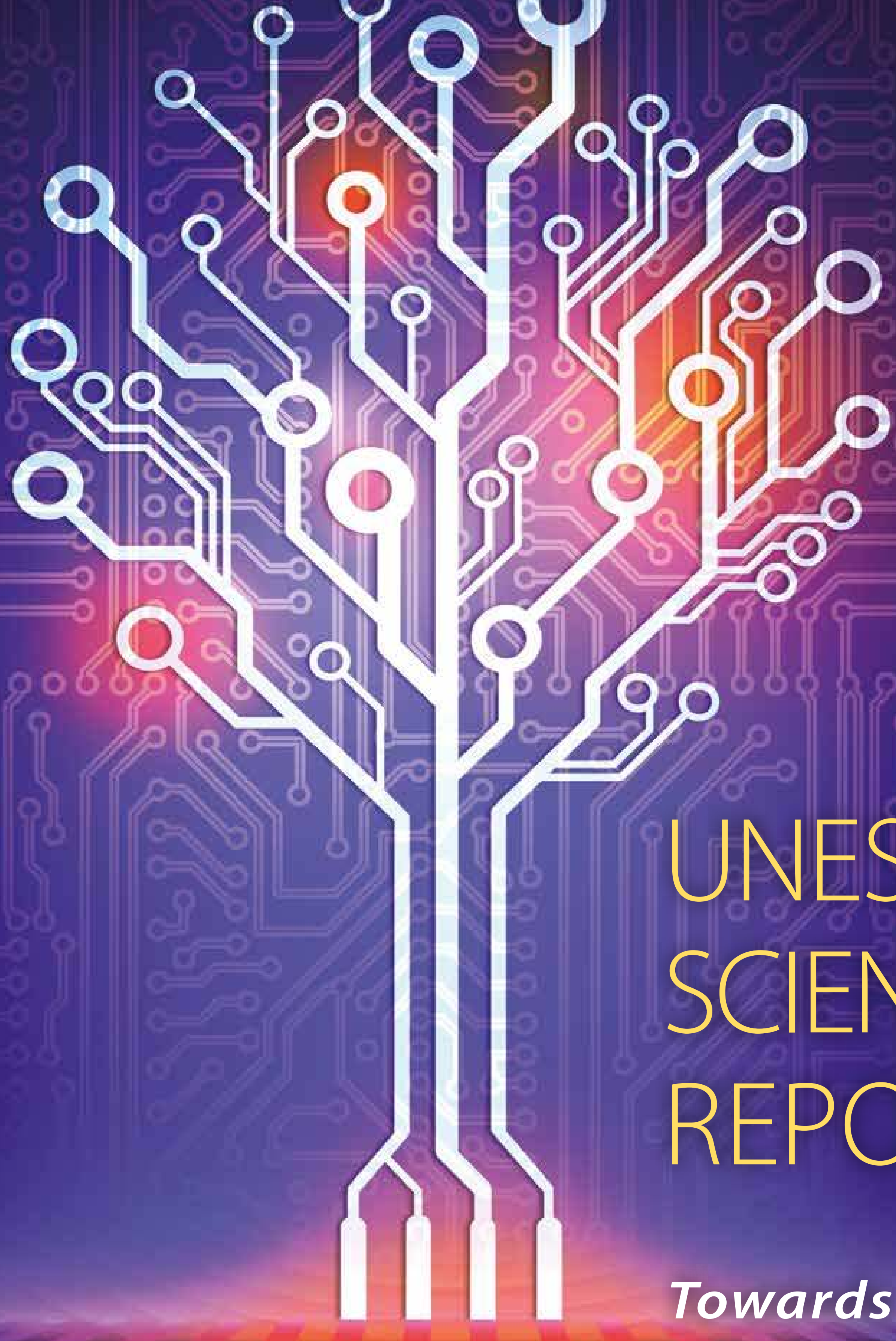

UNESCO SCIENCE REPORT

Towards 2030

UNESCO Publishing

United Nations
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UNESCO SCIENCE REPORT

