda

Mercado Commún del Sur (MERCOSUR)
Argentina; Brazil; Paraguay; Uruguay; Venezuela

North Atlantic Treaty Organization
Albania; Bulgaria; Belgium; Canada; Croatia; Czech Republic; Denmark; Estonia; France; Germany; Greece; Hungary; Iceland; Italy; Latvia; Lithuania; Luxembourg; Netherlands; Norway; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Turkey; UK; USA

Organization of American States
Antigua and Barbuda; Argentina; Bahamas; Barbados; Belize; Bolivia; Brazil; Canada; Chile; Colombia; Costa Rica; Cuba; Dominica; Dominican Republic; Ecuador; El Salvador; Grenada; Guatemala; Guyana; Haiti; Honduras; Jamaica; Mexico; Nicaragua; Panama; Paraguay; Peru; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Suriname; Trinidad and Tobago; United States of America; Uruguay; Venezuela

Organization of the Black Sea Economic Cooperation
Albania; Armenia; Azerbaijan; Bulgaria; Georgia; Greece; Moldova; Romania; Russian Federation; Serbia; Turkey; Ukraine

Organization of the Islamic Conference
Afghanistan; Albania; Algeria; Azerbaijan; Bahrain; Bangladesh; Benin; Brunei Darussalam; Burkina Faso; Cameroon; Chad; Comoros; Côte d'Ivoire; Djibouti; Egypt; Gabon; Gambia; Guinea; Guinea Bissau; Guyana; Indonesia; Iran; Iraq; Kazakhstan; Kuwait; Oman; Jordan; Kazakhstan; Lebanon; Libya; Maldives; Malaysia; Mali; Mauritania; Morocco; Mozambique; Niger; Nigeria; Palestine; Pakistan; Qatar; Saudi Arabia; Senegal; Sierra Leone; Somalia; Sudan; Suriname; Syrian Arab Republic; Tajikistan; Togo; Turkey; Turkmenistan; Tunisia; Uganda; United Arab Emirates; Uzbekistan; Yemen

Organization for Security and Co-operation in Europe
Albania; Andorra; Armenia; Austria; Azerbaijan; Belarus; Belgium; Bosnia and Herzegovina; Bulgaria; Canada; Croatia; Cyprus; Czech Republic; Denmark; Estonia; Finland; France; Georgia; Germany; Greece; Holy See; Hungary; Iceland; Ireland; Italy; Kazakhstan; Kyrgyzstan; Latvia; Liechtenstein; Lithuania; Luxembourg; Malta; Moldova; Monaco; Mongolia; Montenegro; Netherlands; Norway; Poland; Portugal; Romania; Russian Federation; San Marino; Serbia; Slovakia; Spain; Sweden; Slovenia; Switzerland; Tajikistan; Turkey; Turkmenistan; Ukraine; Uzbekistan; United Kingdom of Great Britain and Northern Ireland; United States of America; Former Yugoslav Republic of Macedonia

Pacific Islands Forum
Australia; Cook Islands; Federated States of Micronesia; Fiji; Kiribati; Nauru; New Zealand; Niue; Palau; Papua New Guinea; Republic of Marshall Islands; Samoa; Solomon Islands; Tonga; Tuvalu; Vanuatu

Annex 1: Composition of regions and sub-regions

Secretariat of the Pacific Community
American Samoa ; Cook Islands; Federated States of Micronesia; Fiji; French Polynesia; Guam; Kiribati; Marshall Islands; Nauru; New Caledonia; Niue; Northern Mariana Islands ; Palau; Papua New Guinea ; Pitcairn Islands; Samoa; Solomon Islands; Tokelau; Tonga ; Tuvalu; Vanuatu; Wallis and Futuna

Shanghai Cooperation Organisation
China; Kazakhstan; Kyrgyzstan; Russian Federation Tajikistan; Turkmenistan; Uzbekistan

Southern African Development Community
Angola; Botswana; Democratic Republic of the Congo; Lesotho; Madagascar; Malawi; Mauritius; Mozambique; Namibia; Seychelles; South Africa; Swaziland; United Republic of Tanzania; Zambia; Zimbabwe

West African Economic and Monetary Union
Benin; Burkina Faso; Côte d'Ivoire; Guinea-Bissau; Mali; Niger; Senegal; Togo

World Trade Organization
Albania; Andorra; Angola; Antigua and Barbuda; Argentina; Armenia; Australia; Austria; Azerbaijan; Bahrain; Bangladesh; Barbados; Belarus; Belgium; Belize; Benin; Bolivia; Bosnia and Herzegovina; Botswana; Brazil; Brunei Darussalam; Bulgaria; Burkina Faso; Burundi; Canada; Cape Verde; Cambodia; Central African Republic; Chad; Chile; China; Colombia; Republic of Congo; Costa Rica; Côte d'Ivoire; Croatia; Cuba; Cyprus; Czech Republic; Democratic Republic of Congo; Denmark; Djibouti; Dominica; Dominican Republic; Ecuador; Egypt; El Salvador; Estonia; Fiji; Finland; France; Gabon; The Gambia; Georgia; Germany; Ghana; Greece; Grenada; Guatemala; Guinea; Guinea-Bissau; Haiti; Honduras; Hong Kong, China; Holy See; Hungary; Iceland; India; Ireland; Israel; Italy; Jamaica; Japan; Jordan; Kazakhstan; Kenya; Republic of Korea; Kuwait; Kyrgyzstan; Lao People's Democratic Republic; Latvia; Lesotho; Liechtenstein; Lithuania; Luxembourg; Macao, China; Madagascar; Malawi; Malaysia; Maldives; Malta; Mauritania; Mauritius; Mexico; Moldova; Monaco; Mongolia; Montenegro; Morocco; Mozambique; Myanmar; Namibia; Nepal; Netherlands; New Zealand; Nicaragua; Niger; Nigeria; Norway; Oman; Pakistan; Panama; Papua New Guinea; Paraguay; Peru; Philippines; Poland; Portugal; Qatar; Romania; Russian Federation; Rwanda; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Samoa; San Marino; Saudi Arabia; Senegal; Sierra Leone; Singapore; Serbia; Slovakia; Slovenia; Solomon Islands; South Africa; Spain; Sri Lanka; Suriname; Swaziland; Sweden; Switzerland; Taiwan, China; Tajikistan; United Republic of Tanzania; Thailand; Togo; Tonga; Trinidad and Tobago; Tunisia; Turkey; Turkmenistan; Uganda; Ukraine; United Arab Emirates; United Kingdom of Great Britain and Northern Ireland; United States of America; ; Uruguay; Uzbekistan; Vanuatu; Venezuela; Viet Nam; Yemen; Former Yugoslav Republic of Macedonia; Zambia; Zimbabwe

Annex 2: Glossary

Brownfield investment
Investment in an existing site used for commercial purposes, such as a factory, airport, power plant or steel mill, in order to expand the business or upgrade the facilities and thereby improve the return on investment; see also greenfield investment

Business accelerator
A model which provides start-ups with training, facilities, mentorship and partners; accelerators invest in their start-ups, unlike business incubators (see next entry)

Business incubator
A model which provides start-ups with training, facilities, mentorship and partners; incubators do not invest in their start-ups, unlike business accelerators (see previous entry)

Business sector (*for R&D data*)
All public and private firms, organizations and institutions whose primary activity is the market production of goods or services (other than higher education) for sale to the general public at an economically significant price; includes the private non-profit institutions mainly serving them

Capital expenditure (*for R&D data*)
Annual gross expenditure on fixed assets used in the R&D programmes of statistical units, which should be reported in full for the period when the expenditure occurred and should not be registered as an element of depreciation

Current costs *(for R&D data)*
Composed of labour costs and other current costs; labour costs of R&D personnel consist of annual wages, salaries and all associated costs or fringe benefits; other current costs comprise non-capital purchases of materials, supplies and equipment to support R&D

Disruptive innovation
Dynamic start-ups which may be working on innovation with potential to create new markets and disrupt the business model of their more established competitors, including large corporations; increasingly, corporations are opting to support these start-ups through business accelerators and business incubators (see above), as this approach can be more cost-effective than the acquisition of the new technology; they also stand to gain insights into the future of their market and defuse disruptive innovation; examples of corporations that have invested in disruptive innovation incubators and accelerators are Allianz, Google, LinkedIn, Microsoft, Samsung, Starbucks, Telefonica and Turner

Dutch Disease
Economic term describing the cause and effect relationship between a resource boom and a decline in manufacturing; the term was coined in 1977 by *The Economist* to describe the decline of the manufacturing sector in the Netherlands after the discovery of a large natural gas field in 1959; a resource boom fuels demand for labour, causing production to shift towards the booming sector, such as hydrocarbons or minerals, to the detriment of manufacturing; a secondary effect is the appreciation of the national currency, which causes export-oriented manufacturing to suffer

***Ex post* evaluation**
Assesses the relevance, effectiveness, impact and sustainability of a completed project on the basis of international criteria

Fields of education
According to the International Standard Classification of Education 1997: *Science*: life sciences, physical sciences, mathematics and statistics; computer sciences; *Engineering, Manufacturing and Construction*: engineering and engineering trades; manufacturing and processing; architecture and building; *Agriculture*: agriculture, forestry and fishery; veterinary science. *Health and Welfare*: medicine; medical services; nursing; dental services; social care; social work

Fields of science and technology
According to the OECD's Revised Fields of Science and Technology Classification (2007), these are: natural sciences; engineering and technology; medical and health sciences; agricultural sciences; social sciences and humanities; **natural sciences** include: mathematics; computer and information sciences; physical sciences; chemical sciences; earth and related environmental sciences; and biological sciences; **engineering and technology** include: civil engineering; electrical, electronic, information engineering; mechanical engineering; chemical engineering; materials engineering; medical engineering; environmental engineering; environmental biotechnology; industrial biotechnology; and nanotechnology; **medical and health sciences** include: basic medicine; clinical medicine; health sciences; health biotechnology; and other medical sciences; **agricultural sciences** include: agriculture, forestry and fisheries; animal and dairy science; veterinary sciences; and agricultural biotechnology; **social sciences** include: psychology; economics and business; educational sciences; sociology; law; political science; social and economic geography; media and communications; **humanities** include: history and archaeology; languages and literature; philosophy, ethics and religion; and art

Firms with abandoned or ongoing innovation activities
Firms that did not necessarily implement innovations but had abandoned or ongoing innovation activities to develop them. Unless otherwise specified, the term covers product or process innovation, regardless of organizational or marketing innovation

Full-time equivalence (*for R&D data*)
A measure of the actual volume of human resources devoted to R&D that is especially useful for international comparisons; one full-time equivalent (FTE) may be thought of as a one person-year; a person who normally spends 30% of their time on R&D and the rest on other activities (such as teaching, university administration and student counselling) should be considered as a 0.3 FTE; similarly, if a full-time R&D worker is employed at an R&D unit for only six months, this results in an FTE of 0.5 for that year

Gender parity
Purely a numerical concept; for R&D statistics, gender parity is reached when women represent between 45% and 55% of the total number of researchers

Reaching gender parity in education implies that the same proportion of boys and girls – relative to their respective age groups – would enter the education system and participate in its different cycles

GERD as a percentage of GDP
The total intramural expenditure on R&D performed in the national territory or region during a given year, expressed as a percentage of GDP of the national territory or region.

Gini index
Measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. A Gini index of zero represents perfect equality and 100 perfect inequality. Relatively equal societies typically have an index close to 30, very unequal ones in the upper 40s and above

Global Competitive Index
A tool developed by the World Economic Forum that ranks countries according to three types of attribute: '*basic requirements*' encompass institutions, infrastructure, macro-economic stability, health and primary education; '*efficiency enhancers*' include higher education and training, labour market efficiency, financial market sophistication, market size and technological readiness; '*innovation and sophistication*' factors cover business sophistication and innovation

Government expenditure on tertiary education as a percentage of GDP
Total general (local, regional and central) government expenditure on tertiary education (current, capital, and transfers), expressed as a percentage of GDP; includes expenditure funded by transfers from international sources to government

Government sector (*for R&D data*)
All departments, offices and other bodies which furnish, but normally do not sell to the community, those common services (other than higher education) that cannot otherwise be conveniently and economically provided, as well as those that administer the state and the community's socio-economic policy; and the non-profit institutions controlled and mainly financed by government but not administered by the higher education sector; public enterprises are included in the business enterprise sector

Greenfield investment
Investment in a factory, airport, power plant, steel mill or other physical commerce-related structure where no facilities existed previously. A parent company may construct new facilities in the same country or a foreign country; governments may offer prospective companies incentives to set up a greenfield investment (tax breaks, subsidies, etc.), as most parent companies tend to create jobs in the foreign country, in addition to infrastructure; see also brownfield investment

Gross domestic expenditure on R&D (GERD)
All expenditure on R&D performed within a statistical unit or sector of the national economy during a specific period, whatever the source of funds

Gross domestic product
The sum of gross value added by all resident producers in the economy, including distributive trades and transport, plus any product taxes and minus any subsidies not included in the value of the products

Gross enrolment ratio
Number of students enrolled in a given level of education, regardless of age, expressed as a percentage of the official school-age population corresponding to the same level of education; for the tertiary level, the population used is the

five-year age group starting from the official secondary school graduation age

Gross fixed capital formation
Consists of investment in land improvements (fences, ditches, drains, etc.); plant, machinery and equipment purchases; and the construction of roads, railways and the like, including commercial and industrial buildings, offices, schools, hospitals and private residences, without taking into account the depreciation of assets.

Head count (*for R&D data*)
Data on the total number of persons who are mainly or partially employed in R&D; this includes staff employed both 'full-time' and 'part-time'; these data allow links to be made with other data series, such as education and employment data, or the results of population censuses; they are also the basis for calculating indicators analysing the characteristics of the R&D labour force with respect to age, gender or national origin

Higher education sector (*for R&D data*)
All universities, colleges of technology and other institutions of post-secondary education, whatever their source of finance or legal status; and all research institutes, experimental stations and clinics operating under the direct control of or administered by or associated with higher education institutions

Innovation
The implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations

Innovation-active firms
Firms that had innovation activities during the observation period, regardless of whether the activity resulted in the implementation of an innovation; unless otherwise specified, the term covers product or process innovation, regardless of organizational or marketing innovation

Innovation activities
All scientific, technological, organizational, financial and commercial steps which actually lead, or are intended to lead, to the implementation of innovation; Some innovation activities are themselves innovative, others are not novel activities but are necessary for the implementation of innovation; also includes R&D that is not directly related to the development of a specific innovation

Innovative firms
Firms that have implemented an innovation; unless otherwise specified, the term is used to refer to product or process innovative firms, which are also known as product or process innovators

Innovation Union Scoreboard
Tool used by the European Union (EU) to monitor each year the performance of Member States and European countries with pre-accession status, via 25 indicators; countries are classified into four categories: innovation leaders (well above the EU average); innovation followers (above or close to the EU average); moderate innovators (below the EU average) and modest innovators (well below the EU average)

Knowledge Economy Index
A composite set of indicators reflecting: the incentives offered by the economic and institutional sectors to make efficient use of existing and new knowledge and nurture entrepreneurship; the population's level of education and skills; an efficient innovation ecosystem comprised of firms, research centres, universities and other organizations; information and communication technologies

Knowledge Index
A composite of indicators reflecting the population's level of education and skills; an efficient innovation ecosystem comprised of firms, research centres, universities and other organizations; information and communication technologies

Marketing innovation
The implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion, or pricing

Organizational innovation
The implementation of a new organizational method in the firm's business practices, workplace organization or external relations

Patent and non-patent citations
The references provided in the search report that are used to assess an invention's patentability and help to define the legitimacy of the claims of a new patent application; as they refer to the prior art, they indicate the knowledge that preceded the invention and may also be cited to show the lack of novelty of the citing invention; however, citations also indicate the legal boundaries of the claims of the patent in question; they therefore serve an important legal function,

since they delimit the scope of the property rights awarded by the patent

Patent family
A set of patents taken in various countries for protecting a single invention; an inventor seeking protection files a first application (priority) generally in their country of residence; the inventor then has a 12-month legal delay for applying or not for protection for the original invention in other countries; patent families, as opposed to patents, are provided with the intention of improving international comparability: the home advantage is suppressed; the values of the patents are homogeneous

Private non-profit sector (*for R&D data*)
Non-market, private non-profit institutions serving households (i.e. the general public); and private individuals or households

Product innovation
The implementation of a good or service that is new or significantly improved with respect to its characteristics or intended uses; includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics

Process innovation
The implementation of a new or significantly improved production or delivery method, including significant changes to a technique, equipment and/or software

Purchasing power parities
A given sum of money, when converted into US dollars at the purchasing power parity rate (PPP$), will buy the same basket of goods and services in all countries; this conversion is used to facilitate international comparisons

Research and experimental development (R&D)
Covers basic research, applied research and experimental development, both formal R&D in R&D units and informal or occasional R&D

R&D personnel
All persons employed directly in R&D, as well as those providing direct services such as R&D managers, administrators and clerical staff; persons providing an indirect service, such as canteen and security staff, are excluded; R&D personnel may be classified by occupation (preferred for international comparisons) or by level of formal qualification

Researchers
Professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems, as well as in the management of the projects concerned

Rule of law
The legal principle that law should govern a nation, as opposed to being governed by arbitrary decisions of individual government officials

Scientific and technological services
Activities concerned with research and experimental development (see earlier entry) that contribute to the generation, dissemination and application of scientific and technical knowledge

Sources of information for innovation
Sources that provide information for new projects involving innovation or contribute to the completion of existing projects; they provide access to knowledge without the need to pay for the knowledge itself, although there may be marginal fees for access, such as membership of trade associations, attendance at conferences, subscriptions to journals

Triadic patent family
A set of patents registered at the European Patent Office, and the Japan Patent Office and granted by the US Patent and Trademark Office which share one or more priorities; triadic patent families are consolidated to eliminate double counting of patents filed at different offices by the same inventor for the same invention


3041.05
2988.88

3: Statistical annex

Table S1: Socio–economic indicators, various years

	Population (000's)	Population growth (annual %)	Life expectancy at birth, total (years)	Unemployment, total (% of total labour force)	GDP in current prices (current PPP$ – millions)		GDP per capita (current PPP$)	
	2014	2014	2013	2013	2007	2013	2007	2013
North America								
Canada	35 525	0.97	81.40	7.10	1 290 073	1 502 939	39 226	42 753
United States of America	322 583	0.79	78.84	7.40	14 477 600	16 768 100	48 061	53 042
Latin America								
Argentina	41 803	0.86	76.19	7.50	–	–	–	–
Belize	340	2.34	73.90	14.60	2 222	2 817	7 763	8 487
Bolivia	10 848	1.64	67.22	2.60	44 218	65 426	4 570	6 131
Brazil	202 034	0.83	73.89	5.90	2 291 377	3 012 934	12 060	15 037
Chile	17 773	0.87	79.84	6.00	277 331	386 614	16 638	21 942
Colombia	48 930	1.25	73.98	10.50	430 916	600 341	9 684	12 424
Costa Rica	4 938	1.34	79.92	7.60	50 798	67 605	11 382	13 876
Ecuador	15 983	1.54	76.47	4.20	118 844	171 385	8 329	10 890
El Salvador	6 384	0.68	72.34	6.30	42 637	49 228	6 963	7 764
Guatemala	15 860	2.50	71.99	2.80	86 653	112 865	6 506	7 297
Guyana	804	0.51	66.21	11.10	3 733	5 234	4 845	6 546
Honduras	8 261	1.99	73.80	4.20	29 065	37 189	4 049	4 593
Mexico	123 799	1.19	77.35	4.90	1 551 985	2 002 543	13 670	16 370
Nicaragua	6 169	1.45	74.79	7.20	21 474	28 230	3 838	4 643
Panama	3 926	1.59	77.58	4.10	43 045	75 028	12 330	19 416
Paraguay	6 918	1.68	72.27	5.20	36 921	55 049	6 028	8 093
Peru	30 769	1.29	74.81	3.90	228 549	357 648	8 068	11 774
Suriname	544	0.86	71.03	7.80	6 280	8 667	12 304	16 071
Uruguay	3 419	0.34	77.05	6.60	44 067	66 759	13 200	19 594
Venezuela	30 851	1.46	74.64	7.50	450 739	553 325	16 298	18 198
Caribbean								
Antigua and Barbuda	91	1.02	75.83	–	2 068	1 892	24 504	21 028
Bahamas	383	1.37	75.07	13.60	8 196	8 779	23 960	23 264
Barbados	286	0.50	75.30	12.20	4 201	4 411^{-1}	15 206	15 574^{-1}
Cuba	11 259	–0.06	79.24	3.20	179 772	211 947^{-2}	15 907	18 796^{-2}
Dominica	72	0.47	76.60^{-11}	–	648	745	9 151	10 343
Dominican Rep.	10 529	1.20	73.45	14.90	92 793	126 784	9 651	12 186
Grenada	106	0.38	72.74	–	1 175	1 233	11 347	11 645
Haiti	10 461	1.39	63.06	7.00	14 405	17 571	1 514	1 703
Jamaica	2 799	0.54	73.47	15.00	22 696	24 141	8 524	8 893
St Kitts and Nevis	55	1.10	71.34^{-11}	–	1 062	1 159	21 036	21 396
St Lucia	184	0.72	74.79	–	1 705	1 912	10 021	10 488
St Vincent and the Grenadines	109	0.00	72.50	–	1 063	1 147	9 749	10 491
Trinidad and Tobago	1 344	0.23	69.93	5.80	37 038	40 833	28 272	30 446
European Union								
Austria	8 526	0.37	80.89	4.90	325 501	382 263	39 238	45 079
Belgium	11 144	0.36	80.39	8.40	389 125	464 923	36 621	41 575
Bulgaria	7 168	–0.76	74.47	12.90	97 975	114 292	12 985	15 732
Croatia	4 272	–0.41	77.13	17.70	83 945	90 861	18 924	21 351
Cyprus	1 153	1.04	79.80	15.80	22 334	24 494	28 488	28 224
Czech Rep.	10 740	0.36	78.28	6.90	274 806	305 101	26 683	29 018
Denmark	5 640	0.37	80.30	7.00	211 218	245 834	38 674	43 782
Estonia	1 284	–0.27	76.42	8.80	29 269	34 035	21 831	25 823
Finland	5 443	0.32	80.83	8.20	198 374	216 146	37 509	39 740
France	64 641	0.54	81.97	10.40	2 178 975	2 474 881	34 040	37 532
Germany	82 652	–0.09	81.04	5.30	3 022 124	3 539 320	36 736	43 884
Greece	11 128	0.00	80.63	27.30	324 007	283 041	29 025	25 667
Hungary	9 933	–0.22	75.27	10.20	193 771	230 867	19 270	23 334
Ireland	4 677	1.08	81.04	13.10	205 290	210 037	46 668	45 684
Italy	61 070	0.13	82.29	12.20	1 971 193	2 125 098	33 731	35 281
Latvia	2 041	–0.45	73.98	11.10	39 032	45 422	17 739	22 569
Lithuania	3 008	–0.29	74.16	11.80	61 649	75 284	19 079	25 454
Luxembourg	537	1.20	81.80	5.90	38 890	49 472	81 023	91 048
Malta	430	0.27	80.75	6.50	9 607	12 332	23 621	29 127
Netherlands	16 802	0.26	81.10	6.70	709 976	775 728	43 340	46 162
Poland	38 221	0.01	76.85	10.40	643 934	912 404	16 892	23 690
Portugal	10 610	0.02	80.37	16.50	265 937	290 756	25 224	27 804
Romania	21 640	–0.27	74.46	7.30	275 071	379 134	13 172	18 974
Slovakia	5 454	0.07	76.26	14.20	115 184	143 437	21 431	26 497
Slovenia	2 076	0.17	80.28	10.20	55 863	59 448	27 681	28 859
Spain	47 066	0.30	82.43	26.60	1 483 742	1 542 768	32 807	33 094
Sweden	9 631	0.63	81.70	8.10	371 092	428 736	40 565	44 658
United Kingdom	63 489	0.56	80.96	7.50	2 294 882	2 452 672	37 423	38 259
Southeast Europe								
Albania	3 185	0.38	77.54	16.00	22 748	28 774	7 659	9 931
Bosnia and Herzegovina	3 825	–0.12	76.28	28.40	30 167	36 515	7 798	9 536
FYR Macedonia	2 108	0.06	75.19	29.00	19 422	24 468	9 264	11 612
Montenegro	622	0.03	74.76	19.80	7 689	8 781	12 446	14 132
Serbia	9 468	–0.44	75.14	22.20	77 164	93 276	10 454	13 020

	GDP growth (annual %)				GDP per economic sector (share of GDP)				Inflation, consumer prices (annual %)	Internet users per 100 inhabitants	Mobile phone subscriptions per 100 inhabitants	Human Development Index (rank)	Global Innovation Index (rank)
					Agriculture	Services	Industry	Manufact–uring (subset of industry)					
	2007	2009	2011	2013	2013				2014	2013	2013	2013	2015
	2.01	-2.71	2.53	2.02	1.52^{-3}	70.79^{-3}	27.69^{-3}	10.68^{-3}	1.91	85.80	80.61	8	16
	1.77	-2.80	1.60	2.22	1.31^{-1}	77.71^{-1}	20.98^{-1}	12.96^{-1}	1.62	84.20	95.53	5	5
	8.00	0.05	8.55	2.93	6.98	64.56	28.46	15.27	–	59.90	162.53	49	72
	1.11	0.71	2.10	1.53	15.34	65.55	19.11	11.47	0.65^{-1}	31.70	52.61	84	–
	4.56	3.36	5.17	6.78	13.32	48.56	38.12	13.27	5.78	39.50	97.70	113	104
	6.10	–0.33	2.73	2.49	5.71	69.32	24.98	13.13	6.33	51.60	135.31	79	70
	5.16	-1.04	5.84	4.07	3.44	61.28	35.29	11.48	4.40	66.50	134.29	41	42
	6.90	1.65	6.59	4.68	6.12	56.67	37.21	12.31	2.88	51.70	104.08	98	67
	7.94	-1.02	4.51	3.50	5.64	69.16	25.20	16.06	4.53	45.96	145.97	68	51
	2.19	0.57	7.87	4.64	9.37	51.97	38.66	13.05	3.57	40.35	111.46	98	119
	3.84	-3.13	2.22	1.68	10.84	62.20	26.95	20.17	1.11	23.11	136.19	115	99
	6.30	0.53	4.16	3.69	11.31	59.68	29.01	20.24	3.42	19.70	140.39	125	101
	7.02	3.32	5.44	5.22	21.92	45.30	32.78	3.71	1.83^{-1}	33.00	69.41	121	86
	6.19	-2.43	3.84	2.56	13.39	59.32	27.29	18.81	6.13	17.80	95.92	129	113
	3.15	-4.70	4.04	1.07	3.48	61.71	34.81	17.76	4.02	43.46	85.84	71	57
	5.29	-2.76	5.69	4.61	16.92	52.21	30.87	19.33	6.02	15.50	111.98	132	130
	12.11	3.97	10.77	8.35	3.47^{-1}	74.41^{-1}	22.11^{-1}	5.75^{-1}	2.64	42.90	162.97	65	62
	5.42	-3.97	4.34	14.22	21.59	50.00	28.41	11.63	5.03	36.90	103.69	111	88
	8.52	1.05	6.45	5.79	7.31^{-6}	51.58^{-6}	41.11^{-6}	18.01^{-6}	3.23	39.20	98.08	82	71
	5.11	3.01	5.27	2.88	7.01	44.37	48.62	16.41	3.35	37.40	161.07	100	–
	6.54	2.35	7.34	4.40	9.96	64.65	25.40	12.61	8.88	58.10	154.62	50	68
	8.75	-3.20	4.18	1.34	5.79^{-3}	42.05^{-3}	52.16^{-3}	13.92^{-3}	40.64^{-1}	54.90	101.61	67	132
	9.50	-12.04	-1.79	–0.07	2.28	79.66	18.05	2.95	1.06^{-1}	63.40	127.09	61	–
	1.45	-4.18	1.06	0.67	1.98	79.74	18.28	4.32	1.18	72.00	76.05	51	–
	1.67	-4.14	0.76	0.01^{-1}	1.47^{-1}	82.86^{-1}	15.67^{-1}	6.94^{-1}	1.80^{-1}	75.00	108.10	59	37
	7.26	1.45	2.71	–	5.00^{-2}	74.48^{-2}	20.53^{-2}	10.72^{-2}	–	25.71	17.71	44	–
	6.05	-1.14	–0.08	–0.91	17.17	68.78	14.04	3.47	$–0.05^{-1}$	59.00	129.96	93	–
	8.47	0.94	2.93	4.58	6.32	66.75	26.93	15.92	3.00	45.90	88.43	102	89
	6.12	-6.61	0.76	2.42	5.61	79.19	15.20	3.65	$–0.04^{-1}$	35.00	125.59	79	–
	3.34	3.08	5.52	4.30	–	–	–	–	4.57	10.60	69.40	168	–
	1.40	-4.41	1.70	1.27	6.72^{-1}	72.46^{-1}	20.82^{-1}	9.22^{-1}	8.29	37.80	102.24	96	96
	2.83	-5.60	1.70	4.21	1.68	72.78	25.54	11.01	0.72^{-1}	80.00	142.09	73	–
	–0.47	0.65	1.24	–0.43	3.06	82.56	14.38	3.07	1.47^{-1}	35.20	116.31	97	–
	3.31	-2.10	–0.48	1.66	7.12	75.15	17.73	4.72	0.81^{-1}	52.00	114.63	91	–
	4.75	-4.39	-1.60	1.60	0.62	42.86	56.53	6.38	5.20^{-1}	63.80	144.94	64	80
	3.62	-3.80	3.07	0.23	1.44	70.34	28.22	18.50	1.61	80.62	156.23	21	18
	3.00	-2.62	1.64	0.27	0.83	76.67	22.50	14.22	0.34	82.17	110.90	21	25
	6.91	-5.01	1.98	1.07	5.47	66.60	27.94	–	-1.42	53.06	145.19	58	39
	5.15	-7.38	–0.28	–0.94	4.25	68.57	27.18	13.97	–0.21	66.75	114.51	47	40
	5.13	-1.67	0.40	-5.40	2.08^{-5}	78.33^{-5}	19.59^{-5}	7.56^{-5}	-1.35	65.45	96.36	32	34
	5.53	-4.84	1.96	–0.70	2.61	60.70	36.69	24.89	0.34	74.11	127.73	28	24
	0.82	-5.09	1.15	–0.49	1.36	75.78	22.85	13.73	0.56	94.63	127.12	10	10
	7.90	-14.74	8.28	1.63	3.59	67.46	28.95	15.86	–0.14	80.00	159.66	33	23
	5.18	-8.27	2.57	-1.21	2.68	70.45	26.87	16.62	1.04	91.51	171.57	24	6
	2.36	-2.94	2.08	0.29	1.69	78.49	19.82	11.34	0.51	81.92	98.50	20	21
	3.27	-5.64	3.59	0.11	0.86	68.43	30.71	22.22	0.91	83.96	120.92	6	12
	3.54	-4.39	-8.86	-3.32	3.80	82.41	13.79	8.48	-1.31	59.87	116.82	29	45
	0.51	-6.55	1.81	1.53	4.37	65.41	30.22	22.76	–0.24	72.64	116.43	43	35
	4.93	-6.37	2.77	0.17	1.56	74.34	24.10	19.44	0.20	78.25	102.76	11	8
	1.47	-5.48	0.59	-1.93	2.31	74.42	23.27	14.86	0.24	58.46	158.82	26	31
	9.98	-17.95	5.30	4.11	4.14^{-3}	74.05^{-3}	21.81^{-3}	12.18^{-3}	0.63	75.23	228.40	48	33
	9.84	-14.74	6.00	3.25	3.46^{-3}	68.72^{-3}	27.81^{-3}	–	0.08	68.45	151.34	35	38
	6.46	-5.33	2.61	1.99	0.34	87.47	12.19	5.18	0.63	93.78	148.64	21	9
	4.28	-2.80	1.40	2.90	1.92^{-3}	65.38^{-3}	32.70^{-3}	13.41^{-3}	0.31	68.91	129.75	39	26
	4.20	-3.30	1.66	–0.73	1.97	75.88	22.16	12.11	0.99	93.96	113.73	4	4
	7.20	2.63	4.76	1.67	3.30	63.45	33.25	18.84	0.11	62.85	149.08	35	46
	2.49	-2.98	-1.83	-1.36	2.29	76.65	21.05	12.67	–0.28	62.10	113.04	41	30
	6.26	-6.80	2.31	3.50	6.35	50.40	43.25	–	1.07	49.76	105.58	54	54
	10.68	-5.29	2.70	1.42	4.04	62.73	33.23	20.24	–0.08	77.88	113.91	37	36
	6.94	-7.80	0.61	-1.00	2.14	65.85	32.02	22.32	0.20	72.68	110.21	25	28
	3.77	-3.57	–0.62	-1.23	2.77	73.89	23.34	–	–0.15	71.57	106.89	27	27
	3.40	-5.18	2.66	1.50	1.44	72.71	25.85	16.47	–0.18	94.78	124.40	12	3
	2.56	-4.31	1.65	1.73	0.65	79.16	20.19	9.70	1.46	89.84	124.61	14	2
	5.90	3.35	2.55	1.42	22.24	62.49	15.27	8.94	1.63	60.10	116.16	95	87
	6.84	-2.91	0.96	2.48	8.46	64.43	27.10	13.24	–0.93	67.90	91.10	86	79
	6.15	–0.92	2.80	3.10	10.45	63.38	26.17	11.63	–0.28	61.20	106.17	84	56
	10.66	-5.66	3.23	3.34	9.80	71.36	18.84	5.03	–0.71	56.80	159.95	51	41
	5.89	-3.12	1.40	2.60	8.99^{-1}	60.72^{-1}	30.29^{-1}	18.07^{-1}	2.08	51.50	119.39	77	63

Table S1: Socio–economic indicators, various years

	Population (000's)	Population growth (annual %)	Life expectancy at birth, total (years)	Unemployment, total (% of total labour force)	GDP in current prices (current PPP$ – millions)		GDP per capita (current PPP$)	
	2014	2014	2013	2013	2007	2013	2007	2013
Other Europe and West Asia								
Armenia	2 984	0.25	74.54	16.20	19 373	23 147	6 480	7 776
Azerbaijan	9 515	1.07	70.69	5.50	107 072	161 433	12 477	17 143
Belarus	9 308	–0.53	72.47	5.80	118 019	166 789	12 345	17 620
Georgia	4 323	–0.42	74.08	14.30	23 816	32 128	5 427	7 160
Iran, Islamic Rep. of	78 470	1.31	74.07	13.20	995 290	1 207 413	13 860	15 590
Israel	7 822	1.14	82.06	6.30	195 303	261 858	27 201	32 491
Moldova, Rep. of	3 461	–0.74	68.81	5.10	12 094	16 622	3 381	4 671
Russian Federation	142 468	–0.26	71.07	5.60	2 377 503	3 623 076	16 729	25 248
Turkey	75 837	1.20	75.18	10.00	975 733	1 407 448	14 040	18 783
Ukraine	44 941	–0.66	71.16	7.90	373 877	399 853	8 039	8 790
European Free Trade Assoc.								
Iceland	333	1.09	83.12	5.60	12 147	13 552	38 986	41 859
Liechtenstein	37[-2]	0.99[-2]	82.38	–	–	–	–	–
Norway	5 092	0.97	81.45	3.50	262 828	327 192	55 812	64 406
Switzerland	8 158	0.99	82.75	4.40	357 994	460 605	47 409	56 950
Sub–Saharan Africa								
Angola	22 137	3.05	51.87	6.80	107 683	166 108	6 079	7 736
Benin	10 600	2.64	59.29	1.00	13 255	18 487	1 522	1 791
Botswana	2 039	0.86	47.41	18.40	23 820	31 837	12 437	15 752
Burkina Faso	17 420	2.82	56.28	3.10	17 783	28 526	1 249	1 684
Burundi	10 483	3.10	54.10	6.90	5 593	7 843	672	772
Cabo Verde	504	0.95	74.87	7.00	2 582	3 201	5 338	6 416
Cameroon	22 819	2.51	55.04	4.00	46 126	62 982	2 415	2 830
Central African Rep.	4 709	1.99	50.14	7.60	3 061	2 787	745	604
Chad	13 211	2.96	51.16	7.00	17 680	26 787	1 653	2 089
Comoros	752	2.36	60.86	6.50	847	1 063	1 339	1 446
Congo	4 559	2.46	58.77	6.50	17 372	26 101	4 622	5 868
Congo, Dem. Rep. of	69 360	2.70	49.94	8.00	34 290	54 633	600	809
Côte d'Ivoire	20 805	2.38	50.76	4.00	47 874	65 224	2 667	3 210
Djibouti	886	1.52	61.79	–	1 805	2 618	2 260	2 999
Equatorial Guinea	778	2.74	53.11	8.00	22 192	25 563	34 696	33 768
Eritrea	6 536	3.16	62.75	7.20	6 118	7 572	1 174	1 196
Ethiopia	96 506	2.52	63.62	5.70	65 402	129 859	813	1 380
Gabon	1 711	2.34	63.44	19.60	23 436	32 204	16 192	19 264
Gambia	1 909	3.18	58.83	7.00	2 202	3 072	1 440	1 661
Ghana	26 442	2.05	61.10	4.60	57 529	103 413	2 554	3 992
Guinea	12 044	2.51	56.09	1.80	11 388	14 718	1 133	1 253
Guinea–Bissau	1 746	2.41	54.27	7.10	1 836	2 398	1 237	1 407
Kenya	45 546	2.65	61.68	9.20	85 923	123 968	2 276	2 795
Lesotho	2 098	1.10	49.33	24.70	3 604	5 344	1 843	2 576
Liberia	4 397	2.37	60.53	3.70	1 841	3 770	523	878
Madagascar	23 572	2.78	64.69	3.60	26 784	32 416	1 383	1 414
Malawi	16 829	2.81	55.23	7.60	8 287	12 763	604	780
Mali	15 768	3.00	55.01	8.20	18 892	25 123	1 485	1 642
Mauritius	1 249	0.38	74.46	8.30	16 243	22 296	13 103	17 714
Mozambique	26 473	2.44	50.17	8.30	17 459	28 548	787	1 105
Namibia	2 348	1.92	64.34	16.90	15 868	22 073	7 626	9 583
Niger	18 535	3.87	58.44	5.10	10 683	16 337	752	916
Nigeria	178 517	2.78	52.50	7.50	627 891	972 664	4 266	5 602
Rwanda	12 100	2.71	63.99	0.60	10 164	17 354	1 024	1 474
Sao Tome and Principe	198	2.50	66.26	–	388	573	2 378	2 971
Senegal	14 548	2.89	63.35	10.30	24 042	31 687	2 019	2 242
Seychelles	93	0.50	74.23	–	1 670	2 193	19 636	24 587
Sierra Leone	6 205	1.84	45.55	3.20	6 376	9 407	1 177	1 544
Somalia	10 806	2.91	55.02	6.90	–	–	–	–
South Africa	53 140	0.69	56.74	24.90	552 487	683 974	11 355	12 867
South Sudan	11 739	3.84	55.24	–	–	22 928	–	2 030
Swaziland	1 268	1.45	48.94	22.50	6 933	8 353	6 108	6 685
Tanzania	50 757	3.01	61.49	3.50	73 946	116 832	1 852	2 443
Togo	6 993	2.55	56.49	6.90	6 727	9 479	1 153	1 391
Uganda	38 845	3.31	59.19	3.80	39 569	62 918	1 288	1 674
Zambia	15 021	3.26	58.09	13.30	33 098	57 071	2 733	3 925
Zimbabwe	14 599	3.13	59.77	5.40	18 817	25 923	1 477	1 832
Arab States								
Algeria	39 929	1.82	71.01	9.80	406 365	522 262	11 578	13 320
Bahrain	1 344	0.89	76.67	7.40	42 068	58 417	40 750	43 851
Egypt	83 387	1.61	71.13	12.70	662 430	909 941	8 924	11 089
Iraq	34 769	2.93	69.47	16.00	302 127	499 627	10 512	14 951
Jordan	7 505	3.13	73.90	12.60	55 395	76 116	9 785	11 783
Kuwait	3 479	3.24	74.46	3.10	227 278	272 521[-1]	88 957	83 840[-1]
Lebanon	4 966	2.94	80.13	6.50	51 183	76 722	12 364	17 174
Libya	6 253	0.83	75.36	19.60	154 764	130 519	26 766	21 046