Towards 2030

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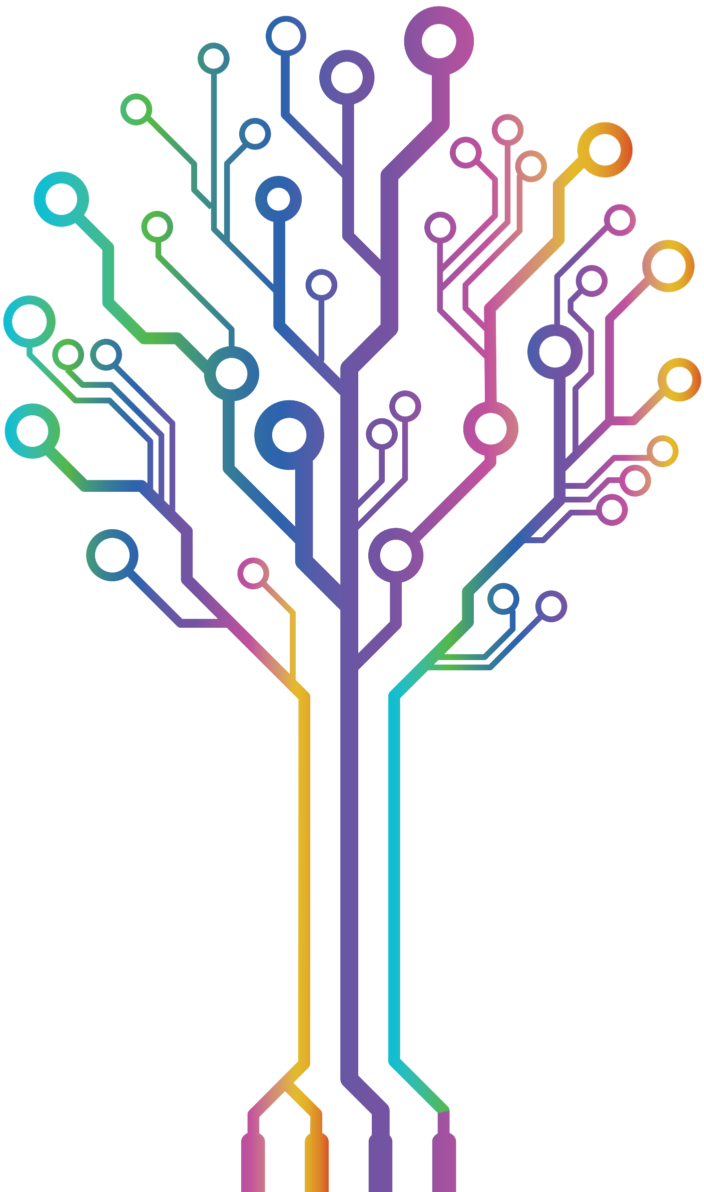

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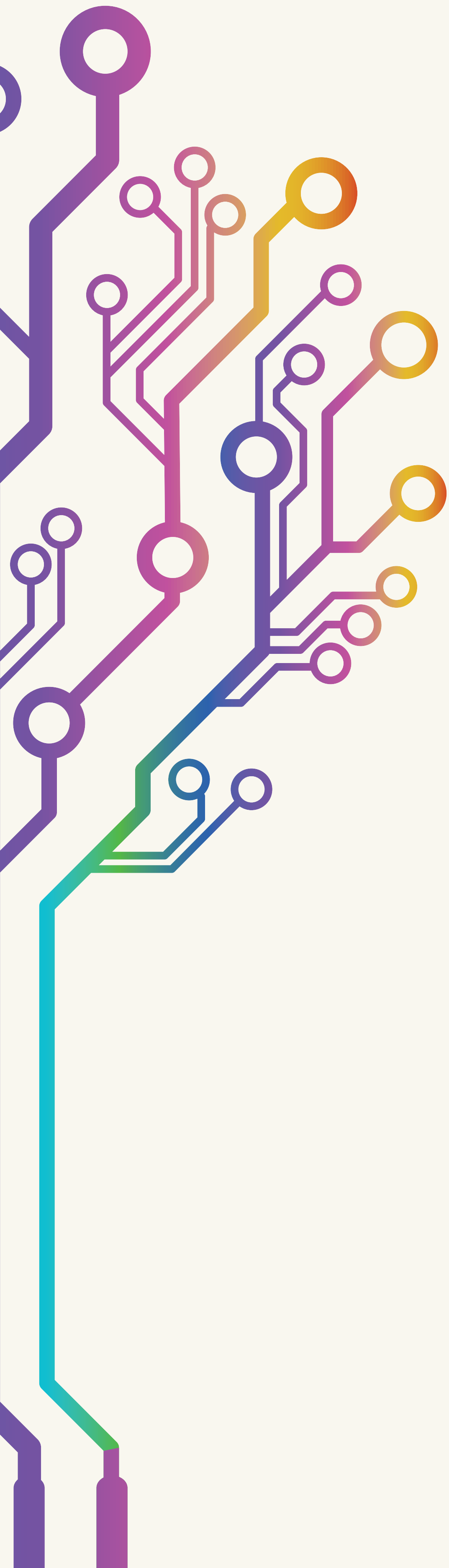

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Foreword

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.

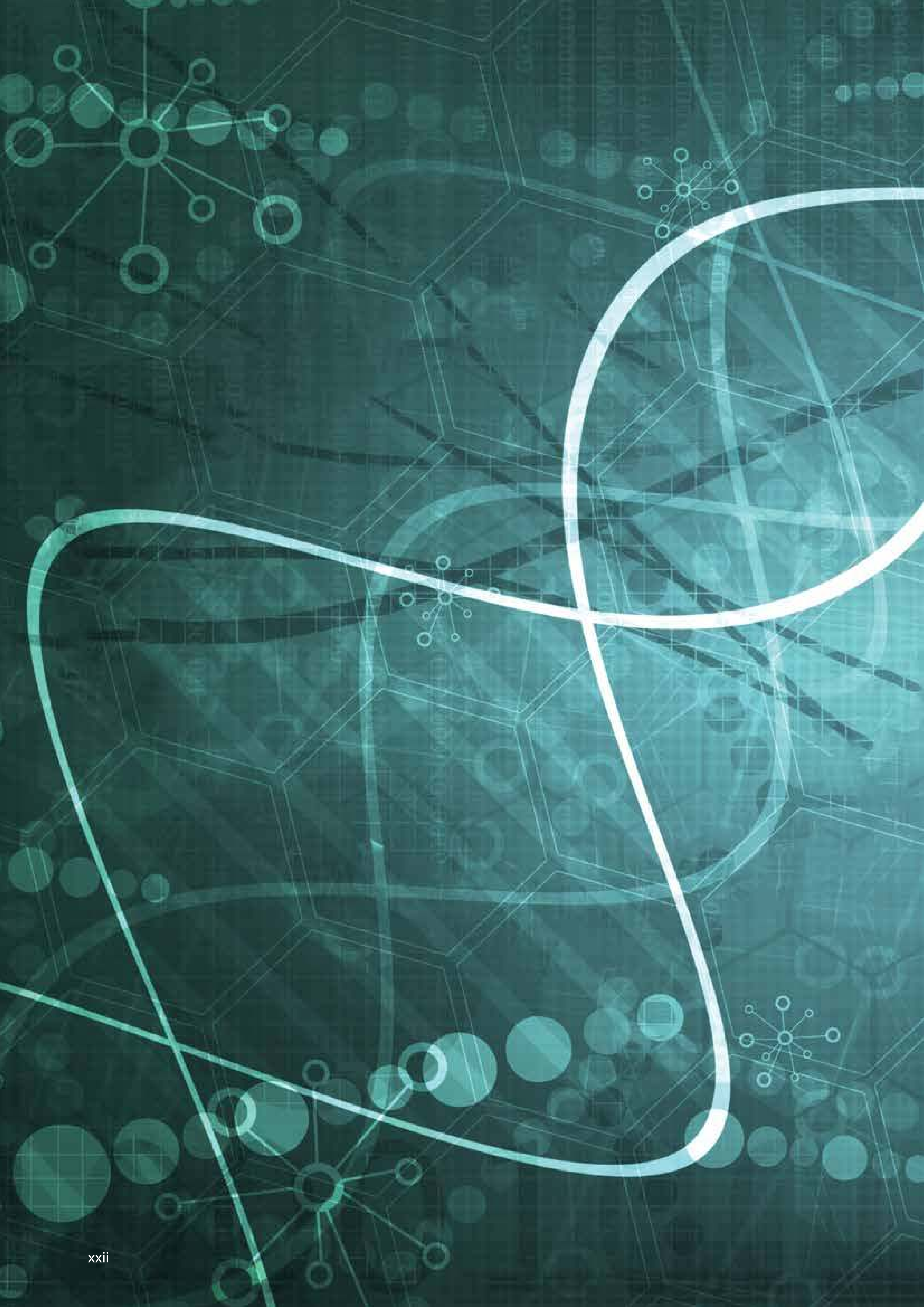
With all this, we face the challenge of mobilizing these accelerating trends of scientific enterprise, knowledge, mobility and international co-operation to inform policy and take the world on a more sustainable path.

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.

Irina Bokova



Perspectives on emerging issues

International students studying alongside Indian students at 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.

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 been 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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1. See this workshop's final report: https://wiki.creativecommons.org/wiki/Data_governance_workshop

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).

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.

1. see: www.futureearth.org

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 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

Douglas Nakashima, *Head, Local and Indigenous Knowledge Systems programme, UNESCO*

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 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 the target it shares with the EU of a 3% 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