	GDP growth (annual %)				GDP per economic sector (share of GDP)				Inflation, consumer prices (annual %)	Internet users per 100 inhabitants	Mobile phone subscriptions per 100 inhabitants	Human Development Index (rank)	Global Innovation Index (rank)
					Agriculture	Services	Industry	Manufact–uring (subset of industry)					
	2007	2009	2011	2013	2013				2014	2013	2013	2013	2015
	13.75	-14.15	4.70	3.50	21.94	46.58	31.48	11.41	2.98	46.30	112.42	87	61
	25.05	9.41	0.07	5.80	5.66	32.27	62.07	4.52	2.42^{-1}	58.70	107.61	76	93
	8.60	0.20	5.54	0.89	9.11	48.65	42.24	26.84	18.12	54.17	118.79	53	53
	12.34	-3.78	7.20	3.32	9.41	66.57	24.02	13.40	3.07	43.10	115.03	79	73
	7.82	3.94	3.00	-5.80	10.22^{-6}	45.31^{-6}	44.47^{-6}	10.55^{-6}	17.24	31.40	84.25	75	106
	6.27	1.90	4.19	3.25	–	–	–	–	0.48	70.80	122.85	19	22
	3.00	-6.00	6.80	8.90	15.04	68.39	16.57	13.64	5.09	48.80	106.01	114	44
	8.54	-7.82	4.26	1.32	3.95	59.78	36.27	14.82	7.83	61.40	152.84	57	48
	4.67	-4.83	8.77	4.12	8.49	64.44	27.07	17.63	8.85	46.25	92.96	69	58
	7.90	-14.80	5.20	1.88	10.43	62.64	26.94	13.71	12.21	41.80	138.06	83	64
	9.72	-5.15	2.13	3.46	7.73^{-1}	67.81^{-1}	24.47^{-1}	13.48^{-1}	2.03	96.55	108.11	13	13
	3.33	-1.16	–	–	–	–	–	–	–	93.80	104.07	18	–
	2.65	-1.63	1.34	0.65	1.55	57.66	40.79	7.29	2.03	95.05	116.27	1	20
	4.14	-2.13	1.80	1.92	0.71	73.56	25.73	18.69	–0.01	86.70	136.78	3	1
	22.59	2.41	3.92	6.80	10.06	32.14	57.80	7.21	7.28	19.10	61.87	149	120
	4.63	2.66	3.26	5.64	36.52	49.46	14.01	8.17	-1.10	4.90	93.26	165	–
	8.68	-7.84	6.18	5.83	2.54	60.54	36.92	5.68	4.40	15.00	160.64	109	90
	4.11	2.87	6.63	6.65	22.87	47.76	29.38	6.42	–0.26	4.40	66.38	181	102
	4.79	3.47	4.19	4.59	39.83	42.44	17.73	9.46	4.38	1.30	24.96	180	136
	15.17	-1.27	3.97	0.54	8.10^{-1}	74.87^{-1}	17.03^{-1}	–	–0.24	37.50	100.11	123	103
	3.26	1.93	4.14	5.56	22.89	47.24	29.87	14.39	1.95^{-1}	6.40	70.39	152	110
	8.12	8.91	3.30	-36.00	54.32^{-1}	31.95^{-1}	13.73^{-1}	6.48^{-1}	1.50^{-1}	3.50	29.47	185	–
	3.27	4.22	0.08	3.97	51.50	33.09	15.41	2.70	0.15^{-1}	2.30	35.56	184	–
	0.80	1.95	2.60	3.50	37.08	50.40	12.52	7.02	2.30^{-1}	6.50	47.28	159	–
	-1.58	7.47	3.42	3.44	4.36	23.62	72.02	4.30	5.97^{-1}	6.60	104.77	140	–
	6.26	2.86	6.87	8.48	20.79	40.97	38.24	16.55	1.63^{-1}	2.20	41.82	186	–
	1.77	3.25	-4.39	8.70	22.28	55.45	22.27	12.75	0.46	2.60	95.45	171	116
	5.10	5.00	5.39	5.00	3.86^{-6}	79.26^{-6}	16.89^{-6}	2.45^{-6}	2.42^{-1}	9.50	27.97	170	–
	13.14	-8.07	5.00	-4.84	–	6.44	–	–	6.35^{-1}	16.40	67.47	144	–
	1.43	3.88	8.68	1.33	14.53^{-4}	63.03^{-4}	22.44^{-4}	5.65^{-4}	–	0.90	5.60	182	–
	11.46	8.80	11.18	10.49	45.03	43.02	11.95	4.04	7.39	1.90	27.25	173	127
	5.55	-2.90	7.10	5.89	4.02^{-1}	31.96^{-1}	64.02^{-1}	–	0.48^{-1}	9.20	214.75	112	–
	3.63	6.45	-4.33	4.80	–	–	–	–	5.95	14.00	99.98	172	112
	6.46	3.99	15.01	7.59	21.86	49.61	28.53	5.78	15.49	12.30	108.19	138	108
	1.76	–0.28	3.91	2.30	20.24	42.09	37.67	6.48	11.89^{-1}	1.60	63.32	179	139
	3.20	3.31	9.03	0.33	43.68	42.65	13.67	–	-1.02	3.10	74.09	177	–
	6.99	3.31	6.12	5.74	29.51	50.67	19.81	11.72	6.88	39.00	71.76	147	92
	4.73	3.36	2.84	5.49	8.30^{-1}	59.88^{-1}	31.82^{-1}	11.65^{-1}	5.34	5.00	86.30	162	118
	15.69	13.76	9.13	11.31	38.84^{-1}	44.75^{-1}	16.41^{-1}	3.32^{-1}	7.57^{-1}	4.60	59.40	175	–
	6.24	-4.01	1.45	2.41	26.37	57.48	16.15	–	6.08	2.20	36.91	155	125
	9.49	9.04	4.35	4.97	26.96	54.25	18.79	10.74	24.43	5.40	32.33	174	98
	4.30	4.46	2.73	2.15	42.26^{-1}	35.01^{-1}	22.73^{-1}	–	0.89	2.30	129.07	176	105
	5.90	3.00	3.90	3.20	3.22	72.49	24.29	17.04	3.22	39.00	123.24	63	49
	7.28	6.48	7.44	7.44	28.99	50.22	20.79	10.86	4.26^{-1}	5.40	48.00	178	95
	6.62	0.30	5.12	5.12	6.14	60.49	33.36	13.16	5.35	13.90	118.43	127	107
	3.15	–0.71	2.31	4.10	37.20	43.36	19.44	6.11	–0.92	1.70	39.29	187	134
	6.83	6.93	4.89	5.39	21.00	57.01	21.99	9.03	8.06	38.00	73.29	152	128
	7.61	6.27	7.85	4.68	33.39	51.73	14.88	5.20	1.27	8.70	56.80	151	94
	2.00	4.02	4.94	4.00	19.78^{-2}	64.29^{-2}	15.93^{-2}	6.41^{-2}	6.43	23.00	64.94	142	–
	4.94	2.42	2.07	2.80	17.52	58.44	24.03	13.56	-1.08	20.90	92.93	163	84
	10.06	-1.11	7.92	5.28	2.37	86.28	11.34	6.27	1.39	50.40	147.34	71	65
	8.04	3.15	5.77	5.52	59.47	32.57	7.96	2.04	7.33	1.70	65.66	183	–
	–	–	–	–	–	–	–	–	–	1.50	49.38	–	–
	5.36	-1.54	3.21	2.21	2.32	67.79	29.90	13.23	5.56	48.90	145.64	118	60
	–	5.04	-4.64	13.13	–	–	–	–	47.28^{-3}	–	25.26	–	–
	3.50	1.25	–0.66	2.78	7.48^{-2}	44.83^{-2}	47.69^{-2}	43.83^{-2}	5.62^{-1}	24.70	71.47	148	123
	7.15	5.40	7.92	7.28	33.85	42.97	23.18	7.36	6.13	4.40	55.72	159	117
	2.29	3.51	4.88	5.12	30.76^{-2}	53.70^{-2}	15.54^{-2}	8.09^{-2}	0.01	4.50	62.53	166	140
	8.41	7.25	9.67	3.27	25.26	53.98	20.76	10.01	4.29	16.20	44.09	164	111
	8.35	9.22	6.34	6.71	9.64	56.50	33.85	8.18	7.81	15.40	71.50	141	124
	-3.65	5.98	11.91	4.48	12.00	56.90	31.10	12.82	1.63^{-1}	18.50	96.35	156	133
	3.40	1.60	2.80	2.80	10.54	41.85	47.61	–	2.92	16.50	100.79	93	126
	8.29	2.54	2.10	5.34	–	–	–	–	2.77	90.00	165.91	44	59
	7.09	4.67	1.76	2.10	14.51	46.32	39.17	15.65	10.20	49.56	121.51	110	100
	1.38	5.81	10.21	4.21	–	–	–	–	1.88^{-1}	9.20	96.10	120	–
	8.18	5.48	2.56	2.83	3.40	66.91	29.69	19.42	2.81	44.20	141.80	77	75
	5.99	-7.08	10.21	8.31^{-1}	0.35	26.34	73.31	6.77	2.53	75.46	190.29	46	77
	9.40	10.30	2.00	0.90	7.18	73.07	19.76	8.63	3.99^{-4}	70.50	80.56	65	74
	6.00	2.10	-62.08	-10.88	1.87^{-5}	19.94^{-5}	78.20^{-5}	4.49^{-5}	2.61^{-1}	16.50	165.04	55	–

Table S1: Socio–economic indicators, various years

	Population (000's)	Population growth (annual %)	Life expectancy at birth, total (years)	Unemployment, total (% of total labour force)	GDP in current prices (current PPP$ – millions)		GDP per capita (current PPP$)	
	2014	2014	2013	2013	2007	2013	2007	2013
Mauritania	3 984	2.40	61.51	31.00	8 523	11 836	2 560	3 043
Morocco	33 493	1.46	70.87	9.20	170 875	241 682	5 489	7 198
Oman	3 926	7.78	76.85	7.90	108 310	150 236^{-1}	42 148	45 334^{-1}
Palestine	4 436	2.51	73.20	23.40	13 218	19 916^{-1}	3 782	4 921^{-1}
Qatar	2 268	4.47	78.61	0.50	138 537	296 517	120 210	136 727
Saudi Arabia	29 369	1.86	75.70	5.70	999 859	1 546 500	38 581	53 644
Sudan	38 764	2.08	62.04	15.20	129 873	128 053	3 096	3 373
Syrian Arab Rep.	21 987	0.40	74.72	10.80	–	–	–	–
Tunisia	11 117	1.09	73.65	13.30	92 335	121 107	9 030	11 124
United Arab Emirates	9 446	1.06	77.13	3.80	453 316	550 915^{-1}	78 194	59 845^{-1}
Yemen	24 969	2.27	63.09	17.40	86 896	96 636	4 102	3 959
Central Asia								
Kazakhstan	16 607	1.01	70.45	5.20	268 714	395 463	17 354	23 214
Kyrgyzstan	5 625	1.39	70.20	8.00	12 902	18 376	2 449	3 213
Mongolia	2 881	1.48	67.55	4.90	14 472	26 787	5 577	9 435
Tajikistan	8 409	2.42	67.37	10.70	12 714	20 620	1 788	2 512
Turkmenistan	5 307	1.27	65.46	10.60	35 860	73 383	7 381	14 004
Uzbekistan	29 325	1.34	68.23	10.70	88 095	156 295	3 279	5 168
South Asia								
Afghanistan	31 281	2.36	60.93	8.00	32 219	59 459	1 223	1 946
Bangladesh	158 513	1.22	70.69	4.30	297 842	461 644	2 034	2 948
Bhutan	766	1.53	68.30	2.10	3 525	5 583	5 189	7 405
India	1 267 402	1.21	66.46	3.60	4 156 058	6 783 778	3 586	5 418
Maldives	352	1.88	77.94	11.60	2 832	4 022	9 186	11 657
Nepal	28 121	1.16	68.40	2.70	43 493	62 400	1 676	2 245
Pakistan	185 133	1.63	66.59	5.10	647 797	838 164	3 952	4 602
Sri Lanka	21 446	0.81	74.24	4.20	124 345	199 466	6 205	9 738
Southeast Asia								
Brunei Darussalam	423	1.29	78.57	3.80	26 973	29 987	70 714	71 777
Cambodia	15 408	1.79	71.75	0.30	30 059	46 027	2 187	3 041
China	1 393 784	0.59	75.35	4.60	8 796 899	16 161 655	6 675	11 907
China, Hong Kong SAR	7 260	0.77	83.83	3.30	299 425	382 490	43 293	53 216
China, Macao SAR	575	1.59	80.34	1.80	37 088	80 765	75 197	142 599
Indonesia	252 812	1.17	70.82	6.30	1 544 770	2 388 997	6 688	9 561
Japan	127 000	–0.11	83.33	4.00	4 264 207	4 612 630	33 314	36 223
Korea, DPR	25 027	0.53	69.81	4.60	–	–	–	–
Korea, Rep. of	49 512	0.50	81.46	3.10	1 354 518	1 660 385	27 872	33 062
Lao PDR	6 894	1.82	68.25	1.40	18 685	32 644	3 107	4 822
Malaysia	30 188	1.57	75.02	3.20	489 960	693 535	18 273	23 338
Myanmar	53 719	0.86	65.10	3.40	–	–	–	–
Philippines	100 096	1.72	68.71	7.10	435 875	643 088	4 904	6 536
Singapore	5 517	1.93	82.35	2.80	294 619	425 259	64 207	78 763
Thailand	67 223	0.32	74.37	0.70	743 320	964 518	11 249	14 394
Timor–Leste	1 152	1.71	67.52	4.40	1 266	2 386^{-1}	1 246	2 076^{-1}
Viet Nam	92 548	0.94	75.76	2.00	310 033	474 958	3 681	5 294
Oceania								
Australia	23 630	1.22	82.20	5.70	761 369	999 241	36 556	43 202
New Zealand	4 551	1.01	81.41	6.20	121 926	154 281	28 866	34 732
Cook Islands	16	0.27	–	–	–	–	–	–
Fiji	887	0.67	69.92	8.10	5 610	6 829	6 716	7 750
Kiribati	104	1.54	68.85	–	157	190	1 679	1 856
Marshall Islands	53	0.26	65.24^{-13}	–	170	205	3 255	3 901
Micronesia	104	0.34	68.96	–	323	352	3 073	3 395
Nauru	11	1.91	–	–	–	–	–	–
Niue	1	-2.12	–	–	–	–	–	–
Palau	21	0.63	69.13^{-8}	–	298	316	14 811	15 096
Papua New Guinea	7 476	2.09	62.43	2.10	11 472	19 349	1 793	2 643
Samoa	192	0.76	73.26	–	983	1 098	5 393	5 769
Solomon Islands	573	2.05	67.72	3.80	805	1 161	1 637	2 069
Tonga	106	0.43	72.64	–	454	559	4 438	5 304
Tuvalu	11	0.53	–	–	30	36	3 044	3 645
Vanuatu	258	2.17	71.69	–	587	756	2 670	2 991

Source:
Population: United Nations, Department of Economic and Social Affairs, Population Division, 2013; World Population Prospects: The 2012 Revision
Human Development Index (rank): Human Development Report 2014: Sustaining Human Progress: Reducing Vulnerabilities and Building Resilience, Human Development Report Office (HDRO), United Nations Development Programme (UNDP)
Global Innovation Index (rank): Cornell University, INSEAD, and WIPO (2015): The Global Innovation Index 2015: Effective Innovation Policies for Development, Fontainebleau, Ithaca, and Geneva. GDP related data and all the other data not specified under above sources: World Bank; World Development Indicators, as of April 2015

	GDP growth (annual %)				GDP per economic sector (share of GDP)				Inflation, consumer prices (annual %)	Internet users per 100 inhabitants	Mobile phone subscriptions per 100 inhabitants	Human Development Index (rank)	Global Innovation Index (rank)
					Agriculture	Services	Industry	Manufact–uring (subset of industry)					
	2007	2009	2011	2013	2013				2014	2013	2013	2013	2015
	1.02	-1.22	3.99	6.72	15.46	43.02	41.53	4.14	4.13^{-1}	6.20	102.53	161	–
	2.71	4.76	4.99	4.38	16.57	54.90	28.53	15.44	0.44	56.00	128.53	129	78
	4.45	6.11	0.88	5.76^{-1}	1.27	31.39	67.34	10.67	1.01	66.45	154.65	56	69
	-1.77	20.94	7.89	-4.43	5.33^{-1}	69.60^{-1}	25.07^{-1}	16.24^{-1}	2.75^{-5}	46.60	73.74	107	–
	17.99	11.96	13.02	6.32	0.09	30.28	69.62	9.94	2.99	85.30	152.64	31	50
	5.99	1.83	8.57	3.95	1.84	37.59	60.57	10.09	2.67	60.50	184.20	34	43
	11.52	3.23	-3.29	-6.00	28.15	50.17	21.68	8.19	29.96^{-1}	22.70	72.85	166	141
	5.70	–	–	–	17.94^{-6}	49.09^{-6}	32.97^{-6}	–	36.70^{-2}	26.20	56.13	118	–
	6.23	3.61	–0.51	2.52	8.61	61.41	29.98	16.97	4.94	43.80	115.60	90	76
	3.18	-5.24	4.89	5.20	0.66	40.33	59.02	8.53	2.34	88.00	171.87	40	47
	3.34	4.13	-15.09	4.16	10.15^{-7}	40.61^{-7}	49.25^{-7}	7.76^{-7}	10.97^{-1}	20.00	69.01	154	137
	8.90	1.20	7.50	6.00	4.93	58.18	36.89	11.64	6.72	54.00	184.69	70	82
	8.54	2.89	5.96	10.53	17.73	55.59	26.67	15.59	7.53	23.40	121.45	125	109
	10.25	-1.27	17.51	11.74	16.47	50.26	33.27	7.17	13.02	17.70	124.18	103	66
	7.80	3.80	7.40	7.40	27.41	50.84	21.75	11.19	6.10	16.00	91.83	133	114
	11.06	6.10	14.70	10.20	14.55^{-1}	37.01^{-1}	48.44^{-1}	–	–	9.60	116.89	103	–
	9.50	8.10	8.30	8.00	19.14	54.59	26.27	10.51	–	38.20	74.31	116	122
	13.74	21.02	6.11	1.93	23.97	54.84	21.19	12.10	4.62	5.90	70.66	169	–
	7.06	5.05	6.46	6.01	16.28	56.09	27.64	17.27	6.99	6.50	74.43	142	129
	17.93	6.66	7.89	2.04	17.08	38.27	44.65	8.98	8.21	29.90	72.20	136	121
	9.80	8.48	6.64	6.90	17.95	51.31	30.73	17.26	6.35	15.10	70.78	135	81
	10.56	-3.64	6.48	3.71	4.20^{-1}	73.28^{-1}	22.52^{-1}	7.08^{-1}	2.12	44.10	181.19	103	–
	3.41	4.53	3.42	3.78	35.10	49.19	15.71	6.59	8.37	13.30	76.85	145	135
	4.83	2.83	2.75	4.41	25.11	53.81	21.08	14.01	7.19	10.90	70.13	146	131
	6.80	3.54	8.25	7.25	10.76	56.78	32.46	17.71	3.28	21.90	95.50	73	85
	0.15	-1.76	3.43	-1.75	0.73	31.03	68.24	12.35	–0.19	64.50	112.21	30	–
	10.21	0.09	7.07	7.41	33.52	40.83	25.65	16.44	3.86	6.00	133.89	136	91
	14.16	9.21	9.30	7.67	10.01	46.09	43.89	31.83	1.99	45.80	88.71	91	29
	6.46	-2.46	4.79	2.93	0.06	92.74	7.20	1.46	4.43	74.20	237.35	15	11
	14.33	1.71	21.29	11.89	0.00^{-1}	93.76^{-1}	6.24^{-1}	0.71^{-1}	6.04	65.80	304.08	–	–
	6.35	4.63	6.49	5.78	14.43	39.87	45.69	23.70	6.39	15.82	125.36	108	97
	2.19	-5.53	–0.45	1.61	1.22^{-1}	73.18^{-1}	25.60^{-1}	18.17^{-1}	2.74	86.25	117.63	17	19
	–	–	–	–	–	–	–	–	–	0.00^{-1}	9.72	–	–
	5.46	0.71	3.68	2.97	2.34	59.11	38.55	31.10	1.27	84.77	111.00	15	14
	7.60	7.50	8.04	8.52	26.51	40.43	33.06	8.25	6.36^{-1}	12.50	68.14	139	–
	6.30	-1.51	5.19	4.73	9.31	50.18	40.51	23.92	3.14	66.97	144.69	62	32
	13.64^{-3}	–	–	–	48.35^{-9}	35.44^{-9}	16.21^{-9}	11.57^{-9}	5.52^{-1}	1.20	12.83	150	138
	6.62	1.15	3.66	7.18	11.23	57.65	31.12	20.40	4.13	37.00	104.50	117	83
	9.11	–0.60	6.06	3.85	0.03	74.86	25.11	18.76	1.04	73.00	155.92	9	7
	5.04	-2.33	0.08	1.77	11.98	45.47	42.55	32.94	1.90	28.94	140.05	89	55
	11.45	12.96	14.67	7.84^{-1}	18.42^{-1}	61.83^{-1}	19.75^{-1}	0.86^{-1}	0.44	1.10	57.38	128	–
	7.13	5.40	6.24	5.42	18.38	43.31	38.31	17.49	4.09	43.90	130.89	121	52
	3.76	1.73	2.32	2.51	2.45	70.73	26.82	7.13	2.49	83.00	106.84	2	17
	3.54	2.21	2.33	2.50	7.18^{-3}	69.07^{-3}	23.75^{-3}	12.18^{-3}	0.84	82.78	105.78	7	15
	–	–	–	–	–	–	–	–	–	–	–	–	–
	–0.85	-1.39	2.71	3.47	12.22	67.63	20.15	14.50	0.54	37.10	105.60	88	115
	7.52	–0.67	2.74	2.97	25.28^{-3}	66.51^{-3}	8.21^{-3}	5.55^{-3}	–	11.50	16.61	133	–
	3.77	-1.66	0.02	2.99	–	–	–	–	–	11.70	1.27^{-8}	–	–
	-2.06	0.96	2.05	-4.00	28.21^{-2}	62.65^{-2}	9.22^{-2}	0.49^{-2}	–	27.80	30.32	124	–
	–	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–	–
	1.85	-10.75	5.33	–0.33	5.33	86.42	8.25	1.11	–	26.97^{-9}	85.79	60	–
	7.15	6.14	10.67	5.54	37.80^{-9}	23.33^{-9}	38.87^{-9}	7.05^{-9}	4.96^{-1}	6.50	40.98	157	–
	6.32	-4.81	5.15	-1.14	–	–	–	–	–0.41	15.30	47.19^{-6}	106	–
	7.32	-4.73	10.70	2.95	35.65^{-7}	57.59^{-7}	6.75^{-7}	4.85^{-7}	5.39^{-1}	8.00	57.57	157	–
	-4.14	3.24	2.88	0.50	19.17^{-1}	59.34^{-1}	21.49^{-1}	6.43^{-1}	2.51	35.00	54.59	100	–
	6.35	-4.43	8.45	1.30	22.16	69.11	8.73	–	–	37.00	34.43	–	–
	5.18	3.31	1.21	1.97	27.98	63.22	8.80	3.61	0.80	11.30	50.34	131	–

Abbreviations:
GDP: gross domestic product
PPP$: purchasing power parity dollars

NB: See Key To All Tables at the end of Table S10.

Table S2: R&D expenditure by sector of performance and source of funds, 2009 and 2013 (%)

	R&D expenditure by sector of performance (%)									
	2009					2013				
	Business enterprise	Government	Higher education	Private non-profit	Not elsewhere classified	Business enterprise	Government	Higher education	Private non-profit	Not elsewhere classified
North America										
Canada	53.23	10.45	35.91	0.41	–	50.52	9.15[v]	39.80[v]	0.52	–
United States of America	69.55[o]	11.93	14.03[o]	4.48[o,r]	–	69.83[-1,o,v]	12.31[-1,v]	13.83[-1,o,v]	4.03[-1,o,r]	–[-1]
Latin America										
Argentina	22.26	44.73	31.32	1.69	–	21.47[-1]	45.59[-1]	31.17[-1]	1.76[-1]	–[-1]
Belize	–	–	–	–	–	–	–	–	–	–
Bolivia	25.00[-7]	21.00[-7]	41.00[-7]	13.00[-7]	–[-7]	–	–	–	–	–
Brazil	–	–	–	–	–	–	–	–	–	–
Chile	29.32	3.34	39.81	27.53	–	34.43[-1]	4.08[-1]	34.27[-1]	27.23[-1]	–[-1]
Colombia	19.77	4.62	49.83	25.79	–	23.12	7.57	42.32	26.99	–
Costa Rica	25.71	23.49	48.99	1.82	–	15.85[-2]	36.59[-2]	45.23[-2]	2.32[-2]	0.02[-2]
Ecuador	40.85	42.04	12.97	4.14	–	58.12[-2]	24.52[-2]	14.19[-2]	3.17[-2]	–[-2]
El Salvador	–	–	100.00	–	–	–[-1]	–[-1]	100.00[-1]	–[-1]	–[-1]
Guatemala	2.00[q]	11.16[q]	84.67[q]	2.17[q]	–	0.17[-1,q]	16.54[-1,q]	82.32[-1,q]	0.96[-1,q]	–[-1]
Guyana	–	–	–	–	–	–	–	–	–	–
Honduras	–	–	–	–	–	–	–	–	–	–
Mexico	41.07	26.81	29.21	2.91	–	37.97	31.39	29.10	1.55	–
Nicaragua	–	–	–	–	–	–	–	–	–	–
Panama	1.75	51.71	2.44	44.08	0.01	2.00[-2]	64.30[-2]	2.46[-2]	31.30[-2]	–[-2]
Paraguay	–[-1]	28.32[-1]	59.86[-1]	11.82[-1]	0.00[-1]	–[-1]	31.62[-1]	59.92[-1]	8.46[-1]	–[-1]
Peru	29.17[-5]	25.63[-5]	38.11[-5]	7.08[-5]	0.00[-5]	–	–	–	–	–
Suriname	–	–	–	–	–	–	–	–	–	–
Uruguay	34.44	27.12	34.60	2.73	1.11	17.99[-1]	34.01[-1]	43.44[-1]	4.56[-1]	–[-1]
Venezuela	–	–	–	–	–	–	–	–	–	–
Caribbean										
Antigua and Barbuda	–	–	–	–	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–	–	–	–	–
Barbados	–	–	–	–	–	–	–	–	–	–
Cuba	–	–	–	–	–	–	–	–	–	–
Dominica	–	–	–	–	–	–	–	–	–	–
Dominican Rep.	–	–	–	–	–	–	–	–	–	–
Grenada	–	–	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–	–	–
Jamaica	–	–	–	–	–	–	–	–	–	–
St Kitts and Nevis	–	–	–	–	–	–	–	–	–	–
St Lucia	–	–	–	–	–	–	–	–	–	–
St Vincent and the Grenadines	86.67[-7]	13.33[-7]	–[-7]	–[-7]	–[-7]	–	–	–	–	–
Trinidad and Tobago	2.18	61.27	36.54	–	–	–[-1]	63.29[-1]	36.69[-1]	–[-1]	0.01[-1]
European Union										
Austria	68.09	5.34	26.10	0.48	–	68.78[r,v]	5.14[r,v]	25.59[r,v]	0.49[r,v]	–
Belgium	66.26	8.94	23.79	1.00	–	69.10[v]	8.80[v]	21.68[v]	0.43[v]	–
Bulgaria	29.96	55.24	14.04	0.76	–	61.08	29.67	8.65	0.60	–
Croatia	40.42	27.16	32.31	0.12	–	50.10	25.53	24.36	–	–
Cyprus	19.80	20.42	46.12	13.66	–	15.45[v]	14.40[v]	57.26[v]	12.89[v]	–
Czech Rep.	56.50	23.26	19.70	0.54	–	54.12	18.31	27.23	0.34	–
Denmark	69.78	2.07	27.72	0.42	–	65.43[r,v]	2.39[r,v]	31.77[r,v]	0.40[r,v]	–
Estonia	44.69	10.99	42.16	2.17	–	47.72	8.93	42.30	1.06	–
Finland	71.42	9.10	18.90	0.58	–	68.86	8.92	21.52	0.71	–
France	61.69	16.31	20.80	1.20	–	64.75[v]	13.15[s,v]	20.75[v]	1.35[v]	–
Germany	67.56	14.82[c]	17.62	–[g]	–	66.91[r,v]	15.09[c,r,v]	18.00[r,v]	–[g]	–
Greece	28.59[-2]	20.92[-2,r]	49.23[-2,r]	1.26[-2,r]	–[-2]	33.34[s]	27.98[s]	37.43[s]	1.25	–
Hungary	57.24[t]	20.06[t]	20.94[t]	–	–	69.43[t]	14.89[t]	14.39[t]	–	–
Ireland	68.30	5.05	26.65[r]	–	–	72.03[-1,r]	4.85[-1]	23.12[-1,r]	–[-1]	–[-1]
Italy	53.30	13.14	30.26	3.30	–	53.98[v]	14.92[v]	28.21[v]	2.88[v]	–
Latvia	36.39	24.71	38.90	–	–	28.24	28.89	42.87	–	–
Lithuania	24.39	23.41	52.20	–	–	25.46	19.83	54.71	–	–
Luxembourg	75.89	16.10	8.01	–	–	61.38[s,v]	23.30[r,v]	15.32[r,v]	–	–
Malta	63.36	4.73	31.91	–	–	54.26	10.18[v]	35.56[v]	–	–
Netherlands	47.08	12.75[c]	40.17	–[g]	–	57.54[s,v]	10.68[c,v]	31.78[v]	–[g]	–
Poland	28.50	34.31	37.07	0.13	–	43.62	26.83	29.26	0.29	–
Portugal	47.30	7.31	36.58	8.81	–	47.57[v]	5.79[v]	37.84[v]	8.80[v]	–
Romania	40.18	34.91	24.74	0.17	–	30.66[s]	49.23[s]	19.72[s]	0.40[s]	–
Slovakia	41.05	33.89[p]	25.01	0.05	–	46.26	20.48[p]	33.10	0.15	–
Slovenia	64.61	20.76	14.56	0.07	–	76.53[s]	13.01[s]	10.42[s]	0.04[s]	–
Spain	51.90	20.07	27.83	0.20	–	53.08	18.72	28.03	0.17	–
Sweden	70.64	4.42	24.87	0.07[q]	–	68.95	3.68[q]	27.14	0.22[s]	–
United Kingdom	60.41	9.16	27.95	2.48[r]	–	64.51[r,v]	7.31[r,v]	26.30[r,v]	1.88[r,v]	–
Southeast Europe										
Albania	0.00[-1]	52.10[-1,q]	47.90[-1,q]	0.00[-1]	–[-1]	–	–	–	–	–
Bosnia and Herzegovina	–[-2]	12.60[-2,q]	68.75[-2,q]	1.06[-2,q]	17.59[-2,q]	58.42[s]	5.81[s]	35.64[s]	0.12[s]	–
FYR Macedonia	21.14	46.41	32.45	–	–	11.50[-3]	43.78[-3]	44.72[-3]	–[-3]	–[-3]
Montenegro	5.15[-2]	14.87[-2]	79.98[-2]	0.00[-2]	–[-2]	49.31[s]	16.00[s]	32.02[s]	2.68[s]	–[s]
Serbia	14.32	30.87	54.78	0.03	–	13.27	33.36	53.34	0.03	–

	R&D expenditure by source of funds (%)												
	2009						2013						
	Business enterprise	Government	Higher education	Private non–profit	Abroad	Not elsewhere classified	Business enterprise	Government	Higher education	Private non–profit	Abroad	Not elsewhere classified	
													North America
	48.52	34.56[r]	6.73[r]	3.13	7.07	–	46.45[v]	34.86[r,v]	8.85[r,v]	3.88[v]	5.95[v]	–	Canada
	60.90[o]	32.65[o]	2.94[o]	3.51[o]	–[g]	–	59.13[-1,o,s,v]	30.79[-1,o,v]	2.98[-1,o,v]	3.30[-1,o,v]	3.80[-1,g]	–[-1]	United States of America
													Latin America
	21.44	73.18	3.84	0.87	0.67	0.00	21.34[-1]	74.01[-1]	3.11[-1]	0.96[-1]	0.58[-1]	–[-1]	Argentina
	–	–	–	–	–	–	–	–	–	–	–	–	Belize
	5.20	51.19	26.55	2.05	1.86	13.15	–	–	–	–	–	–	Bolivia
	45.54	52.29	2.16	–	–	–	43.07[-1]	54.93[-1]	2.00[-1]	–[-1]	–[-1]	–[-1]	Brazil
	26.96	38.32	13.96	1.70	19.05	–	34.95[-1]	35.96[-1]	9.42[-1]	2.13[-1]	17.54[-1]	–[-1]	Chile
	18.68	56.12	16.70	5.10	3.40	–	29.02	45.77	14.83	8.00	2.38	–	Colombia
	28.73	53.04	–	2.82	1.66	13.74	18.85[-2]	61.98[-2]	–[-2]	0.74[-2]	6.54[-2]	11.89[-2]	Costa Rica
	0.19[h]	41.21[h]	7.45[h]	0.51[h]	9.80[h]	40.84[h]	0.42[-2,h]	28.45[-2,h]	8.09[-2,h]	0.47[-2,h]	4.46[-2,h]	58.12[-2,h]	Ecuador
	23.13	64.58	0.63	0.12	11.25	0.30	2.75[-1]	11.73[-1]	74.33[-1]	2.63[-1]	9.15[-1]	–[-1]	El Salvador
	–	22.78[q]	29.48[q]	–	47.74[q]	–	–[-1]	23.51[-1,q]	27.48[-1,q]	–[-1]	49.01[-1,q]	–[-1]	Guatemala
	–	–	–	–	–	–	–	–	–	–	–	–	Guyana
	–	–	–	–	–	–	–	–	–	–	–	–	Honduras
	39.06	53.17	5.75	0.27	1.75	–	31.65	65.50	1.52	0.67	0.66	–	Mexico
	–	–	–	–	–	–	–	–	–	–	–	–	Nicaragua
	3.61	50.00	4.99	16.43	24.95	0.01	18.86[-2]	46.73[-2]	5.00[-2]	8.66[-2]	20.73[-2]	0.02[-2]	Panama
	0.25[-1]	76.20[-1]	9.20[-1]	2.10[-1]	12.25[-1]	–[-1]	0.85[-1]	82.55[-1]	3.71[-1]	2.86[-1]	7.71[-1]	2.32[-1]	Paraguay
	–	–	–	–	–	–	–	–	–	–	–	–	Peru
	–	–	–	–	–	–	–	–	–	–	–	–	Suriname
	38.86	32.99	24.62	0.59	1.83	1.11	15.03[-1]	32.97[-1]	43.43[-1]	0.92[-1]	7.65[-1]	–[-1]	Uruguay
	–	–	–	–	–	–	–	–	–	–	–	–	Venezuela
													Caribbean
	–	–	–	–	–	–	–	–	–	–	–	–	Antigua and Barbuda
	–	–	–	–	–	–	–	–	–	–	–	–	Bahamas
	–	–	–	–	–	–	–	–	–	–	–	–	Barbados
	15.01	75.01	–	–	9.98	–	19.99	69.99	–	–	10.02	–	Cuba
	–	–	–	–	–	–	–	–	–	–	–	–	Dominica
	–	–	–	–	–	–	–	–	–	–	–	–	Dominican Rep.
	–	–	–	–	–	–	–	–	–	–	–	–	Grenada
	–	–	–	–	–	–	–	–	–	–	–	–	Haiti
	–	–	–	–	–	–	–	–	–	–	–	–	Jamaica
	–	–	–	–	–	–	–	–	–	–	–	–	St Kitts and Nevis
	–	–	–	–	–	–	–	–	–	–	–	–	St Lucia
	–	–	–	–	–	–	–	–	–	–	–	–	St Vincent and the Grenadines
	–	–	–	–	–	–	–	–	–	–	–	–	Trinidad and Tobago
													European Union
	47.06	34.91	0.67	0.56	16.79	–	44.12[r,v]	39.07[c,r,v]	–[g]	0.46[r,v]	16.36[r,v]	–	Austria
	58.62	25.31	3.21	0.75	12.11	–	60.15[-2]	23.42[-2]	2.87[-2]	0.60[-2]	12.96[-2]	–[-2]	Belgium
	30.23	60.47	0.74	0.18	8.38	–	19.51	31.62	0.13	0.46	48.27	–	Bulgaria
	39.79	51.19	1.95	0.12	6.96	–	42.79	39.74	1.68	0.31	15.50	–	Croatia
	15.73	69.00	2.76	0.45	12.06	–	10.86[-1]	66.38[-1]	4.59[-1]	0.69[-1]	17.48[-1]	–[-1]	Cyprus
	39.76	47.77	1.18	0.02	11.28	–	37.60	34.74	0.45	0.06	27.15	–	Czech Rep.
	62.14	26.14	–[g]	3.12	8.61	–	59.78[r,v]	29.27[r,v]	–[g]	3.78[r,v]	7.18[r,v]	–	Denmark
	38.49	48.82	0.69	0.68	11.33	–	42.05	47.22	0.27	0.11	10.34	–	Estonia
	68.10	24.00	0.14	1.15	6.61	–	60.84	26.03[s]	0.23	1.36	11.54	–	Finland
	52.27	38.71	1.20	0.79	7.03	–	55.38[-1,s]	34.97[-1,s]	1.22[-1,s]	0.82[-1,s]	7.62[-1,s]	–[-1]	France
	66.13	29.77	–	0.26	3.85	–	66.07[-1]	29.21[-1]	–[-1]	0.39[-1]	4.32[-1]	–[-1]	Germany
	33.48[r]	54.75[r]	2.12[r]	0.94[r]	8.71[r]	–	30.28	52.27	2.60	0.86	13.98	–	Greece
	46.43	41.98	–	0.69	10.90	–	46.80	35.88	–	0.75	16.57	–	Hungary
	52.09[r]	29.80[r]	1.11[r]	0.50[r]	16.51[r]	–	50.34[-1,r]	27.26[-1,r]	0.64[-1,r]	0.41[-1,r]	21.36[-1,r]	–[-1]	Ireland
	44.16	42.15	1.26	3.01	9.42	–	44.29[-1]	42.55[-1]	0.94[-1]	2.78[-1]	9.45[-1]	–[-1]	Italy
	36.90	44.74	3.00	–	15.36	–	21.79	23.94	2.65	–	51.61	–	Latvia
	30.81	52.68	3.21	0.29	13.01	–	27.47	34.54	0.13	0.75	37.11	–	Lithuania
	70.27	24.26	0.04	0.07	5.37	–	47.81[-2]	30.52[-2]	0.06[-2]	1.20[-2]	20.41[-2]	–[-2]	Luxembourg
	51.57	30.01	0.00	0.05	18.37	–	44.35[v]	33.86[v]	1.29[v]	0.18[v]	20.33[v]	–	Malta
	45.15	40.89	0.29	2.82	10.85	–	47.10[s,v]	34.33[s,v]	0.39[s,v]	3.91[s,v]	14.27[s,v]	–	Netherlands
	27.10	60.44	6.70	0.26	5.50	–	37.33	47.24	2.13	0.18	13.12	–	Poland
	43.87	45.46	2.85	3.73	4.09	–	46.04[-1]	43.13[-1]	3.58[-1]	2.08[-1]	5.17[-1]	–[-1]	Portugal
	34.75	54.92	1.91	0.08	8.34	–	31.02[s]	52.29[s]	1.15[s]	0.05[s]	15.50[s]	–	Romania
	35.11	50.56[q]	0.59	0.96	12.78	–	40.19	38.90[q]	2.74	0.20	17.97	–	Slovakia
	57.98	35.66	0.29	0.03	6.04	–	63.85[s]	26.87[s]	0.35[s]	0.02[s]	8.91[s]	–	Slovenia
	43.36	47.10	3.45	0.63	5.46	–	46.30	41.63	4.08	0.63	7.36	–	Spain
	59.14	27.26	0.63	2.58	10.39	–	60.95[q]	28.20[q]	0.99[q]	3.05[q]	6.80[q]	–	Sweden
	44.54[r]	32.55	1.28[r]	4.99[r]	16.64[r]	–	46.55[r,v]	26.99[r,v]	1.09[r,v]	4.73[r,v]	20.65[r,v]	–	United Kingdom
													Southeast Europe
	3.26[-1,q]	80.80[-1,q]	8.57[-1,q]	0.00[-1]	7.37[-1,q]	–[-1]	–	–	–	–	–	–	Albania
	–	–	–	–	–	–	1.83	25.35	0.00	0.00	53.90	18.92	Bosnia and Herzegovina
	7.79[-7,r]	76.31[-7,r]	7.33[-7,r]	0.02[-7,r]	8.55[-7,r]	–[-7]	–	–	–	–	–	–	FYR Macedonia
	–	–	–	–	–	–	42.32	31.66	3.50	0.02	22.52	–	Montenegro
	8.33	62.87	20.86	0.76	7.18	–	7.53	59.51	25.12	0.03	7.81	–	Serbia

Table S2: R&D expenditure by sector of performance and source of funds, 2009 and 2013 (%)