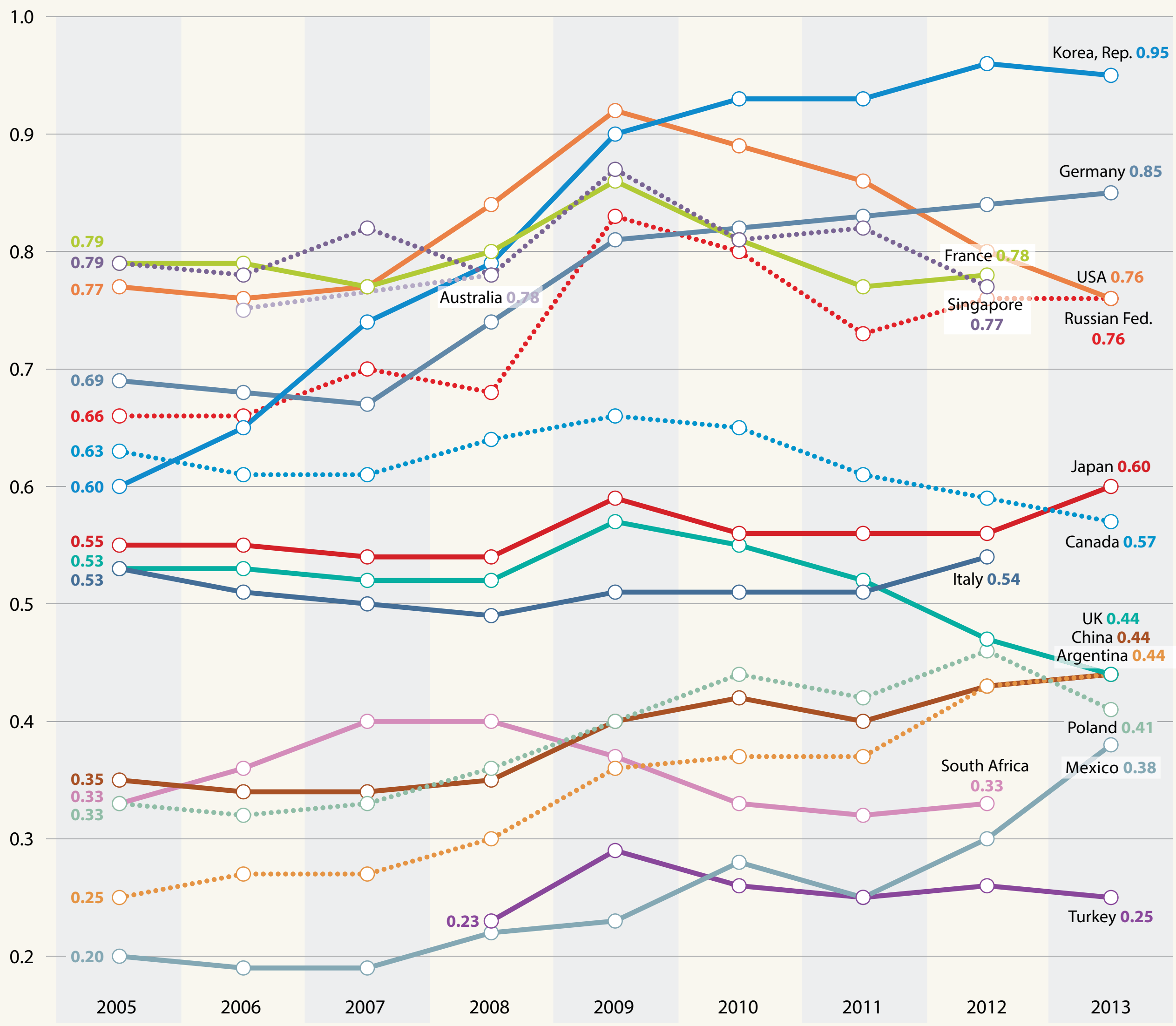
b: break in series with previous year for which data are shown

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 (%)**



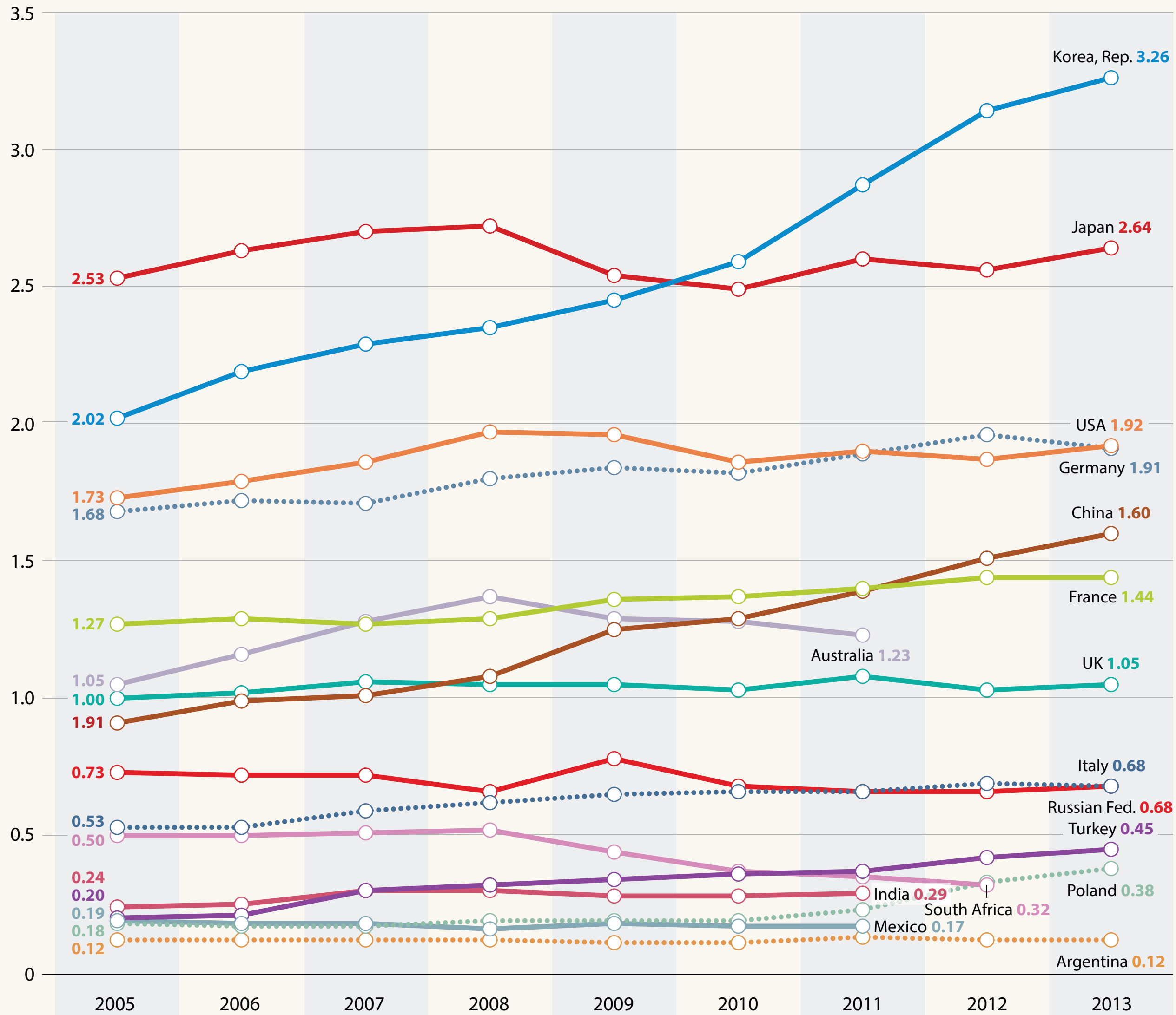
Source: OECD's Main Science and Technology Indicators, September 2015

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 commit-ment 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.

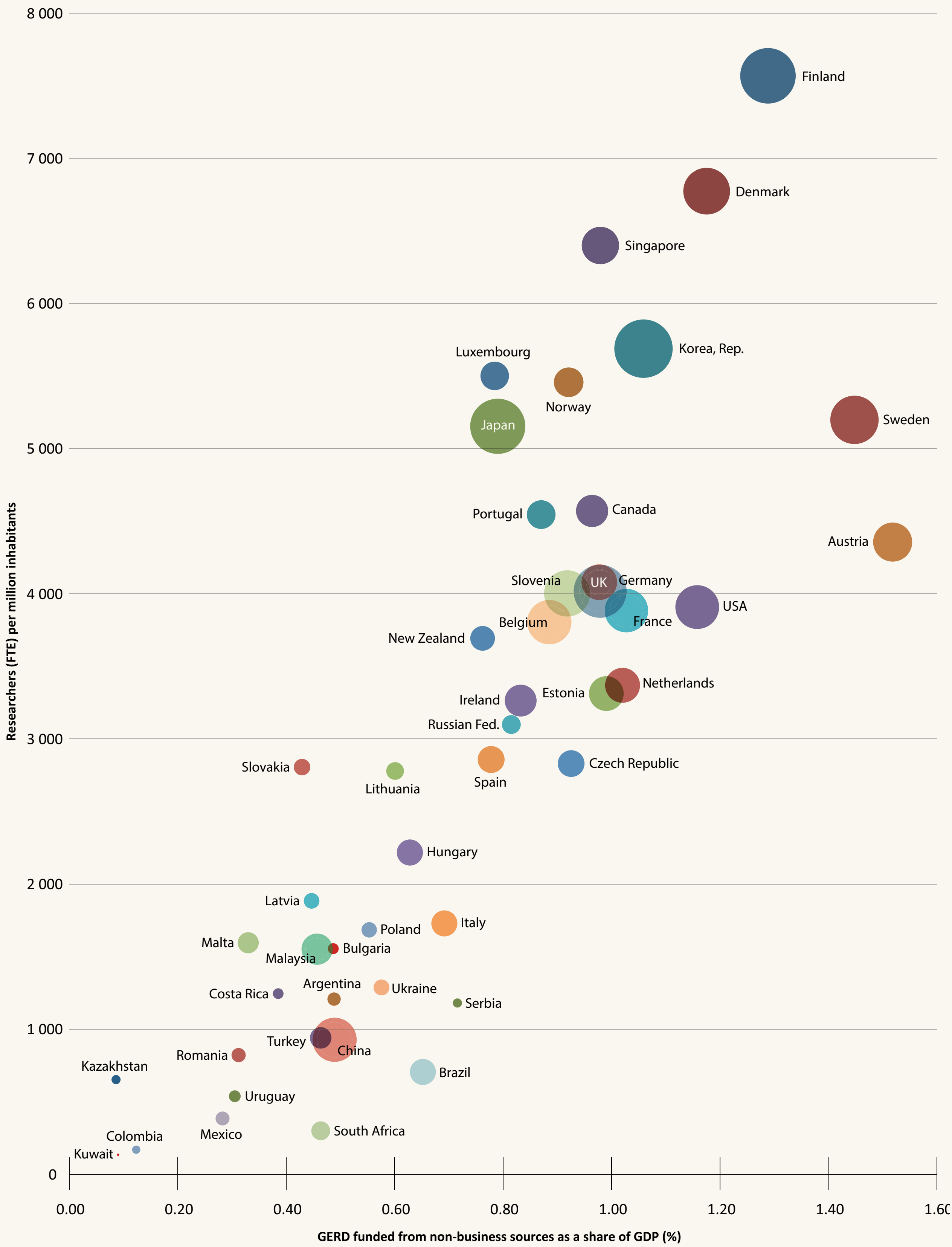
GERD encompasses both public and private investment in R&D. The share of GERD performed by the business enterprise sector (BERD) tends to be higher in economies with a greater focus on technology-based competitiveness in manufacturing, as reflected in their higher BERD/GDP ratio (Chapter 2). Among the 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.