	R&D expenditure by sector of performance (%)									
	2009					2013				
	Business enterprise	Government	Higher education	Private non-profit	Not elsewhere classified	Business enterprise	Government	Higher education	Private non-profit	Not elsewhere classified
Other Europe and West Asia										
Armenia	–	89.65[q]	10.35[q]	–	–	–	88.63[q]	11.37[q]	–	–
Azerbaijan	22.00	71.73	6.27	0.00	–	10.33	85.49	4.02	0.16	–
Belarus	56.39	29.96	13.62	0.03	–	65.32	23.82	10.84	0.02	–
Georgia	–[-4]	73.18[-4]	26.82[-4]	–[-4]	–[-4]	–	72.31[s,u]	27.69[s,u]	–	–
Iran, Islamic Rep. of	10.61[-1]	56.07[-1]	33.32[-1]	–[-1]	–[-1]	–	–	–	–	–
Israel	83.53[p]	1.85[p]	13.32[p]	1.30[p]	–	82.74[p]	2.13[p]	14.07[p]	1.05[p]	–
Moldova, Rep. of	11.30	77.08	11.62	–	–	19.86	69.78	10.37	–	–
Russian Federation	62.38	30.26	7.13	0.23	–	60.60	30.26	9.01	0.13	–
Turkey	40.00	12.57	47.43	–	–	47.49	10.42	42.09	–	–
Ukraine	54.77	38.68	6.54	0.00	–	55.26	38.58	6.17	–	–
European Free Trade Assoc.										
Iceland	50.32	22.09	25.13	2.46	–	53.14[-2]	17.74[-2,s]	26.37[-2]	2.75[-2,s]	–[-2]
Liechtenstein	–	–	–	–	–	–	–	–	–	–
Norway	51.57	16.38	32.04	–	–	52.54	15.97	31.50	–	–
Switzerland	73.50[-1]	0.74[-1]	24.17[-1]	1.60[-1]	–[-1]	69.26[-1]	0.76[-1]	28.15[-1]	1.84[-1]	–[-1]
Sub–Saharan Africa										
Angola	–	–	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–	–	–
Botswana	15.57[-4]	79.40[-4]	1.21[-4]	3.83[-4]	–[-4]	10.71[-1,s]	41.63[-1,s]	22.95[-1,s]	24.71[-1,s]	–[-1]
Burkina Faso	–[-2]	72.22[-2]	–[-2]	21.12[-2]	6.67[-2]	–	–	–	–	–
Burundi	–[-1]	92.83[-1,q]	6.96[-1,q]	0.21[-1,q]	–[-1]	–[-3]	87.15[-3,q]	4.81[-3,q]	8.04[-3,q]	–[-3]
Cabo Verde	–	–	–	–	–	–[-2]	–[-2]	100.00[-2]	–[-2]	–[-2]
Cameroon	–	–	–	–	–	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of	–	100.00	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–	–	–
Ethiopia	–[-2]	84.41[-2]	14.60[-2]	0.99[-2]	–[-2]	1.17	24.49	74.10	0.23	–
Gabon	–	–	–	–	–	–	–	–	–	–
Gambia	–	–	–	–	–	–[-2]	54.44[-2,b]	–[-2]	45.56[-2,b]	–[-2]
Ghana	4.94[-2]	92.76[-2]	2.30[-2]	–[-2]	–[-2]	0.15[-3,s]	96.05[-3,s]	3.80[-3]	0.01[-3]	–[-3]
Guinea	–	–	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–	–	–
Kenya	11.68[-2]	35.36[-2]	29.84[-2]	23.12[-2]	–[-2]	8.66[-3,s]	40.64[-3,s]	39.05[-3,s]	11.65[-3,s]	–[-3]
Lesotho	–	7.67[q]	92.33[q]	–	–	–[-2]	–[-2]	100.00[-2,q]	–[-2]	–[-2]
Liberia	–	–	–	–	–	–	–	–	–	–
Madagascar	–	34.50	65.50	–	–	–[-2]	56.39[-2,s]	43.61[-2,s]	–[-2]	–[-2]
Malawi	–	–	–	–	–	–	–	–	–	–
Mali	2.97[-2,q]	–[-2]	97.03[-2,q]	–[-2]	–[-2]	–[-3]	82.58[-3]	17.42[-3]	–[-3]	–[-3]
Mauritius	–	–	–	–	–	–[-1]	73.36[-1]	24.76[-1]	1.86[-1]	–[-1]
Mozambique	–[-1]	95.45[-1]	–[-1]	4.55[-1]	–[-1]	–[-3]	54.88[-3]	35.99[-3]	9.13[-3]	–[-3]
Namibia	–	–	–	–	–	12.82[-3]	–[-3]	87.18[-3]	–[-3]	–[-3]
Niger	–	–	–	–	–	–	–	–	–	–
Nigeria	–[-2]	35.19[-2]	64.81[-2]	–[-2]	–[-2]	–	–	–	–	–
Rwanda	–	–	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–	–	–
Senegal	0.86[-1]	33.48[-1]	40.66[-1]	25.00[-1]	–[-1]	0.34[-3]	52.05[-3]	31.43[-3]	16.18[-3]	–[-3]
Seychelles	–[-4]	97.05[-4]	–[-4]	2.95[-4]	–[-4]	–	–	–	–	–
Sierra Leone	–	–	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–	–	–
South Africa	53.16	21.60	24.34	0.90	–	44.28[-1]	22.89[-1]	30.72[-1]	2.11[-1]	–[-1]
South Sudan	–	–	–	–	–	–	–	–	–	–
Swaziland	–	–	–	–	–	–	–	–	–	–
Tanzania	–[-2]	42.10[-2]	54.12[-2]	3.79[-2]	–[-2]	–[-3]	13.75[-3]	86.25[-3]	–[-3]	–[-3]
Togo	–	–	–	–	–	–[-1]	39.83[-1]	60.17[-1]	–[-1]	–[-1]
Uganda	8.23	64.35	17.56	9.85	–	34.77[-3,s]	38.58[-3]	25.41[-3]	1.25[-3]	–[-3]
Zambia	2.02[-1]	19.32[-1]	78.17[-1]	0.48[-1]	–[-1]	–	–	–	–	–
Zimbabwe	–	–	–	–	–	–	–	–	–	–
Arab states										
Algeria	–	–	–	–	–	–	–	–	–	–
Bahrain	–	–	–	–	–	–	–	100.00[q]	–	–
Egypt	–	45.41	54.72	–	–	–	44.54	55.46	–	–
Iraq	–	93.84	6.16	–	–	–[-2]	91.96[-2]	8.04[-2]	–[-2]	–[-2]
Jordan	–	–	–	–	–	–	–	–	–	–
Kuwait	–	100.00	–	–	–	–	38.91	60.85	–	0.25
Lebanon	–	–	–	–	–	–	–	–	–	–

	R&D expenditure by source of funds (%)											
	2009						2013					
	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not elsewhere classified	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not elsewhere classified
Other Europe and West Asia												
Armenia	–	55.57^{q}	0.00	–	3.91^{q}	40.51^{q}	–	66.31^{q}	–	–	2.79^{q}	30.90^{q}
Azerbaijan	24.76	74.35	0.00^{g}	0.82	0.07	–	30.49^{s}	68.20^{s}	0.82^{s}	0.33	0.16	–
Belarus	28.82	62.56	0.00	0.13	8.49	–	43.79	48.26	–	–	7.95	–
Georgia	–	–	–	–	–	–	–	–	–	–	–	–
Iran, Islamic Rep. of	30.92^{-1}	61.64^{-1}	7.45^{-1}	–$^{-1}$	–$^{-1}$	–$^{-1}$	–	–	–	–	–	–
Israel	37.53^{p}	12.84^{p}	1.29^{p}	1.65^{p}	46.70^{p}	–	35.60$^{-1,p}$	12.13$^{-1,p}$	1.75$^{-1,p}$	1.74$^{-1,p}$	48.77$^{-1,p}$	–$^{-1}$
Moldova, Rep. of	–^{g}	–^{g}	–^{g}	–^{g}	6.49	93.51	–^{g}	–^{g}	–^{g}	–^{g}	11.80	88.20
Russian Federation	26.59	66.46	0.39	0.10	6.46	–	28.16	67.64	1.04	0.12	3.03	–
Turkey	40.97	33.96	20.29	3.66	1.13	–	48.87	26.55	20.44	3.30	0.83	–
Ukraine	25.90	49.77	0.31	0.08	22.29	1.65	28.99	47.73	0.18	0.14	21.61	1.34
European Free Trade Assoc.												
Iceland	47.81	40.24	0.00	0.58	11.38	–	49.85$^{-2,s}$	39.99$^{-2,s}$	1.36$^{-2,s}$	0.58$^{-2,s}$	8.22$^{-2,s}$	–$^{-2}$
Liechtenstein	–	–	–	–	–	–	–	–	–	–	–	–
Norway	43.61	46.77	0.43	0.99	8.20	–	43.15	45.79	0.53	1.02	9.51	–
Switzerland	68.19^{-1}	22.84^{-1}	2.33^{-1}	0.69^{-1}	5.95^{-1}	–$^{-1}$	60.78^{-1}	25.42^{-1}	1.16^{-1}	0.57^{-1}	12.07^{-1}	–$^{-1}$
Sub–Saharan Africa												
Angola	–	–	–	–	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–	–	–	–	–
Botswana	–	–	–	–	–	–	5.81^{-1}	73.88^{-1}	12.56^{-1}	0.74^{-1}	6.81^{-1}	0.20^{-1}
Burkina Faso	11.93	9.05	12.22	1.27	59.61	5.92	–	–	–	–	–	–
Burundi	–$^{-1}$	59.87$^{-1,q}$	0.21$^{-1,q}$	–$^{-1}$	39.92$^{-1,q}$	–$^{-1}$	–	–	–	–	–	–
Cabo Verde	–	–	–	–	–	–	–$^{-2}$	100.00$^{-2,l,q}$	–$^{-2}$	–$^{-2}$	–$^{-2}$	–$^{-2}$
Cameroon	–	–	–	–	–	–	–	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of	–	100.00	–	–	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–	–	–	–	–
Ethiopia	–$^{-2}$	71.74^{-2}	0.00$^{-2,g}$	0.73^{-2}	27.00^{-2}	0.53^{-2}	0.75	79.07	1.80	0.23	2.15	16.01
Gabon	29.26	58.09	9.55	–	3.09	0.01	–	–	–	–	–	–
Gambia	–	–	–	–	–	–	–$^{-2}$	38.54$^{-2,b}$	–$^{-2}$	45.56$^{-2,b}$	15.90$^{-2,b}$	–$^{-2}$
Ghana	50.86^{-2}	36.55^{-2}	0.65^{-2}	–$^{-2}$	11.95^{-2}	–$^{-2}$	0.10$^{-3,s}$	68.30$^{-3,s}$	0.27^{-3}	0.11^{-3}	31.22^{-3}	–$^{-3}$
Guinea	–	–	–	–	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–	–	–	–	–
Kenya	16.83^{-2}	26.15^{-2}	26.16^{-2}	13.24^{-2}	17.62^{-2}	–$^{-2}$	4.34$^{-3,s}$	25.96$^{-3,s}$	19.03$^{-3,s}$	3.53$^{-3,s}$	47.14$^{-3,s}$	–$^{-3}$
Lesotho	3.38^{q}	14.96^{q}	2.80^{q}	–	–	78.86^{q}	–$^{-2}$	–$^{-2}$	44.66$^{-2,c,q}$	–$^{-2}$	3.45$^{-2,q}$	51.89$^{-2,q}$
Liberia	–	–	–	–	–	–	–	–	–	–	–	–
Madagascar	–	89.42^{e}	–^{n}	–	10.58	–	–$^{-2}$	100.00$^{-2,e,s}$	–$^{-2,n}$	–$^{-2}$	–$^{-2}$	–$^{-2}$
Malawi	–	–	–	–	–	–	–	–	–	–	–	–
Mali	10.10$^{-2,q}$	40.86$^{-2,q}$	–$^{-2}$	–$^{-2}$	49.04$^{-2,q}$	–$^{-2}$	–$^{-3}$	91.19$^{-3,s}$	–$^{-3}$	–$^{-3}$	8.81^{-3}	–$^{-3}$
Mauritius	–$^{-4}$	100.00$^{-4,b,u}$	–$^{-4}$	–$^{-4}$	–$^{-4}$	–$^{-4}$	0.27$^{-1,h}$	72.43$^{-1,h}$	20.73$^{-1,h}$	0.11$^{-1,h}$	6.43$^{-1,h}$	–$^{-1}$
Mozambique	–$^{-1}$	31.13^{-1}	–$^{-1}$	4.55^{-1}	64.32^{-1}	–$^{-1}$	–$^{-3}$	18.84$^{-3,e}$	–$^{-3,n}$	3.02^{-3}	78.14^{-3}	–$^{-3}$
Namibia	–	–	–	–	–	–	19.83^{-3}	78.64^{-3}	–$^{-3}$	–$^{-3}$	1.53^{-3}	–$^{-3}$
Niger	–	–	–	–	–	–	–	–	–	–	–	–
Nigeria	0.16^{-2}	96.36^{-2}	0.08^{-2}	1.73^{-2}	1.04^{-2}	0.64^{-2}	–	–	–	–	–	–
Rwanda	–	–	–	–	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–	–	–	–	–
Senegal	4.04^{-1}	57.06^{-1}	0.30^{-1}	0.27^{-1}	38.27^{-1}	0.05^{-1}	4.10^{-3}	47.62^{-3}	0.03^{-3}	3.23^{-3}	40.53^{-3}	4.49^{-3}
Seychelles	–	–	–	–	–	–	–	–	–	–	–	–
Sierra Leone	–	–	–	–	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–	–	–	–	–
South Africa	42.51	44.44	0.05	0.88	12.11	–	38.34^{-1}	45.38^{-1}	0.77^{-1}	2.46^{-1}	13.06^{-1}	–$^{-1}$
South Sudan	–	–	–	–	–	–	–	–	–	–	–	–
Swaziland	–	–	–	–	–	–	–	–	–	–	–	–
Tanzania	–$^{-2}$	60.58^{-2}	0.00^{-2}	1.06^{-2}	38.36^{-2}	–$^{-2}$	0.08^{-3}	57.53^{-3}	0.33^{-3}	0.05^{-3}	42.00^{-3}	–$^{-3}$
Togo	–	–	–	–	–	–	–$^{-1}$	84.87^{-1}	–$^{-1}$	3.08^{-1}	12.06^{-1}	–$^{-1}$
Uganda	8.23	48.07	17.56	0.08	26.06	–	13.67^{-3}	21.94^{-3}	1.04^{-3}	6.05^{-3}	57.30^{-3}	–$^{-3}$
Zambia	3.23^{-1}	94.83^{-1}	–$^{-1}$	0.32^{-1}	1.62^{-1}	–$^{-1}$	–	–	–	–	–	–
Zimbabwe	–	–	–	–	–	–	–	–	–	–	–	–
Arab states												
Algeria	–	–	–	–	–	–	–	–	–	–	–	–
Bahrain	–	–	–	–	–	–	0.00^{l,q}	68.40^{l,q}	0.00^{l,q}	1.16^{l,q}	30.44^{l,q}	–^{l,q}
Egypt	–	–	–	–	–	–	–	–	–	–	–	–
Iraq	–	100.00^{e}	–^{n}	–	–	–	0.00^{-2}	100.00$^{-2,e}$	–$^{-2,n}$	0.00^{-2}	0.00^{-2}	–$^{-2}$
Jordan	–	–	–	–	–	–	–	–	–	–	–	–
Kuwait	2.33^{k}	96.49^{k}	–	–	1.18^{k}	–	1.41^{h}	92.95^{h}	0.17^{h}	5.47^{h}	0.00^{h}	–^{h}
Lebanon	–	–	–	–	–	–	–	–	–	–	–	–

Table S2: R&D expenditure by sector of performance and source of funds, 2009 and 2013 (%)

	R&D expenditure by sector of performance (%)									
	2009					2013				
	Business enterprise	Government	Higher education	Private non–profit	Not elsewhere classified	Business enterprise	Government	Higher education	Private non–profit	Not elsewhere classified
Libya	–	–	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	–	–	–	–
Morocco	22.05[-3]	25.60[-3]	52.35[-3]	–[-3]	–[-3]	29.94[-3]	23.07[-3]	47.00[-3]	–[-3]	–[-3]
Oman	–	–	–	–	–	24.08	41.58	34.33	0.01	–
Palestine	–	–	–	–	–	–	–	–	–	–
Qatar	–	–	–	–	–	25.84[-1]	32.28[-1]	41.88[-1]	–[-1]	–[-1]
Saudi Arabia	–	–	–	–	–	–	–	–	–	–
Sudan	33.71[-4,r]	39.20[-4,r]	27.09[-4,r]	–[-4]	–[-4]	–	–	–	–	–
Syrian Arab Rep.	–	–	–	–	–	–	–	–	–	–
Tunisia	–	–	–	–	–	–	–	–	–	–
United Arab Emirates	–	–	–	–	–	28.62[-2,r]	39.65[-2,r]	29.33[-2,r]	2.40[-2,r]	–[-2,r]
Yemen	–	–	–	–	–	–	–	–	–	–
Central Asia										
Kazakhstan	32.75	38.51	15.19	13.55	–	29.43	29.68	30.69	10.20	–
Kyrgyzstan	23.36	65.18	11.46	0.00	–	23.33[-2]	62.04[-2]	14.63[-2]	0.00[-2]	–[-2]
Mongolia	5.52[q]	64.37	9.69[q]	0.00[q]	20.41[q]	5.45[q]	84.30[q]	10.25[q]	–	–
Tajikistan	–	86.22	13.78	–	–	–	88.26	11.74	–	–
Turkmenistan	–	–	–	–	–	–	–	–	–	–
Uzbekistan	–	–	–	–	–	–	–	–	–	–
South Asia										
Afghanistan	–	–	–	–	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–	–	–	–	–
India	34.16[f]	61.69	4.15	0.00[m]	–	35.46[-2,f]	60.48[-2]	4.06[-2]	0.00[-2,m]	–[-2]
Maldives	–	–	–	–	–	–	–	–	–	–
Nepal	–	100.00[u]	–	–	–	–[-3]	100.00[-3,u]	–[-3]	–[-3]	–[-3]
Pakistan	–	74.99	25.01	–	–	–	67.06	32.94	–	–
Sri Lanka	18.32[-1,f]	56.91[-1]	24.78[-1]	0.00[-1,m]	–[-1]	43.75[-3,s]	44.75[-3]	11.49[-3]	0.02[-3,q,s]	–[-3]
Southeast Asia										
Brunei Darussalam	–[-5]	91.59[-5]	8.41[-5]	0.00[-5]	–[-5]	–	–	–	–	–
Cambodia	12.08[-7,q,r]	25.33[-7,q,r]	11.80[-7,q,r]	50.79[-7,q,r]	–[-7,r]	–	–	–	–	–
China	73.23	18.71	8.07	–	–	76.61	16.16	7.23	–	–
China, Hong Kong SAR	42.65[f]	4.08	53.26	0.00[m]	–	44.87[-1,f]	4.00[-1]	51.14[-1]	–[-1,m]	–[-1]
China, Macao SAR	0.00[-1]	0.00[-1]	98.63[-1]	1.37[-1]	–[-1]	0.37	–	96.24	2.87	0.51
Indonesia	18.85[r]	43.22[r]	37.93[r]	–	–	25.68[r]	39.39[r]	34.93[r]	–	–[r]
Japan	75.76	9.21	13.41	1.61	–	76.09	9.17	13.47	1.28	–
Korea, DPR	–	–	–	–	–	–	–	–	–	–
Korea, Rep. of	74.26	13.02	11.08	1.64	–	78.51	10.91	9.24	1.33	–
Lao PDR	36.89[-7,q]	50.91[-7,q]	12.20[-7,q]	0.00[-7]	–[-7]	–	–	–	–	–
Malaysia	69.86	6.38	23.77	0.00	–	64.45[-1]	6.88[-1]	28.67[-1]	0.01[-1]	–[-1]
Myanmar	–	–	–	–	–	–	–	–	–	–
Philippines	56.95[-2]	17.65[-2]	23.25[-2]	2.15[-2]	–[-2]	–	–	–	–	–
Singapore	61.63	11.30	27.06	–	–	60.94[-1]	10.01[-1]	29.05[-1]	–[-1]	–[-1]
Thailand	41.21	32.75	24.94	1.11	–	50.61[-2]	18.87[-2]	30.14[-2]	0.38[-2]	–[-2]
Timor–Leste	–	–	–	–	–	–	–	–	–	–
Viet Nam	14.55[-7]	66.43[-7]	17.91[-7]	1.12[-7]	–[-7]	26.01[-2]	58.32[-2]	14.37[-2]	1.29[-2]	–[-2]
Oceania										
Australia	61.10[-1]	12.09[-1]	24.18[-1]	2.63[-1]	–[-1]	57.86[-2]	11.21[-2,r]	28.06[-2,r]	2.98[-2,r]	–[-2]
New Zealand	41.76	25.28	32.96	–	–	45.45[-2]	22.70[-2]	31.85[-2]	–[-2]	–[-2]
Cook Islands	–	–	–	–	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–	–	–	–	–
Nauru	–	–	–	–	–	–	–	–	–	–
Niue	–	–	–	–	–	–	–	–	–	–
Palau	–	–	–	–	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–	–	–

Source: UNESCO Institute for Statistics (UIS), August, 2015

N.B.: See Key To All Tables at the end of Table S10.

R&D expenditure by source of funds (%)												
2009						2013						
Business enterprise	Government	Higher education	Private non-profit	Abroad	Not elsewhere classified	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not elsewhere classified	
–	–	–	–	–	–	–	–	–	–	–	–	Libya
–	–	–	–	–	–	–	–	–	–	–	–	Mauritania
22.70^{-3}	26.12^{-3}	48.56^{-3}	–$^{-3}$	2.61^{-3}	–$^{-3}$	29.94^{-3}	23.07^{-3}	45.28^{-3}	–$^{-3}$	1.71^{-3}	–$^{-3}$	Morocco
–	–	–	–	–	–	24.55	48.60	24.44	0.07	0.00	2.34^{r}	Oman
–	–	–	–	–	–	–	–	–	–	–	–	Palestine
–	–	–	–	–	–	24.18^{-1}	31.18^{-1}	36.56^{-1}	5.60^{-1}	2.42^{-1}	0.05^{-1}	Qatar
–	–	–	–	–	–	–	–	–	–	–	–	Saudi Arabia
–	–	–	–	–	–	–	–	–	–	–	–	Sudan
–	–	–	–	–	–	–	–	–	–	–	–	Syrian Arab Rep.
16.00	79.00^{e}	–^{n}	0.00	5.10	–	18.70^{-1}	76.90$^{-1,e}$	–$^{-1,n}$	0.00^{-1}	4.40^{-1}	–$^{-1}$	Tunisia
–	–	–	–	–	–	–	–	–	–	–	–	United Arab Emirates
–	–	–	–	–	–	–	–	–	–	–	–	Yemen
												Central Asia
50.74^{-1}	31.37^{-1}	14.74^{-1}	2.20^{-1}	0.96^{-1}	–$^{-1}$	28.92	63.68	–	–	0.76	6.64	Kazakhstan
36.38^{-4}	63.62^{-4}	0.00^{-4}	0.00^{-4}	0.01^{-4}	–$^{-4}$	38.58$^{-2,s}$	57.66$^{-2,s}$	1.43$^{-2,s}$	0.00^{-2}	0.87$^{-2,s}$	1.45$^{-2,s}$	Kyrgyzstan
2.90^{q}	61.52^{q}	1.96^{q}	0.00	1.44^{q}	32.17^{q}	8.31^{q}	73.95^{q}	1.83^{q}	–	4.90^{q}	11.02^{q}	Mongolia
1.08^{t}	82.07^{t}	0.64^{t}	–	–	16.14^{t}	–	92.45	0.21	–	0.21	7.13	Tajikistan
–	–	–	–	–	–	–	–	–	–	–	–	Turkmenistan
–	–	–	–	–	–	–	–	–	–	–	–	Uzbekistan
												South Asia
–	–	–	–	–	–	–	–	–	–	–	–	Afghanistan
–	–	–	–	–	–	–	–	–	–	–	–	Bangladesh
–	–	–	–	–	–	–	–	–	–	–	–	Bhutan
–	–	–	–	–	–	–	–	–	–	–	–	India
–	–	–	–	–	–	–	–	–	–	–	–	Maldives
–	–	–	–	–	–	–	–	–	–	–	–	Nepal
–	84.03	12.11	1.66	0.92	1.28	–	75.26^{h}	20.00^{h}	1.71^{h}	1.31^{h}	1.71^{h}	Pakistan
19.89$^{-1,f}$	71.80$^{-1,e}$	0.00$^{-1,n}$	0.00$^{-1,m}$	4.27^{-1}	4.04^{-1}	40.93$^{-3,s}$	55.90^{-3}	0.19^{-3}	0.00^{-3}	2.72^{-3}	0.26^{-3}	Sri Lanka
												Southeast Asia
1.58^{-5}	91.01^{-5}	7.41^{-5}	0.00^{-5}	0.00^{-5}	–$^{-5}$	–	–	–	–	–	–	Brunei Darussalam
–$^{-7}$	17.93$^{-7,q,r}$	–$^{-7}$	43.00$^{-7,q,r}$	28.44$^{-7,q,r}$	10.62$^{-7,q,r}$	–	–	–	–	–	–	Cambodia
71.74^{t}	23.41^{t}	–	–	1.35^{t}	–	74.60^{t}	21.11^{t}	–	–	0.89^{t}	–	China
45.83^{f}	47.96	0.12	0.00^{m}	6.09	–	49.73$^{-1,f}$	45.60^{-1}	0.02^{-1}	–$^{-1,m}$	4.65^{-1}	–$^{-1}$	China, Hong Kong SAR
0.18^{-1}	91.74^{-1}	6.42^{-1}	1.37^{-1}	0.00^{-1}	0.28^{-1}	–	90.55	8.13	1.32	0.00	–	China, Macao SAR
14.69$^{-8,f,q}$	84.51^{-8}	0.15^{-8}	0.00$^{-8,m}$	–$^{-8}$	0.65^{-8}	–	–	–	–	–	–	Indonesia
75.27	17.67^{r}	5.91^{r}	0.74	0.42	–	75.48	17.30^{r}	5.86^{r}	0.83	0.52	–	Japan
–	–	–	–	–	–	–	–	–	–	–	–	Korea, DPR
71.08	27.40	0.90	0.41	0.21	–	75.68	22.83	0.73	0.46	0.30	–	Korea, Rep. of
36.01$^{-7,q}$	8.00$^{-7,q}$	2.00$^{-7,q}$	0.00$^{-7,g}$	53.99$^{-7,q}$	–$^{-7}$	–	–	–	–	–	–	Lao PDR
68.52	27.12	4.08	0.00	0.23	0.05	60.20^{-1}	29.68^{-1}	2.50^{-1}	0.00^{-1}	4.59^{-1}	3.03^{-1}	Malaysia
–	–	–	–	–	–	–	–	–	–	–	–	Myanmar
61.96^{-2}	26.08^{-2}	6.38^{-2}	0.91^{-2}	4.12^{-2}	0.55^{-2}	–	–	–	–	–	–	Philippines
52.14	40.38	1.54	–	5.95	–	53.37^{-1}	38.54^{-1}	2.18^{-1}	–$^{-1}$	5.91^{-1}	–$^{-1}$	Singapore
41.43	37.89	17.80	0.32	1.00	1.57	51.74^{-2}	30.48^{-2}	13.48^{-2}	0.46^{-2}	2.50^{-2}	1.34^{-2}	Thailand
–	–	–	–	–	–	–	–	–	–	–	–	Timor–Leste
18.06^{-7}	74.11^{-7}	0.66$^{-7,f}$	0.00$^{-7,g}$	6.33^{-7}	0.84^{-7}	28.40^{-2}	64.47^{-2}	3.13^{-2}	0.00^{-2}	3.99^{-2}	–$^{-2}$	Viet Nam
												Oceania
61.91^{-1}	34.60^{-1}	0.12^{-1}	1.77^{-1}	1.61^{-1}	–$^{-1}$	–	–	–	–	–	–	Australia
39.01	44.72	8.30	2.84	5.22	–	39.96^{-2}	41.41^{-2}	9.45^{-2}	2.78^{-2}	6.32^{-2}	–$^{-2}$	New Zealand
–	–	–	–	–	–	–	–	–	–	–	–	Cook Islands
–	–	–	–	–	–	–	–	–	–	–	–	Fiji
–	–	–	–	–	–	–	–	–	–	–	–	Kiribati
–	–	–	–	–	–	–	–	–	–	–	–	Marshall Islands
–	–	–	–	–	–	–	–	–	–	–	–	Micronesia
–	–	–	–	–	–	–	–	–	–	–	–	Nauru
–	–	–	–	–	–	–	–	–	–	–	–	Niue
–	–	–	–	–	–	–	–	–	–	–	–	Palau
–	–	–	–	–	–	–	–	–	–	–	–	Papua New Guinea
–	–	–	–	–	–	–	–	–	–	–	–	Samoa
–	–	–	–	–	–	–	–	–	–	–	–	Solomon Islands
–	–	–	–	–	–	–	–	–	–	–	–	Tonga
–	–	–	–	–	–	–	–	–	–	–	–	Tuvalu
–	–	–	–	–	–	–	–	–	–	–	–	Vanuatu

Table S3: R&D expenditure as a share of GDP and in purchasing power parity (PPP) dollars, 2009-2013

	R&D expenditure as percentage of GDP					R&D expenditure in current PPP$ (000s)		R&D expenditure per capita (current PPP$)	
	2009	2010	2011	2012	2013	2009	2013	2009	2013
North America									
Canada	1.92	1.84	1.79	1.72	1.63[v]	25 027 663	24 565 364[v]	741.5	698.2[v]
United States of America	2.82[o]	2.74[o]	2.77[o]	2.81[o,v]	–	406 000 000[o]	453 544 000[-1,o,v]	1 311.8[o]	1 428.5[-1,o,v]
Latin America									
Argentina	0.48	0.49	0.52	0.58	–	3 418 556	5 159 124[-1]	85.4	125.6[-1]
Belize	–	–	–	–	–	–	–	–	–
Bolivia	0.16	–	–	–	–	78 248	–	7.8	–
Brazil	1.15	1.20	1.20	1.24	–	28 401 334	35 780 779[-1]	146.8	180.1[-1]
Chile	0.35	0.33	0.35	0.36	–	963 991	1 343 656[-1]	56.7	76.9[-1]
Colombia	0.21	0.21	0.22	0.22	0.23	973 270	1 365 135	21.2	28.3
Costa Rica	0.54	0.48	0.47	–	–	287 185	285 072[-2]	62.4	60.2[-2]
Ecuador	0.39	0.40	0.34	–	–	515 346	512 117[-2]	34.9	33.6[-2]
El Salvador	0.08	0.07	0.03	0.03	–	33 277	14 554[-1]	5.4	2.3[-1]
Guatemala	0.06[q]	0.04[q]	0.05[q]	0.04[q]	–	51 110[q]	47 958[-1,q]	3.7[q]	3.2[-1,q]
Guyana	–	–	–	–	–	–	–	–	–
Honduras	0.04[-5]	–	–	–	–	9 214[-5]	–	1.4[-5]	–
Mexico	0.43	0.45	0.42	0.43	0.50	7 008 035	9 984 730	60.2	81.6
Nicaragua	0.03[-7]	–	–	–	–	5 307[-7]	–	1.0[-7]	–
Panama	0.14	0.15	0.18	–	–	69 339	109 671[-2]	19.2	29.3[-2]
Paraguay	0.05[-1]	–	0.06	0.09	–	21 903[-1]	41 865[-1]	3.5[-1]	6.3[-1]
Peru	0.16[-5]	–	–	–	–	263 109[-5]	–	9.6[-5]	–
Suriname	–	–	–	–	–	–	–	–	–
Uruguay	0.44	0.41	0.42	0.24	–	218 160	151 748[-1]	64.9	44.7[-1]
Venezuela	–	–	–	–	–	–	–	–	–
Caribbean									
Antigua and Barbuda	–	–	–	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–	–	–	–
Barbados	–	–	–	–	–	–	–	–	–
Cuba	0.61	0.61	0.27[s]	0.41[s]	0.47	1 199 443	582 720[-2,s]	106.3	51.7[-2,s]
Dominica	–	–	–	–	–	–	–	–	–
Dominican Rep.	–	–	–	–	–	–	–	–	–
Grenada	–	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–	–
Jamaica	0.06[-7]	–	–	–	–	8 586[-8]	–	3.3[-8]	–
St Kitts and Nevis	–	–	–	–	–	–	–	–	–
St Lucia	–	–	–	–	–	–	–	–	–
St Vincent and the Grenadines	0.12[-7]	–	–	–	–	874[-7]	–	8.1[-7]	–
Trinidad and Tobago	0.06	0.05	0.04	0.05	–	21 309	19 232[-1]	16.1	14.4[-1]
European Union									
Austria	2.61	2.74[r]	2.68	2.81[r]	2.81[r,v]	8 860 472	10 752 629[r,v]	1 058.4	1 265.7[r,v]
Belgium	1.97	2.05	2.15	2.24[r]	2.28[v]	8 044 797	10 603 427[v]	740.6	954.9[v]
Bulgaria	0.51	0.59	0.55	0.62	0.65	548 901	742 690	73.7	102.8
Croatia	0.84	0.74	0.75	0.75	0.81	725 389	739 806	166.8	172.5
Cyprus	0.49	0.49	0.50	0.47	0.52[v]	124 114	127 783[v]	113.8	112.0[v]
Czech Rep.	1.30	1.34	1.56	1.79	1.91	3 660 339	5 812 939	349.1	543.2
Denmark	3.07	2.94	2.97	3.02	3.06[r,v]	6 717 152	7 513 404[r,v]	1 215.9	1 337.1[r,v]
Estonia	1.40	1.58	2.34	2.16	1.74	376 400	592 193	288.9	460.0
Finland	3.75	3.73	3.64	3.43	3.32	7 514 757	7 175 592	1 406.2	1 322.4[r,v]
France	2.21	2.18[s]	2.19	2.23	2.23[v]	49 757 013	55 218 177[s,v]	791.2	858.9[s,v]
Germany	2.73	2.72	2.80	2.88	2.85[r,v]	82 822 155	100 991 319[r,v]	995.7	1 220.8[r,v]
Greece	0.63[r]	0.60[r]	0.67	0.69	0.80	2 130 452[r]	2 273 861	192.0[r]	204.3
Hungary	1.14	1.15	1.20	1.27	1.41	2 382 736	3 249 569	237.5	326.4
Ireland	1.63[r]	1.62[r]	1.53[r]	1.58[r]	–	3 066 688[r]	3 271 465[-1,r]	695.3[r]	714.9[-1,r]
Italy	1.22	1.22	1.21	1.26	1.25[v]	24 648 791	26 520 408[v]	409.3	434.8[v]
Latvia	0.46	0.60	0.70	0.66	0.60	165 357	271 937	78.3	132.6
Lithuania	0.84	0.79	0.91	0.91	0.96	479 801	723 289	154.7	239.7
Luxembourg	1.72	1.50	1.41	1.16[s]	1.16[v]	683 894	571 469[s,v]	1 373.0	1 077.5[s,v]
Malta	0.54	0.68	0.72	0.90	0.89[v]	58 056	109 275[v]	137.3	254.7[v]
Netherlands	1.69	1.72	1.89[s]	1.97	1.98[v]	12 370 154	15 376 725[s,v]	746.9	917.5[s,v]
Poland	0.67	0.72	0.75	0.89	0.87	4 864 696	7 918 126	127.4	207.2
Portugal	1.58	1.53	1.46	1.37	1.36[v]	4 376 952	3 942 649[v]	413.7	371.7[v]
Romania	0.47	0.46	0.50s	0.49	0.39	1 487 584	1 480 720[s]	67.9	68.2[s]
Slovakia	0.47	0.62	0.67	0.81	0.83	592 782	1 190 627	109.3	218.5
Slovenia	1.82	2.06	2.43[s]	2.58	2.59	1 019 332	1 537 841[s]	498.6	742.2[s]
Spain	1.35	1.35	1.32	1.27	1.24	20 554 768	19 133 196	449.2	407.7
Sweden	3.42	3.22[r]	3.22	3.28[r]	3.30[q]	12 599 701	14 151 281[q]	1 353.3	1 478.5[q]
United Kingdom	1.75[r]	1.69r	1.69	1.63[r]	1.63[r,v]	39 432 832[r]	39 858 849[r,v]	639.1[r]	631.3[r,v]
Southeast Europe									
Albania	0.15[-1,q]	–	–	–	–	39 832[-1,q]	–	12.6[-1,q]	–
Bosnia and Herzegovina	0.02[q]	–	–	0.27[s]	0.33	7 027[q]	119 480[s]	1.8[q]	31.2[s]
FYR Macedonia	0.20	0.22	0.22	0.33	0.47	45 820	113 957	21.8	54.1
Montenegro	1.15[-2]	–	0.41[s]	–	0.38[s]	88 338[-2]	33 218[s]	143.0[-2]	53.5[s]
Serbia	0.87	0.74	0.72	0.91	0.73	748 598	677 967	77.2	71.3
Other Europe and West Asia									
Armenia	0.29[q]	0.24[q]	0.27[q]	0.25[q]	0.24[q]	53 140[q]	54 826[q]	17.9[q]	18.4[q]
Azerbaijan	0.25	0.22	0.21	0.22	0.21	332 970	341 284	37.1	36.3
Belarus	0.64	0.69	0.70	0.67	0.69	860 424	1 145 209	90.3	122.4
Georgia	0.18[-4]	–	–	–	0.13[s,u]	32 338[-4]	42 214[s,u]	7.2[-4]	9.7[s,u]

	R&D expenditure as percentage of GDP					R&D expenditure in current PPP$ (000s)		R&D expenditure per capita (current PPP$)	
	2009	2010	2011	2012	2013	2009	2013	2009	2013
Iran, Islamic Rep. of	0.31[i]	0.31[i]	–	–	–	3 345 394[i]	3 521 024[-3,i]	45.5[i]	47.3[-3,i]
Israel	4.15[p]	3.96[p]	4.10[p]	4.25[p]	4.21[p]	8 506 846[p]	11 032 853[p]	1 169.5[p]	1 426.7[p]
Moldova, Rep. of	0.53	0.44	0.40	0.42	0.35	66 168	58 989	18.4	16.9
Russian Federation	1.25	1.13	1.09	1.12	1.12	34 654 585	40 694 501	241.2	284.9
Turkey	0.85	0.84	0.86	0.92	0.95	8 867 131	13 315 099	124.5	177.7
Ukraine	0.86	0.83	0.74	0.75	0.77	2 867 129	3 067 360	62.0	67.8
European Free Trade Assoc.									
Iceland	2.66	–	2.49[s]	–	–	337 939	314 837[-2,s]	1 076.9	977.6[-2,s]
Liechtenstein	–	–	–	–	–	–	–	–	–
Norway	1.76	1.68	1.65	1.65	1.69	4 676 887	5 519 606	967.2	1 094.6
Switzerland	2.73[-1]	–	–	2.96	–	10 525 201[-1]	13 251 396[-1]	1 375.3[-1]	1 657.0[-1]
Sub–Saharan Africa									
Angola	–	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–	–
Botswana	0.53[-4]	–	–	0.26[s]	–	102 226[-4]	76 096[-1,s]	54.5[-4]	38.0[-1,s]
Burkina Faso	0.20	–	–	–	–	39 877	–	2.6	–
Burundi	0.14[q]	0.14[q]	0.12[q]	–	–	9 014[q]	8 460[-2,q]	1.0[q]	0.9[-2,q]
Cabo Verde	–	–	0.07[l,q]	–	–	–	2 211[-2,l,q]	–	4.5[-2,l,q]
Cameroon	–	–	–	–	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of	0.08[k,u]	–	–	–	–	30 743[k,u]	–	0.5[k,u]	–
Côte d'Ivoire	–	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–	–
Ethiopia	0.17[-2,q]	0.24[s]	–	–	0.61	111 769[-2,q]	787 350[s]	1.4[-2,q]	8.4[s]
Gabon	0.58	–	–	–	–	137 154	–	90.3	–
Gambia	0.02[q]	–	0.13[b]	–	–	445[q]	3 544[-2,b]	0.3[q]	2.0[-2,b]
Ghana	0.23[-2]	0.38[s]	–	–	–	133 220[-2]	274 351[-3,s]	5.9[-2]	11.3[-3,s]
Guinea	–	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–	–
Kenya	0.36[-2,q]	0.79[s]	–	–	–	305 213[-2,q]	788 126[-3,s]	8.1[-2,q]	19.3[-3,s]
Lesotho	0.03[q]	–	0.01[l,q]	–	–	1 200[q]	599[-2,l,q]	0.6[q]	0.3[-2,l,q]
Liberia	–	–	–	–	–	–	–	–	–
Madagascar	0.15[q]	0.11[q,s]	0.11[q]	–	–	41 544[q]	31 484[-2,q,s]	2.0[q]	1.5[-2,q,s]
Malawi	–	–	–	–	–	–	–	–	–
Mali	0.25[-2,i,q]	0.66[h]	–	–	–	47 068[-2,i,q]	150 785[-3,h]	3.7[-2,i,q]	10.8[-3,h]
Mauritius	0.37[-4,b,u]	–	–	0.18[h,s]	–	51 912[-4,b,u]	38 584[-1,h,s]	42.8[-4,b,u]	31.1[-1,h,s]
Mozambique	0.16[-1,h,j,q]	0.42[h,s]	–	–	–	30 012[-1,h,j,q]	92 445[-3,h,s]	1.3[-1,h,j,q]	3.9[-3,h,s]
Namibia	–	0.14[i,q]	–	–	–	–	25 516[-3,i,q]	–	11.7[-3,i,q]
Niger	–	–	–	–	–	–	–	–	–
Nigeria	0.22[-2,h]	–	–	–	–	1 374 841[-2,h]	–	9.3[-2,h]	–
Rwanda	–	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–	–
Senegal	0.37[-1]	0.54	–	–	–	93 586[-1]	149 726[-3]	7.6[-1]	11.6[-3]
Seychelles	0.30[-4]	–	–	–	–	3 955[-4]	–	45.4[-4]	–
Sierra Leone	–	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–	–
South Africa	0.84	0.74	0.73	0.73	–	4 818 930	4 824 364[-1]	94.7	92.1[-1]
South Sudan	–	–	–	–	–	–	–	–	–
Swaziland	–	–	–	–	–	–	–	–	–
Tanzania	0.34[-2,h,q]	0.38[h,q]	–	–	–	251 377[-2,h,q]	348 185[-3,h,q]	6.1[-2,h,q]	7.7[-3,h,q]
Togo	–	0.25[h]	–	0.22[h]	–	–	19 622[-1,h]	–	3.0[-1,h]
Uganda	0.36	0.48	–	–	–	170 176	240 005[-3]	5.2	7.1[-3]
Zambia	0.28[-1]	–	–	–	–	101 149[-1]	–	8.1[-1]	–
Zimbabwe	–	–	–	–	–	–	–	–	–
Arab states									
Algeria	0.07[-4,q]	–	–	–	–	241 164[-4,q]	–	7.1[-4,q]	–
Bahrain	0.04[l,q]	0.04[l,q]	0.04[l,q]	0.04[l,q]	0.04[l,q]	18 124[l,q]	24 516[l,q]	15.2[l,q]	18.4[l,q]
Egypt	0.43[h]	0.43[h]	0.53[h]	0.54[h]	0.68[h]	3 306 085[h]	6 169 203[h]	43.1[h]	75.2[h]
Iraq	0.05[h,u]	0.04[h,u]	0.03[h,u]	–	–	159 710[h,u]	146 269[-2,h,u]	5.3[h,u]	4.6[-2,h,u]
Jordan	0.43[-1]	–	–	–	–	263 201[-1]	–	44.5[-1]	–
Kuwait	0.11[k,q]	0.10[k,q]	0.10[k,q]	0.10[k,q]	0.30[h,s]	249 477[k,q]	264 911[-1,k,q]	87.5[k,q]	81.5[-1,k,q]
Lebanon	–	–	–	–	–	–	–	–	–
Libya	–	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	–	–	–
Morocco	0.64[-3]	0.73	–	–	–	1 030 143[-3]	1 494 848[-3]	33.9[-3]	47.2[-3]
Oman	–	–	0.13[r]	0.21	0.17	–	309 780[-1]	–	93.5[-1]
Palestine	–	–	–	–	–	–	–	–	–
Qatar	–	–	–	0.47	–	–	1 296 303[-1]	–	632.2[-1]
Saudi Arabia	0.07[q]	–	–	–	–	832 203[q]	–	31.1[q]	–
Sudan	0.30[-4,b,r]	–	–	–	–	298 413[-4,b,r]	–	9.4[-4,b,r]	–
Syrian Arab Rep.	–	–	–	–	–	–	–	–	–
Tunisia	0.71	0.68	0.71	0.68	–	728 030	790 712[-1]	69.3	72.7[-1]
United Arab Emirates	–	–	0.49[r]	–	–	–	2 461 027[-2,r]	–	275.7[-2,r]
Yemen	–	–	–	–	–	–	–	–	–