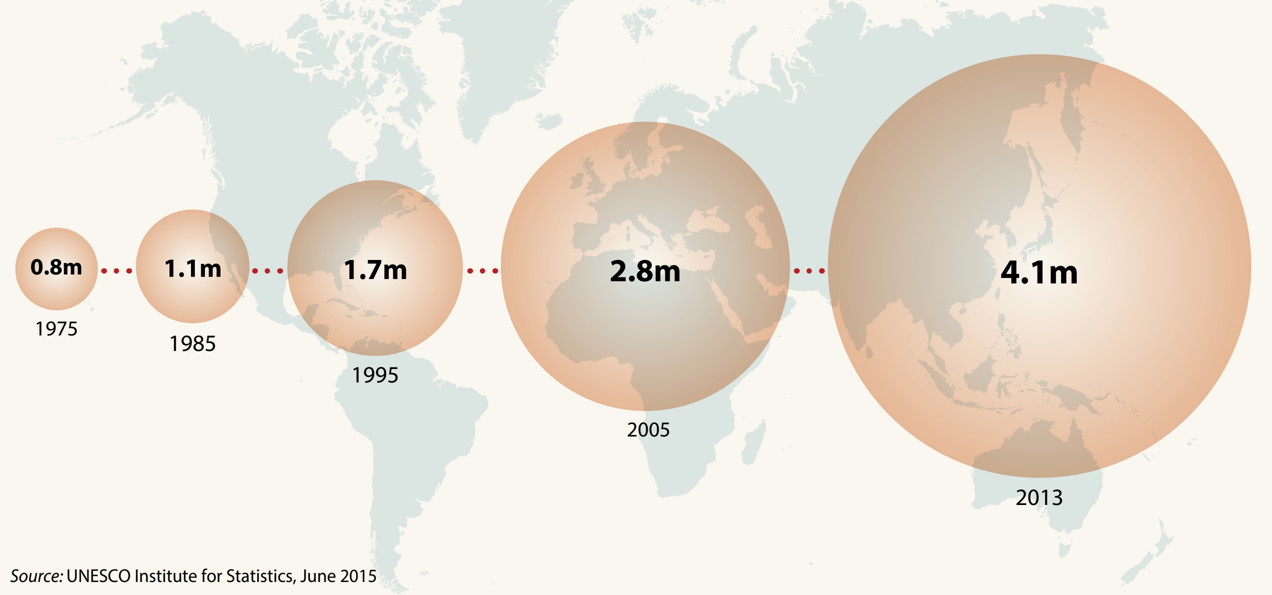
The EU remains the world leader for the number of researchers, with a 22.2% share. Since 2011, China (19.1%) has overtaken the USA (16.7%), as predicted by the *UNESCO Science Report 2010*, despite a downward readjustment of the Chinese figures since this publication's release. Japan's world share has 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 Russia 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, the region with the greatest share of publications: 39.3%