Table S3: R&D expenditure as a share of GDP and in purchasing power parity (PPP) dollars, 2009-2013

	R&D expenditure as percentage of GDP					R&D expenditure in current PPP$ (000s)		R&D expenditure per capita (current PPP$)	
	2009	2010	2011	2012	2013	2009	2013	2009	2013
Central Asia									
Kazakhstan	0.23	0.15	0.16	0.17	0.17	661 567	691 400	42.0	42.1
Kyrgyzstan	0.16	0.16	0.16	–	–	23 648	25 179[-2]	4.5	4.7[-2]
Mongolia	0.30[q]	0.28[q]	0.27[q]	0.28[q]	0.25[q]	48 720[q]	68 029[q]	18.2[q]	24.0[q]
Tajikistan	0.09[h]	0.09[h]	0.12[h]	0.11[h]	0.12[h]	12 546[h]	24 269[h]	1.7[h]	3.0[h]
Turkmenistan	–	–	–	–	–	–	–	–	–
Uzbekistan	–	–	–	–	–	–	–	–	–
South Asia									
Afghanistan	–	–	–	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–	–	–	–
India	0.82	0.80[r]	0.82[r]	–	–	39 400 485	48 062 976[-2,r]	33.1	39.4[-2,r]
Maldives	–	–	–	–	–	–	–	–	–
Nepal	0.26[q,u]	0.30[q,u]	–	–	–	128 477[q,u]	158 906[-3,q,u]	4.8[q,u]	5.9[-3,q,u]
Pakistan	0.45[h]	–	0.33[h]	–	0.29[h]	3 118 457[h]	2 443 292[h]	18.3[h]	13.4[h]
Sri Lanka	0.11[-1]	0.16	–	–	–	153 681[-1]	240 005[-3]	7.5[-1]	11.6[-3]
Southeast Asia									
Brunei Darussalam	0.04[-5,q]	–	–	–	–	8 708[-5,q]	–	24.1[-5,q]	–
Cambodia	0.05[-7,q,r]	–	–	–	–	7 901[-7,q,r]	–	0.6[-7,q,r]	–
China	1.70	1.76	1.84	1.98	2.08	184 170 641	336 577 729	136.3	242.9
China, Hong Kong SAR	0.77	0.75	0.72	0.73	–	2 369 983	2 663 088[-1]	338.2	372.5[-1]
China, Macao SAR	0.05[q]	0.05[q]	0.04[q]	0.05[q]	0.05[q]	21 945[q]	41 151[q]	42.1[q]	72.7[q]
Indonesia	0.08[q,r]	–	–	–	0.09[r]	1 466 763[q,r]	2 126 345[r]	6.2[q,r]	8.5[r]
Japan	3.36	3.25	3.38	3.34	3.47	136 953 957	160 246 832	1 075.4	1 260.4
Korea, DPR	–	–	–	–	–	–	–	–	–
Korea, Rep. of	3.29	3.47	3.74	4.03	4.15	45 987 242	68 937 037	954.8	1 399.4
Lao PDR	0.04[-7,q]	–	–	–	–	4 289[-7,q]	–	0.8[-7,q]	–
Malaysia	1.01	1.07	1.06	1.13	–	5 248 826	7 351 372[-1]	188.9	251.4[-1]
Myanmar	0.16[-7,q]	–	–	–	–	–	–	–	–
Philippines	0.11[-2]	–	–	–	–	477 841[-2]	–	5.4[-2]	–
Singapore	2.16	2.01	2.16	2.02	–	6 612 088	8 152 867[-1]	1 331.9	1 537.3[-1]
Thailand	0.25	–	0.39	–	–	1 915 168	3 303 858[-2]	28.9	49.6[-2]
Timor–Leste	–	–	–	–	–	–	–	–	–
Viet Nam	0.18[-7]	–	0.19	–	–	340 429[-7]	789 059[-2]	4.1[-7]	8.8[-2]
Oceania									
Australia	2.40[-1]	2.39[r]	2.25[r]	–	–	19 132 997[-1]	20 955 599[-2,r]	883.9[-1]	921.5[-2,r]
New Zealand	1.28	–	1.27	–	–	1 655 439	1 766 588[-2]	382.9	400.2[-2]
Cook Islands	–	–	–	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–	–	–	–
Nauru	–	–	–	–	–	–	–	–	–
Niue	–	–	–	–	–	–	–	–	–
Palau	–	–	–	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–	–

Note: UNESCO Institute for Statistics (UIS), August, 2015

Sources for background data:
GDP and PPP conversion factor (local currency per international $): World Bank; World Development Indicators, as of April 2015.
Population: United Nations, Department of Economic and Social Affairs, Population Division, 2013; *World Population Prospects: The 2012 Revision*

N.B.: See Key To All Tables at the end of Table S10.

Table S4: Public expenditure on tertiary education, 2008 and 2013

	Public expenditure on tertiary education as % of GDP		Public expenditure per tertiary student as % of GDP per capita		Public expenditure on tertiary education as % of total public expenditure on education	
	2008	2013	2008	2013	2008	2013
North America						
Canada	1.61	1.88^{-2}	–	–	34.44	35.60^{-2}
United States of America	1.24	1.36^{-2}	20.43	20.08^{-2}	23.33	26.11^{-2}
Latin America						
Argentina	0.77	1.02^{-1}	13.29	15.44^{-1}	17.66	19.94^{-1}
Belize	0.52	0.59^{-1}	25.90	22.66^{-1}	9.19	–
Bolivia	2.05	1.61^{-1}	–	–	29.09	25.00^{-1}
Brazil	0.86	1.04^{-1}	27.67	28.49^{-1}	15.91	16.37^{-1}
Chile	0.55	0.96^{-1}	11.51	15.01^{-1}	14.51	21.12^{-1}
Colombia	0.86	0.87	26.17	20.01	22.05	17.73
Costa Rica	–	1.43	–	33.83	–	20.75
Ecuador	1.08^{+2}	1.11^{-1}	–	–	26.58^{+2}	26.66^{-1}
El Salvador	0.42^{+1}	0.29^{-2}	17.85^{+1}	11.18^{-2}	10.46^{+1}	8.39^{-2}
Guatemala	0.34	0.35	–	18.43	10.80	12.30
Guyana	0.25^{+1}	0.16^{-1}	27.06^{+1}	14.52^{-1}	7.34^{+1}	5.06^{-1}
Honduras	0.89^{+2}	1.08	39.92^{+2}	47.74	–	18.49
Mexico	0.92	0.93^{-2}	40.16	37.34^{-2}	18.86	18.13^{-2}
Nicaragua	1.14^{+2}	1.14^{-3}	–	–	26.05^{+2}	26.05^{-3}
Panama	–	0.74^{-1}	–	20.13^{-1}	–	–
Paraguay	0.70^{+2}	1.11^{-1}	20.03^{+2}	–	18.54^{+2}	22.40^{-1}
Peru	0.45	0.55	–	–	15.71	16.82
Suriname	–	–	–	–	–	–
Uruguay	–	1.19^{-2}	–	–	–	26.83^{-2}
Venezuela	1.55^{+1}	–	20.92^{+1}	–	22.60^{+1}	–
Caribbean						
Antigua and Barbuda	0.19^{+1}	–	15.63^{+1}	–	7.35^{+1}	–
Bahamas	–	–	–	–	–	–
Barbados	1.53	2.08	–	–	30.09	–
Cuba	5.34	4.47^{-3}	61.10	62.99^{-3}	37.98	34.83^{-3}
Dominica	–	–	–	–	–	–
Dominican Rep.	–	$–^{-1}$	–	$–^{-1}$	–	$–^{-1}$
Grenada	–	–	–	–	–	–
Haiti	–	–	–	–	–	–
Jamaica	0.97	1.10	42.38	40.09	15.71	17.61
St Kitts and Nevis	–	–	–	–	–	–
St Lucia	0.24^{+1}	0.21^{-2}	14.66^{+1}	14.54^{-2}	6.30^{+1}	5.01^{-2}
St Vincent and the Grenadines	0.31^{+1}	0.36^{-3}	–	–	5.42^{+1}	7.01^{-3}
Trinidad and Tobago	–	–	–	–	–	–
European Union						
Austria	1.44	1.51^{-2}	42.09	35.00^{-2}	27.19	26.86^{-2}
Belgium	1.34	1.43^{-1}	35.66	33.33^{-1}	21.32	22.00^{-2}
Bulgaria	0.84	0.62^{-2}	23.70	16.04^{-2}	19.40	16.98^{-2}
Croatia	0.94	0.92^{-2}	28.99	25.61^{-2}	21.96	22.16^{-2}
Cyprus	1.85	1.48^{-2}	57.03	39.23^{-2}	24.99	20.45^{-2}
Czech Rep.	0.89	1.11^{-2}	23.54	26.00^{-2}	23.71	25.79^{-2}
Denmark	2.12	2.39^{-2}	50.50	51.31^{-2}	28.30	27.90^{-2}
Estonia	1.10	1.28^{-2}	21.51	24.56^{-2}	19.87	25.09^{-2}
Finland	1.81	2.06^{-1}	31.11	36.14^{-1}	31.00	28.56^{-1}
France	1.21	1.23^{-1}	35.94	35.28^{-1}	22.20	22.34^{-1}
Germany	1.18	1.35^{-2}	–	–	26.65	28.13^{-2}
Greece	–	–	–	–	–	–
Hungary	1.01	0.80^{-1}	24.39	20.93^{-1}	20.01	23.39^{-2}
Ireland	1.27	1.27^{-2}	32.00	29.64^{-2}	23.26	21.73^{-2}
Italy	0.81	0.80^{-2}	23.56	24.19^{-2}	18.33	19.36^{-2}
Latvia	0.99	0.95^{-1}	16.88	19.93^{-1}	17.33	20.72^{-1}
Lithuania	1.03	1.47^{-2}	16.15	23.82^{-2}	21.20	28.45^{-2}
Luxembourg	–	–	–	–	–	–
Malta	1.03	1.50^{-1}	44.71	51.52^{-1}	17.69	22.17^{-1}
Netherlands	1.42	1.59^{-1}	38.82	33.51^{-1}	27.77	28.79^{-1}
Poland	1.04	1.11^{-2}	18.35	20.55^{-2}	20.54	22.82^{-2}
Portugal	0.91	1.01^{-2}	25.47	26.88^{-2}	19.34	19.70^{-2}
Romania	1.20^{+1}	0.78^{-1}	22.24^{+1}	–	28.28^{+1}	26.16^{-1}
Slovakia	0.76	0.94^{-1}	17.89	23.08^{-1}	21.53	23.98^{-1}
Slovenia	1.19	1.35^{-2}	20.83	25.83^{-2}	23.30	24.20^{-2}
Spain	1.04	0.97^{-1}	26.80	23.18^{-1}	23.08	22.31^{-1}
Sweden	1.73	1.89^{-2}	39.11	38.47^{-2}	27.01	29.08^{-2}
United Kingdom	0.80	1.27^{-2}	21.18	32.01^{-2}	15.71	22.10^{-2}
Southeast Europe						
Albania	–	–	–	–	–	–
Bosnia and Herzegovina	–	–	–	–	–	–
FYR Macedonia	–	–	–	–	–	–
Montenegro	–	–	–	–	–	–
Serbia	1.29	1.29^{-1}	39.75	40.06^{-1}	27.30	29.12^{-1}
Other Europe and West Asia						
Armenia	0.36	0.20	7.54	5.07	11.29	8.72
Azerbaijan	0.28	0.36^{-2}	13.45	18.05^{-2}	11.34	14.63^{-2}
Belarus	0.91^{+1}	0.93	15.56^{+1}	15.62	20.07^{+1}	17.58
Georgia	0.34	0.38^{-1}	11.40	17.18^{-1}	11.58	19.17^{-1}

Table S4: Public expenditure on tertiary education, 2008 and 2013

	Public expenditure on tertiary education as % of GDP		Public expenditure per tertiary student as % of GDP per capita		Public expenditure on tertiary education as % of total public expenditure on education	
	2008	2013	2008	2013	2008	2013
Iran, Islamic Rep. of	0.99	0.84	20.95	14.77	20.67	22.94
Israel	0.89	0.91^{-2}	20.10	19.41^{-2}	16.00	16.22^{-2}
Moldova, Rep. of	1.54	1.47^{-1}	38.18	41.83^{-1}	18.65	17.56^{-1}
Russian Federation	0.95	–	14.25	–	23.11	–
Turkey	–	–	–	–	–	–
Ukraine	2.03	2.16^{-1}	32.93	41.17^{-1}	31.53	32.41^{-1}
European Free Trade Assoc.						
Iceland	1.42	1.37^{-2}	27.17	23.17^{-2}	19.70	19.42^{-2}
Liechtenstein	–	–	–	–	–	–
Norway	2.05	1.96^{-2}	45.91	42.23^{-2}	31.99	29.89^{-2}
Switzerland	1.27^{+1}	1.33^{-1}	42.19^{+1}	39.40^{-1}	25.14^{+1}	26.31^{-1}
Sub–Saharan Africa						
Angola	–	–	–	–	–	–
Benin	0.72	1.05	102.67	–	17.64	21.04
Botswana	3.94^{+1}	–	159.02^{+1}	–	41.51^{+1}	–
Burkina Faso	0.74^{+2}	0.93	225.08^{+2}	210.92	18.84^{+2}	21.72
Burundi	1.10	1.31	434.66	297.08	21.21	24.23
Cabo Verde	0.62	0.78	45.28	29.76	11.27	15.82
Cameroon	0.26	0.23^{-1}	34.74	–	8.85	7.77^{-1}
Central African Rep.	0.23	0.34^{-2}	99.63	111.93^{-2}	17.48	27.29^{-2}
Chad	0.29^{+1}	0.37^{-2}	159.53^{+1}	182.41^{-2}	12.38^{+1}	16.28^{-2}
Comoros	1.14	–	–	–	14.61	–
Congo	0.68^{+2}	0.71	–	84.71	10.87^{+2}	–
Congo, Dem. Rep. of	0.37^{+2}	0.37^{-3}	–	–	24.00^{+2}	24.00^{-3}
Côte d'Ivoire	–	–	–	–	–	–
Djibouti	0.74^{+2}	0.74^{-3}	191.60^{+2}	191.60^{-3}	16.50^{+2}	16.50^{-3}
Equatorial Guinea	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–
Ethiopia	0.16^{+2}	0.16^{-3}	24.21^{+2}	24.21^{-3}	3.54^{+2}	3.54^{-3}
Gabon	–	–	–	–	–	–
Gambia	0.32	0.30^{-1}	–	–	9.03	7.36^{-1}
Ghana	1.49	1.07^{-2}	180.80	92.78^{-2}	25.85	13.13^{-2}
Guinea	0.84	1.23	107.93	131.61	34.42	34.64
Guinea–Bissau	–	–	–	–	–	–
Kenya	–	–	–	–	–	–
Lesotho	4.72	–	–	–	36.38	–
Liberia	–	0.10^{-1}	–	9.34^{-1}	–	3.56^{-1}
Madagascar	0.45	0.29	143.53	67.49	15.36	13.74
Malawi	1.30^{+2}	2.18	–	–	29.80^{+2}	28.36
Mali	0.61	0.85^{-1}	118.71	130.04^{-1}	16.06	20.34^{-1}
Mauritius	0.33	0.29	15.85	8.92	10.21	8.02
Mozambique	–	0.91	–	183.43	–	13.69
Namibia	0.64	1.93^{-3}	–	–	9.91	23.09^{-3}
Niger	0.34	0.80^{-1}	396.20	631.00^{-1}	9.41	17.61^{-1}
Nigeria	–	–	–	–	–	–
Rwanda	0.96	0.71	217.70	104.75	25.41	14.02
Sao Tome and Principe	–	–	–	–	–	–
Senegal	1.24	1.38^{-3}	166.00	193.48^{-3}	24.55	24.57^{-3}
Seychelles	–	1.18^{-2}	–	545.71^{-2}	–	32.51^{-2}
Sierra Leone	0.50	0.73	–	–	20.83	25.93
Somalia	–	–	–	–	–	–
South Africa	0.63	0.74	–	38.73	13.01	12.41
South Sudan	–	0.20^{-2}	–	–	–	25.34^{-2}
Swaziland	1.62	1.01^{-2}	–	–	21.55	12.84^{-2}
Tanzania	1.27	0.76^{+1}	–	–	29.85	21.40^{+1}
Togo	0.69	0.98	–	102.75	20.10	22.21
Uganda	0.37^{+1}	0.30	108.51^{+1}	–	11.30^{+1}	13.76
Zambia	–	–	–	–	–	–
Zimbabwe	0.27^{+1}	0.45^{-3}	–	62.00^{-3}	–	22.82^{-3}
Arab states						
Algeria	1.17	–	–	–	26.97	–
Bahrain	–	0.60	–	–	–	–
Egypt	–	–	–	–	–	–
Iraq	–	–	–	–	–	–
Jordan	–	–	–	–	–	–
Kuwait	–	–	–	–	–	–
Lebanon	0.59	0.74	12.55	15.55	28.98	28.74
Libya	–	–	–	–	–	–
Mauritania	0.67	0.46	190.41	93.30	16.72	11.58
Morocco	0.90	1.11	70.73	–	16.23	17.70
Oman	1.13^{+1}	–	39.60^{+1}	–	26.88^{+1}	–
Palestine	–	–	–	–	–	–
Qatar	–	–	–	–	–	–
Saudi Arabia	–	–	–	–	–	–
Sudan	–	–	–	–	–	–
Syrian Arab Rep.	1.15	1.24^{-4}	44.77	49.00^{-4}	24.94	24.22^{-4}
Tunisia	1.57	1.75	–	56.59	25.00	–
United Arab Emirates	–	–	–	–	–	–
Yemen	–	–	–	–	–	–

	Public expenditure on tertiary education as % of GDP		Public expenditure per tertiary student as % of GDP per capita		Public expenditure on tertiary education as % of total public expenditure on education	
	2008	2013	2008	2013	2008	2013
Central Asia						
Kazakhstan	0.36	0.40^{-4}	–	–	13.90	13.13^{-4}
Kyrgyzstan	0.97	0.89^{-1}	19.04	–	16.44	12.03^{-1}
Mongolia	0.36^{+2}	0.21^{-2}	5.89^{+2}	3.37^{-2}	6.68^{+2}	3.83^{-2}
Tajikistan	0.49	0.46	18.93	19.33	14.25	–
Turkmenistan	–	0.28^{-1}	–	–	–	9.23^{-1}
Uzbekistan	–	–	–	–	–	–
South Asia						
Afghanistan	–	–	–	–	–	–
Bangladesh	0.27	0.23^{-2}	30.83	17.44^{-2}	13.26	–
Bhutan	0.93	1.02	150.89	102.12	19.40	18.23
India	1.17^{+1}	1.28^{-1}	74.31^{+1}	54.88^{-1}	36.45^{+1}	33.19^{-1}
Maldives	–	0.58^{-1}	–	–	–	9.35^{-1}
Nepal	0.51	0.50^{-3}	46.63	35.39^{-3}	13.46	10.65^{-3}
Pakistan	–	0.80	–	75.18	–	32.23
Sri Lanka	0.37^{+1}	0.32^{-1}	–	24.19^{-1}	18.19^{+1}	18.73^{-1}
Southeast Asia						
Brunei Darussalam	0.50^{+2}	1.20^{+1}	32.22^{+2}	57.09^{+1}	24.38^{+2}	31.92^{+1}
Cambodia	0.38^{+2}	0.38^{-3}	27.83^{+2}	27.83^{-3}	14.54^{+2}	14.54^{-3}
China	–	–	–	–	–	–
China, Hong Kong SAR	1.02	1.16^{-1}	27.81	30.37^{-1}	31.16	33.02^{-1}
China, Macao SAR	0.82	2.28^{-1}	16.30	49.03^{-1}	36.64	68.14^{-1}
Indonesia	0.32	0.61^{-1}	16.89	24.27^{-1}	10.98	17.18^{-1}
Japan	0.65	0.76	21.09	–	18.86	20.00
Korea, DPR	–	–	–	–	–	–
Korea, Rep. of	0.62	0.86	9.49	–	13.92	–
Lao PDR	–	–	–	–	–	–
Malaysia	2.15^{+1}	2.19^{-2}	59.63^{+1}	60.88^{-2}	35.94^{+1}	36.97^{-2}
Myanmar	–	–	–	–	–	–
Philippines	0.28	0.32^{-4}	9.66	10.51^{-4}	10.42	11.96^{-4}
Singapore	0.91	1.04	–	22.59	32.59	35.28
Thailand	0.79	0.71^{-1}	21.63	19.52^{-1}	21.18	14.42^{-1}
Timor–Leste	0.93^{+1}	1.87^{-2}	58.52^{+1}	–	8.14^{+1}	19.79^{-2}
Viet Nam	1.08	1.05^{-1}	55.71	41.24^{-1}	22.16	16.67^{-1}
Oceania						
Australia	1.04	1.18^{-2}	19.78	19.99^{-2}	22.46	23.20^{-2}
New Zealand	1.62	1.86^{-1}	27.94	31.46^{-1}	28.92	25.33^{-1}
Cook Islands	–	a^{-}	–	a^{-}	–	a^{-}
Fiji	–	0.56^{-2}	–	–	–	12.96^{-2}
Kiribati	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–
Nauru	–	–	–	–	–	–
Niue	–	–	–	–	–	–
Palau	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–
Samoa	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–
Tonga	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–
Vanuatu	0.34	–	–	–	5.86	–

Source: UNESCO Institute for Statistics

N.B.: See key to all tables at the end of Table S10.

Table S5: Tertiary graduates in 2008 and 2013 and graduates in science, engineering, agriculture and health in 2013

	2008		2013					
	Tertiary graduates		Tertiary graduates		Science			
	MF (000s)	Females (%)	MF (000s)	Females (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
North America								
Canada	–	–	–	–	–	–	–	–
United States of America	2 782.27	58.5	3 308.49^{-1}	58.4^{-1}	41.14^{-1}	235.23^{-1}	16.67^{-1}	40.94^{-1}
Latin America								
Argentina	235.86	65.7	123.24^{-1}	60.8^{-1}	9.07^{-2}	5.65^{-2}	0.73^{-2}	–
Belize	–	–	–	–	0.30	–	a	a
Bolivia	–	–	–	–	–	–	–	–
Brazil	917.11	60.3	1 111.46^{-1}	60.8^{-1}	18.30^{-1}	40.10^{-1}	–	–
Chile	92.23	54.0	147.55^{-1}	56.0^{-1}	4.29^{-1}	2.82^{-1}	0.24^{-1}	40.00^{-1}
Colombia	134.92	42.6	344.07	55.3	9.06	5.36	0.08	35.44
Costa Rica	38.16^{+2}	63.3^{+2}	44.58	63.2	0.28	2.34	0.01	42.86
Ecuador	70.19	58.8	79.19^{-1}	58.5^{-1}	1.54^{-1}	–	0^{-1}	a^{-1}
El Salvador	15.80	58.2	23.62	56.6	0	0.24	0	a
Guatemala	–	–	20.83	58.3	–	–	–	–
Guyana	1.75	70.0	1.84^{-1}	74.9^{-1}	0^{-1}	0.11^{-1}	a^{-1}	a^{-1}
Honduras	15.41^{+2}	–	18.67	63.1	0.01	0.52	a	a
Mexico	420.48	54.3	533.87^{-1}	53.5^{-1}	0.50^{-1}	28.29^{-1}	0.79^{-1}	46.56^{-1}
Nicaragua	–	–	–	–	–	–	–	–
Panama	21.06	66.0	22.79^{-1}	65.4^{-1}	0.27^{-1}	–	0^{-1}	a^{-1}
Paraguay	–	–	–	–	0.18^{-1}	–	–	–
Peru	–	–	–	–	14.00^{-1}	–	–	–
Suriname	–	–	–	–	–	–	–	–
Uruguay	9.47	65.1	–	–	0.02^{-3}	0.55^{-3}	0.03^{-3}	66.67^{-3}
Venezuela	–	–	–	–	–	–	–	–
Caribbean								
Antigua and Barbuda	0.15^{+1}	77.0^{+1}	0.25^{-1}	87.8^{-1}	0.01^{-1}	0.00^{-1}	0^{-1}	a^{-1}
Bahamas	–	–	–	–	–	–	–	–
Barbados	2.26^{+2}	–	2.39^{-2}	68.4^{-2}	0.13^{-2}	0.18^{-2}	0.00^{-2}	100.00^{-2}
Cuba	103.76	47.9	133.29	62.6	a	3.57	0.08	39.74
Dominica	–	–	–	–	–	–	–	–
Dominican Rep.	–	–	41.11^{-1}	64.1^{-1}	0.00^{-1}	–	a^{-1}	a^{-1}
Grenada	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–
Jamaica	–	–	–	–	–	–	–	–
St Kitts and Nevis	–	–	–	–	–	–	–	–
St Lucia	–	–	0.58	–	0	–	a	a
St Vincent and the Grenadines	–	–	–	–	–	–	–	–
Trinidad and Tobago	–	–	–	–	–	–	–	–
European Union								
Austria	43.65	51.6	85.28	56.0	1.12	5.97	0.60	35.93
Belgium	97.25	58.7	110.42^{-1}	59.3^{-1}	1.55^{-1}	3.82^{-1}	0.52^{-1}	34.87^{-1}
Bulgaria	54.91	61.4	64.09^{-1}	60.8^{-1}	0.06^{-1}	2.91^{-1}	0.16^{-1}	52.90^{-1}
Croatia	26.94	58.4	39.82^{-1}	59.3^{-1}	0.73^{-1}	2.38^{-1}	0.24^{-1}	60.25^{-1}
Cyprus	4.23	61.6	6.17^{-1}	60.3^{-1}	0.09^{-1}	0.41^{-1}	0.02^{-1}	52.63^{-1}
Czech Rep.	88.98	58.1	107.77^{-1}	62.2^{-1}	0.30^{-1}	9.07^{-1}	0.72^{-1}	39.97^{-1}
Denmark	49.75	57.8	66.47	57.5	0.46	4.70	0.34	35.22
Estonia	11.35	69.3	11.44^{-1}	67.5^{-1}	0.19^{-1}	0.90^{-1}	0.08^{-1}	52.63^{-1}
Finland	43.01^{+1}	62.8^{+1}	52.73	60.1	0	3.42	0.34	39.35
France	628.09	54.9	726.54	56.1	6.22	55.64	6.50	40.01
Germany	–	–	–	–	–	–	–	–
Greece	66.96	59.3	66.33^{-1}	59.1^{-1}	1.64^{-1}	6.24^{-1}	0.29^{-1}	33.33^{-1}
Hungary	63.33	66.8	69.92^{-1}	64.0^{-1}	0.60^{-1}	3.47^{-1}	0.29^{-1}	37.54^{-1}
Ireland	60.07	56.3	60.02^{-1}	54.5^{-1}	1.40^{-1}	5.23^{-1}	0.51^{-1}	45.12^{-1}
Italy	398.19	59.5	374.99^{-1}	62.3^{-1}	0^{-1}	24.97^{-1}	2.69^{-1}	52.58^{-1}
Latvia	24.17	71.5	21.61	69.0	0.18	1.04	0.07	54.41
Lithuania	42.55	66.7	39.27	63.3	a	2.05	0.08	49.35
Luxembourg	0.34	49.4	1.57	53.6	0.00	0.13	0.03	32.00
Malta	2.79	59.4	3.46^{-1}	57.4^{-1}	0.15^{-1}	0.22^{-1}	0.00^{-1}	0^{-1}
Netherlands	124.23	56.7	152.05^{-1}	56.5^{-1}	0.01^{-1}	8.64^{-1}	0.83^{-1}	33.41^{-1}
Poland	558.02	65.8	638.96^{-1}	66.0^{-1}	a	38.20	–	–
Portugal	84.01	59.6	94.87	59.8	a	6.57	0.93	54.03
Romania	311.48	63.7	259.63^{-2}	61.6^{-2}	a^{-2}	12.56^{-2}	0.52^{-2}	53.74^{-2}
Slovakia	65.03	64.2	70.03	63.6	0.01	4.81	0.34	53.35
Slovenia	17.22	62.8	20.60^{-1}	60.3^{-1}	0.23^{-1}	1.29^{-1}	0.15^{-1}	38.96^{-1}
Spain	291.04	58.4	391.96^{-1}	56.2^{-1}	4.10^{-1}	23.27^{-1}	3.48^{-1}	47.42^{-1}
Sweden	60.43	63.5	69.14^{-1}	61.6^{-1}	0.66^{-1}	4.24^{-1}	0.87^{-1}	41.64^{-1}
United Kingdom	676.20	57.9	791.95	57.1	14.70	105.01	8.49	45.59
Southeast Europe								
Albania	15.65	64.4	30.37	65.0	a	2.13	0.04	44.19
Bosnia and Herzegovina	15.77	58.7	21.21	60.0	a	1.41	0.01	25.00
FYR Macedonia	11.20	59.7	11.36	56.3	a	1.15	0.02	56.25
Montenegro	–	–	–	–	–	–	–	–
Serbia	36.33	60.4	47.80	58.4	a	4.73	0.12	58.33

	2013											
	Engineering, manufacturing and construction				Agriculture				Health and welfare			
	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
	–	–	–	–	–	–	–	–	–	–	–	–
	66.85^{-1}	161.86^{-1}	9.11^{-1}	23.33^{-1}	8.52^{-1}	25.05^{-1}	0.99^{-1}	44.31^{-1}	227.17^{-1}	330.11^{-1}	16.09^{-1}	72.64^{-1}
	5.72^{-2}	8.68^{-2}	0.09^{-2}	45.45^{-2}	1.50^{-2}	3.27^{-2}	0.08^{-2}	–	20.66^{-2}	18.68^{-2}	0.12^{-2}	55.65^{-2}
	0	–	a	a	0.02	–	a	a	0	–	a	a
	–	–	–	–	–	–	–	–	–	–	–	–
	13.60^{-1}	60.94^{-1}	–	–	2.09^{-1}	16.75^{-1}	–	–	2.76^{-1}	158.82^{-1}	–	–
	11.99^{-1}	9.22^{-1}	0.08^{-1}	37.18^{-1}	1.28^{-1}	2.31^{-1}	0.04^{-1}	34.09^{-1}	17.22^{-1}	14.34^{-1}	0.03^{-1}	34.38^{-1}
	21.16	38.50	0.07	17.57	3.84	2.48	0.02	47.06	6.23	19.35	0.03	67.65
	0.14	2.78	0	a	0.10	0.60	0.00	0	0.07	6.32	0	a
	1.53^{-1}	–	0^{-1}	a^{-1}	0.32^{-1}	–	0^{-1}	a^{-1}	1.17^{-1}	–	0^{-1}	a^{-1}
	2.70	2.31	0	a	0.14	0.19	0	a	1.66	2.36	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	0.14^{-1}	0^{-1}	a^{-1}	a^{-1}	0.03^{-1}	0^{-1}	a^{-1}	a^{-1}	0.25^{-1}	0^{-1}	a^{-1}	a^{-1}
	0.04	2.11	a	a	0.05	0.59	a	a	0.08	1.29	a	a
	18.11^{-1}	95.23^{-1}	0.60^{-1}	39.53^{-1}	0.08^{-1}	8.70^{-1}	0.22^{-1}	46.33^{-1}	1.72^{-1}	46.32^{-1}	0.09^{-1}	61.29^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	0.60^{-1}	–	0.00^{-1}	75.00^{-1}	0.04^{-1}	–	0^{-1}	a^{-1}	0.47^{-1}	–	0^{-1}	a^{-1}
	0.01^{-1}	–	–	–	0.02^{-1}	–	–	–	0.21^{-1}	–	–	–
	10.58^{-1}	–	–	–	3.71^{-1}	–	–	–	20.90^{-1}	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	0.02^{-3}	0.57^{-3}	0.00^{-3}	33.33^{-3}	0.06^{-3}	0.33^{-3}	0^{-3}	a^{-3}	0.10^{-3}	1.99^{-3}	0.00^{-3}	50.00^{-3}
	–	–	–	–	–	–	–	–	–	–	–	–
	0^{-1}	0^{-1}	0^{-1}	a^{-1}	0^{-1}	0^{-1}	0^{-1}	a^{-1}	0.02^{-1}	0^{-1}	0^{-1}	a^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	0.04^{-2}	0^{-2}	a^{-2}	a^{-2}	0.00^{-2}	0^{-2}	a^{-2}	a^{-2}	0.17^{-2}	0.03^{-2}	0.00^{-2}	100.00^{-2}
	a	1.87	0.06	40.35	a	2.70	0.05	40.38	a	43.21	0.07	39.44
	–	–	–	–	–	–	–	–	–	–	–	–
	0.13^{-1}	–	a^{-1}	a^{-1}	0.04^{-1}	–	a^{-1}	a^{-1}	0.06^{-1}	–	a^{-1}	a^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	a	a	0.03	–	a	a	0.05	–	a	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	8.59	7.05	0.43	26.30	0.68	0.53	0.07	59.15	0.52	4.92	0.22	59.00
	3.05^{-1}	8.67^{-1}	0.56^{-1}	30.59^{-1}	0.76^{-1}	1.57^{-1}	0.12^{-1}	46.96^{-1}	12.28^{-1}	10.16^{-1}	0.51^{-1}	59.49^{-1}
	0.64^{-1}	8.98^{-1}	0.15^{-1}	32.41^{-1}	0.01^{-1}	1.00^{-1}	0.03^{-1}	40.63^{-1}	0.55^{-1}	3.62^{-1}	0.09^{-1}	50.55^{-1}
	1.42^{-1}	4.56^{-1}	0.16^{-1}	34.16^{-1}	0.32^{-1}	1.11^{-1}	0.10^{-1}	36.89^{-1}	1.46^{-1}	1.44^{-1}	0.24^{-1}	53.36^{-1}
	0.04^{-1}	0.76^{-1}	0.01^{-1}	37.50^{-1}	0.01^{-1}	0.03^{-1}	0^{-1}	a^{-1}	0.07^{-1}	0.17^{-1}	0^{-1}	a^{-1}
	0.44^{-1}	12.21^{-1}	0.55^{-1}	22.57^{-1}	0.08^{-1}	3.70^{-1}	0.18^{-1}	51.37^{-1}	3.02^{-1}	7.21^{-1}	0.20^{-1}	48.04^{-1}
	1.93	5.63	0.48	28.84	0.20	0.49	0.21	53.81	0.36	13.09	0.50	60.92
	0.39^{-1}	0.94^{-1}	0.03^{-1}	27.27^{-1}	0.01^{-1}	0.25^{-1}	0.01^{-1}	88.89^{-1}	0.97^{-1}	0.38^{-1}	0.01^{-1}	50.00^{-1}
	0	10.48	0.45	30.38	0	1.03	0.06	61.82	0	10.41	0.33	66.36
	46.05	61.59	1.80	31.81	4.31	4.59	0	a	31.78	81.81	0.38	55.97
	–	–	–	–	–	–	–	–	–	–	–	–
	5.24^{-1}	5.32^{-1}	0.28^{-1}	27.14^{-1}	1.30^{-1}	1.49^{-1}	0.08^{-1}	41.77^{-1}	3.85^{-1}	3.27^{-1}	0.57^{-1}	50.62^{-1}
	0.19^{-1}	7.18^{-1}	0.10^{-1}	22.22^{-1}	0.16^{-1}	1.17^{-1}	0.10^{-1}	58.76^{-1}	1.07^{-1}	4.69^{-1}	0.20^{-1}	51.78^{-1}
	2.90^{-1}	4.02^{-1}	0.20^{-1}	23.53^{-1}	0.45^{-1}	0.34^{-1}	0.02^{-1}	46.67^{-1}	2.44^{-1}	7.13^{-1}	0.21^{-1}	54.93^{-1}
	0^{-1}	45.82^{-1}	2.04^{-1}	35.46^{-1}	0^{-1}	6.60^{-1}	0.69^{-1}	53.78^{-1}	0^{-1}	59.25^{-1}	1.24^{-1}	100.00^{-1}
	0.36	2.16	0.06	32.76	0.03	0.20	0.01	30.00	1.51	2.40	0.03	80.00
	a	6.47	0.12	38.84	a	0.68	0.02	61.90	a	4.40	0.05	80.77
	0.01	79.00	0.01	22.22	0	0.00	0	a	0.04	–	0	a
	0.10^{-1}	0.19^{-1}	0.00^{-1}	0^{-1}	0.01^{-1}	0^{-1}	0^{-1}	a^{-1}	0.01^{-1}	0.66^{-1}	0.00^{-1}	50.00^{-1}
	0.08^{-1}	11.50^{-1}	1.02^{-1}	25.71^{-1}	0.02^{-1}	1.53^{-1}	0.21^{-1}	58.69^{-1}	0.22^{-1}	25.54^{-1}	0.73^{-1}	66.62^{-1}
	a	65.99	–	–	a	8.16	–	–	0.37	71.17	–	–
	a	16.40	0.86	39.09	a	1.37	0.05	59.18	a	15.93	0.39	66.33
	0.01^{-2}	37.12^{-2}	2.18^{-2}	38.63^{-2}	a^{-2}	3.99^{-2}	0.30^{-2}	52.96^{-2}	0.14^{-2}	27.37^{-2}	0.77^{-2}	62.84^{-2}
	0.02	8.65	0.52	33.40	0	1.18	0.06	53.57	0.22	12.79	0.22	65.02
	1.55^{-1}	1.77^{-1}	0.10^{-1}	28.28^{-1}	0.17^{-1}	0.35^{-1}	0.06^{-1}	67.86^{-1}	0.31^{-1}	0.99^{-1}	0.05^{-1}	60.87^{-1}
	13.92^{-1}	41.54^{-1}	0.80^{-1}	30.30^{-1}	0.83^{-1}	4.47^{-1}	0.30^{-1}	56.38^{-1}	16.32^{-1}	40.43^{-1}	1.51^{-1}	56.42^{-1}
	2.39^{-1}	10.88^{-1}	0.83^{-1}	25.93^{-1}	0.35^{-1}	0.40^{-1}	0.06^{-1}	53.45^{-1}	0.91^{-1}	15.38^{-1}	0.97^{-1}	62.37^{-1}
	10.32	57.31	3.59	24.41	2.10	5.00	0.31	54.89	35.96	84.04	4.30	57.03
	a	2.24	0.01	20.00	a	0.97	0.02	31.25	a	4.40	0.01	91.67
	a	1.75	0.03	14.71	a	0.82	0.01	50.00	a	2.37	0.06	63.33
	a	1.21	0.03	36.36	a	0.29	0.01	80.00	a	0.93	0.03	54.84
	–	–	–	–	–	–	–	–	–	–	–	–
	a	7.31	0.16	37.50	a	1.08	0.06	32.20	a	4.40	0.23	59.05

Table S5: Tertiary graduates in 2008 and 2013 and graduates in science, engineering, agriculture and health in 2013

	2008		2013					
	Tertiary graduates		Tertiary graduates		Science			
	MF (000s)	Females (%)	MF (000s)	Females (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
Other Europe and West Asia								
Armenia	35.00^{+2}	61.5^{+2}	–	–	0^{-3}	2.52^{-3}	0.11^{-3}	22.52^{-3}
Azerbaijan	49.20	53.5	47.04^{-1}	52.1^{-1}	0.19^{-1}	4.27^{-1}	0.10^{-1}	27.00^{-1}
Belarus	112.88	–	137.46	60.8	0	2.43	0.21	50.48
Georgia	17.73^{+2}	60.4^{+2}	17.68	56.8	0.43	1.64	0.06	55.56
Iran, Islamic Rep. of	457.57^{+1}	52.0^{+1}	716.10	45.6	1.19	53.83	0.77	40.08
Israel	–	–	–	–	–	–	–	–
Moldova, Rep. of	27.06	58.4	34.81	59.6	0.48	1.28	0.05	55.56
Russian Federation	2 064.47^{+1}	–	–	–	30.32^{-2}	97.20^{-2}	–	–
Turkey	444.76	46.0	607.98^{-1}	47.1^{-1}	17.01^{-1}	34.19^{-1}	1.16^{-1}	50.73^{-1}
Ukraine	610.23	–	621.79	55.0	7.54	30.83	1.27	50.90
European Free Trade Assoc.								
Iceland	3.63	66.2	4.10^{-1}	64.5^{-1}	0.01^{-1}	0.31^{-1}	0.01^{-1}	35.71^{-1}
Liechtenstein	0.18	30.1	0.31^{-1}	30.2^{-1}	a^{-1}	0^{-1}	0^{-1}	a^{-1}
Norway	35.21	60.6	44.75	58.7	0.11	2.74	0.49	39.84
Switzerland	67.33	48.6	81.91	48.3	0.02	5.56	1.07	35.21
Sub-Saharan Africa								
Angola	–	–	13.55	48.0	–	–	–	–
Benin	14.64^{+1}	31.2^{+1}	16.71^{-2}	29.7^{-2}	–	–	–	–
Botswana	–	–	6.55	–	0.26	0.52	0	–
Burkina Faso	9.48^{+2}	–	16.15	31.8	–	–	–	–
Burundi	2.79^{+2}	28.4^{+2}	7.31^{-1}	30.7^{-1}	0^{-1}	–	0^{-1}	a^{-1}
Cabo Verde	–	–	–	–	–	0.12	0	a
Cameroon	33.99	–	36.31^{-2}	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	0.09	–	–
Congo	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–
Djibouti	0.64^{+1}	–	–	–	a^{-2}	–	a^{-2}	a^{-2}
Equatorial Guinea	–	–	–	–	–	–	–	–
Eritrea	3.02^{+2}	–	2.71^{+1}	26.3^{+1}	0.03^{+1}	–	a^{+1}	a^{+1}
Ethiopia	65.37	24.1	–	–	0^{-3}	10.62^{-3}	0.01^{-3}	0^{-3}
Gabon	–	–	–	–	–	–	–	–
Gambia	–	–	–	–	–	–	–	–
Ghana	–	–	79.74	40.7	1.12	6.46	0.01	12.50
Guinea	–	–	–	–	–	1.03	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–
Kenya	–	–	–	–	–	–	–	–
Lesotho	–	–	4.75	65.2	0.04	0.07	0	a
Liberia	3.16^{+2}	30.0^{+2}	4.39^{-1}	38.2^{-1}	–	–	–	–
Madagascar	16.40	47.5	25.26	47.9	0.36	2.24	0.02	34.78
Malawi	–	–	–	–	–	–	–	–
Mali	–	–	–	–	–	–	–	–
Mauritius	–	–	–	–	–	–	–	–
Mozambique	7.05	44.6	10.26	44.9	a	0.21	0	a
Namibia	5.53	58.4	–	–	–	–	–	–
Niger	1.87	–	–	–	–	–	–	–
Nigeria	–	–	–	–	–	–	–	–
Rwanda	–	–	16.05^{-1}	42.7^{-1}	–	–	–	–
Sao Tome and Principe	a	a	–	–	a^{-1}	–	a^{-1}	a^{-1}
Senegal	–	–	–	–	–	–	–	–
Seychelles	a	a	0.08	85.9	0	–	a	a
Sierra Leone	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–
South Africa	–	–	183.86^{-1}	59.8^{-1}	6.44^{-1}	–	0.57^{-1}	40.53^{-1}
South Sudan	–	–	–	–	–	–	–	–
Swaziland	–	–	2.53	38.8	0	0.28	0.01	37.50
Tanzania	–	–	–	–	–	–	–	–
Togo	–	–	–	–	–	–	–	–
Uganda	–	–	–	–	–	–	–	–
Zambia	–	–	–	–	–	–	–	–
Zimbabwe	30.51^{+2}	45.2^{+2}	13.64	47.6	0.85	0.46	0	a
Arab states								
Algeria	154.84^{+1}	62.5^{+1}	255.44	62.1	–	23.47	–	–
Bahrain	–	–	5.28^{+1}	60.5^{+1}	0.17^{+1}	0.23^{+1}	0.00^{+1}	50.00^{+1}
Egypt	–	–	510.36	52.1	0	20.85	0.60	45.13
Iraq	–	–	–	–	–	–	–	–
Jordan	–	–	60.69^{-2}	48.4^{-2}	0.44^{-2}	2.79^{-2}	0.03^{-2}	52.00^{-2}
Kuwait	–	–	12.72	58.3	a	0.23	a	a
Lebanon	32.30	55.3	54.21	55.8	0^{-2}	3.74^{-2}	0.00^{-2}	100.00^{-2}
Libya	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	a	a
Morocco	62.73	32.0	–	–	–	–	–	–

	2013											
	Engineering, manufacturing and construction				Agriculture				Health and welfare			
	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
	0.20^{-3}	2.68^{-3}	0.06^{-3}	10.17^{-3}	0.17^{-3}	1.09^{-3}	0.02^{-3}	43.75^{-3}	3.74^{-3}	0.89^{-3}	0.03^{-3}	17.24^{-3}
	0.90^{-1}	2.11^{-1}	0.05^{-1}	13.33^{-1}	0.03^{-1}	0.08^{-1}	0.02^{-1}	31.58^{-1}	2.03^{-1}	1.57^{-1}	0.02^{-1}	39.13^{-1}
	17.02	15.98	0.22	37.05	5.98	4.73	0.09	50.00	3.17	3.56	0.18	51.67
	0.23	1.03	0.07	40.00	0.08	0.44	0.01	36.36	0.17	2.09	0.03	63.64
	102.68	155.87	0.62	17.10	4.77	20.98	0.29	27.59	2.98	18.05	2.31	42.73
	–	–	–	–	–	–	–	–	–	–	–	–
	2.61	4.50	0.04	45.95	0.14	0.47	0.01	30.77	1.23	–	0.06	43.86
	179.08^{-2}	246.39^{-2}	–	–	8.43^{-2}	20.49^{-2}	–	–	64.30^{-2}	48.11^{-2}	–	–
	43.18^{-1}	30.96^{-1}	0.63^{-1}	34.39^{-1}	11.39^{-1}	7.82^{-1}	0.25^{-1}	38.15^{-1}	12.85^{-1}	21.43^{-1}	4.61^{-1}	46.33^{-1}
	40.49	84.38	1.58	35.47	5.67	14.52	0.41	51.09	22.45	15.27	0.46	59.35
	0^{-1}	0.41^{-1}	0.00^{-1}	33.33^{-1}	0.00^{-1}	0.03^{-1}	0^{-1}	a^{-1}	0^{-1}	0.58^{-1}	0.01^{-1}	76.92^{-1}
	a^{-1}	0.04^{-1}	0.00^{-1}	0^{-1}	a^{-1}	0^{-1}	0^{-1}	a^{-1}	a^{-1}	0^{-1}	0.01^{-1}	100.00^{-1}
	1.71	3.74	0.15	22.88	0.02	0.29	0.02	42.86	0.05	9.04	0.47	58.51
	0.04	10.90	0.47	25.75	0	1.32	0.11	81.13	0.27	9.61	0.85	53.72
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	0.26	0.20	0	–	0.03	0.14	0	–	0.57	0.11	0	–
	–	–	–	–	–	–	–	–	–	–	–	–
	0^{-1}	–	0^{-1}	a^{-1}	0^{-1}	–	0^{-1}	a^{-1}	0^{-1}	–	0.15^{-1}	20.95^{-1}
	–	–	0	a	–	–	0	a	–	–	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a^{-2}	0^{-2}	a^{-2}	a^{-2}	a^{-2}	0^{-2}	a^{-2}	a^{-2}	a^{-2}	0^{-2}	a^{-2}	a^{-2}
	–	–	–	–	–	–	–	–	–	–	–	–
	0.51^{+1}	–	a^{+1}	a^{+1}	0.07^{+1}	–	a^{+1}	a^{+1}	0.11^{+1}	–	a^{+1}	a^{+1}
	0^{-3}	5.01^{-3}	0^{-3}	a^{-3}	0^{-3}	7.87^{-3}	0.01^{-3}	0^{-3}	0^{-3}	5.40^{-3}	0.10^{-3}	17.71^{-3}
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	2.47	3.09	0.00	0	0.91	1.59	0.02	25.00	1.55	2.68	0.01	16.67
	–	2.18	–	–	–	0.90	–	–	–	2.89	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	0.13	–	0	a	0.10	0.05	0	a	0.51	0.10	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	0.40	2.08	0.02	0	0.01	0.29	0.00	50.00	0.27	0.61	0.24	57.87
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a	0.38	0.01	0	a	0.47	0	a	a	0.56	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a^{-1}	–	a^{-1}	a^{-1}	a^{-1}	–	a^{-1}	a^{-1}	a^{-1}	–	a^{-1}	a^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	0	–	a	a	0	–	a	a	0	–	a	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	5.73^{-1}	–	0.15^{-1}	17.57^{-1}	1.37^{-1}	–	0.09^{-1}	39.78^{-1}	2.07^{-1}	–	0.17^{-1}	62.72^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	0	0.13	0	a	0	0.15	0.01	42.86	0	0.33	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	2.70	0.00	0	a	0.02	0.26	0	a	0.18	–	0	a
	–	30.68	–	–	–	3.65	–	–	–	5.96	–	–
	0.21^{+1}	0.42^{+1}	0^{+1}	a^{+1}	0^{+1}	0.00^{+1}	0^{+1}	a^{+1}	0.04^{+1}	0.27^{+1}	0^{+1}	a^{+1}
	0	38.42	0.31	27.01	0	10.86	0.72	42.82	0	65.58	1.29	50.54
	–	–	–	–	–	–	–	–	–	–	–	–
	0.20^{-2}	1.95^{-2}	0.00^{-2}	0^{-2}	0.01^{-2}	1.80^{-2}	0.01^{-2}	37.50^{-2}	0^{-2}	1.00^{-2}	0^{-2}	a^{-2}
	2.41	0.77	a	a	a	–	a	a	0.66	0.39	a	a
	0.88^{-2}	3.31^{-2}	0.00^{-2}	25.00^{-2}	0^{-2}	0.17^{-2}	0^{-2}	a^{-2}	0.97^{-2}	2.84^{-2}	0^{-2}	a^{-2}
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	a	a	–	–	a	a	–	–	a	a
	–	–	–	–	–	–	–	–	–	–	–	–

Table S5: Tertiary graduates in 2008 and 2013 and graduates in science, engineering, agriculture and health in 2013

	2008		2013					
	Tertiary graduates		Tertiary graduates		Science			
	MF (000s)	Females (%)	MF (000s)	Females (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
Oman	11.54^{+1}	58.7^{+1}	16.68	56.1	0.53	1.56	0.00	100.00
Palestine	25.28	57.7	35.28	59.5	0.48	2.35	0	a
Qatar	1.79	66.7	2.28	60.8	0.04	0.08	a	a
Saudi Arabia	112.13	57.4	141.20	51.1	6.52	19.13	0.03	32.00
Sudan	–	–	124.49	51.2	3.46	8.76	0.13	31.25
Syrian Arab Rep.	51.32	51.5	58.69	56.2	–	–	–	–
Tunisia	–	–	65.42	65.9	a	16.92	0.31	60.33
United Arab Emirates	14.32	60.8	25.68	55.6	0.59	1.50	0	a
Yemen	–	–	–	–	–	–	–	–
Central Asia								
Kazakhstan	–	–	238.22	56.3	0.63	4.38	0.07	60.27
Kyrgyzstan	35.58	60.8	50.23	60.1	0.15	1.63	0.11	56.36
Mongolia	29.60	65.6	37.75	64.5	0.02	2.00	0.01	55.56
Tajikistan	–	–	46.80	37.9	0.28	–	0.07	–
Turkmenistan	–	–	–	–	0^{+1}	0.39^{+1}	–	–
Uzbekistan	73.73	38.7	77.22^{-2}	44.3^{-2}	a^{-2}	5.71^{-2}	0.15^{-2}	29.61^{-2}
South Asia								
Afghanistan	9.27	16.7	–	–	–	–	–	–
Bangladesh	184.91	–	316.02^{-1}	41.8^{-1}	0^{-1}	35.02^{-1}	0.13^{-1}	43.75^{-1}
Bhutan	–	–	1.63	34.2	0	–	a	a
India	–	–	–	–	–	–	–	–
Maldives	–	–	–	–	–	–	–	–
Nepal	44.46	–	61.52	48.3	a	2.36	0.00	25.00
Pakistan	–	–	–	–	–	–	–	–
Sri Lanka	27.91^{+2}	58.5^{+2}	34.92	57.6	0.24^{-1}	2.66^{-1}	0.05^{-1}	54.17^{-1}
Southeast Asia								
Brunei Darussalam	1.54	66.5	1.91	64.1	0.09	0.10	0	a
Cambodia	16.71	27.5	–	–	–	–	–	–
China	7 071.05	47.9	9 366.20	50.7	–	–	–	–
China, Hong Kong SAR	–	–	–	–	–	–	–	–
China, Macao SAR	6.79	48.6	6.07	59.9	0.00	0.20	0.02	21.05
Indonesia	799.37^{+1}	–	–	–	13.41^{-4}	30.81^{-4}	–	–
Japan	1 033.77	48.5	980.90^{-1}	48.3^{-1}	0^{-1}	28.07^{-1}	2.42^{-1}	23.65^{-1}
Korea, DPR	–	–	–	–	–	–	–	–
Korea, Rep. of	605.28	49.0	618.28	50.5	5.21	37.36	1.63	29.53
Lao PDR	18.99^{+1}	42.3^{+1}	37.38	45.4	0.78	0.68	0	a
Malaysia	206.59	58.6	261.82^{-1}	56.6^{-1}	12.98^{-1}	11.44^{-1}	0.55^{-1}	40.44^{-1}
Myanmar	–	–	295.94^{-1}	64.6^{-1}	5.13^{-1}	122.78^{-1}	0.20^{-1}	89.00^{-1}
Philippines	481.33^{+2}	56.0^{+2}	564.77	56.8	18.83	63.86	0.21	62.15
Singapore	–	–	–	–	–	–	–	–
Thailand	541.89	55.0	–	–	–	–	–	–
Timor–Leste	–	–	–	–	–	–	–	–
Viet Nam	243.52	43.1	406.07	43.0	0	0.00	0	a
Oceania								
Australia	306.90	55.9	386.63^{-2}	57.3^{-2}	4.65^{-2}	26.36^{-2}	1.74^{-2}	44.83^{-2}
New Zealand	54.45	60.9	71.93^{-1}	59.4^{-1}	2.80^{-1}	6.36^{-1}	0.36^{-1}	47.21^{-1}
Cook Islands	a	a	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–
Kiribati	a	a	a^{-1}	a^{-1}	a^{-1}	0^{-1}	a^{-1}	a^{-1}
Marshall Islands	–	–	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–	–	–
Nauru	a	a	–	–	–	–	–	–
Niue	a	a	–	–	–	–	–	–
Palau	–	–	0.09	57.4	a	0.00	a	a
Papua New Guinea	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–
Solomon Islands	a	a	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–
Tuvalu	a	a	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–

Source: UNESCO Institute for Statistics (UIS)

N.B.: See Key To All Tables at the end of Table S10.

	2013											
	Engineering, manufacturing and construction				Agriculture				Health and welfare			
	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
	0.64	2.52	0.00	0	0.45	0.05	0.00	0	2.42	0.47	0	a
	0.48	2.09	0	a	0	0.17	0	a	1.30	1.77	0	a
	0.27	0.29	a	a	a	–	a	a	0.03	0.22	a	a
	7.87	5.30	0.02	5.88	0.02	0.43	0.00	0	2.45	7.38	0.14	25.17
	2.91	4.96	0.03	21.43	0.02	3.00	0.03	34.48	0.97	13.75	0.06	37.70
	–	–	–	–	–	–	–	–	–	–	–	–
	a	11.02	0.12	49.18	a	0.90	0.01	50.00	a	5.81	0	a
	0.22	3.52	0	a	0	–	0	a	0.07	1.71	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	14.66	31.80	0.04	37.84	3.55	–	0.01	18.18	4.18	–	0	a
	1.05	6.17	0.08	40.74	0.15	–	0.01	10.00	1.94	–	0.05	66.00
	0.07	4.22	0.01	36.36	0.01	0.81	0.01	91.67	0.62	2.34	0.02	78.95
	0.97	–	0.02	–	0.23	–	0.03	–	5.90	–	0.02	–
	1.16^{+1}	0.93^{+1}	–	–	0.30^{+1}	0.13^{+1}	–	–	0.30^{+1}	0.30^{+1}	–	–
	a^{-2}	10.34^{-2}	0.12^{-2}	22.88^{-2}	a^{-2}	2.70^{-2}	0.06^{-2}	29.31^{-2}	a^{-2}	3.53^{-2}	0.13^{-2}	55.30^{-2}
	–	–	–	–	–	–	–	–	–	–	–	–
	0^{-1}	14.12^{-1}	0.09^{-1}	14.94^{-1}	0^{-1}	3.87^{-1}	0.07^{-1}	43.24^{-1}	0^{-1}	5.00^{-1}	0.27^{-1}	39.26^{-1}
	0.17	–	a	a	0.07	–	a	a	0.06	–	a	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a	0.14	0.00	0	a	–	0	a	a	1.30	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	0.48^{-1}	1.07^{-1}	0.01^{-1}	60.00^{-1}	0.34^{-1}	0.75^{-1}	0.03^{-1}	64.52^{-1}	0.26^{-1}	1.19^{-1}	0.23^{-1}	44.21^{-1}
	0.18	0.04	0	a	0	–	0	a	0.04	0.04	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	0	0.11	0.00	33.33	0	0.00	0	a	0.01	0.36	0.01	14.29
	41.29^{-4}	87.82^{-4}	–	–	14.39^{-4}	33.06^{-4}	–	–	13.94^{-4}	32.05^{-4}	–	–
	41.67^{-1}	122.98^{-1}	3.56^{-1}	14.35^{-1}	3.04^{-1}	21.83^{-1}	1.00^{-1}	31.27^{-1}	69.74^{-1}	52.26^{-1}	5.26^{-1}	31.23^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	54.09	90.63	3.14	14.37	1.78	5.36	0.32	25.55	46.58	39.77	2.52	46.79
	1.59	–	0	a	1.25	–	0	a	0.47	–	0	a
	32.23^{-1}	23.09^{-1}	0.63^{-1}	26.34^{-1}	2.42^{-1}	2.43^{-1}	0.07^{-1}	32.86^{-1}	12.23^{-1}	18.02^{-1}	0.20^{-1}	46.80^{-1}
	5.73^{-1}	5.61^{-1}	0.06^{-1}	72.41^{-1}	0^{-1}	1.54^{-1}	0^{-1}	a^{-1}	2.14^{-1}	1.71^{-1}	0.06^{-1}	83.33^{-1}
	15.24	47.10	0.06	48.28	4.07	9.65	0.07	55.41	4.39	53.11	0.16	69.14
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	61.27	36.72	0.09	13.98	8.17	13.27	0.01	0	7.46	7.33	0.01	41.67
	8.10^{-2}	21.07^{-2}	0.88^{-2}	25.51^{-2}	1.96^{-2}	1.79^{-2}	0.28^{-2}	49.64^{-2}	19.15^{-2}	45.82^{-2}	0.99^{-2}	63.44^{-2}
	1.41^{-1}	3.60^{-1}	0.13^{-1}	29.77^{-1}	0.57^{-1}	0.38^{-1}	0.02^{-1}	73.33^{-1}	2.01^{-1}	9.19^{-1}	0.15^{-1}	58.39^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a^{-1}	0^{-1}	a^{-1}	a^{-1}	a^{-1}	0^{-1}	a^{-1}	a^{-1}	a^{-1}	0^{-1}	a^{-1}	a^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a	0.01	a	a	a	0.01	a	a	a	0.01	a	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–

Table S6: Total researchers and researchers per million inhabitants, 2009 and 2013

	Researchers in full–time equivalents					
	2009			2013		
	Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants
North America						
Canada	150 220	–	4 451	156 550[-1]	–	4 494[-1]
United States of America	1 250 984[r]	–	4 042[r]	1 265 064[-1,r]	–	3 984[-1,r]
Latin America						
Argentina	43 717	50.52	1 092	51 598[-1]	51.61[-1]	1 256[-1]
Belize	–	–	–	–	–	–
Bolivia	1 422	–	142	1 646[-3]	–	162[-3]
Brazil	129 102	–	667	138 653[-3]	–	710[-3]
Chile	4 859[q]	31.41[q]	286[q]	6 798[-1,q]	31.66[-1,q]	389[-1,q]
Colombia	7 500	36.54	164	7 702[-1]	37.15[-1]	161[-1]
Costa Rica	4 479[b]	51.33[-1]	973[b]	6 107[-2,b]	45.04[-2,h]	1 289[-2,b]
Ecuador	1 739	39.81	118	2 736[-2]	39.30[-2]	179[-2]
El Salvador	–	–	–	–	–	–
Guatemala	554[q]	35.20[q]	40[q]	411[-1,q]	41.85[-1,q]	27[-1,q]
Guyana	–	–	–	–	–	–
Honduras	–	–	–	–	–	–
Mexico	42 973	–	369	46 125[-2]	–	386[-2]
Nicaragua	–	–	–	–	–	–
Panama	394	–	109	438[-2]	30.59[-2]	117[-2]
Paraguay	466[-1]	–	75[-1]	1 081[-1]	–	162[-1]
Peru	–	–	–	–	–	–
Suriname	–	–	–	–	–	–
Uruguay	1 617	–	481	1 803	47.48	529
Venezuela	5 209[q]	53.41[q]	182[q]	8 686[-1,q]	–	290[-1,q]
Caribbean						
Antigua and Barbuda	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–
Barbados	–	–	–	–	–	–
Cuba	–	–	–	–	–	–
Dominica	–	–	–	–	–	–
Dominican Rep.	–	–	–	–	–	–
Grenada	–	–	–	–	–	–
Haiti	–	–	–	–	–	–
Jamaica	–	–	–	–	–	–
St Kitts and Nevis	–	–	–	–	–	–
St Lucia	–	–	–	–	–	–
St Vincent and the Grenadines	–	–	–	–	–	–
Trinidad and Tobago	–	–	–	–	–	–
European Union						
Austria	34 664	22.40	4 141	39 923[r,v]	22.80[-2]	4 699[r,v]
Belgium	38 225	31.56	3 519	44 649[v]	31.73[-2]	4 021[v]
Bulgaria	11 968	48.43	1 607	12 275	49.61[-1]	1 699
Croatia	6 931	48.82	1 593	6 529	49.82[-1]	1 522
Cyprus	873	37.57	801	885[v]	37.51[-1]	776[v]
Czech Rep.	28 759	26.04	2 743	34 271	24.72[-1]	3 202
Denmark	36 789	29.77	6 659	40 858[r,v]	31.59[-2]	7 271[r,v]
Estonia	4 314	41.63	3 311	4 407	42.84[-1]	3 424
Finland	40 849	–	7 644	39 196[s]	–	7 223[s]
France	234 366[p]	–	3 727[p]	265 177[s,v]	26.05[-1,q]	4 125[s,v]
Germany	317 307	20.57	3 815	360 310[r,v]	22.08[-2]	4 355[r,v]
Greece	21 014[-2,r]	31.71[-4]	1 899[-2,r]	29 055[s]	38.92[-2,s]	2 611[s]
Hungary	20 064	30.42	2 000	25 038	28.41[-1]	2 515
Ireland	14 189[r]	32.79[r]	3 217[r]	15 732[-1,r]	30.27[-2,r]	3 438[-1,r]
Italy	101 840	34.19	1 691	117 973[v]	35.75[-1]	1 934[v]
Latvia	3 621	50.35	1 714	3 625	50.85[-1]	1 768
Lithuania	8 490	50.45	2 737	8 557	50.18[-1]	2 836
Luxembourg	2 396	22.30	4 811	2 615[s,v]	24.18[-2]	4 931[s,v]
Malta	494	29.15	1 168	878[v]	28.18[-1]	2 047[v]
Netherlands	46 958	–	2 835	72 325[s,v]	26.56[-1]	4 316[s,v]
Poland	61 105	38.15	1 600	71 472	36.73[-1]	1 870
Portugal	39 834	44.66	3 765	43 321[v]	44.49[-1]	4 084[v]
Romania	19 271	44.85	879	18 704[s]	44.78[-1,s]	862[s]
Slovakia	13 290	42.19	2 450	14 727	41.79	2 702
Slovenia	7 446	33.75	3 642	8 707[s]	33.99[-1,s]	4 202[s]
Spain	133 803	38.51	2 924	123 225	38.47[-1]	2 626
Sweden	47 160[q]	29.70[q]	5 065[q]	62 294[q,s]	30.19[-2,q,s]	6 509[q,s]
United Kingdom	256 124[r]	–	4 151[r]	259 347[r,v]	–	4 108[r,v]
Southeast Europe						
Albania	467[-1,q]	44.33[-1,q]	148[-1,q]	–	–	–
Bosnia and Herzegovina	745[-2,q]	–	193[-2,q]	829[s]	36.50	216[s]
FYR Macedonia	893	53.86	425	1 402	51.04	665
Montenegro	–	–	–	404	48.68[-2,r]	650
Serbia	10 444	47.72	1 076	12 342	50.00[-1]	1 298

Researchers in head counts						
2009			2013			
Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants	
						North America
–	–	–	–	–	–	Canada
–	–	–	–	–	–	United States of America
						Latin America
67 245	51.91	1 680	81 748^{-1}	52.66^{-1}	1 990^{-1}	Argentina
–	–	–	–	–	–	Belize
1 947	63.23	195	2 153^{-3}	62.75^{-3}	212^{-3}	Bolivia
216 672	–	1 120	234 797^{-3}	–	1 203^{-3}	Brazil
8 770^{q}	32.30^{q}	516^{q}	10 447$^{-1,q}$	30.97$^{-1,q}$	598$^{-1,q}$	Chile
16 201	37.19	354	16 127^{-1}	37.75^{-1}	338^{-1}	Colombia
7 223^{b}	43.26^{h}	1 570^{b}	8 848$^{-2,b}$	42.65$^{-2,h}$	1 868$^{-2,b}$	Costa Rica
2 413	38.96	164	4 027^{-2}	37.37^{-2}	264^{-2}	Ecuador
455	35.16	74	662	38.82	104	El Salvador
756^{q}	35.19^{q}	54^{q}	666$^{-1,q}$	44.74$^{-1,q}$	44$^{-1,q}$	Guatemala
–	–	–	–	–	–	Guyana
539^{-6}	26.53^{-6}	81^{-6}	–	–	–	Honduras
42 973	31.57$^{-6,r}$	369	46 125^{-2}	–	386^{-2}	Mexico
326^{-5}	42.48$^{-7,q}$	61^{-5}	–	–	–	Nicaragua
482	41.12^{-5}	133	552$^{-2,s}$	–	148$^{-2,s}$	Panama
850^{-1}	51.76^{-1}	136^{-1}	1 704^{-1}	51.68^{-1}	255^{-1}	Paraguay
4 965^{-5}	–	181^{-5}	–	–	–	Peru
–	–	–	–	–	–	Suriname
2 596	51.58	773	2 403	49.11	705	Uruguay
6 829^{q}	54.52^{q}	239^{q}	10 256$^{-1,q}$	56.29$^{-1,q}$	342$^{-1,q}$	Venezuela
						Caribbean
–	–	–	–	–	–	Antigua and Barbuda
–	–	–	–	–	–	Bahamas
–	–	–	–	–	–	Barbados
5 448	46.64	483	4 477	46.59	397	Cuba
–	–	–	–	–	–	Dominica
–	–	–	–	–	–	Dominican Rep.
–	–	–	–	–	–	Grenada
–	–	–	–	–	–	Haiti
–	–	–	–	–	–	Jamaica
–	–	–	–	–	–	St Kitts and Nevis
–	–	–	–	–	–	St Lucia
21^{-7}	–	194^{-7}	–	–	–	St Vincent and the Grenadines
787	52.86	595	914^{-1}	43.76^{-1}	683^{-1}	Trinidad and Tobago
						European Union
59 341	28.44	7 088	65 609^{-2}	28.99^{-2}	7 780^{-2}	Austria
55 858	32.71	5 142	63 207^{-2}	33.47^{-2}	5 743^{-2}	Belgium
14 699	47.62	1 974	15 219^{-1}	48.61^{-1}	2 091^{-1}	Bulgaria
12 108	46.42	2 783	11 402^{-1}	47.71^{-1}	2 647^{-1}	Croatia
1 696	35.55	1 555	1 914^{-1}	37.30^{-1}	1 695^{-1}	Cyprus
43 092	28.86	4 109	47 651^{-1}	27.50^{-1}	4 470^{-1}	Czech Rep.
54 049	31.75	9 784	58 568^{-1}	34.78$^{-1,r}$	10 463^{-1}	Denmark
7 453	42.48	5 720	7 634^{-1}	43.99^{-1}	5 914^{-1}	Estonia
55 797	31.42	10 441	56 704^{-1}	32.25^{-1}	10 484^{-1}	Finland
296 093	26.92^{p}	4 708	356 469$^{-1,s}$	25.59$^{-1,q,s}$	5 575$^{-1,s}$	France
487 242	24.96	5 857	522 010^{-2}	26.80^{-2}	6 297^{-2}	Germany
33 396^{-4}	36.37^{-4}	3 025^{-4}	45 239$^{-2,s}$	36.71$^{-2,s}$	4 069$^{-2,s}$	Greece
35 267	32.11	3 516	37 019^{-1}	30.94^{-1}	3 711^{-1}	Hungary
20 901^{r}	34.23^{r}	4 739^{r}	22 131^{-2}	32.43^{-2}	4 893^{-2}	Ireland
149 314	33.84	2 479	157 960^{-1}	35.50^{-1}	2 594^{-1}	Italy
6 324	52.37	2 994	7 995^{-1}	52.81^{-1}	3 880^{-1}	Latvia
13 882	51.01	4 475	17 677^{-1}	52.36^{-1}	5 839^{-1}	Lithuania
2 951	21.21	5 924	3 267^{-2}	24.00^{-2}	6 327^{-2}	Luxembourg
945	29.42	2 235	1 451^{-1}	29.50^{-1}	3 392^{-1}	Malta
54 505	25.88	3 291	104 265$^{-1,s}$	26.31$^{-1,s}$	6 238$^{-1,s}$	Netherlands
98 165	39.52	2 570	103 627^{-1}	38.29^{-1}	2 712^{-1}	Poland
75 206	44.33	7 108	81 750^{-1}	45.02^{-1}	7 709^{-1}	Portugal
30 645	44.73	1 398	27 838$^{-1,s}$	45.14$^{-1,s}$	1 280$^{-1,s}$	Romania
21 832	42.47	4 024	24 441	42.70	4 484	Slovakia
10 444	35.66	5 109	12 362$^{-1,s}$	35.80$^{-1,s}$	5 979$^{-1,s}$	Slovenia
221 314	38.11	4 837	215 544^{-1}	38.81^{-1}	4 610^{-1}	Spain
72 864	35.68	7 826	80 039^{-2}	37.22^{-2}	8 471^{-2}	Sweden
385 489^{r}	37.93^{r}	6 248^{r}	442 385$^{-1,r}$	37.83$^{-1,r}$	7 046$^{-1,r}$	United Kingdom
						Southeast Europe
1 721$^{-1,q}$	44.33$^{-1,q}$	545$^{-1,q}$	–	–	–	Albania
2 953$^{-2,q}$	–	763$^{-2,q}$	1 245^{s}	38.88	325^{s}	Bosnia and Herzegovina
1 795	51.25	855	2 867	49.15	1 361	FYR Macedonia
671^{-2}	41.28^{-2}	1 086^{-2}	1 546$^{-2,s}$	49.87^{-2}	2 491$^{-2,s}$	Montenegro
12 006	47.44	1 237	13 249^{-1}	49.64^{-1}	1 387^{-1}	Serbia

Table S6: Total researchers and researchers per million inhabitants, 2009 and 2013

	Researchers in full–time equivalents					
	2009			2013		
	Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants
Other Europe and West Asia						
Armenia	–	–	–	–	–	–
Azerbaijan	–	–	–	–	–	–
Belarus	–	–	–	–	–	–
Georgia	–	–	–	–	–	–
Iran, Islamic Rep. of	52 256[i]	24.21[i]	711[i]	54 813[-3,i]	26.96[-3,i]	736[-3,i]
Israel	–	–	–	63 728[-1,p,r]	21.19[-2,p]	8 337[-1,p,r]
Moldova, Rep. of	2 861	48.03	794	2 623	47.85	752
Russian Federation	442 263	–	3 078	440 581	–	3 085
Turkey	57 759	33.37	811	89 075	32.96	1 189
Ukraine	61 858[q]	43.89[-2]	1 337[q]	52 626[q]	–	1 163[q]
European Free Trade Assoc.						
Iceland	2 505	39.93	7 983	2 258[-2,s]	35.96[-2,s]	7 012[-2,s]
Liechtenstein	–	–	–	–	–	–
Norway	26 273	–	5 433	28 343	–	5 621
Switzerland	25 142[-1]	–	3 285[-1]	35 950[-1]	–	4 495[-1]
Sub–Saharan Africa						
Angola	–	–	–	1 150[-2]	27.83[-2]	57[-2]
Benin	–	–	–	–	–	–
Botswana	–	–	–	352[-1]	26.64[-1]	176[-1]
Burkina Faso	–	–	–	742[-3]	21.61[-3]	48[-3]
Burundi	–	–	–	–	–	–
Cabo Verde	60[-7,q]	–	131[-7,q]	25[-2,l,q,s]	36.00[-2,l,q]	51[-2,l,q,s]
Cameroon	–	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–
Chad	–	–	–	–	–	–
Comoros	–	–	–	–	–	–
Congo	102[-9,q]	12.78[-9]	33[-9,q]	–	–	–
Congo, Dem. Rep. of	–	–	–	–	–	–
Côte d'Ivoire	1 269[-4,q]	16.55[-4,q]	73[-4,q]	–	–	–
Djibouti	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–
Ethiopia	1 615[-2]	7.74[-2]	20[-2]	4 267[s]	13.04	45[s]
Gabon	–	–	–	–	–	–
Gambia	179	20.00[-1]	110	59[-2,q,s]	20.48[-2]	34[-2,q,s]
Ghana	392[-2]	17.59[-2]	17[-2]	941[-3,s]	17.30[-3]	39[-3,s]
Guinea	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–
Kenya	2 105[-2,q]	17.84[-2,r]	56[-2,q]	9 305[-3,s]	20.00[-3]	227[-3,s]
Lesotho	46[q]	41.03[q]	23[q]	12[-2,l,q]	32.77[-2,q]	6[-2,l,q]
Liberia	–	–	–	–	–	–
Madagascar	930[q]	31.72	45[q]	1 106[-2,q,s]	34.18[-2]	51[-2,q,s]
Malawi	406[-2]	21.86[-2]	30[-2]	732[-3,h]	18.55[-3]	49[-3,h]
Mali	513[-3,q]	13.26[-3,q]	42[-3,q]	443[-3]	14.06[-3]	32[-3]
Mauritius	–	–	–	228[-1,h]	41.44[-1,h]	184[-1,h]
Mozambique	273[h,i,q]	33.72[q]	12[h,i,q]	912[-3,h,s]	32.24[-3]	38[-3,h,s]
Namibia	–	–	–	–	–	–
Niger	101[-4,q]	–	8[-4,q]	–	–	–
Nigeria	5 677[-2,h,q]	23.35[-2,q]	39[-2,h,q]	–	–	–
Rwanda	123[l,q]	34.17[l]	12[l,q]	–	–	–
Sao Tome and Principe	–	–	–	–	–	–
Senegal	4 527[-1]	23.81[-1]	370[-1]	4 679[-3]	24.83[-3]	361[-3]
Seychelles	13[-4,q]	30.77[-4,q]	149[-4,q]	–	–	–
Sierra Leone	–	–	–	–	–	–
Somalia	–	–	–	–	–	–
South Africa	19 793	39.02	389	21 383[-1]	43.42[-1]	408[-1]
South Sudan	–	–	–	–	–	–
Swaziland	–	–	–	–	–	–
Tanzania	–	–	–	1 600[-3,h,q]	24.59[-3]	36[-3,h,q]
Togo	216[-2,h]	12.21[-2,q]	37[-2,h]	242[-1,h,s]	9.45[-1]	36[-1,h,s]
Uganda	–	–	–	1 263[-3]	26.26[-3]	37[-3]
Zambia	536[-1]	34.33[-1]	43[-1]	–	–	–
Zimbabwe	–	–	–	1 305[-1,h]	25.45[-1]	95[-1,h]
Arab states						
Algeria	5 593[-4,q]	36.53[-4,q]	165[-4,q]	–	–	–
Bahrain	39[l,q]	41.03[l,q]	33[l,q]	67[l,q]	50.75[l,q]	50[l,q]
Egypt	35 158[q]	36.00	458[q]	47 652[h]	43.69[h]	581[h]
Iraq	12 048[b,h]	34.06[h]	399[b,h]	13 559[-2,b,h]	33.94[-2,h]	426[-2,b,h]
Jordan	–	–	–	–	–	–
Kuwait	402[k,q]	37.06[k,q]	141[k,q]	439[-1,k,q]	36.22[-1,k,q]	135[-1,k,q]
Lebanon	–	–	–	–	–	–

Researchers in head counts						
2009			2013			
Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants	
						Other Europe and West Asia
5 542[q]	45.69[q]	1 867[q]	3 870[q]	48.14[q]	1 300[q]	Armenia
11 041	52.35	1 229	15 784	53.34	1 677	Azerbaijan
20 543	42.72	2 157	18 353	41.06	1 961	Belarus
8 112[-4]	52.70[-4]	1 813[-4]	–	–	–	Georgia
101 144[i]	23.69[i]	1 375[i]	115 762[-3,i]	25.86[-3,i]	1 555[-3,i]	Iran, Islamic Rep. of
–	–	–	–	–	–	Israel
3 561	47.32	988	3 250	47.97	932	Moldova, Rep. of
369 237[q]	41.90[q]	2 570[q]	369 015[q]	40.88[q]	2 584[q]	Russian Federation
114 436	36.29	1 606	166 097	36.23	2 217	Turkey
76 147	44.82	1 646	65 641	45.82	1 451	Ukraine
						European Free Trade Assoc.
3 754	42.59	11 963	3 270[-2,s]	37.34[-2,s]	10 154[-2,s]	Iceland
–	–	–	–	–	–	Liechtenstein
44 762	35.23	9 257	46 747[-1]	36.20[-1]	9 361[-1]	Norway
45 874[-1]	30.18[-1]	5 994[-1]	60 278[-1]	32.41[-1]	7 537[-1]	Switzerland
						Sub–Saharan Africa
–	–	–	1 482[-2]	27.06[-2]	73[-2]	Angola
1 000[-2,q,r]	–	115[-2,q,r]	–	–	–	Benin
1 732[-4,q]	30.77[-4,q]	923[-4,q]	690[-1,s]	27.25[-1,s]	344[-1,s]	Botswana
187[-2,q]	13.37[-2]	13[-2,q]	1 144[-3,s]	23.08[-3,s]	74[-3,s]	Burkina Faso
362[q]	13.81	41[q]	379[-2,q]	14.51[-2]	40[-2,q]	Burundi
107[-7,q]	52.34[-7]	233[-7,q]	128[-2,l,q,s]	39.84[-2,l,q]	261[-2,l,q,s]	Cabo Verde
4 562[-1]	21.79[-1]	233[-1]	–	–	–	Cameroon
134[q]	41.46[-2,l]	31[q]	–	–	–	Central African Rep.
–	–	–	–	–	–	Chad
–	–	–	–	–	–	Comoros
–	–	–	–	–	–	Congo
12 470[b]	–	206[b]	–	–	–	Congo, Dem. Rep. of
2 397[-4,q]	16.48[-4,q]	138[-4,q]	–	–	–	Côte d'Ivoire
–	–	–	–	–	–	Djibouti
–	–	–	–	–	–	Equatorial Guinea
–	–	–	–	–	–	Eritrea
2 377[-2]	7.40[-2]	30[-2]	8 221[s]	13.30	87[s]	Ethiopia
531[q]	22.39[q]	350[q]	–	–	–	Gabon
179	20.00[-1]	110	60[-2,q,s]	20.00[-2]	35[-2,q,s]	Gambia
636[-2]	17.92[-2]	28[-2]	2 542[-3,s]	18.29[-3]	105[-3,s]	Ghana
2 117[-9,q]	5.76[-9,q]	242[-9,q]	–	–	–	Guinea
–	–	–	–	–	–	Guinea–Bissau
3 509[-2,q]	17.84[-2]	93[-2,q]	13 012[-3,s]	25.65[-3]	318[-3,s]	Kenya
229[q]	41.03[q]	115[q]	42[-2,l,q]	30.95[-2,q]	21[-2,l,q]	Lesotho
–	–	–	–	–	–	Liberia
1 817[q]	33.90	89[q]	2 364[-2,q,s]	35.36[-2]	109[-2,q,s]	Madagascar
733[-2]	23.19[-2]	53[-2]	1 843[-3,h]	19.53[-3]	123[-3,h]	Malawi
877[-2,i,q]	10.60[-2,q]	69[-2,i,q]	898[-3]	16.04[-3]	64[-3]	Mali
–	–	–	353[-1,h]	41.93[-1,h]	285[-1,h]	Mauritius
771[h,i,q]	33.72[q]	33[h,i,q]	1 588[-3,h,s]	32.24[-3]	66[-3,h,s]	Mozambique
–	–	–	748[-3]	43.72[-3]	343[-3]	Namibia
129[-4,q]	–	10[-4,q]	–	–	–	Niger
17 624[-2,h,q]	23.30[-2,q]	120[-2,h,q]	–	–	–	Nigeria
564[l,q]	21.81[l]	54[l,q]	–	–	–	Rwanda
–	–	–	–	–	–	Sao Tome and Principe
7 859[-1]	24.05[-1]	642[-1]	8 170[-3]	24.86[-3]	631[-3]	Senegal
14[-4,q]	35.71[-4,q]	161[-4,q]	–	–	–	Seychelles
–	–	–	–	–	–	Sierra Leone
–	–	–	–	–	–	Somalia
40 797	40.76	802	42 828[-1]	43.72[-1]	818[-1]	South Africa
–	–	–	–	–	–	South Sudan
–	–	–	–	–	–	Swaziland
2 755[-2,h,q]	20.25[-2]	67[-2,h,q]	3 102[-3,h,q]	25.44[-3]	69[-3,h,q]	Tanzania
834[-2,h]	12.02[-2,q]	143[-2,h]	639[-1,h,s]	10.17[-1]	96[-1,h,s]	Togo
1 703	40.40	52	2 823[-3,s]	24.34[-3]	83[-3,s]	Uganda
612[-1]	30.72[-1]	49[-1]	–	–	–	Zambia
–	–	–	2 739[-1,h]	25.26[-1]	200[-1,h]	Zimbabwe
						Arab states
13 805[-4,q]	34.83[-4,q]	406[-4,q]	–	–	–	Algeria
397[l,q]	33.75[l,q]	333[l,q]	510[l,q]	41.18[l,q]	383[l,q]	Bahrain
89 114[q]	37.34	1 161[q]	110 772[h]	42.77[h]	1 350[h]	Egypt
36 470[b,h]	34.16[h]	1 209[b,h]	40 521[-2,b,h]	34.17[-2,h]	1 273[-2,b,h]	Iraq
11 310[-1,q]	22.54[-1]	1 913[-1,q]	–	–	–	Jordan
402[k,q]	37.06[k,q]	141[k,q]	4 025[h,s]	37.34[h,s]	1 195[h,s]	Kuwait
–	–	–	–	–	–	Lebanon