60.1%

Growth in publications with authors from Africa between 2008 and 2014

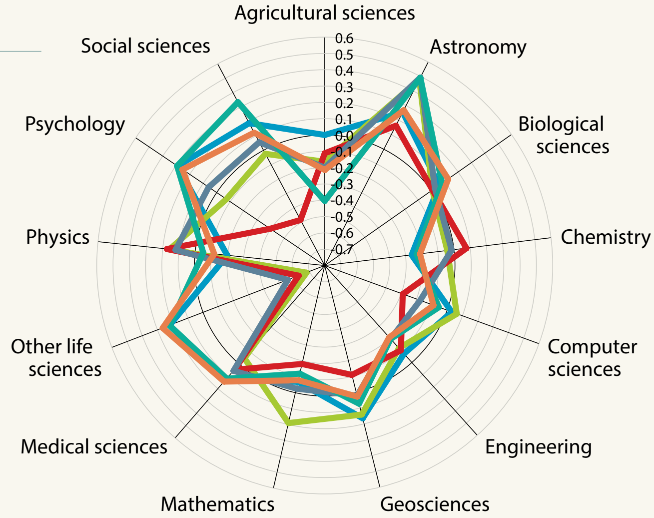
109.6%

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

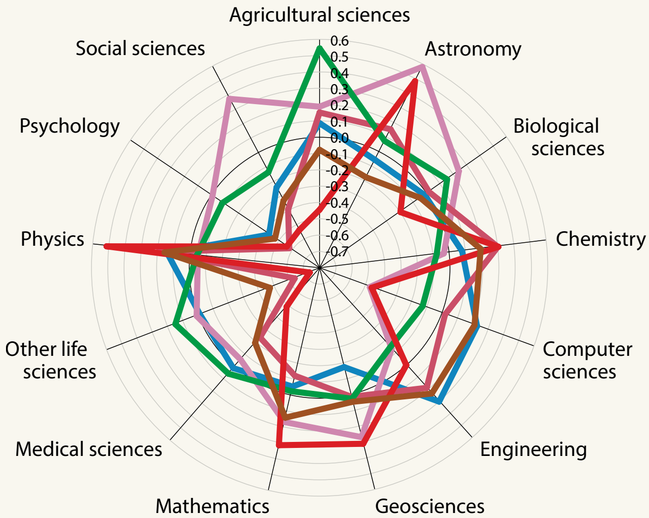
Scientific specialization in large advanced economies