Table S6: Total researchers and researchers per million inhabitants, 2009 and 2013

	Researchers in full–time equivalents					
	2009			2013		
	Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants
Libya	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–
Morocco	20 703$^{-1,q}$	29.49^{-1}	669$^{-1,q}$	27 714$^{-2,q}$	31.79^{-2}	864$^{-2,q}$
Oman	–	–	–	497^{h}	23.54^{h}	137^{h}
Palestine	567	33.57^{-2}	145	2 492^{h}	–	576^{h}
Qatar	–	–	–	1 203^{-1}	20.23^{-1}	587^{-1}
Saudi Arabia	–	–	–	–	–	–
Sudan	–	–	–	–	–	–
Syrian Arab Rep.	–	–	–	–	–	–
Tunisia	13 300	–	1 265	15 159^{-1}	–	1 394^{-1}
United Arab Emirates	–	–	–	–	–	–
Yemen	–	–	–	–	–	–
Central Asia						
Kazakhstan	5 593	–	355	12 552^{s}	–	763^{s}
Kyrgyzstan	–	–	–	–	–	–
Mongolia	–	–	–	–	–	–
Tajikistan	–	–	–	–	–	–
Turkmenistan	–	–	–	–	–	–
Uzbekistan	–	–	–	15 029$^{-2,b}$	39.14^{-2}	534$^{-2,b}$
South Asia						
Afghanistan	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–
India	154 827^{-4}	14.85$^{-4,q}$	137^{-4}	192 819^{-3}	14.28^{-3}	160^{-3}
Maldives	–	–	–	–	–	–
Nepal	1 500$^{-7,r}$	–	62$^{-7,r}$	–	–	–
Pakistan	27 602^{h}	23.67	162^{h}	30 244^{h}	31.27^{h}	166^{h}
Sri Lanka	1 972^{-1}	38.89^{-1}	96^{-1}	2 140^{-3}	39.35^{-3}	103^{-3}
Southeast Asia						
Brunei Darussalam	102$^{-5,q}$	–	282$^{-5,q}$	–	–	–
Cambodia	223$^{-7,q,r}$	22.60$^{-7,q,r}$	18$^{-7,q,r}$	–	–	–
China	1 152 311	–	853	1 484 040	–	1 071
China, Hong Kong SAR	19 283	–	2 752	21 236^{-1}	–	2 971^{-1}
China, Macao SAR	300^{q}	29.68^{q}	575^{q}	527^{q}	32.18^{q}	931^{q}
Indonesia	21 349^{q,r}	–	90^{q,r}	–	–	–
Japan	655 530	–	5 147	660 489	–	5 195
Korea, DPR	–	–	–	–	–	–
Korea, Rep. of	244 077	–	5 068	321 842	–	6 533
Lao PDR	87$^{-7,q}$	–	16$^{-7,q}$	–	–	–
Malaysia	29 608	47.69	1 065	52 052^{-1}	47.01^{-1}	1 780^{-1}
Myanmar	837$^{-7,q}$	–	17$^{-7,q}$	–	–	–
Philippines	6 957^{-2}	50.81^{-2}	78^{-2}	–	–	–
Singapore	30 530	–	6 150	34 141^{-1}	–	6 438^{-1}
Thailand	22 000	50.29	332	36 360^{-2}	53.10^{-2}	546^{-2}
Timor–Leste	–	–	–	–	–	–
Viet Nam	9 328^{-7}	–	113^{-7}	–	–	–
Oceania						
Australia	92 649^{-1}	–	4 280^{-1}	–	–	–
New Zealand	16 100	–	3 724	16 300^{-2}	–	3 693^{-2}
Cook Islands	–	–	–	–	–	–
Fiji	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–
Nauru	–	–	–	–	–	–
Niue	–	–	–	–	–	–
Palau	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–
Samoa	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–
Tonga	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–

Source:
UNESCO Institute for Statistics (UIS), August, 2015

Sources for background data:
Population: United Nations, Department of Economic and Social Affairs, Population Division, 2013; World Population Prospects: The 2012 Revision

Researchers in head counts						
2009			2013			
Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants	
460^{q}	24.75	77^{q}	–	–	–	Libya
–	–	–	–	–	–	Mauritania
29 276$^{-1,q}$	27.60^{-1}	946$^{-1,q}$	36 732$^{-2,q}$	30.19^{-2}	1 146$^{-2,q}$	Morocco
–	–	–	1 235^{h}	21.13^{h}	340^{h}	Oman
1 550	18.77	396	4 533^{h}	22.59^{h}	1 048^{h}	Palestine
–	–	–	1 725^{-1}	21.86^{-1}	841^{-1}	Qatar
1 271^{k,q}	1.42	47^{k,q}	–	–	–	Saudi Arabia
11 208$^{-4,b,r}$	40.00$^{-4,r}$	355$^{-4,b,r}$	–	–	–	Sudan
–	–	–	–	–	–	Syrian Arab Rep.
28 274	–	2 690	30 127^{-1}	–	2 770^{-1}	Tunisia
–	–	–	–	–	–	United Arab Emirates
–	–	–	–	–	–	Yemen
						Central Asia
10 095	48.46	641	17 195^{s}	51.46^{s}	1 046^{s}	Kazakhstan
2 290	43.45	435	2 224^{-2}	43.21^{-2}	412^{-2}	Kyrgyzstan
1 748^{q}	48.11^{q}	654^{q}	1 912^{q}	48.90^{q}	673^{q}	Mongolia
1 722	38.79^{-3}	231	2 152^{h}	33.83	262^{h}	Tajikistan
–	–	–	–	–	–	Turkmenistan
30 273	42.99	1 105	30 890^{-2}	40.92^{-2}	1 097^{-2}	Uzbekistan
						South Asia
–	–	–	–	–	–	Afghanistan
–	–	–	–	–	–	Bangladesh
–	–	–	–	–	–	Bhutan
–	–	–	–	–	–	India
–	–	–	–	–	–	Maldives
3 000$^{-7,r}$	15.00$^{-7,r}$	124$^{-7,r}$	5 123$^{-3,q,s}$	7.79^{-3}	191$^{-3,q,s}$	Nepal
54 689^{h}	26.97	322^{h}	60 699^{h}	29.78^{h}	333^{h}	Pakistan
4 037^{-1}	39.86^{-1}	197^{-1}	5 162^{-3}	36.92^{-3}	249^{-3}	Sri Lanka
						Southeast Asia
244$^{-5,q}$	40.57^{-5}	676$^{-5,q}$	–	–	–	Brunei Darussalam
744$^{-7,q,r}$	20.70$^{-7,q,r}$	59$^{-7,q,r}$	–	–	–	Cambodia
–	–	–	2 069 650^{-1}	–	1 503^{-1}	China
23 014	–	3 284	24 934^{-1}	–	3 488^{-1}	China, Hong Kong SAR
658^{q}	32.37^{q}	1 261^{q}	1 110^{q}	34.50^{q}	1 960^{q}	China, Macao SAR
41 143^{r}	30.58^{-4}	173^{q,r}	–	–	–	Indonesia
889 341	13.62	6 983	892 406	14.63	7 019	Japan
–	–	–	–	–	–	Korea, DPR
323 175	15.80	6 710	410 333	18.18	8 329	Korea, Rep. of
209$^{-7,q}$	22.97$^{-7,r}$	38$^{-7,q}$	–	–	–	Lao PDR
53 304	50.91	1 918	75 257^{-1}	49.92^{-1}	2 574^{-1}	Malaysia
4 725$^{-7,q}$	85.46$^{-7,b}$	96$^{-7,q}$	–	–	–	Myanmar
11 490^{-2}	52.25^{-2}	129^{-2}	–	–	–	Philippines
34 387	28.49	6 927	38 432^{-1}	29.57^{-1}	7 247^{-1}	Singapore
38 506	51.08	581	51 178^{-2}	52.66^{-2}	769^{-2}	Thailand
–	–	–	–	–	–	Timor–Leste
41 117^{-7}	42.77^{-7}	498^{-7}	105 230$^{-2,s}$	41.67$^{-2,s}$	1 170$^{-2,s}$	Viet Nam
						Oceania
–	–	–	–	–	–	Australia
27 000	51.99^{-8}	6 246	28 100^{-2}	–	6 366^{-2}	New Zealand
–	–	–	–	–	–	Cook Islands
–	–	–	–	–	–	Fiji
–	–	–	–	–	–	Kiribati
–	–	–	–	–	–	Marshall Islands
–	–	–	–	–	–	Micronesia
19$^{-6,q}$	15.79$^{-6,q}$	1 925$^{-6,q,r}$	–	–	–	Nauru
–	–	–	–	–	–	Niue
–	–	–	–	–	–	Palau
–	–	–	–	–	–	Papua New Guinea
–	–	–	–	–	–	Samoa
–	–	–	–	–	–	Solomon Islands
–	–	–	–	–	–	Tonga
–	–	–	–	–	–	Tuvalu
–	–	–	–	–	–	Vanuatu

Note:
* The year for the share of female researchers may not be the same as the year for total researchers for some countries.

N.B.: See Key To All Tables at the end of Table S10.

Table S7: Researchers by field of science, 2013 or closest year (%)

	Year	Researchers by field of science in head counts (%)								
		Natural sciences	Engineering and technology	Medical and health sciences	Agricultural sciences	Natural sciences and engineering	Social sciences	Humanities	Social sciences and humanities	Not elsewhere classified
North America										
Canada		–	–	–	–	–	–	–	–	–
United States of America		–	–	–	–	–	–	–	–	–
Latin America										
Argentina	2012	26.73	18.65	13.42	10.96	69.76	21.18	9.06	30.24	–
Belize		–	–	–	–	–	–	–	–	–
Bolivia	2010	25.41	21.32	15.84	15.23	77.80	16.54	5.67	22.20	–
Brazil		–	–	–	–	–	–	–	–	–
Chile	2008	21.36	25.91	16.94	12.31	76.52	18.20	5.26	23.48	–
Colombia	2012	18.72	11.38	15.67	6.42	52.19	36.83	7.66	44.49	3.32
Costa Rica	2011	8.07[h]	8.36[h]	7.59[h]	7.29[h]	31.32[h]	8.91[h]	1.82[h]	10.73[h]	57.96[d]
Ecuador	2011	14.63	20.14	11.27	11.37	57.41	35.09	7.50	42.59	–
El Salvador	2013	39.27	19.64	15.56	4.68	79.15	17.52	3.32	20.85	–
Guatemala	2012	20.42[q]	16.22[q]	19.82[q]	18.32[q]	74.77[q]	18.77[q]	6.46[q]	25.23[q]	–
Guyana		–	–	–	–	–	–	–	–	–
Honduras		–	–	–	–	–	–	–	–	–
Mexico	2003	16.71	35.43	12.34	9.58	74.07	17.40	8.53	25.93	–
Nicaragua		–	–	–	–	–	–	–	–	–
Panama	2008	19.65	8.21	14.69	5.62	48.16	17.93	–	17.93[q]	33.91
Paraguay	2008	13.18	15.06	12.24	20.94	61.41	23.29	9.88	33.18	5.41
Peru		–	–	–	–	–	–	–	–	–
Suriname		–	–	–	–	–	–	–	–	–
Uruguay	2013	28.80	10.45	12.78	15.36	67.37	23.26	9.28	32.54	0.08
Venezuela	2009	11.76[q]	13.11[q]	22.16[q]	16.75[q]	63.77[q]	36.23[q]	–	36.23[q]	–
Caribbean										
Antigua and Barbuda		–	–	–	–	–	–	–	–	–
Bahamas		–	–	–	–	–	–	–	–	–
Barbados		–	–	–	–	–	–	–	–	–
Cuba		–	–	–	–	–	–	–	–	–
Dominica		–	–	–	–	–	–	–	–	–
Dominican Rep.		–	–	–	–	–	–	–	–	–
Grenada		–	–	–	–	–	–	–	–	–
Haiti		–	–	–	–	–	–	–	–	–
Jamaica		–	–	–	–	–	–	–	–	–
St Kitts and Nevis		–	–	–	–	–	–	–	–	–
St Lucia		–	–	–	–	–	–	–	–	–
St Vincent and the Grenadines		–	–	–	–	–	–	–	–	–
Trinidad and Tobago	2012	24.73	29.54	14.44	10.50	79.21	20.79	–	20.79[q]	–
European Union										
Austria		–	–	–	–	–	–	–	–	–
Belgium		–	–	–	–	–	–	–	–	–
Bulgaria	2012	24.59	27.33	13.48	7.91	73.31	15.99	10.70	26.69	–
Croatia	2012	15.54	30.74	20.93	7.04	74.26	15.69	10.05	25.74	–
Cyprus	2012	28.32	24.45	4.96	2.98	60.71	25.34	13.95	39.29	–
Czech Rep.	2012	27.08	39.52	11.88	4.55	83.04	9.36	7.61	16.96	–
Denmark		–	–	–	–	–	–	–	–	–
Estonia	2012	24.88[h,r]	10.87[h,r]	6.75[h,r]	4.14[h,r]	46.63[h,r]	13.57[h,r]	13.09[h,r]	26.66[h,r]	26.71[d,r]
Finland		–	–	–	–	–	–	–	–	–
France		–	–	–	–	–	–	–	–	–
Germany		–	–	–	–	–	–	–	–	–
Greece	2011	14.98	34.49	21.23	5.22	75.91	12.12	11.97	24.09	–
Hungary	2012	26.87	33.35	10.85	5.18	76.24	13.23	10.54	23.76	–
Ireland		–	–	–	–	–	–	–	–	–
Italy		–	–	–	–	–	–	–	–	–
Latvia	2012	21.56[h,r]	19.01[h,r]	9.14[h,r]	5.90[h,r]	55.62[h,r]	19.34[h,r]	10.81[h,r]	30.14[h,r]	14.23[d,r]
Lithuania	2012	17.31[h,r]	14.73[h,r]	11.92[h,r]	2.74[h,r]	46.70[h,r]	26.77[h,r]	15.00[h,r]	41.77[h,r]	11.53[d,r]
Luxembourg		–	–	–	–	–	–	–	–	–
Malta	2012	23.57	27.98	14.40	2.89	68.85	16.47	9.44	25.91	5.24
Netherlands	2012	17.02	42.92	14.58	7.74	82.26	14.35	3.39	17.74	–
Poland	2012	18.35	32.15	14.66	5.89	71.05	16.45	12.50	28.95	–
Portugal	2012	21.92	29.62	16.51	2.72	70.77	18.13	11.10	29.23	–
Romania	2012	17.20	46.93	9.24	4.50	77.86	15.91	6.23	22.14	–
Slovakia	2013	16.55	32.74	12.33	4.11	65.73	20.29	13.98	34.27	–
Slovenia	2012	24.82	39.39	13.82	5.82	83.87	9.58	6.56	16.14	–
Spain		–	–	–	–	–	–	–	–	–
Sweden		–	–	–	–	–	–	–	–	–
United Kingdom		–	–	–	–	–	–	–	–	–
Southeast Europe										
Albania	2008	8.66[q]	13.83[q]	9.06[q]	19.17[q]	50.73[q]	13.71[q]	35.56[q]	49.27[q]	–
Bosnia and Herzegovina	2013	16.55	40.48	2.49	14.30	73.82	19.68	5.46	25.14	1.04
FYR Macedonia	2012	4.89	16.67	30.93	8.87	61.36	18.47	20.17	38.64	–
Montenegro	2011	6.73	21.67	28.53	4.27	61.19	18.82	19.99	38.81	–
Serbia	2012	20.58	23.95	9.37	13.37	67.27	19.02	13.71	32.73	–

		Researchers by field of science in head counts (%)								
	Year	Natural sciences	Engineering and technology	Medical and health sciences	Agricultural sciences	Natural sciences and engineering	Social sciences	Humanities	Social sciences and humanities	Not elsewhere classified
Other Europe and West Asia										
Armenia	2013	56.69[q]	14.11[q]	9.92[q]	1.16[q]	81.89[q]	5.61[q]	12.51[q]	18.11[q]	–
Azerbaijan	2013	32.78	16.09	11.11	6.65	66.63	13.36	20.01	33.37	–
Belarus	2013	18.59	61.00	4.77	5.76	90.12	7.52	2.36	9.88	–
Georgia	2005	29.34	14.95	9.90	11.33	65.52	9.38	19.08	28.46	6.02
Iran, Islamic Rep. of	2010	13.67[i]	25.14[i]	20.79[i]	18.78[i]	78.37[i]	21.63[c,i]	–[g,i]	21.63[i]	–[i]
Israel		–	–	–	–	–	–	–	–	–
Moldova, Rep. of	2013	35.94	13.78	14.06	12.34	76.12	12.65	11.23	23.88	–
Russian Federation	2013	23.19[q]	61.00[q]	4.43[q]	3.22[q]	91.84[q]	4.98[q]	3.18[q]	8.16[q]	–
Turkey	2013	10.06	35.86	22.13	4.50	72.55	18.39	9.06	27.45	–
Ukraine	2013	25.16	42.00	6.40	8.06	81.61	7.07	3.17	10.24	8.15
European Free Trade Assoc.										
Iceland		–	–	–	–	–	–	–	–	–
Liechtenstein		–	–	–	–	–	–	–	–	–
Norway	2012	–	–	–	–	76.06	–	–	23.70	0.24
Switzerland		–	–	–	–	–	–	–	–	–
Sub–Saharan Africa										
Angola	2011	23.14	18.62	9.24	12.96	63.97	30.97	5.06	36.03	–
Benin		–	–	–	–	–	–	–	–	–
Botswana	2012	37.54	11.01	22.61	20.00	91.16	2.17	0.14	2.32	6.52
Burkina Faso	2010	13.90	16.52	42.05	10.58	83.04	9.18	4.46	13.64	3.32
Burundi	2011	–	–	–	19.79[j]	19.79[q]	1.06[j]	–	1.06[q]	79.16[e]
Cabo Verde	2011	15.63[l,q]	35.94[l,q]	3.91[l,q]	1.56[l,q]	57.03[l,q]	22.66[l,q]	20.31[l,q]	42.97[l,q]	–
Cameroon		–	–	–	–	–	–	–	–	–
Central African Rep.	2009	36.57[q]	2.99[q]	13.43[q]	9.70[q]	62.69[q]	8.96[q]	24.63[q]	33.58[q]	3.73[q]
Chad		–	–	–	–	–	–	–	–	–
Comoros		–	–	–	–	–	–	–	–	–
Congo		–	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of		–	–	–	–	–	–	–	–	–
Côte d'Ivoire		–	–	–	–	–	–	–	–	–
Djibouti		–	–	–	–	–	–	–	–	–
Equatorial Guinea		–	–	–	–	–	–	–	–	–
Eritrea		–	–	–	–	–	–	–	–	–
Ethiopia	2013	15.29	9.48	18.48	30.26	73.51	16.81	7.21	24.02	2.47
Gabon	2009	13.18[q]	4.71[q]	4.52[q]	8.10[q]	30.51[q]	22.41[q]	12.99[q]	35.40[q]	34.09[q]
Gambia	2011	–	–	40.00	60.00	100.00[q]	–	–	–	–
Ghana	2010	17.19	11.41	17.98	14.20	60.78	21.01	15.11	36.11	3.11
Guinea		–	–	–	–	–	–	–	–	–
Guinea–Bissau		–	–	–	–	–	–	–	–	–
Kenya	2010	3.67	13.73	25.45	40.51	83.37	9.45	7.19	16.63	–
Lesotho	2011	23.81[l,q]	19.05[l,q]	–	54.76[l,q]	97.62[l,q]	2.38[l,q]	–	2.38[l,q]	–
Liberia		–	–	–	–	–	–	–	–	–
Madagascar	2011	37.18	10.62	9.52	7.15	64.47	19.37	9.73	29.10	6.43
Malawi	2010	15.63[h]	20.18[h]	18.61[h]	16.93[h]	71.35[h]	18.45[h]	10.20[h]	28.65[h]	–
Mali	2006	46.04[q]	8.58[q]	13.59[q]	11.89[q]	80.10	13.03[q]	6.88[q]	19.90	–
Mauritius	2012	21.81[r]	10.20[r]	10.20[r]	33.71[r]	75.92[r]	16.43[r]	5.95[r]	22.38[r]	1.70[r]
Mozambique	2010	19.27	22.04	13.16	8.94	63.41	34.13	2.46	36.59	–
Namibia	2010	10.96	2.41	6.82	42.91	63.10	15.91	5.75	21.66	15.24
Niger		–	–	–	–	–	–	–	–	–
Nigeria		–	–	–	–	–	–	–	–	–
Rwanda		–	–	–	–	–	–	–	–	–
Sao Tome and Principe		–	–	–	–	–	–	–	–	–
Senegal	2010	18.00	1.98	19.60	1.60	41.19	50.67	6.40	57.07	1.74
Seychelles	2005	78.57	–	–	14.29	92.86[q]	–	–	–	7.14
Sierra Leone		–	–	–	–	–	–	–	–	–
Somalia		–	–	–	–	–	–	–	–	–
South Africa		–	–	–	–	–	–	–	–	–
South Sudan		–	–	–	–	–	–	–	–	–
Swaziland		–	–	–	–	–	–	–	–	–
Tanzania		–	–	–	–	–	–	–	–	–
Togo	2012	15.65[h]	6.10[h]	18.78[h]	14.71[h]	55.24[h]	2.35[h]	41.94[h]	44.29[h]	0.47[h]
Uganda	2010	17.43	12.15	10.06	11.52	51.17	37.38	11.45	48.83	–
Zambia		–	–	–	–	–	–	–	–	–
Zimbabwe	2012	30.05[h]	13.33[h]	0.18[h]	13.91[h]	57.47[h]	22.16[h]	15.48[h]	37.64[h]	4.89[h]
Arab states										
Algeria	2005	24.27[l,q]	37.63[q]	8.15[l,q]	8.40[q]	78.44[q]	9.40[l,q]	12.16[q]	21.56[q]	–
Bahrain	2013	8.24[l,q]	15.88[l,q]	43.53[l,q]	0.39[l,q]	68.04[l,q]	15.29[l,q]	5.69[l,q]	20.98[l,q]	10.98[l,q]
Egypt	2013	8.08[l]	7.20[l]	31.76[l]	4.12[l]	51.16[l]	16.83[l]	11.41[l]	28.24[l]	20.61[k]
Iraq	2011	17.75[b,h]	18.86[b,h]	12.39[b,h]	9.36[b,h]	58.35[b,h]	32.33[b,h]	9.30[b,h]	41.63[b,h]	0.02[h]
Jordan	2008	8.20	18.80	12.61	2.93	42.53	3.99	18.13	22.12	35.35
Kuwait	2013	14.34[h]	13.37[h]	11.85[h]	5.17[h]	44.72[h]	8.77[h]	13.34[h]	22.11[h]	33.17[h]
Lebanon		–	–	–	–	–	–	–	–	–
Libya		–	–	–	–	–	–	–	–	–

Table S7: Researchers by field of science, 2013 or closest year (%)

	Year	Researchers by field of science in head counts (%)								
		Natural sciences	Engineering and technology	Medical and health sciences	Agricultural sciences	Natural sciences and engineering	Social sciences	Humanities	Social sciences and humanities	Not elsewhere classified
Mauritania		–	–	–	–	–	–	–	–	–
Morocco	2011	33.71	7.56	10.40	1.80	53.46	26.10	20.44	46.54	–
Oman	2013	15.55[h]	13.04[h]	6.48[h]	25.26[h]	60.32h	24.29[h]	13.20[h]	37.49[h]	2.19[h]
Palestine	2013	16.55[h]	10.90[h]	5.85[h]	4.83[h]	38.12h	27.69[h]	34.19[h]	61.88[h]	–[h]
Qatar	2012	9.33	42.67	26.03	1.62	79.65	14.26	4.81	19.07	1.28
Saudi Arabia	2009	16.76[k]	43.04[k]	0.71[k]	2.60[k]	63.10k	–[k]	0.47[k]	0.47[k]	36.43[k]
Sudan	2005	17.86[r]	27.18[r]	22.29[r]	6.00[r]	73.32r	16.06[r]	8.10[r]	24.16[r]	2.52[r]
Syrian Arab Rep.		–	–	–	–	–	–	–	–	–
Tunisia		–	–	–	–	–	–	–	–	–
United Arab Emirates		–	–	–	–	–	–	–	–	–
Yemen		–	–	–	–	–	–	–	–	–
Central Asia										
Kazakhstan	2013	29.61	29.05	6.21	12.50	77.38	10.33	12.29	22.62	–
Kyrgyzstan	2011	26.66	25.49	17.67	9.53	79.36	6.92	11.65	18.57	2.07[r]
Mongolia	2013	37.45[q]	12.76[q]	9.94[q]	15.90[q]	76.05q	23.95[c,q]	–	23.95[q]	–
Tajikistan	2013	23.65	9.57	17.38	21.93	72.54	15.57	11.90	27.46	–
Turkmenistan		–	–	–	–	–	–	–	–	–
Uzbekistan	2011	22.37	16.13	11.85	6.06	56.40	22.07	21.53	43.60	–
South Asia										
Afghanistan		–	–	–	–	–	–	–	–	–
Bangladesh		–	–	–	–	–	–	–	–	–
Bhutan		–	–	–	–	–	–	–	–	–
India		–	–	–	–	–	–	–	–	–
Maldives		–	–	–	–	–	–	–	–	–
Nepal		–	–	–	–	–	–	–	–	–
Pakistan	2013	23.37[h]	17.45[h]	15.66[h]	13.03[h]	69.52h	17.12[h]	9.89[h]	27.01[h]	3.47[h]
Sri Lanka	2010	28.30	22.22	16.35	20.34	87.21	7.81[c]	–[g]	7.81	4.98
Southeast Asia										
Brunei Darussalam		–	–	–	–	–	–	–	–	–
Cambodia		–	–	–	–	–	–	–	–	–
China		–	–	–	–	–	–	–	–	–
China, Hong Kong SAR		–	–	–	–	–	–	–	–	–
China, Macao SAR	2013	10.45	14.23	13.87	–	38.56q	41.80[q]	18.56[q]	60.36[q]	1.08[q]
Indonesia	2005	11.07[i]	11.12[i]	7.28[i]	13.39[i]	42.86i	18.16[i]	7.34[i]	25.50[i]	31.64
Japan	2013	18.27	47.92	14.57	4.33	85.08	5.90	3.37	11.52	3.40
Korea, DPR		–	–	–	–	–	–	–	–	–
Korea, Rep. of	2013	12.55	68.09	5.68	2.46	88.78	6.15	5.08	11.22	–
Lao PDR		–	–	–	–	–	–	–	–	–
Malaysia	2012	27.61	42.78	3.89	6.61	80.89	16.09	3.02	19.11	–
Myanmar	2002	14.12	34.41	4.68	1.82	55.03	42.46	2.52	44.97	–
Philippines	2007	15.63	34.87	8.18	22.42	81.11	15.22	2.32	17.55	1.35
Singapore	2012	16.31	61.04	16.63	2.05	96.02	–	–	–	3.98
Thailand	2011	8.97[h]	12.31[h]	12.57[h]	8.86[h]	42.72h	26.81[h]	2.62[h]	29.43[h]	27.86
Timor–Leste		–	–	–	–	–	–	–	–	–
Viet Nam		–	–	–	–	–	–	–	–	–
Oceania										
Australia		–	–	–	–	–	–	–	–	–
New Zealand		–	–	–	–	–	–	–	–	–
Cook Islands		–	–	–	–	–	–	–	–	–
Fiji		–	–	–	–	–	–	–	–	–
Kiribati		–	–	–	–	–	–	–	–	–
Marshall Islands		–	–	–	–	–	–	–	–	–
Micronesia		–	–	–	–	–	–	–	–	–
Nauru		–	–	–	–	–	–	–	–	–
Niue		–	–	–	–	–	–	–	–	–
Palau		–	–	–	–	–	–	–	–	–
Papua New Guinea		–	–	–	–	–	–	–	–	–
Samoa		–	–	–	–	–	–	–	–	–
Solomon Islands		–	–	–	–	–	–	–	–	–
Tonga		–	–	–	–	–	–	–	–	–
Tuvalu		–	–	–	–	–	–	–	–	–
Vanuatu		–	–	–	–	–	–	–	–	–

Source: UNESCO Institute for Statistics (UIS), August, 2015

N.B.: See Key To All Tables at the end of Table S10.

Table S8: Scientific publications by country, 2005-2014

	Number of publications										Publications per million inhabitants	
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2008	2014
North America												
Canada	39 879	42 648	43 917	46 829	48 713	49 728	51 508	51 459	54 632	54 631	1 403	1 538
United States of America	267 521	275 884	280 806	289 769	294 630	301 826	312 374	306 688	324 047	321 846	945	998
Latin America												
Argentina	5 056	5 429	5 767	6 406	6 779	7 234	7 664	7 657	8 060	7 885	161	189
Belize	12	12	6	8	5	13	12	13	19	16	27	47
Bolivia	120	131	179	192	184	173	186	155	212	207	20	19
Brazil	17 106	19 102	23 621	28 244	30 248	31 449	34 006	34 165	37 041	37 228	147	184
Chile	2 912	3 090	3 429	3 737	4 254	4 477	5 008	5 320	5 604	6 224	222	350
Colombia	871	1 040	1 333	1 967	2 155	2 503	2 790	2 957	3 189	2 997	44	61
Costa Rica	302	304	316	389	381	394	413	379	391	474	86	96
Ecuador	203	200	263	281	349	295	299	369	425	511	19	32
El Salvador	20	17	15	18	23	34	42	41	32	42	3	7
Guatemala	63	52	65	63	87	94	85	105	115	101	5	6
Guyana	18	8	17	17	10	23	14	16	18	23	22	29
Honduras	25	30	23	30	34	39	46	49	56	35	4	4
Mexico	6 899	6 992	7 891	8 559	8 738	9 047	9 842	10 093	10 957	11 147	74	90
Nicaragua	39	55	37	55	50	62	57	70	52	54	10	9
Panama	156	191	226	250	244	294	292	325	343	326	70	83
Paraguay	28	29	39	34	37	54	65	58	67	57	5	8
Peru	334	387	452	499	539	551	621	633	713	783	17	25
Suriname	13	6	6	7	6	6	7	22	22	11	14	20
Uruguay	425	441	463	582	605	603	733	653	728	824	174	241
Venezuela	1 097	1 125	1 128	1 325	1 200	1 174	1 040	913	1 010	788	47	26
Caribbean												
Antigua and Barbuda	5	4	5	7	2	4	1	2	4	1	82	11
Bahamas	8	9	17	12	12	12	20	17	26	33	34	86
Barbados	44	42	39	50	41	52	67	63	55	52	180	182
Cuba	662	713	733	804	772	717	818	804	817	749	71	67
Dominica	5	2	6	2	4	12	10	9	10	10	28	138
Dominican Rep.	20	19	26	34	26	39	45	52	63	49	3	5
Grenada	17	30	57	72	83	81	95	112	106	152	693	1 430
Haiti	14	23	16	20	18	24	48	39	48	60	2	6
Jamaica	136	126	143	157	159	169	177	178	151	117	58	42
St Kitts and Nevis	1	3	1	3	9	10	6	14	20	40	59	730
St Lucia	2	2	2	1	0	9	2	1	2	0	6	0
St Vincent and the Grenadines	0	2	1	0	1	3	2	3	1	2	0	18
Trinidad and Tobago	136	110	137	142	154	152	169	161	149	146	108	109
European Union												
Austria	8 644	8 865	9 502	10 049	10 407	11 127	11 939	11 746	12 798	13 108	1 205	1 537
Belgium	12 572	12 798	13 611	14 467	15 071	15 962	16 807	16 719	18 119	18 208	1 343	1 634
Bulgaria	1 756	1 743	2 241	2 266	2 310	2 172	2 153	2 244	2 266	2 065	302	288
Croatia	1 624	1 705	2 037	2 391	2 739	2 897	3 182	3 103	3 004	2 932	548	686
Cyprus	258	302	346	408	508	610	638	707	855	814	379	706
Czech Rep.	5 799	6 535	7 157	7 783	8 206	8 835	9 222	9 324	9 998	10 781	748	1 004
Denmark	8 747	9 116	9 411	9 817	10 257	11 285	12 387	12 763	13 982	14 820	1 786	2 628
Estonia	745	783	943	952	1 055	1 189	1 286	1 290	1 513	1 567	728	1 221
Finland	7 987	8 475	8 542	8 814	8 928	9 274	9 666	9 571	10 206	10 758	1 657	1 976
France	52 476	54 516	55 254	59 304	60 893	61 626	63 418	62 371	66 057	65 086	948	1 007
Germany	73 573	75 191	76 754	79 402	82 452	85 095	88 836	88 322	92 975	91 631	952	1 109
Greece	7 597	8 729	9 294	9 706	10 028	9 987	10 141	9 929	9 871	9 427	876	847
Hungary	4 864	5 007	5 053	5 541	5 330	5 023	5 619	5 739	5 931	6 059	552	610
Ireland	3 941	4 375	4 613	5 161	5 519	6 173	6 552	6 244	6 691	6 576	1 186	1 406
Italy	40 111	42 396	44 810	47 139	49 302	50 069	52 290	52 679	57 943	57 472	787	941
Latvia	319	298	369	420	406	395	555	528	592	586	196	287
Lithuania	885	1 127	1 666	1 714	1 668	1 660	1 899	1 793	1 768	1 827	545	607
Luxembourg	175	208	223	327	398	472	594	613	755	854	671	1 591
Malta	61	60	76	109	96	111	122	151	207	207	259	481
Netherlands	22 225	22 971	23 505	24 646	26 500	28 148	29 396	30 018	32 172	31 823	1 493	1 894
Poland	13 843	15 129	16 032	18 210	18 506	19 172	20 396	21 486	22 822	23 498	477	615
Portugal	5 245	6 455	6 238	7 448	8 196	8 903	9 992	10 679	11 953	11 855	705	1 117
Romania	2 543	2 934	3 983	5 165	6 100	6 628	6 485	6 657	7 550	6 651	235	307
Slovakia	1 931	2 264	2 473	2 709	2 635	2 758	2 856	2 883	2 989	3 144	500	576
Slovenia	2 025	2 081	2 396	2 795	2 840	2 912	3 265	3 265	3 458	3 301	1 375	1 590
Spain	29 667	32 130	34 558	37 078	39 735	41 828	45 318	46 435	49 435	49 247	820	1 046
Sweden	16 445	16 895	17 184	17 270	17 981	18 586	19 403	19 898	21 611	21 854	1 870	2 269
United Kingdom	70 201	73 377	75 763	77 116	78 867	81 553	84 360	83 405	89 429	87 948	1 257	1 385
Southeast Europe												
Albania	37	30	39	58	65	88	146	127	144	154	18	48
Bosnia and Herzegovina	91	91	252	278	286	360	398	347	312	323	72	84
FYR Macedonia	106	134	179	201	211	235	263	273	282	330	96	157
Montenegro	42	59	64	94	102	130	155	152	171	191	152	307
Serbia	1 600	1 741	2 303	2 783	3 327	3 659	4 244	5 064	4 941	4 764	285	503
Other Europe and West Asia												
Armenia	381	404	418	560	497	574	670	775	705	691	188	232
Azerbaijan	237	238	227	299	389	457	522	497	424	425	34	45
Belarus	978	945	914	1 033	998	964	1 067	1 133	1 046	1 077	108	116
Georgia	305	363	327	338	358	381	485	570	515	527	77	122
Iran,Islamic Rep. of	4 676	6 148	9 020	11 244	14 460	16 951	21 509	23 092	24 713	25 588	155	326

Table S8: Scientific publications by country, 2005-2014

	Number of publications										Publications per million inhabitants	
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2008	2014
Israel	9 884	10 395	10 351	10 576	10 371	10 541	10 853	10 665	11 066	11 196	1 488	1 431
Moldova,Rep. of	213	222	180	228	258	227	258	230	242	248	63	72
Russian Federation	24 694	24 068	25 606	27 418	27 861	26 869	28 285	26 183	28 649	29 099	191	204
Turkey	13 830	14 734	17 281	18 493	20 657	21 374	22 065	22 251	23 897	23 596	263	311
Ukraine	4 029	3 935	4 205	5 020	4 450	4 445	4 909	4 601	4 834	4 895	108	109
European Free Trade Assoc.												
Iceland	427	458	490	575	623	753	716	810	866	864	1 858	2 594
Liechtenstein	33	36	37	46	41	50	41	55	48	52	1 293	1 398
Norway	6 090	6 700	7 057	7 543	8 110	8 499	9 327	9 451	9 947	10 070	1 579	1 978
Switzerland	16 397	17 809	18 341	19 131	20 336	21 361	22 894	23 205	25 051	25 308	2 500	3 102
Sub–Saharan Africa												
Angola	17	13	15	15	32	29	28	36	40	45	1	2
Benin	86	121	132	166	174	194	221	228	253	270	18	25
Botswana	112	152	148	162	133	114	175	156	171	210	84	103
Burkina Faso	116	159	149	193	214	220	268	296	241	272	13	16
Burundi	8	5	14	8	9	20	19	16	17	18	1	2
Cabo Verde	1	6	1	3	10	15	2	11	19	25	6	50
Cameroon	303	395	431	482	497	561	579	553	652	706	25	31
Central African Rep.	20	20	21	17	24	22	23	29	29	32	4	7
Chad	21	25	12	14	18	11	20	13	14	26	1	2
Comoros	3	0	6	3	1	3	6	3	2	0	5	0
Congo	56	81	86	69	77	89	86	92	84	111	18	24
Congo,Dem. Rep. of	21	14	26	38	69	82	109	119	144	114	1	2
Côte d'Ivoire	110	128	155	183	201	205	216	238	194	208	10	10
Djibouti	2	2	3	2	6	6	9	7	6	15	2	17
Equatorial Guinea	1	2	2	2	5	4	5	5	2	4	3	5
Eritrea	26	29	29	15	19	11	13	3	17	22	3	3
Ethiopia	281	293	382	402	484	514	630	638	790	865	5	9
Gabon	70	78	79	82	88	86	117	94	113	137	55	80
Gambia	68	97	71	95	87	97	73	100	111	124	60	65
Ghana	208	227	276	293	333	427	421	477	546	579	13	22
Guinea	12	30	22	16	23	27	23	25	35	49	2	4
Guinea–Bissau	19	17	27	20	19	21	24	22	29	37	13	21
Kenya	571	690	763	855	892	1 035	1 196	1 131	1 244	1 374	22	30
Lesotho	5	14	11	12	21	18	23	26	19	16	6	8
Liberia	4	4	0	6	1	8	8	9	13	11	2	3
Madagascar	114	140	158	152	156	166	182	181	209	188	8	8
Malawi	116	129	183	218	199	244	280	296	296	322	15	19
Mali	71	97	82	93	112	126	149	170	142	141	7	9
Mauritius	49	51	42	44	49	70	61	85	90	89	36	71
Mozambique	55	60	79	84	95	100	157	134	137	158	4	6
Namibia	80	76	65	64	77	57	92	96	121	139	30	59
Niger	68	66	68	81	75	78	94	81	81	108	5	6
Nigeria	1 001	1 150	1 608	1 977	2 076	2 258	2 098	1 756	1 654	1 961	13	11
Rwanda	13	25	36	34	58	66	90	85	114	143	3	12
Sao Tome and Principe	0	2	1	1	1	3	1	1	1	3	6	15
Senegal	210	188	229	228	258	279	343	349	340	338	19	23
Seychelles	12	21	25	21	18	19	31	31	44	34	234	364
Sierra Leone	5	4	7	12	18	23	25	26	29	45	2	7
Somalia	0	2	0	1	3	2	2	2	3	7	0	1
South Africa	4 235	4 711	5 152	5 611	6 212	6 628	7 682	7 934	8 790	9 309	112	175
South Sudan	1	5	3	5	15	8	8	9	8	0	1	0
Swaziland	22	10	18	21	26	52	41	33	40	25	18	20
Tanzania	323	396	428	426	506	541	552	557	666	770	10	15
Togo	34	36	38	44	38	50	68	47	55	61	7	9
Uganda	244	294	406	403	485	577	644	625	702	757	13	19
Zambia	96	116	130	134	130	170	203	204	230	245	11	16
Zimbabwe	173	178	219	217	188	199	227	240	257	310	17	21
Arab states												
Algeria	795	977	1 190	1 339	1 597	1 658	1 758	1 842	2 081	2 302	37	58
Bahrain	93	117	121	114	135	129	130	122	166	155	102	115
Egypt	2 919	3 202	3 608	4 147	4 905	5 529	6 657	6 960	7 613	8 428	55	101
Iraq	89	124	180	195	253	279	352	482	735	841	7	24
Jordan	641	673	835	989	1 022	1 038	1 009	976	1 099	1 093	167	146
Kuwait	526	541	571	659	631	635	637	546	618	604	244	174
Lebanon	462	555	549	621	640	690	701	810	938	1 009	148	203
Libya	70	90	107	126	125	159	123	141	162	181	21	29
Mauritania	27	20	20	14	19	15	21	23	23	23	4	6
Morocco	990	1 009	1 088	1 214	1 236	1 355	1 474	1 496	1 579	1 574	39	47
Oman	283	277	323	327	365	383	447	444	505	591	126	151
Palestine	72	68	75	65	62	52	66	70	85	14	17	3
Qatar	109	128	168	217	238	339	407	517	817	1 242	160	548
Saudi Arabia	1 362	1 450	1 574	1 910	2 273	3 551	5 773	7 226	8 903	10 898	72	371
Sudan	120	110	147	150	215	282	283	244	274	309	4	8
Syrian Arab Rep.	168	153	192	218	211	318	340	304	304	229	11	10
Tunisia	1 214	1 503	1 749	2 068	2 439	2 607	2 900	2 739	2 866	3 068	199	276
United Arab Emirates	530	601	621	713	842	888	1 057	1 096	1 277	1 450	105	154
Yemen	41	52	57	64	106	114	164	162	175	202	3	8

	Number of publications										Publications per million inhabitants	
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2008	2014
Central Asia												
Kazakhstan	200	210	255	221	269	247	276	330	499	600	14	36
Kyrgyzstan	46	47	51	54	51	57	65	67	95	82	10	15
Mongolia	67	71	99	126	166	173	145	167	209	203	48	70
Tajikistan	32	32	45	49	39	51	53	61	67	46	7	5
Turkmenistan	5	6	8	3	6	9	12	19	13	24	1	5
Uzbekistan	296	289	335	306	350	328	363	284	313	323	11	11
South Asia												
Afghanistan	7	10	8	23	19	36	31	39	34	44	1	1
Bangladesh	511	584	669	797	881	995	1 079	1 216	1 302	1 394	5	9
Bhutan	8	23	5	8	16	27	28	23	35	36	12	47
India	24 703	27 785	32 610	37 228	38 967	41 983	45 961	46 106	50 691	53 733	32	42
Maldives	1	2	5	4	5	5	5	8	5	16	13	46
Nepal	158	212	218	253	295	349	336	365	457	455	10	16
Pakistan	1 142	1 553	2 534	3 089	3 614	4 522	5 629	5 522	6 392	6 778	18	37
Sri Lanka	283	279	322	430	432	419	461	475	489	599	21	28
Southeast Asia												
Brunei Darussalam	29	31	37	43	48	49	46	64	79	106	111	250
Cambodia	54	70	92	86	126	139	136	168	191	206	6	13
China	66 151	79 740	89 068	102 368	118 749	131 028	153 446	170 189	205 268	256 834	76	184
China,Hong Kong SAR	7 220	7 592	7 440	7 660	8 141	8 527	9 258	9 133	9 725	852	1 099	117
China,Macao SAR	63	96	79	121	143	201	226	368	488	46	238	80
Indonesia	554	612	629	709	893	992	1 103	1 222	1 426	1 476	3	6
Japan	76 950	77 083	75 801	76 244	75 606	74 203	75 924	72 769	75 870	73 128	599	576
Korea,DPR	11	10	11	36	29	34	19	37	21	23	1	1
Korea,Rep. of	25 944	28 202	28 750	33 431	36 659	40 156	43 836	45 765	48 663	50 258	698	1 015
Lao PDR	36	55	47	58	60	95	114	133	126	129	9	19
Malaysia	1 559	1 813	2 225	2 852	4 266	5 777	7 607	7 738	8 925	9 998	104	331
Myanmar	41	41	42	39	43	47	56	52	59	70	1	1
Philippines	486	494	578	663	706	730	873	779	894	913	7	9
Singapore	6 111	6 493	6 457	7 075	7 669	8 459	9 032	9 430	10 280	10 553	1 459	1 913
Thailand	2 503	3 089	3 710	4 335	4 812	5 214	5 790	5 755	6 378	6 343	65	94
Timor–Leste	2	8	3	0	3	3	0	4	6	1	0	1
Viet Nam	570	656	750	943	963	1 207	1 387	1 669	2 105	2 298	11	25
Oceania												
Australia	24 755	27 049	28 649	30 922	33 284	35 228	38 505	39 899	44 926	46 639	1 429	1 974
New Zealand	4 942	5 119	5 373	5 681	5 854	6 453	6 811	6 917	7 303	7 375	1 328	1 620
Cook Islands	1	1	3	0	0	2	3	4	6	7	0	446
Fiji	61	67	67	65	62	59	74	83	98	106	77	120
Kiribati	0	2	2	0	0	0	1	0	3	5	0	48
Marshall Islands	1	5	0	1	6	1	1	5	1	5	19	95
Micronesia	4	7	7	3	9	9	3	7	6	12	29	115
Nauru	0	0	0	0	0	0	1	0	0	1	0	93
Niue	0	0	1	0	0	0	0	0	0	3	0	2 214
Palau	7	9	11	4	6	4	7	5	8	12	197	571
Papua New Guinea	44	51	84	78	76	81	100	112	89	110	12	15
Samoa	3	9	1	1	0	0	0	3	1	4	5	21
Solomon Islands	6	7	8	4	6	11	17	8	11	17	8	30
Tonga	0	4	5	4	2	3	6	2	1	6	39	57
Tuvalu	0	1	0	0	0	0	0	1	1	3	0	264
Vanuatu	12	9	7	9	16	12	21	18	19	19	40	74

Source: data from Thomson Reuters' Web of Science, Science Citation Index Expanded, compiled for UNESCO by Science–Metrix, May 2015

Sources for background data:
Population: United Nations, Department of Economic and Social Affairs, Population Division, 2013; *World Population Prospects: The 2012 Revision*

Table S9: Publications by major field of science, 2008 and 2014

	Publications by field of science													
	Total		Agricultural sciences		Astronomy		Biological sciences		Chemistry		Computer sciences		Engineering	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
North America														
Canada	46 829	54 631	1 192	1 347	614	833	10 136	9 723	3 144	3 269	1 109	1 274	4 527	5 346
United States of America	289 769	321 846	5 165	5 121	4 405	5 068	71 105	65 773	20 000	21 500	5 460	5 909	21 155	23 863
Latin America														
Argentina	6 406	7 885	331	407	132	155	1 788	1 906	696	663	49	103	388	540
Belize	8	16	1	0	0	0	1	3	0	0	0	0	0	0
Bolivia	192	207	11	9	6	0	77	75	8	2	0	0	4	6
Brazil	28 244	37 228	2 508	3 150	207	340	6 024	7 113	2 088	2 695	244	510	1 689	2 478
Chile	3 737	6 224	148	204	370	807	728	918	298	350	68	148	265	396
Colombia	1 967	2 997	128	120	4	12	341	485	160	221	16	38	112	297
Costa Rica	389	474	15	28	1	2	157	171	10	19	2	3	10	12
Ecuador	281	511	10	28	1	1	90	147	3	23	0	7	4	36
El Salvador	18	42	0	1	0	0	9	9	0	0	0	0	0	0
Guatemala	63	101	3	4	0	0	23	25	0	1	0	0	1	2
Guyana	17	23	0	0	0	0	4	5	1	2	1	0	0	0
Honduras	30	35	2	2	0	0	6	10	0	0	1	0	0	0
Mexico	8 559	11 147	365	561	214	289	1 984	2 320	718	828	85	243	756	1 051
Nicaragua	55	54	1	2	0	0	11	14	1	0	0	0	0	0
Panama	250	326	2	13	2	1	151	143	3	1	0	1	0	2
Paraguay	34	57	1	2	0	1	15	19	0	1	0	2	0	2
Peru	499	783	19	32	1	0	150	215	9	13	3	3	14	26
Suriname	7	11	0	0	0	0	3	1	0	0	0	0	0	2
Uruguay	582	824	43	92	3	1	157	232	57	58	8	22	23	26
Venezuela	1 325	788	65	74	12	22	300	175	135	62	13	9	107	61
Caribbean														
Antigua and Barbuda	7	1	0	0	0	0	2	0	0	0	0	0	0	0
Bahamas	12	33	0	0	0	0	5	11	0	0	0	0	0	0
Barbados	50	52	1	0	0	0	15	5	3	7	3	1	0	1
Cuba	804	749	84	31	2	6	195	179	99	46	6	31	62	61
Dominica	2	10	0	0	0	0	0	5	0	0	0	0	0	0
Dominican Rep.	34	49	2	2	0	0	12	15	1	1	0	0	1	2
Grenada	72	152	1	4	0	0	25	51	1	1	0	1	0	0
Haiti	20	60	0	1	0	0	3	15	2	0	0	0	1	0
Jamaica	157	117	6	8	0	0	19	38	8	10	0	0	7	0
St Kitts and Nevis	3	40	0	1	0	0	0	10	0	0	0	0	0	1
St Lucia	1	0	0	0	0	0	1	0	0	0	0	0	0	0
St Vincent and the Grenadines	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Trinidad and Tobago	142	146	5	12	1	0	27	21	5	12	0	4	9	12
European Union														
Austria	10 049	13 108	139	206	171	248	2 009	2 246	771	915	216	329	786	1 015
Belgium	14 467	18 208	413	492	213	418	3 032	3 214	1 225	1 417	272	338	1 103	1 440
Bulgaria	2 266	2 065	84	36	50	46	334	274	379	281	25	28	152	137
Croatia	2 391	2 932	77	117	15	51	367	436	241	232	16	42	237	265
Cyprus	408	814	4	19	3	4	48	85	40	57	26	27	68	103
Czech Rep.	7 783	10 781	253	342	123	159	1 691	2 054	1 142	1 422	163	249	650	923
Denmark	9 817	14 820	344	454	103	380	2 445	2 923	577	905	102	186	604	968
Estonia	952	1 567	31	57	20	27	242	355	73	126	15	24	92	122
Finland	8 814	10 758	207	201	131	224	2 018	1 981	622	739	186	285	683	1 074
France	59 304	65 086	1 093	1 151	1 251	1 690	10 855	10 456	6 242	6 144	1 181	1 622	5 245	5 804
Germany	79 402	91 631	1 450	1 505	1 757	2 466	15 133	15 314	8 698	9 119	1 035	1 404	5 812	6 982
Greece	9 706	9 427	299	257	82	146	1 361	1 161	726	637	362	402	1 131	956
Hungary	5 541	6 059	95	116	58	112	1 143	1 119	716	587	79	110	279	330
Ireland	5 161	6 576	293	363	95	119	1 023	1 114	404	476	115	132	380	528
Italy	47 139	57 472	1 095	1 455	1 044	1 414	8 347	8 635	3 850	3 991	950	1 171	3 825	5 280
Latvia	420	586	9	29	5	4	52	82	49	91	8	11	90	92
Lithuania	1 714	1 827	70	65	23	33	140	157	99	143	63	41	362	288
Luxembourg	327	854	3	15	0	1	85	160	19	51	11	55	42	76
Malta	109	207	0	4	0	3	17	29	0	8	2	4	9	19
Netherlands	24 646	31 823	528	656	493	812	5 255	5 634	1 468	1 554	416	461	1 550	1 882
Poland	18 210	23 498	606	823	254	368	2 707	3 569	2 793	3 244	197	381	2 152	2 281
Portugal	7 448	11 855	256	358	89	166	1 358	2 013	1 073	1 243	145	312	918	1 476
Romania	5 165	6 651	37	72	20	65	194	510	688	703	143	142	517	736
Slovakia	2 709	3 144	96	90	49	81	475	496	341	353	49	78	280	314
Slovenia	2 795	3 301	64	85	19	28	427	431	305	309	67	101	402	445
Spain	37 078	49 247	1 703	2 021	712	1 185	7 142	8 203	4 609	4 971	952	1 712	3 335	4 751
Sweden	17 270	21 854	264	295	183	333	4 056	4 071	1 206	1 441	205	320	1 314	2 046
United Kingdom	77 116	87 948	1 048	917	1 708	2 360	16 883	16 360	5 556	5 629	1 335	1 732	5 601	6 704
Southeast Europe														
Albania	58	154	3	7	1	0	6	19	0	6	0	1	3	5
Bosnia and Herzegovina	278	323	4	11	0	1	18	43	1	7	1	8	21	34
FYR Macedonia	201	330	3	16	0	1	38	59	27	18	2	9	11	35
Montenegro	94	191	2	5	1	2	7	18	0	4	2	1	20	27
Serbia	2 783	4 764	44	186	24	49	324	456	223	346	52	121	314	613
Other Europe and West Asia														
Armenia	560	691	0	3	30	23	37	35	66	64	2	3	59	34
Azerbaijan	299	425	1	1	5	4	4	16	75	59	2	4	25	28
Belarus	1 033	1 077	0	6	1	0	69	70	178	143	1	8	161	105

	Publications by field of science															
	Geosciences		Mathematics		Medical sciences		Other life sciences		Physics		Psychology		Social sciences		Unclassified articles	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
	4 095	4 579	1 583	1 471	12 819	15 207	548	623	3 675	3 248	642	660	404	522	2 341	6 529
	17 704	20 386	8 533	8 498	86 244	92 957	3 858	4 043	25 916	22 591	3 258	3 583	2 414	2 681	14 552	39 873
	613	801	203	198	927	1 120	9	10	720	658	35	43	23	50	492	1 231
	3	2	0	0	0	5	1	1	0	0	0	0	0	1	2	4
	25	33	0	0	31	26	0	0	5	6	1	1	6	2	18	47
	1 215	1 977	646	908	6 393	7 683	294	320	2 428	2 542	119	172	97	150	4 292	7 190
	417	616	192	259	638	966	21	26	302	546	16	34	8	46	266	908
	77	153	49	97	268	436	18	9	225	438	5	15	12	19	552	657
	32	43	5	5	57	64	1	1	9	19	0	9	4	3	86	95
	50	65	2	5	45	67	1	0	51	30	2	1	1	0	21	101
	4	4	0	0	3	19	1	0	1	0	0	0	0	0	0	9
	4	2	0	0	24	36	1	0	1	0	0	0	2	1	4	30
	0	8	0	0	5	3	0	1	0	0	0	1	0	1	6	2
	1	3	0	0	11	11	3	0	1	0	0	0	1	1	4	8
	788	892	261	321	1 160	1 383	20	13	1 166	1 177	62	63	39	52	941	1 954
	17	9	0	0	13	13	3	0	1	0	0	0	0	0	8	16
	36	40	0	0	16	35	1	0	0	2	3	10	2	2	34	76
	0	4	0	1	12	11	0	0	0	0	0	0	0	0	6	14
	72	90	3	11	152	177	8	0	13	37	2	4	8	12	45	163
	1	1	0	0	2	4	0	0	0	1	0	0	0	0	1	2
	60	60	17	30	122	139	0	2	42	42	6	8	0	4	44	108
	61	38	63	44	167	106	3	1	106	51	2	2	2	3	289	140
	0	1	0	0	5	0	0	0	0	0	0	0	0	0	0	0
	3	11	0	2	2	2	0	0	0	0	1	1	1	1	0	5
	4	11	1	1	17	12	1	1	3	2	0	1	0	0	2	10
	36	51	19	16	123	137	2	0	79	77	1	0	3	2	93	112
	0	1	0	0	0	2	0	0	1	0	0	0	0	0	1	2
	3	4	0	0	9	14	0	0	0	0	0	0	0	0	6	11
	2	12	0	0	40	51	0	1	0	0	0	1	0	1	3	29
	1	5	0	0	12	22	0	0	0	0	0	2	0	1	1	14
	12	9	4	3	85	28	0	2	0	2	0	0	2	0	14	17
	0	1	0	0	3	16	0	0	0	0	0	0	0	0	0	11
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	22	16	1	1	45	33	0	0	0	0	1	4	6	3	20	28
	646	865	383	476	3 040	3 553	18	28	1 154	1 251	77	104	70	108	569	1 764
	873	1 011	475	429	4 213	5 065	76	93	1 585	1 607	124	168	109	161	754	2 355
	96	87	89	89	209	186	3	4	326	293	3	2	2	1	514	601
	183	207	110	123	432	547	12	28	213	332	2	6	6	10	480	536
	21	87	42	43	48	122	5	16	67	128	2	7	5	8	29	108
	495	744	375	480	1 191	1 390	5	14	1 079	1 435	26	24	64	62	526	1 483
	805	1 083	168	199	3 177	4 487	44	100	859	908	68	107	69	122	452	1 998
	122	163	26	22	124	182	6	6	127	222	3	16	1	9	70	236
	630	816	202	275	2 445	2 376	88	122	972	1 018	84	95	62	112	484	1 440
	4 129	5 195	2 817	2 970	13 035	12 800	81	89	8 888	7 997	393	372	298	403	3 796	8 393
	4 473	5 738	2 417	2 689	21 459	22 170	150	188	11 867	10 439	600	682	422	667	4 129	12 268
	659	808	316	315	2 935	2 543	42	37	953	948	30	38	74	71	736	1 108
	214	305	355	315	1 130	1 199	12	18	753	840	38	42	17	30	652	936
	296	402	156	131	1 387	1 668	91	99	567	597	33	48	36	48	285	851
	2 824	3 654	1 767	1 946	13 661	15 724	128	176	6 058	5 559	247	264	254	405	3 089	7 798
	15	18	12	10	49	69	0	2	93	77	4	4	0	4	34	93
	72	123	86	65	127	200	3	5	248	298	1	3	2	16	418	390
	22	64	18	58	76	137	1	2	26	74	2	6	3	6	19	149
	18	16	5	9	32	63	5	3	8	8	0	1	0	0	13	40
	1 407	1 916	429	399	8 989	11 266	238	290	1 992	1 908	420	465	253	398	1 208	4 182
	963	1 538	770	950	2 593	3 528	13	26	3 171	3 119	25	46	29	77	1 937	3 548
	775	1 131	310	414	984	1 696	17	52	921	1 133	42	75	43	117	517	1 669
	191	349	485	595	374	663	24	32	806	981	3	8	36	60	1 647	1 735
	148	153	123	113	284	340	1	15	472	607	8	3	16	9	367	492
	103	183	139	164	420	460	8	18	396	458	4	20	11	20	430	579
	2 609	3 717	1 491	1 673	8 026	9 557	99	219	4 046	3 927	215	381	242	421	1 897	6 509
	1 195	1 516	374	407	5 319	6 059	296	300	1 724	1 755	136	150	138	178	860	2 983
	5 095	6 099	1 941	2 132	22 842	24 213	953	1 002	7 806	7 074	1 088	1 066	1 008	1 154	4 252	11 506
	18	18	1	8	12	33	0	1	1	0	0	0	0	4	13	52
	5	12	9	23	45	52	0	1	17	21	1	0	0	0	156	110
	13	15	8	13	27	61	0	0	26	21	0	2	0	1	46	79
	3	18	2	11	6	14	0	0	16	9	0	1	0	1	35	80
	85	188	190	230	426	637	3	10	326	515	3	11	2	13	767	1 389
	6	8	44	44	41	28	0	1	250	406	0	2	1	2	24	38
	12	18	36	47	12	9	0	0	99	176	1	0	0	3	27	60
	21	21	52	43	54	46	1	3	317	442	0	1	1	1	177	188

Table S9: Publications by major field of science, 2008 and 2014

	Publications by field of science													
	Total		Agricultural sciences		Astronomy		Biological sciences		Chemistry		Computer sciences		Engineering	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
Georgia	338	527	0	6	15	27	32	38	30	19	3	1	12	20
Iran, Islamic Rep. of	11 244	25 588	544	839	23	106	1 154	2 142	1 965	3 603	266	855	1 740	5 474
Israel	10 576	11 196	165	154	152	240	2 162	1 974	751	765	442	413	639	646
Moldova, Rep. of	228	248	3	5	0	0	8	15	89	55	0	4	15	18
Russian Federation	27 418	29 099	190	186	636	747	2 341	2 440	5 671	5 159	143	154	2 171	2 755
Turkey	18 493	23 596	837	718	42	104	1 805	2 035	1 359	1 704	299	501	2 301	2 835
Ukraine	5 020	4 895	11	32	145	158	190	233	823	781	9	12	707	490
European Free Trade Assoc.														
Iceland	575	864	14	20	0	16	114	139	18	23	14	20	19	51
Liechtenstein	46	52	0	0	0	0	2	3	8	10	0	0	12	7
Norway	7 543	10 070	184	210	32	80	1 451	1 676	374	407	127	178	501	757
Switzerland	19 131	25 308	325	299	285	493	4 190	4 884	1 676	1 951	350	508	1 326	1 658
Sub-Saharan Africa														
Angola	15	45	0	0	0	0	2	9	0	0	0	0	0	3
Benin	166	270	19	36	0	0	65	71	0	0	0	0	0	1
Botswana	162	210	12	4	0	0	37	55	16	8	2	0	7	4
Burkina Faso	193	272	14	15	0	0	57	64	3	2	0	0	4	12
Burundi	8	18	0	0	0	0	2	2	1	1	0	0	0	0
Cabo Verde	3	25	0	0	0	0	1	3	0	1	0	0	1	1
Cameroon	482	706	47	31	0	2	132	180	30	20	4	3	20	37
Central African Rep.	17	32	0	0	0	0	9	7	0	0	0	0	0	0
Chad	14	26	0	0	0	1	3	5	0	0	0	0	0	0
Comoros	3	0	0	0	0	0	1	0	0	0	0	0	0	0
Congo	69	111	4	3	0	0	27	31	2	2	0	0	0	1
Congo, Dem. Rep. of	38	114	0	2	0	0	15	29	0	2	0	0	0	2
Côte d'Ivoire	183	208	6	10	0	1	55	60	12	9	0	0	1	3
Djibouti	2	15	0	0	0	0	1	1	1	2	0	0	0	0
Equatorial Guinea	2	4	0	0	0	0	0	1	0	0	0	0	0	0
Eritrea	15	22	2	2	0	0	3	5	0	2	0	0	0	1
Ethiopia	402	865	56	63	0	3	77	147	3	20	1	0	4	19
Gabon	82	137	0	2	0	0	45	49	0	0	0	0	1	3
Gambia	95	124	1	0	0	0	42	46	0	0	0	0	1	0
Ghana	293	579	31	45	0	0	92	91	6	15	0	3	7	20
Guinea	16	49	0	2	0	0	5	12	1	0	0	0	0	2
Guinea–Bissau	20	37	0	0	0	0	9	14	0	0	0	0	0	0
Kenya	855	1 374	91	85	0	0	351	403	6	9	0	4	8	22
Lesotho	12	16	1	3	0	0	1	2	1	0	1	0	0	3
Liberia	6	11	1	0	0	0	2	5	0	0	0	0	1	1
Madagascar	152	188	6	9	0	0	69	56	3	3	0	0	2	3
Malawi	218	322	8	9	0	0	54	91	0	0	0	0	0	3
Mali	93	141	6	15	0	0	37	36	1	2	0	0	0	4
Mauritius	44	89	0	4	0	0	9	30	4	7	0	2	5	2
Mozambique	84	158	3	4	0	0	20	29	1	3	0	0	0	1
Namibia	64	139	0	0	12	10	21	35	0	3	0	0	1	5
Niger	81	108	9	16	0	0	17	22	1	4	0	1	1	0
Nigeria	1 977	1 961	265	144	9	41	271	305	45	102	2	6	87	146
Rwanda	34	143	1	7	0	0	10	30	0	1	0	1	0	2
Sao Tome and Principe	1	3	0	0	0	0	1	2	0	0	0	0	0	0
Senegal	228	338	14	18	0	0	59	76	11	11	1	3	7	5
Seychelles	21	34	0	1	0	0	5	11	0	0	0	0	0	0
Sierra Leone	12	45	0	0	0	0	6	5	0	0	0	0	0	0
Somalia	1	7	0	0	0	0	1	1	0	0	0	0	0	0
South Africa	5 611	9 309	187	302	110	328	1 745	2 187	394	748	48	47	362	641
South Sudan	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Swaziland	21	25	3	1	0	0	6	10	2	2	0	0	0	0
Tanzania	426	770	26	28	0	1	131	172	0	12	0	0	11	22
Togo	44	61	4	5	0	0	10	19	1	2	0	0	4	4
Uganda	403	757	16	21	0	1	148	216	2	3	0	3	4	11
Zambia	134	245	4	10	0	0	46	72	0	1	0	0	1	3
Zimbabwe	217	310	27	35	0	0	64	98	0	2	0	1	3	2
Arab States														
Algeria	1 339	2 302	23	50	4	28	104	168	189	250	42	85	332	596
Bahrain	114	155	2	0	0	1	16	16	3	5	2	6	16	28
Egypt	4 147	8 428	121	254	12	49	579	1 351	874	1 246	75	120	545	1 107
Iraq	195	841	8	19	0	4	12	57	22	85	0	22	19	171
Jordan	989	1 093	66	53	2	5	101	117	116	82	36	50	165	129
Kuwait	659	604	7	6	1	2	84	77	54	40	19	35	110	99
Lebanon	621	1 009	9	24	2	3	94	136	37	63	20	35	62	118
Libya	126	181	0	5	0	0	15	21	19	20	1	2	22	28
Mauritania	14	23	0	0	0	0	3	4	6	0	0	0	0	1
Morocco	1 214	1 574	37	55	6	3	123	147	158	158	16	28	114	166
Oman	327	591	10	15	2	5	38	84	23	59	9	6	53	99
Palestine	65	14	1	0	0	0	9	0	13	1	2	0	6	5
Qatar	217	1 242	0	6	1	14	34	185	11	91	4	54	32	227
Saudi Arabia	1 910	10 898	25	152	2	79	208	1 364	176	1 573	39	356	235	1 469
Sudan	150	309	20	18	1	1	40	55	4	28	2	3	6	13
Syrian Arab Rep.	218	229	39	18	0	0	52	36	12	15	0	0	20	18

	Publications by field of science															
	Geosciences		Mathematics		Medical sciences		Other life sciences		Physics		Psychology		Social sciences		Unclassified articles	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
	20	26	65	69	17	38	1	3	105	222	1	0	3	2	34	56
	451	1 245	491	1 004	1 596	2 355	34	90	1 106	2 336	12	36	21	59	1 841	5 444
	405	473	635	630	2 697	2 918	47	52	1 540	1 280	122	106	91	76	728	1 469
	3	6	8	9	8	25	0	1	73	63	0	0	0	1	21	46
	2 612	3 015	1 524	1 573	1 773	1 352	9	8	7 977	7 941	14	31	21	34	2 336	3 704
	1 229	1 341	508	933	6 248	6 852	107	134	1 028	1 648	17	32	79	103	2 634	4 656
	172	205	379	334	144	205	0	4	1 476	1 510	1	1	2	8	961	922
	140	173	18	6	134	191	14	21	38	54	5	9	4	5	43	136
	1	0	0	0	15	13	0	0	5	9	0	0	0	0	3	10
	1 267	1 576	198	270	2 198	2 593	128	162	497	579	82	102	90	129	414	1 351
	1 345	1 830	391	527	5 444	6 603	87	123	2 498	2 736	156	188	120	163	938	3 345
	1	9	0	0	6	9	1	0	0	0	0	1	0	1	5	13
	11	24	3	2	25	47	0	0	11	23	0	0	1	0	31	66
	29	23	5	19	15	42	5	4	7	5	2	1	3	4	22	41
	5	14	1	4	63	67	0	0	3	6	0	0	1	4	42	84
	2	7	0	0	2	1	0	1	0	0	0	0	1	0	0	6
	0	13	0	3	0	1	0	0	0	0	0	0	0	1	1	2
	40	54	11	26	60	98	1	1	58	56	0	0	4	10	75	188
	2	2	0	0	4	8	0	0	0	0	1	0	0	0	1	15
	3	1	0	0	5	6	0	0	0	1	0	0	1	1	2	11
	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	3	9	3	1	22	36	0	0	0	1	1	0	0	4	7	23
	2	10	0	0	18	35	1	0	0	0	0	0	0	2	2	32
	17	20	11	5	38	45	0	0	4	1	1	1	0	0	38	53
	0	5	0	0	0	3	0	0	0	1	0	0	0	0	0	3
	0	2	0	0	1	0	0	0	0	0	0	0	0	0	1	1
	1	4	1	0	3	3	0	0	1	0	0	0	0	1	4	4
	53	98	8	3	105	198	1	3	15	15	0	3	12	23	67	270
	4	11	1	1	21	30	0	0	1	1	2	1	1	0	6	39
	0	1	0	0	29	39	0	0	0	0	0	0	2	3	20	35
	34	56	3	3	64	157	2	7	2	7	0	1	8	20	44	154
	0	1	0	1	4	18	0	0	0	0	0	0	1	1	5	12
	0	1	0	0	9	12	0	0	0	0	0	0	0	0	2	10
	42	101	1	3	183	306	6	10	5	11	6	9	27	39	129	372
	2	1	0	1	2	2	0	0	1	0	0	0	0	0	3	4
	0	0	0	0	1	4	0	0	1	0	0	0	0	0	0	1
	9	26	7	1	34	25	0	0	3	0	3	4	1	1	15	60
	9	9	0	1	61	118	4	4	1	2	1	0	6	6	74	79
	4	7	0	0	19	43	0	2	1	0	0	0	0	0	25	32
	6	14	6	1	4	7	2	1	2	4	0	0	0	1	6	16
	16	22	1	1	33	48	0	1	0	1	0	0	4	2	6	46
	20	26	0	3	3	26	1	1	3	3	0	0	0	0	3	27
	16	12	2	2	18	18	0	1	1	1	0	0	0	1	16	30
	112	160	29	34	380	377	8	12	26	52	1	6	11	25	731	551
	5	8	0	1	12	49	0	3	0	2	0	1	0	1	6	37
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	26	28	11	17	56	78	0	2	8	10	0	2	3	6	32	82
	8	8	0	0	3	3	0	0	0	0	0	0	0	0	5	11
	2	0	0	0	2	23	0	1	0	0	1	0	0	3	1	13
	0	0	0	0	0	4	0	1	0	0	0	0	0	0	0	1
	576	872	202	355	1 073	1 475	60	58	332	625	39	51	87	126	396	1 494
	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3	0
	1	0	0	2	3	2	1	0	0	1	0	0	0	0	5	7
	40	62	0	0	140	237	6	4	2	6	3	5	12	19	55	202
	1	3	2	1	16	6	0	0	1	1	0	1	0	2	5	17
	18	32	2	3	127	234	8	5	1	2	3	4	9	19	65	203
	6	12	0	0	54	83	1	6	2	1	0	2	5	9	15	46
	27	26	2	2	48	57	1	1	3	1	0	1	6	5	36	79
	79	184	120	162	41	71	1	1	262	374	0	0	2	8	140	325
	7	7	5	4	22	36	1	1	14	19	0	3	1	3	25	26
	212	443	138	222	721	1 453	5	11	456	680	2	3	5	9	402	1 480
	15	68	5	17	50	73	0	1	17	78	0	1	0	3	47	242
	75	71	57	55	145	202	19	56	82	77	1	1	9	7	115	188
	30	33	28	34	130	124	4	3	22	29	1	2	2	5	167	115
	37	62	17	29	247	322	6	13	38	59	0	3	6	8	46	134
	11	16	1	4	13	34	0	0	8	14	0	0	0	0	36	37
	3	7	1	1	0	5	0	0	0	1	0	0	0	0	1	4
	133	148	120	121	240	227	1	1	143	287	2	5	3	5	118	223
	39	67	18	17	50	95	0	7	38	37	0	1	3	0	44	99
	2	1	3	0	9	2	0	0	9	3	2	0	0	0	9	2
	3	26	9	30	59	222	0	13	33	167	0	0	0	12	31	195
	65	484	149	792	463	1 229	8	22	147	942	0	9	4	26	389	2 401
	4	14	1	2	46	67	0	2	5	9	0	0	0	3	21	94
	15	24	5	3	31	48	0	1	13	26	0	0	3	1	28	39

Table S9: Publications by major field of science, 2008 and 2014

	Publications by field of science													
	Total		Agricultural sciences		Astronomy		Biological sciences		Chemistry		Computer sciences		Engineering	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
Tunisia	2 068	3 068	91	167	3	10	429	514	194	302	39	95	281	455
United Arab Emirates	713	1 450	15	13	1	15	125	173	35	120	35	87	126	367
Yemen	64	202	0	2	0	2	7	19	7	25	0	3	5	17
Central Asia														
Kazakhstan	221	600	5	7	4	10	20	44	66	80	1	4	22	78
Kyrgyzstan	54	82	0	3	0	0	7	13	2	4	0	0	5	1
Mongolia	126	203	1	4	0	1	34	51	7	6	0	0	3	9
Tajikistan	49	46	0	1	4	2	5	4	13	6	0	0	3	3
Turkmenistan	3	24	0	0	0	0	0	1	0	0	0	0	0	2
Uzbekistan	306	323	8	8	11	10	28	27	60	49	0	1	22	30
South Asia														
Afghanistan	23	44	0	0	0	0	5	4	0	4	0	0	0	0
Bangladesh	797	1 394	40	82	1	19	196	255	65	84	16	27	70	143
Bhutan	8	36	1	1	0	0	3	10	0	1	0	0	1	0
India	37 228	53 733	1 711	1 604	327	590	5 891	7 529	6 628	9 437	492	1 041	4 875	7 827
Maldives	4	16	0	0	0	0	0	5	0	0	0	0	0	0
Nepal	253	455	6	19	3	0	55	86	2	15	0	0	5	19
Pakistan	3 089	6 778	143	253	4	74	632	1 120	511	438	32	202	240	645
Sri Lanka	430	599	39	44	0	3	70	90	20	29	2	2	26	29
Southeast Asia														
Brunei Darussalam	43	106	0	0	0	0	8	18	1	10	1	2	1	13
Cambodia	86	206	4	7	0	0	25	55	3	1	0	0	1	1
China	102 368	256 834	1 795	4 510	581	1 298	12 870	30 991	21 536	34 956	1 997	7 759	15 109	41 835
China, Hong Kong SAR	7 660	852	51	9	21	5	867	75	631	67	524	74	1 360	185
China, Macao SAR	121	46	2	0	1	1	20	5	5	4	14	7	25	12
Indonesia	709	1 476	37	82	2	2	194	295	56	90	9	15	63	191
Japan	76 244	73 128	1 853	1 438	783	919	14 884	11 792	9 949	8 762	787	882	8 104	6 766
Korea, DPR	36	23	1	0	1	0	5	2	3	1	2	1	10	0
Korea, Rep. of	33 431	50 258	905	1 289	188	339	4 896	6 519	4 137	5 242	812	1 580	6 663	9 624
Lao PDR	58	129	6	11	0	0	14	29	1	1	0	0	1	2
Malaysia	2 852	9 998	120	324	1	7	316	914	582	945	71	391	484	2 231
Myanmar	39	70	3	1	0	0	13	18	1	0	0	0	0	3
Philippines	663	913	99	79	0	0	169	186	24	41	1	3	14	54
Singapore	7 075	10 553	33	62	1	3	981	1 482	859	1 332	344	527	1 541	1 752
Thailand	4 335	6 343	299	299	10	27	1 023	1 247	499	556	44	77	529	714
Timor-Leste	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Viet Nam	943	2 298	48	70	2	12	170	324	41	174	5	100	71	289
Oceania														
Australia	30 922	46 639	1 054	1 224	500	902	7 070	8 683	1 859	2 527	514	952	2 209	4 077
New Zealand	5 681	7 375	400	476	21	64	1 547	1 750	299	308	86	101	318	449
Cook Islands	0	7	0	0	0	0	0	1	0	0	0	0	0	0
Fiji	65	106	4	1	0	0	16	14	7	6	2	6	7	17
Kiribati	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Marshall Islands	1	5	0	1	0	0	0	0	0	0	0	0	0	0
Micronesia	3	12	0	1	0	0	3	4	0	0	0	0	0	0
Nauru	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Niue	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Palau	4	12	1	0	0	0	0	3	0	0	0	0	0	1
Papua New Guinea	78	110	4	1	0	0	46	43	0	2	0	0	0	2
Samoa	1	4	0	1	0	0	0	1	0	0	0	0	0	0
Solomon Islands	4	17	0	0	0	0	1	2	0	0	0	0	0	0
Tonga	4	6	0	1	0	0	0	1	0	0	0	0	0	0
Tuvalu	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Vanuatu	9	19	3	1	0	0	3	3	0	0	0	0	0	0

Source: data from Thomson Reuters' Web of Science, Science Citation Index Expanded, compiled for UNESCO by Science–Metrix, May 2015

Publications by field of science															
Geosciences		Mathematics		Medical sciences		Other life sciences		Physics		Psychology		Social sciences		Unclassified articles	
2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
137	296	131	184	381	292	0	1	175	311	3	4	5	22	199	415
50	74	28	50	165	239	0	9	43	90	0	4	4	9	86	200
5	14	3	6	9	29	0	0	8	25	0	0	0	1	20	59
21	39	16	54	8	41	0	2	30	122	0	5	1	4	27	110
17	23	1	3	8	6	0	0	9	11	0	0	0	0	5	18
33	37	1	9	14	21	1	0	17	25	0	1	1	4	14	35
1	5	4	8	3	2	0	0	9	7	0	0	0	0	7	8
1	3	1	14	0	1	0	0	1	0	0	0	0	0	0	3
6	11	19	41	15	12	0	0	110	105	0	1	1	0	26	28
1	1	0	0	11	20	3	1	0	0	0	0	1	1	2	13
87	82	8	20	115	201	3	0	77	107	1	3	13	12	105	359
1	7	0	0	1	8	0	0	0	2	0	0	1	0	0	7
1 759	2 777	886	1 040	4 805	5 442	32	40	4 910	6 338	22	52	77	107	4 813	9 909
3	6	0	0	0	4	0	0	1	0	0	0	0	0	0	1
28	55	1	1	65	106	0	4	2	12	0	0	5	8	81	130
107	282	103	248	322	496	4	8	361	660	1	2	5	37	624	2 313
43	56	2	2	100	109	4	3	13	86	1	2	4	8	106	136
4	12	2	5	9	18	0	0	2	3	0	0	0	1	15	24
16	19	0	0	27	45	0	3	0	1	0	0	1	6	9	68
5 378	14 266	4 649	9 188	8 700	29 295	70	426	18 011	27 681	75	394	185	616	11 412	53 619
506	37	396	49	1 548	161	88	9	1 081	79	44	6	46	9	497	87
8	1	6	2	11	7	6	0	11	1	1	0	2	1	9	5
114	180	14	16	102	164	1	10	39	62	3	13	10	19	65	337
3 644	3 514	1 560	1 565	17 478	17 360	122	120	12 553	9 287	226	208	158	165	4 143	10 350
2	1	0	2	3	3	0	0	4	5	0	0	0	0	5	8
1 065	1 659	863	1 145	5 702	9 359	196	297	5 360	5 231	43	90	60	155	2 541	7 729
2	19	0	1	22	25	0	0	2	0	0	0	0	3	10	38
156	524	52	149	326	849	8	21	181	654	5	18	12	51	538	2 920
4	9	0	0	13	18	0	0	0	2	0	0	1	2	4	17
82	110	10	6	120	140	3	0	30	53	1	4	8	19	102	218
158	354	203	251	1 032	1 518	18	73	1 272	1 210	21	46	33	57	579	1 886
215	278	53	167	853	1 174	42	36	243	377	10	7	24	34	491	1 350
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
82	195	131	257	120	174	1	5	184	306	1	2	11	9	76	381
2 928	4 215	722	839	8 859	12 218	674	1 006	2 127	2 342	383	589	335	543	1 688	6 522
704	896	148	175	1 396	1 661	82	100	268	302	88	97	81	93	243	903
0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	16	3	1	9	15	1	0	0	0	0	0	1	12	7	18
0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
0	3	0	0	0	1	0	0	0	0	0	0	0	1	0	2
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0
2	7	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1	10	0	0	16	26	0	0	0	0	0	0	0	1	11	25
0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
0	3	0	0	3	8	0	0	0	0	0	0	0	0	0	4
0	2	0	0	3	0	0	0	0	0	0	0	0	0	1	2
0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	4	0	0	2	6	0	0	0	0	0	0	0	1	0	4

Table S10: Scientific publications in international collaboration, 2008-2014

	Total number of publications	Number of publications with international co-authors	Publications with international co-authors (%)	Average citation rate	Percentage of papers in 10% most-cited papers
	2008–2014	2008–2014	2008–2014	2008–2012	2008–2012
North America					
Canada	357 500	180 314	50.4	1.25	13.1
United States of America	2 151 180	749 287	34.8	1.32	14.7
Latin America					
Argentina	51 685	23 847	46.1	0.93	7.1
Belize	86	77	89.5	1.20	14.6
Bolivia	1 309	1 230	94.0	1.40	11.6
Brazil	232 381	65 925	28.4	0.74	5.8
Chile	34 624	21 220	61.3	0.96	9.0
Colombia	18 558	11 308	60.9	0.99	9.0
Costa Rica	2 821	2 300	81.5	1.15	13.2
Ecuador	2 529	2 280	90.2	1.15	12.1
El Salvador	232	219	94.4	1.19	14.4
Guatemala	650	598	92.0	0.95	8.8
Guyana	121	89	73.6	0.90	3.1
Honduras	289	282	97.6	0.97	6.1
Mexico	68 383	30 721	44.9	0.82	6.4
Nicaragua	400	386	96.5	1.04	12.2
Panama	2 074	1 932	93.2	1.56	16.6
Paraguay	372	338	90.9	0.99	8.7
Peru	4 339	3 916	90.3	1.29	12.5
Suriname	81	68	84.0	0.77	7.5
Uruguay	4 728	3 330	70.4	1.09	9.8
Venezuela	7 450	4 183	56.1	0.69	5.6
Caribbean					
Antigua and Barbuda	21	20	95.2	–	–
Bahamas	132	119	90.2	1.01	6.6
Barbados	380	297	78.2	0.93	9.8
Cuba	5 481	3 964	72.3	0.67	5.5
Dominica	57	53	93.0	–	–
Dominican Rep.	308	292	94.8	0.97	9.6
Grenada	701	654	93.3	0.64	4.4
Haiti	257	251	97.7	1.62	14.8
Jamaica	1 108	557	50.3	0.48	4.0
St Kitts and Nevis	102	92	90.2	1.05	11.3
St Lucia	15	14	93.3	–	–
St Vincent and the Grenadines	12	11	91.7	–	–
Trinidad and Tobago	1 073	661	61.6	0.61	5.6
European Union					
Austria	81 174	53 248	65.6	1.30	14.0
Belgium	115 353	74 806	64.8	1.39	15.3
Bulgaria	15 476	8 480	54.8	0.91	7.1
Croatia	20 248	8 861	43.8	0.83	7.0
Cyprus	4 540	3 453	76.1	1.28	13.5
Czech Rep.	64 149	32 788	51.1	0.97	8.8
Denmark	85 311	52 635	61.7	1.50	16.6
Estonia	8 852	5 381	60.8	1.26	13.0
Finland	67 217	38 945	57.9	1.27	12.7
France	438 755	238 170	54.3	1.20	12.7
Germany	608 713	320 067	52.6	1.24	13.5
Greece	69 089	31 843	46.1	1.06	10.3
Hungary	39 242	22 322	56.9	1.01	9.4
Ireland	42 916	25 368	59.1	1.34	14.3
Italy	366 894	168 632	46.0	1.17	12.0
Latvia	3 482	1 942	55.8	0.74	6.7
Lithuania	12 329	4 676	37.9	0.75	5.8
Luxembourg	4 013	3 330	83.0	1.24	13.3
Malta	1 003	665	66.3	1.00	11.8
Netherlands	202 703	118 246	58.3	1.48	16.8
Poland	144 090	49 019	34.0	0.72	5.7
Portugal	69 026	37 997	55.0	1.12	11.2
Romania	45 236	17 192	38.0	0.81	7.5
Slovakia	19 974	11 493	57.5	0.83	7.0
Slovenia	21 836	10 979	50.3	1.04	9.4
Spain	309 076	147 698	47.8	1.16	11.8
Sweden	136 603	84 276	61.7	1.34	14.1
United Kingdom	582 678	325 807	55.9	1.36	15.1

Main foreign collaborators (2008–2014)				
First collaborator	Second collaborator	Third collaborator	Fourth collaborator	Fifth collaborator
United States of America (85 069)	United Kingdom (25 879)	China (19 522)	Germany (19 244)	France (18 956)
China (119 594)	United Kingdom (100 537)	Germany (94 322)	Canada (85 069)	France (62 636)
United States of America (8 000)	Spain (5 246)	Brazil (4 237)	Germany (3 285)	France (3 093)
United States of America (60)	United Kingdom (20)	Canada (9)	Mexico (8)	Australia (7); France (7)
United States of America (425)	Brazil (193)	France (192)	Spain (187)	United Kingdom (144)
United States of America (24 964)	France (8 938)	United Kingdom (8 784)	Germany (8 054)	Spain (7 268)
United States of America (7 850)	Spain (4 475)	Germany (3 879)	France (3 562)	United Kingdom (3 443)
United States of America (4 386)	Spain (3 220)	Brazil (2 555)	United Kingdom (1 943)	France (1 854)
United States of America (1 169)	Spain (365)	Brazil (295)	Mexico (272)	France (260)
United States of America (1 070)	Spain (492)	Brazil (490)	United Kingdom (475)	France (468)
United States of America (108)	Mexico (45)	Spain (38)	Guatemala (34); Honduras (34)	
United States of America (388)	Mexico (116)	Brazil (74)	United Kingdom (63)	Costa Rica (54)
United States of America (45)	Canada (20)	United Kingdom (13)	France (12)	Netherlands (8)
United States of America (179)	Mexico (58)	Brazil (42)	Argentina (41)	Colombia (40)
United States of America (12 873)	Spain (6 793)	France (3 818)	United Kingdom (3 525)	Germany (3 345)
United States of America (157)	Sweden (86)	Mexico (52)	Costa Rica (51)	Spain (48)
United States of America (1 155)	Germany (311)	United Kingdom (241)	Canada (195)	Brazil (188)
United States of America (142)	Brazil (113)	Argentina (88)	Spain (62)	Uruguay (36); Peru (36)
United States of America (2 035)	Brazil (719)	United Kingdom (646)	Spain (593)	France (527)
Netherlands (38)	United States of America (16)	Canada (8)	Brazil (6)	Germany (5); France (5); Ecuador (5)
United States of America (854)	Brazil (740)	Argentina (722)	Spain (630)	France (365)
United States of America (1 417)	Spain (1093)	France (525)	Mexico (519)	Brazil (506)
United States of America (11)	St Vincent and the Grenadines (4); France (4)		United Kingdom (3); St Kitts and Nevis (3); Barbados (3)	
United States of America (97)	Canada (37)	United Kingdom (34)	Germany (8)	Australia (6)
United States of America (139)	United Kingdom (118)	Canada (86)	Germany (48)	Belgium (43); Japan (43)
Spain (1 235)	Mexico (806)	Brazil (771)	United States of America (412)	Germany (392)
United States of America (29)	Canada (7)	United Kingdom (6); Trinidad and Tobago (6); Hungary (6)		
United States of America (168)	United Kingdom (52)	Mexico (49)	Spain (45)	Brazil (38)
United States of America (532)	Iran, Islamic Rep. of (91)	United Kingdom (77)	Poland (63)	Turkey (46)
United States of America (208)	France (38)	United Kingdom (18)	South Africa (14)	Canada (13)
United States of America (282)	United Kingdom (116)	Canada (77)	Trinidad and Tobago (43)	South Africa (28)
United States of America (46)	Canada (17)	South Africa (12)	United Kingdom (10)	China (8)
South Africa (4)	United States of America (3)	St Kitts and Nevis (2); Costa Rica (2); Antigua and Barbuda (2); Barbados (2); United Kingdom (2); Canada (2)		
United States of America (6)	Barbados (4); Antigua and Barbuda (4)		Trinidad and Tobago (3); St Kitts and Nevis (3)	
United States of America (251)	United Kingdom (183)	Canada (95)	India (63)	Jamaica (43)
Germany (21 483)	United States of America (13 783)	United Kingdom (8 978)	Italy (7 678)	France (7 425)
United States of America (18 047)	France (17 743)	United Kingdom (15 109)	Germany (14 718)	Netherlands (14 307)
Germany (2 632)	United States of America (1 614)	Italy (1 566)	France (1 505)	United Kingdom (1 396)
Germany (2 383)	United States of America (2 349)	Italy (1 900)	United Kingdom (1 771)	France (1 573)
Greece (1 426)	United States of America (1 170)	United Kingdom (1 065)	Germany (829)	Italy (776)
Germany (8 265)	United States of America (7 908)	France (5 884)	United Kingdom (5 775)	Italy (4 456)
United States of America (15 933)	United Kingdom (12 176)	Germany (11 359)	Sweden (8 906)	France (6 978)
Finland (1 488)	United Kingdom (1 390)	Germany (1 368)	United States of America (1 336)	Sweden (1 065)
United States of America (10 756)	United Kingdom (8 507)	Germany (8 167)	Sweden (7 244)	France (5 109)
United States of America (62 636)	Germany (42 178)	United Kingdom (40 595)	Italy (32 099)	Spain (25 977)
United States of America (94 322)	United Kingdom (54 779)	France (42 178)	Switzerland (34 164)	Italy (33 279)
United States of America (10 374)	United Kingdom (8 905)	Germany (7 438)	Italy (6 184)	France (5 861)
United States of America (6 367)	Germany (6 099)	United Kingdom (4 312)	France (3 740)	Italy (3 588)
United Kingdom (9 735)	United States of America (7 426)	Germany (4 580)	France (3 541)	Italy (2 751)
United States of America (53 913)	United Kingdom (34 639)	Germany (33 279)	France (32 099)	Spain (24 571)
Germany (500)	United States of America (301)	Lithuania (298)	Russian Federation (292)	United Kingdom (289)
Germany (1 214)	United States of America (1 065)	United Kingdom (982)	France (950)	Poland (927)
France (969)	Germany (870)	Belgium (495)	United Kingdom (488)	United States of America (470)
United Kingdom (318)	Italy (197)	France (126)	Germany (120)	United States of America (109)
United States of America (36 295)	Germany (29 922)	United Kingdom (29 606)	France (17 549)	Italy (15 190)
United States of America (13 207)	Germany (12 591)	United Kingdom (8 872)	France (8 795)	Italy (6 944)
Spain (10 019)	United States of America (8 107)	United Kingdom (7 524)	France (6 054)	Germany (5 798)
France (4 424)	Germany (3 876)	United States of America (3 533)	Italy (3 268)	United Kingdom (2 530)
Czech Rep. (3 732)	Germany (2 719)	United States of America (2 249)	United Kingdom (1 750)	France (1 744)
United States of America (2 479)	Germany (2 315)	Italy (2 195)	United Kingdom (1 889)	France (1 666)
United States of America (39 380)	United Kingdom (28 979)	Germany (26 056)	France (25 977)	Italy (24 571)
United States of America (24 023)	United Kingdom (17 928)	Germany (16 731)	France (10 561)	Italy (9 371)
United States of America (100 537)	Germany (54 779)	France (40 595)	Italy (34 639)	Netherlands (29 606)

Table S10: Scientific publications in international collaboration, 2008-2014

	Total number of publications	Number of publications with international co-authors	Publications with international co-authors (%)	Average citation rate	Percentage of papers in 10% most-cited papers
	2008–2014	2008–2014	2008–2014	2008–2012	2008–2012
Southeast Europe					
Albania	782	471	60.2	0.56	4.0
Bosnia and Herzegovina	2 304	1 397	60.6	0.73	6.4
FYR Macedonia	1 795	1 198	66.7	0.80	6.7
Montenegro	995	731	73.5	0.71	5.8
Serbia	28 782	10 635	37.0	0.89	7.5
Other Europe and West Asia					
Armenia	4 472	2 688	60.1	1.03	9.2
Azerbaijan	3 013	1 598	53.0	0.73	5.6
Belarus	7 318	4 274	58.4	0.79	6.6
Georgia	3 174	2 283	71.9	1.29	10.7
Iran, Islamic Rep. of	137 557	29 366	21.3	0.81	7.4
Israel	75 268	37 142	49.3	1.19	11.9
Moldova, Rep. of	1 691	1 204	71.2	0.77	7.9
Russian Federation	194 364	64 190	33.0	0.52	3.8
Turkey	152 333	28 643	18.8	0.71	5.8
Ukraine	33 154	15 761	47.5	0.59	4.4
European Free Trade Assoc.					
Iceland	5 207	4 029	77.4	1.71	18.3
Liechtenstein	333	302	90.7	1.12	12.3
Norway	62 947	38 581	61.3	1.29	13.4
Switzerland	157 286	108 371	68.9	1.56	18.0
Sub–Saharan Africa					
Angola	225	217	96.4	0.67	6.3
Benin	1 506	1 320	87.6	0.82	6.8
Botswana	1 121	894	79.8	1.14	7.6
Burkina Faso	1 704	1 557	91.4	0.96	8.0
Burundi	107	103	96.3	0.70	10.2
Cabo Verde	85	85	100.0	1.45	18.4
Cameroon	4 030	3 257	80.8	0.71	4.9
Central African Rep.	176	166	94.3	0.84	8.7
Chad	116	110	94.8	0.72	5.1
Comoros	18	18	100.0	–	–
Congo	608	555	91.3	0.90	8.2
Congo, Dem. Rep. of	675	628	93.0	1.00	10.3
Côte d'Ivoire	1 445	1 056	73.1	0.71	7.2
Djibouti	51	45	88.2	–	–
Equatorial Guinea	27	27	100.0	–	–
Eritrea	100	92	92.0	0.71	10.6
Ethiopia	4 323	3 069	71.0	0.82	6.3
Gabon	717	679	94.7	0.98	9.0
Gambia	687	655	95.3	1.24	15.4
Ghana	3 076	2 401	78.1	1.08	8.8
Guinea	198	193	97.5	0.96	7.6
Guinea–Bissau	172	172	100.0	1.09	14.9
Kenya	7 727	6 705	86.8	1.19	11.3
Lesotho	135	123	91.1	0.72	6.7
Liberia	56	56	100.0	–	–
Madagascar	1 234	1 136	92.1	0.89	8.8
Malawi	1 855	1 672	90.1	1.38	13.1
Mali	933	891	95.5	1.17	12.0
Mauritius	488	337	69.1	0.73	5.9
Mozambique	865	834	96.4	1.86	12.6
Namibia	646	583	90.2	0.93	10.0
Niger	598	560	93.6	0.93	9.3
Nigeria	13 780	5 109	37.1	0.60	4.1
Rwanda	590	562	95.3	1.05	9.0
Sao Tome and Principe	11	11	100.0	–	–
Senegal	2 135	1 841	86.2	0.85	8.1
Seychelles	198	190	96.0	0.99	8.1
Sierra Leone	178	171	96.1	0.85	9.1
Somalia	20	20	100.0	–	–
South Africa	52 166	29 473	56.5	1.04	9.8
South Sudan	53	52	98.1	–	–
Swaziland	238	205	86.1	0.91	9.7
Tanzania	4 018	3 588	89.3	1.17	13.0
Togo	363	302	83.2	0.52	2.8
Uganda	4 193	3 686	87.9	1.33	12.9
Zambia	1 316	1 263	96.0	1.25	12.6
Zimbabwe	1 638	1 356	82.8	1.21	11.9

Main foreign collaborators (2008–2014)				
First collaborator	**Second collaborator**	**Third collaborator**	**Fourth collaborator**	**Fifth collaborator**
Italy (144)	Germany (68)	Greece (61)	France (52)	Serbia (46)
Serbia (555)	Croatia (383)	Slovenia (182)	Germany (165)	United States of America (141)
Serbia (243)	Germany (215)	United States of America (204)	Bulgaria (178)	Italy (151)
Serbia (411)	Italy (92)	Germany (91)	France (86)	Russian Federation (81)
Germany (2 240)	United States of America (2 149)	Italy (1 892)	United Kingdom (1 825)	France (1 518)
United States of America (1 346)	Germany (1 333)	France (1 247); Russian Federation (1 247)		Italy (1 191)
Turkey (866)	Russian Federation (573)	United States of America (476)	Germany (459)	United Kingdom (413)
Russian Federation (2 059)	Germany (1 419)	Poland (1 204)	United States of America (1 064)	France (985)
United States of America (1 153)	Germany (1 046)	Russian Federation (956)	United Kingdom (924)	Italy (909)
United States of America (6 377)	Canada (3 433)	United Kingdom (3 318)	Germany (2 761)	Malaysia (2 402)
United States of America (19 506)	Germany (7 219)	United Kingdom (4 895)	France (4 422)	Italy (4 082)
Germany (276)	United States of America (235)	Russian Federation (214)	Romania (197)	France (153)
Germany (17 797)	United States of America (17 189)	France (10 475)	United Kingdom (8 575)	Italy (6 888)
United States of America (10 591)	Germany (4 580)	United Kingdom (4 036)	Italy (3 314)	France (3 009)
Russian Federation (3 943)	Germany (3 882)	United States of America (3 546)	Poland (3 072)	France (2 451)
United States of America (1 514)	United Kingdom (1 095)	Sweden (1 078)	Denmark (750)	Germany (703)
Austria (121)	Germany (107)	Switzerland (100)	United States of America (68)	France (19)
United States of America (10 774)	United Kingdom (8 854)	Sweden (7 540)	Germany (7 034)	France (5 418)
Germany (34 164)	United States of America (33 638)	United Kingdom (20 732)	France (19 832)	Italy (15 618)
Portugal (73)	United States of America (34)	Brazil (32)	United Kingdom (31)	Spain (26); France (26)
France (529)	Belgium (206)	United States of America (155)	United Kingdom (133)	Netherlands (125)
United States of America (367)	South Africa (241)	United Kingdom (139)	Canada (58)	Germany (51)
France (676)	United States of America (261)	United Kingdom (254)	Belgium (198)	Germany (156)
Belgium (38)	China (22)	United States of America (18)	Kenya (16)	United Kingdom (13)
Portugal (42)	Spain (23)	United Kingdom (15)	United States of America (11)	Germany (8)
France (1153)	United States of America (528)	Germany (429)	South Africa (340)	United Kingdom (339)
France (103)	United States of America (32)	Cameroon (30)	Gabon (29)	Senegal (23)
France (66)	Switzerland (28)	Cameroon (20)	United States of America (14); United Kingdom (14)	
France (7)	United Kingdom (4)	Morocco (3); Madagascar (3)		United States of America (2); Italy (2)
France (191)	United States of America (152)	Belgium (132)	United Kingdom (75)	Switzerland (68)
Belgium (286)	United States of America (189)	France (125)	United Kingdom (77)	Switzerland (65)
France (610)	United States of America (183)	Switzerland (162)	United Kingdom (109)	Burkina Faso (93)
France (31)	United States of America (6); United Kingdom (6)		Canada (5)	Spain (4)
United States of America (13)	Spain (11)	United Kingdom (10)	Cameroon (4); South Africa (4)	
United States of America (24)	India (20)	Italy (18)	Netherlands (13)	United Kingdom (11)
United States of America (776)	United Kingdom (538)	Germany (314)	India (306)	Belgium (280)
France (334)	Germany (231)	United States of America (142)	United Kingdom (113)	Netherlands (98)
United Kingdom (473)	United States of America (216)	Belgium (92)	Netherlands (69)	Kenya (67)
United States of America (830)	United Kingdom (636)	Germany (291)	South Africa (260)	Netherlands (256)
France (71)	United Kingdom (38)	United States of America (31)	China (27)	Senegal (26)
Denmark (112)	Sweden (50)	Gambia (40); United Kingdom (40)	–	United States of America (24)
United States of America (2 856)	United Kingdom (1 821)	South Africa (750)	Germany (665)	Netherlands (540)
South Africa (56)	United States of America (34)	United Kingdom (13)	Switzerland (10)	Australia (8)
United States of America (36)	United Kingdom (12)	France (11)	Ghana (6)	Canada (5)
France (530)	United States of America (401)	United Kingdom (180)	Germany (143)	South Africa (78)
United States of America (739)	United Kingdom (731)	South Africa (314)	Netherlands (129); Kenya (129)	
United States of America (358)	France (281)	United Kingdom (155)	Burkina Faso (120)	Senegal (97)
United Kingdom (101)	United States of America (80)	France (44)	India (43)	South Africa (40)
United States of America (239)	Spain (193)	South Africa (155)	United Kingdom (138)	Portugal (113)
South Africa (304)	United States of America (184)	Germany (177)	United Kingdom (161)	Australia (115)
France (238)	United States of America (145)	Nigeria (82)	United Kingdom (77)	Senegal (71)
United States of America (1 309)	South Africa (953)	United Kingdom (914)	Germany (434)	China (329)
United States of America (244)	Belgium (107)	Netherlands (86)	Kenya (83)	United Kingdom (82)
Portugal (5); United Kingdom (5)		United States of America (4)	Denmark (2); Angola (2)	
France (1 009)	United States of America (403)	United Kingdom (186)	Burkina Faso (154)	Belgium (139)
United Kingdom (69)	United States of America (64)	Switzerland (52)	France (41)	Australia (31)
United States of America (87)	United Kingdom (41)	Nigeria (20)	China (16); Germany (16)	
Kenya (9)	Egypt (8)	United Kingdom (6)	United States of America (5)	Switzerland (3)
United States of America (9 920)	United Kingdom (7 160)	Germany (4 089)	Australia (3 448)	France (3 445)
United States of America (33)	United Kingdom (22)	Uganda (16)	Kenya (8); Sudan (8)	
South Africa (104)	United States of America (59)	United Kingdom (45)	Tanzania (12); Switzerland (12)	
United States of America (1 212)	United Kingdom (1 129)	Kenya (398)	Switzerland (359)	South Africa (350)
France (146)	Benin (57)	United States of America (50)	Burkina Faso (47)	Côte d'Ivoire (31)
United States of America (1 709)	United Kingdom (1031)	Kenya (477)	South Africa (409)	Sweden (311)
United States of America (673)	United Kingdom (326)	South Africa (243)	Switzerland (101)	Kenya (100)
South Africa (526)	United States of America (395)	United Kingdom (371)	Netherlands (132)	Uganda (124)

Table S10: Scientific publications in international collaboration, 2008-2014

	Total number of publications	Number of publications with international co-authors	Publications with international co-authors (%)	Average citation rate	Percentage of papers in 10% most-cited papers
	2008–2014	2008–2014	2008–2014	2008–2012	2008–2012
Arab States					
Algeria	12 577	7 432	59.1	0.68	5.2
Bahrain	951	648	68.1	0.53	3.8
Egypt	44 239	22 568	51.0	0.77	6.5
Iraq	3 137	1 915	61.0	0.55	3.7
Jordan	7 226	3 747	51.9	0.80	5.9
Kuwait	4 330	2 115	48.8	0.73	6.1
Lebanon	5 409	3 583	66.2	0.85	7.9
Libya	1 017	810	79.6	0.65	4.7
Mauritania	138	133	96.4	0.87	7.5
Morocco	9 928	6 235	62.8	0.69	5.9
Oman	3 062	2 137	69.8	0.76	6.3
Palestine	414	232	56.0	0.54	3.8
Qatar	3 777	3 279	86.8	1.07	11.5
Saudi Arabia	40 534	29 271	72.2	1.09	10.8
Sudan	1 757	1 325	75.4	0.97	5.9
Syrian Arab Rep.	1 924	1 193	62.0	0.81	6.2
Tunisia	18 687	9 813	52.5	0.66	4.5
United Arab Emirates	7 323	5 272	72.0	0.85	7.7
Yemen	987	841	85.2	0.78	7.7
Central Asia					
Kazakhstan	2 442	1 496	61.3	0.51	4.5
Kyrgyzstan	471	373	79.2	0.67	6.2
Mongolia	1 189	1 134	95.4	0.73	6.2
Tajikistan	366	250	68.3	0.39	2.9
Turkmenistan	86	76	88.4	0.77	7.4
Uzbekistan	2 267	1 373	60.6	0.48	3.0
South Asia					
Afghanistan	226	218	96.5	0.74	9.7
Bangladesh	7 664	5 445	71.0	0.79	6.8
Bhutan	173	157	90.8	0.76	7.6
India	314 669	67 146	21.3	0.76	6.4
Maldives	48	47	97.9	–	–
Nepal	2 510	1 919	76.5	1.02	8.3
Pakistan	35 546	15 034	42.3	0.81	7.2
Sri Lanka	3 305	2 175	65.8	0.96	6.0
Southeast Asia					
Brunei Darussalam	435	315	72.4	0.85	6.6
Cambodia	1 052	999	95.0	1.39	14.3
China	1 137 882	277 145	24.4	0.98	10.0
China, Hong Kong SAR	53 296	34 611	64.9	1.34	14.9
China, Macao SAR	1 593	1 264	79.3	1.24	12.4
Indonesia	7 821	6 712	85.8	0.96	8.4
Japan	523 744	142 163	27.1	0.88	7.8
Korea, DPR	199	175	87.9	0.65	3.1
Korea, Rep. of	298 768	82 513	27.6	0.89	7.9
Lao PDR	715	695	97.2	1.02	10.0
Malaysia	47 163	21 895	46.4	0.83	8.4
Myanmar	366	343	93.7	0.69	6.4
Philippines	5 558	3 864	69.5	1.15	12.1
Singapore	62 498	35 697	57.1	1.47	16.4
Thailand	38 627	19 058	49.3	0.95	8.2
Timor–Leste	17	16	94.1	–	–
Viet Nam	10 572	8 089	76.5	0.86	8.1
Oceania					
Australia	269 403	138 976	51.6	1.31	14.1
New Zealand	46 394	27 305	58.9	1.22	12.0
Cook Islands	22	22	100.0	–	–
Fiji	547	453	82.8	0.93	7.9
Kiribati	9	9	100.0	–	–
Marshall Islands	20	17	85.0	–	–
Micronesia	49	38	77.6	–	–

Main foreign collaborators (2008–2014)				
First collaborator	Second collaborator	Third collaborator	Fourth collaborator	Fifth collaborator
France (4 883)	Saudi Arabia (524)	Spain (440)	United States of America (383)	Italy (347)
Saudi Arabia (137)	Egypt (101)	United Kingdom (93)	United States of America (89)	Tunisia (75)
Saudi Arabia (7 803)	United States of America (4 725)	Germany (2 762)	United Kingdom (2 162)	Japan (1 755)
Malaysia (595)	United Kingdom (281)	United States of America (279)	China (133)	Germany (128)
United States of America (1 153)	Germany (586)	Saudi Arabia (490)	United Kingdom (450)	Canada (259)
United States of America (566)	Egypt (332)	United Kingdom (271)	Canada (198)	Saudi Arabia (185)
United States of America (1 307)	France (1 277)	Italy (412)	United Kingdom (337)	Canada (336)
United Kingdom (184)	Egypt (166)	India (99)	Malaysia (79)	France (78)
France (62)	Senegal (40)	United States of America (18)	Spain (16)	Tunisia (15)
France (3 465)	Spain (1 338)	United States of America (833)	Italy (777)	Germany (752)
United States of America (333)	United Kingdom (326)	India (309)	Germany (212)	Malaysia (200)
Egypt (50)	Germany (48)	United States of America (35)	Malaysia (26)	United Kingdom (23)
United States of America (1 168)	United Kingdom (586)	China (457)	France (397)	Germany (373)
Egypt (7 803)	United States of America (5 794)	United Kingdom (2 568)	China (2 469)	India (2 455)
Saudi Arabia (213)	Germany (193)	United Kingdom (191)	United States of America (185)	Malaysia (146)
France (193)	United Kingdom (179)	Germany (175)	United States of America (170)	Italy (92)
France (5 951)	Spain (833)	Italy (727)	Saudi Arabia (600)	United States of America (544)
United States of America (1505)	United Kingdom (697)	Canada (641)	Germany (389)	Egypt (370)
Malaysia (255)	Egypt (183)	Saudi Arabia (158)	United States of America (106)	Germany (72)
Russian Federation (565)	United States of America (329)	Germany (240)	United Kingdom (182)	Japan (150)
Russian Federation (99)	Turkey (74); Germany (74)		United States of America (56)	Kazakhstan (43)
Japan (301)	United States of America (247)	Russian Federation (242)	Germany (165)	Korea, Rep. of (142)
Pakistan (68)	Russian Federation (58)	United States of America (46)	Germany (26)	United Kingdom (20)
Turkey (50)	Russian Federation (11)	United States of America (6); Italy (6)		Germany (4); China (4)
Russian Federation (326)	Germany (258)	United States of America (198)	Italy (131)	Spain (101)
United States of America (97)	United Kingdom (52)	Pakistan (29)	Japan (26); Egypt (26)	
United States of America (1 394)	Japan (1 218)	United Kingdom (676)	Malaysia (626)	Korea, Rep. of (468)
United States of America (44)	Australia (40)	Thailand (37)	Japan (26)	India (18)
United States of America (21 684)	Germany (8 540)	United Kingdom (7 847)	Korea, Rep. of (6 477)	France (5 859)
India (14)	Italy (11)	United States of America (8)	Australia (6)	United Kingdom (5); Sweden (5); Japan (5)
United States of America (486)	India (411)	United Kingdom (272)	Japan (256)	Korea, Rep. of (181)
United States of America (3 074)	China (2 463)	United Kingdom (2 460)	Saudi Arabia (1 887)	Germany (1 684)
United Kingdom (548)	United States of America (516)	Australia (458)	India (332)	Japan (285)
Malaysia (68)	United Kingdom (47)	United States of America (46)	Australia (44)	Singapore (42)
United States of America (307)	Thailand (233)	France (230)	United Kingdom (188)	Japan (136)
United States of America (119 594)	Japan (26 053)	United Kingdom (25 151)	China, Hong Kong SAR (22 561)	Australia (21 058)
China (22 561)	United States of America (7 396)	Australia (2 768)	United Kingdom (2 675)	Canada (1 679)
China (809)	China, Hong Kong SAR (412)	United States of America (195)	United Kingdom (51)	Portugal (40)
Japan (1 848)	United States of America (1 147)	Australia (1 098)	Malaysia (950)	Netherlands (801)
United States of America (50 506)	China (26 053)	Germany (15 943)	United Kingdom (14 796)	Korea, Rep. of (12 108)
China (85)	Korea, Rep. of (41)	Germany (32)	United States of America (12)	Australia (9)
United States of America (42 004)	Japan (12 108)	China (11 993)	India (6 477)	Germany (6 341)
Thailand (191)	United Kingdom (161)	United States of America (136)	France (125)	Australia (117)
United Kingdom (3 076)	India (2 611)	Australia (2 425)	Iran, Islamic Rep. of (2 402)	United States of America (2 308)
Japan (102)	Thailand (91)	United States of America (75)	Australia (46)	United Kingdom (43)
United States of America (1 298)	Japan (909)	Australia (538)	China (500)	United Kingdom (410)
China (11 179)	United States of America (10 680)	Australia (4 166)	United Kingdom (4 055)	Japan (2 098)
United States of America (6 329)	Japan (4 108)	United Kingdom (2 749)	Australia (2 072)	China (1 668)
Australia (8)	Japan (3); Portugal (3); Czech Rep. (3)			China (2); United States of America (2)
United States of America (1 401)	Japan (1 384)	Korea, Rep. of (1 289)	France (1126)	United Kingdom (906)
United States of America (43 225)	United Kingdom (29 324)	China (21 058)	Germany (15 493)	Canada (12 964)
United States of America (8 853)	Australia (7 861)	United Kingdom (6 385)	Germany (3 021)	Canada (2 500)
United States of America (17)	Australia (11); New Zealand (11)		France (4)	Brazil (3); Japan (3)
Australia (229)	United States of America (110)	New Zealand (94)	United Kingdom (81)	India (66)
Australia (7)	New Zealand (6)	United States of America (5); Fiji (5)		Papua New Guinea (4)
United States of America (11)	Micronesia (6)	Fiji (5); Australia (5)		New Zealand (3); Palau (3); Papua New Guinea (3)
United States of America (26)	Australia (9)	Fiji (8)	Marshall Islands (6)	New Zealand (5); Palau (5)

Table S10: Scientific publications in international collaboration, 2008-2014

	Total number of publications	Number of publications with international co-authors	Publications with international co-authors (%)	Average citation rate	Percentage of papers in 10% most-cited papers
	2008–2014	2008–2014	2008–2014	2008–2012	2008–2012
Nauru	2	2	100.0	–	–
Niue	3	3	100.0	–	–
Palau	46	40	87.0	–	–
Papua New Guinea	646	583	90.2	0.88	9.0
Samoa	9	8	88.9	–	–
Solomon Islands	74	73	98.6	1.00	13.6
Tonga	24	24	100.0	–	–
Tuvalu	5	5	100.0	–	–
Vanuatu	114	108	94.7	0.81	3.3

Source: data from Thomson Reuters' Web of Science, Science Citation Index Expanded, compiled for UNESCO by Science–Metrix, May 2015

KEY TO ALL TABLES:

–: data unavailable
–n/+n: data refer to n years before or after reference year
0: magnitude nil or negligible
a: not applicable
b: overestimated or based on overestimated data
c: including other classes
d: including business enterprise
e: including higher education
f: including private non–profit
g: included elsewhere
h: excluding business enterprise
i: excluding government
j: excluding higher education
k: government only
l: higher education only
m: included in business
n: included in government
o: excluding most or all capital expenditures
p: excluding defence (all or mostly)
q: underestimated or partial data
r: estimation
s: break in series with previous year for which data are shown
t: the sum of the breakdown does not add to the total
u: based on R&D budget
v: provisional data

METHODOLOGICAL NOTE

Bibliographic data

Publication data have been compiled for UNESCO by Science–Metrix from Thomson Reuters' Web of Science, Science Citation Index Expanded, as of May 2015.

Economic data

Data on economic indicators, such as gross domestic product (GDP) and purchasing power parity (PPP), are based on the World Bank's economic data release of April 2015: http://data.worldbank.org/products/wdi. (See the note on the cut–off date.)

It should be noted that, since 2014, the UNESCO Institute for Statistics has used data on total general government expenditure (all sectors) from the International Monetary Fund's *World Economic Outlook* database as the denominator for its indicator entitled Expenditure on education as a percentage of total government expenditure. For more information about the change in methodology, please visit: www.uis.unesco.org/education

	Main foreign collaborators (2008–2014)				
	First collaborator	Second collaborator	Third collaborator	Fourth collaborator	Fifth collaborator
	Australia (2)	Solomon Islands (1); Cook Islands (1); Micronesia (1); Vanuatu (1); France (1); Niue (1); Kiribati (1); Tonga (1); Palau (1); Iceland (1); Marshall Islands (1); Tuvalu (1); United States of America (1); New Zealand (1); Fiji (1); Papua New Guinea (1)			
	Australia (3); Micronesia (3)		France (2); Solomon Islands (2); Cook Islands (2); Papua New Guinea (2); Fiji (2); Palau (2); Vanuatu (2); Tonga (2); Kiribati (2); Tuvalu (2); New Zealand (2); United States of America (2); Iceland (2); Marshall Islands (2)		
	United States of America (27)	Australia (20)	Japan (5); Micronesia (5)		Papua New Guinea (3); Fiji (3); Marshall Islands (3); Philippines (3)
	Australia (375)	United States of America (197)	United Kingdom (103)	Spain (91)	Switzerland (70)
	United States of America (5)	Australia (4)	Japan (1); Ecuador (1); Spain (1); New Zealand (1); Cook Islands (1); Costa Rica (1); France (1); Chile (1); China (1); Fiji (1)		
	Australia (48)	United States of America (15)	Vanuatu (10)	United Kingdom (9)	Fiji (8)
	Australia (17)	Fiji (13)	New Zealand (11)	United States of America (9)	France (3)
	United States of America (3); Japan (3); Australia (3)			Solomon Islands (2); Tonga (2); Cook Islands (2); Iceland (2); New Zealand (2); Kiribati (2); Palau (2); Micronesia (2); Fiji (2); Marshall Islands (2); Papua New Guinea (2); France (2); Niue (2); Vanuatu (2)	
	France (49)	Australia (45)	United States of America (24)	Solomon Islands (10); Japan (10); New Zealand (10)	

Education data
The UNESCO Institute for Statistics compiles education statistics in aggregate form from official administrative sources at the national level. These include data on educational programmes, access, participation, progression, completion, internal efficiency and human and financial resources. These data are collected annually by the UNESCO Institute for Statistics and its partner agencies through the following two major surveys: the education questionnaires by the UNESCO Institute for Statistics and the joint Education Data Collection involving UNESCO, the Organisation for Economic Co–operation and Development (OECD) and Eurostat. These questionnaires can be downloaded from: www.uis.unesco.org/UISQuestionnaires

Innovation data
The UNESCO Institute for Statistics collects data on innovation within the manufacturing industry every two years through its innovation data collection. In addition, the institute obtains innovation data directly from Eurostat and the African Science, Technology and Innovation Indicators (ASTII) Initiative of the African Union/NEPAD Planning and Coordinating Agency for countries which participate in the data collections of these organizations. With a few exceptions, innovation data refer to a three–year reference period that varies from one country to another. The data collected are featured in the institute's international database at: http://data.uis.unesco.org.

Population data
Population data are based on the 2012 revision of the *World Population Prospects* by the United Nations Population Division.

Research and experimental development (R&D) data
The UNESCO Institute for Statistics collects data on resources devoted to research and experimental development (R&D) through its R&D statistics survey. In addition, it obtains data directly from the OECD, Eurostat, the Ibero–American and Inter–American Network on Science and Technology Indicators (RICYT) and the African Science, Technology and Innovation Indicators (ASTII) Initiative of the African Union/NEPAD Planning and Coordinating Agency for countries which participate in the data collections of these organizations.

Data obtained from the OECD are based on the OECD's Research and Development Statistics database released in April 2015. Data obtained from Eurostat are based on the Eurostat Science and Technology database, as of April 2015. Data received from RICYT are as of April 2015. Data obtained from ASTII are based on the *African Innovation Outlook II* (2014) and the *African Innovation Outlook I* (2010). The data collected can be found at: http://data.uis.unesco.org

Cut–off date for data in the Statistical Annex and chapters

R&D and economic data presented in the regional/individual country chapters may not always correspond to the data given in the Statistical Annex or in Chapter 1. The reason for this is that the underlying economic data used to calculate R&D indicators are based on the World Bank's economic data release of April 2015, whereas, in the other chapters, this was based on a previous release of economic data by the World Bank.

TECHNICAL NOTE

Bibliographic data

Number of papers: this is the number of peer–reviewed scientific publications (i.e. articles, reviews and notes only) indexed in the Web of Science database from Thomson Reuters. Publications are assigned to countries according to the field address on the publications. Double counting is avoided at both the national and regional levels. For instance, a paper co–authored by two researchers from Italy and one author from France is counted only once for France and once for Italy but also once for Europe and once for the world.

Number of international collaborations: this is the number of publications involving authors from at least two different countries. For the computation of international collaboration, territories were considered to be part of their respective mainland countries. Thus, collaboration between Guadeloupe and France would not be considered as international co–authorship.

Average of relative citations*:* this is an indicator of the scientific impact of papers produced by a given entity (e.g. the world, a country, an institution) relative to the world average (i.e. the expected number of citations).

Field classification of publications: a classification from the US National Science Foundation encompassing the 14 following fields of science was used to prepare statistics at the level of scientific disciplines: Agricultural sciences, Astronomy, Biological sciences, Chemistry, Computer sciences, Engineering, Geosciences, Mathematics, Medical sciences, Other life sciences, Physics, Psychology, Social sciences and Unclassified fields.

Education data

Data on internationally mobile students that are collected by the UNESCO Institute for Statistics, OECD and Eurostat encompass students who are pursuing a tertiary degree and thus exclude students on exchange programmes. Data on internationally mobile students reported by host countries are used by the UNESCO Institute for Statistics to estimate the number of outbound students from a given country. Not all host countries specify the country of origin of the internationally mobile students that they host and, thus, the number of outbound students from a given country may be underestimated.

Innovation data

The definitions and classifications used to collect innovation data and produce innovation indicators are based on the third edition of the *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data,* published by the OECD and Eurostat in 2005. The key definitions related to innovation data are presented in the glossary of the present report.

R&D data

The definitions and classifications used to collect R&D data are based on the *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development* (OECD). Some of the key definitions related to R&D data are presented in the glossary of the present report.

Two types of R&D indicator are usually compiled: data on R&D personnel measure researchers, technicians & equivalent staff directly involved in R&D, as well as other support staff; data on R&D expenditure measure the total cost of carrying out the R&D activity concerned, including indirect support.

Regional averages for R&D expenditure and researchers presented in Chapter 1 are derived from imputing numbers for missing data on the basis of calculations done by the UNESCO Institute for Statistics.

Patent data

Number of granted patents: this is the number of granted patents indexed in the PATSTAT database for the US Patent and Trademark Office. Patents are assigned to countries according to the country of the inventors on the applications. Double counting is avoided at both the national and regional levels. For instance, a patent application submitted by two inventors from Italy and one inventor from France is counted only once for France and once for Italy but also once for Europe and once for the world.

UNESCO SCIENCE REPORT

Towards 2030

There are fewer grounds today than in the past to deplore a North-South divide in research and innovation. This is one of the key findings of the *UNESCO Science Report: towards 2030.* A large number of countries are now incorporating science, technology and innovation in their national development agenda, in order to make their economies less reliant on raw materials and more rooted in knowledge. Most research and development (R&D) is taking place in high-income countries, but innovation of some kind is now occurring across the full spectrum of income levels according to the first survey of manufacturing companies in 65 countries conducted by the UNESCO Institute for Statistics and summarized in this report.

For many lower-income countries, sustainable development has become an integral part of their national development plans for the next 10–20 years. Among higher-income countries, a firm commitment to sustainable development is often coupled with the desire to maintain competitiveness in global markets that are increasingly leaning towards 'green' technologies. The quest for clean energy and greater energy efficiency now figures among the research priorities of numerous countries.

Another trend is the growing policy interest in local and indigenous knowledge systems in sub-Saharan Africa and Latin America, in particular.

Gender equality remains a challenge for the future. Despite having achieved parity in higher education in many countries, women are still a minority in research positions worldwide.

Written by more than 50 experts who are each covering the country or region from which they hail, the *UNESCO Science Report: towards 2030* provides more country-level information than ever before. The trends and developments in science, technology and innovation policy and governance between 2009 and mid-2015 described here provide essential baseline information on the concerns and priorities of countries that will orient the implementation and drive the assessment of the 2030 Agenda for Sustainable Development in the years to come.

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