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

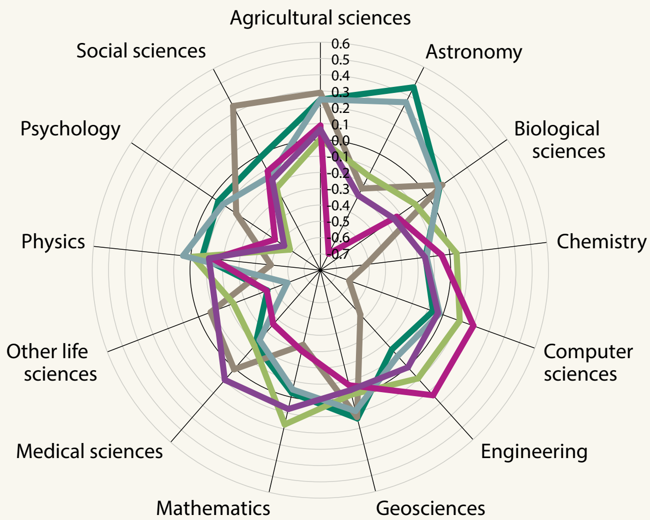


Table 1.5: **Patents submitted to USPTO, 2008 and 2013**

By region or country of inventor

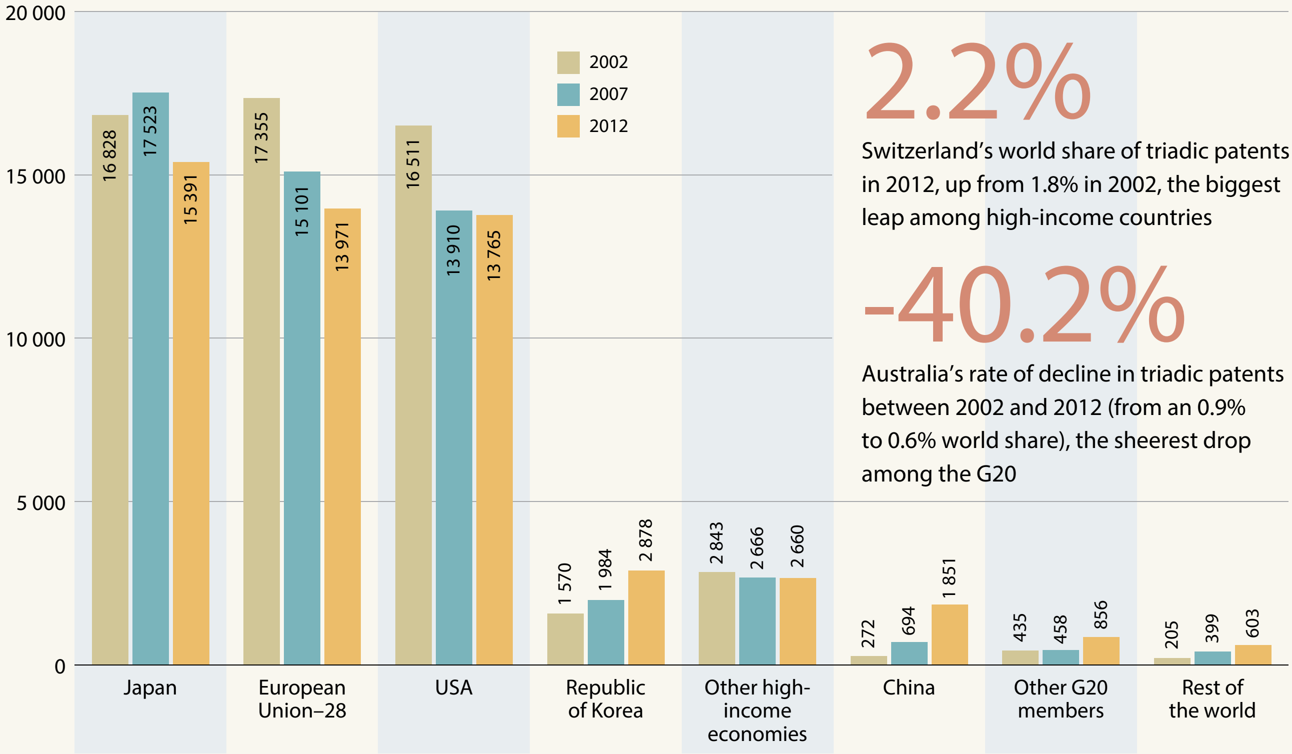
	USPTO patents			
	Total		World share (%)	
	2008	2013	2008	2013
World	**157 768**	**277 832**	**100.0**	**100.0**
High-income economies	149 290	258 411	94.6	93.0
Upper middle-income economies	2 640	9 529	1.7	3.4
Lower middle-income economies	973	3 586	0.6	1.3
Low-income economies	15	59	0.0	0.0
Americas	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



2.2%

Switzerland's world share of triadic patents in 2012, up from 1.8% in 2002, the biggest leap among high-income countries

-40.2%

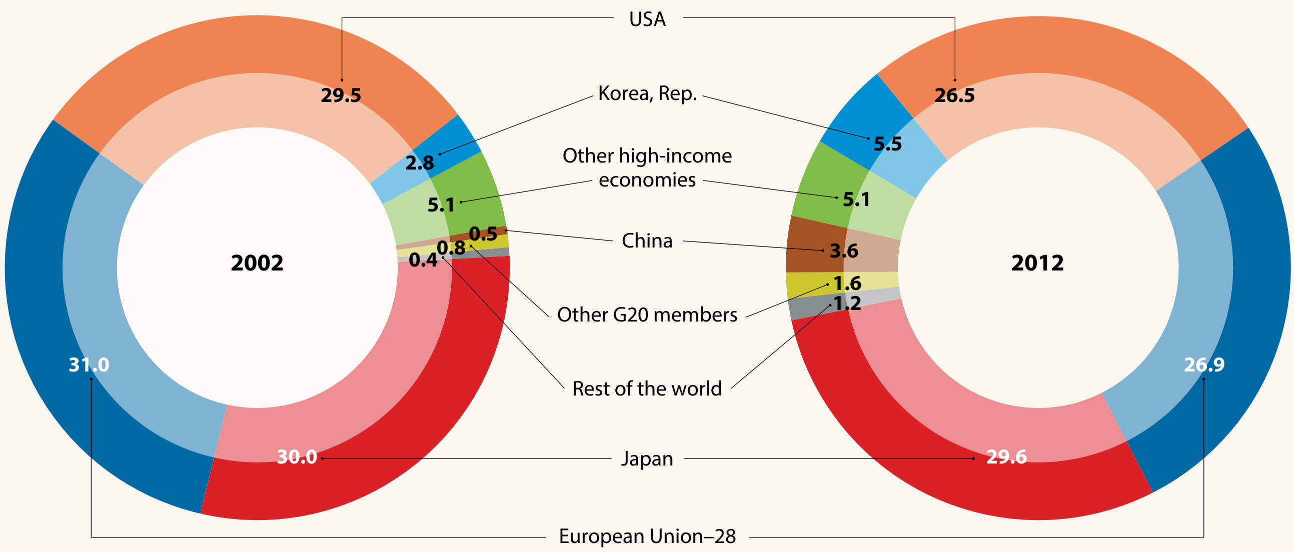
Australia's rate of decline in triadic patents between 2002 and 2012 (from an 0.9% to 0.6% world share), the sheerest drop among the G20

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

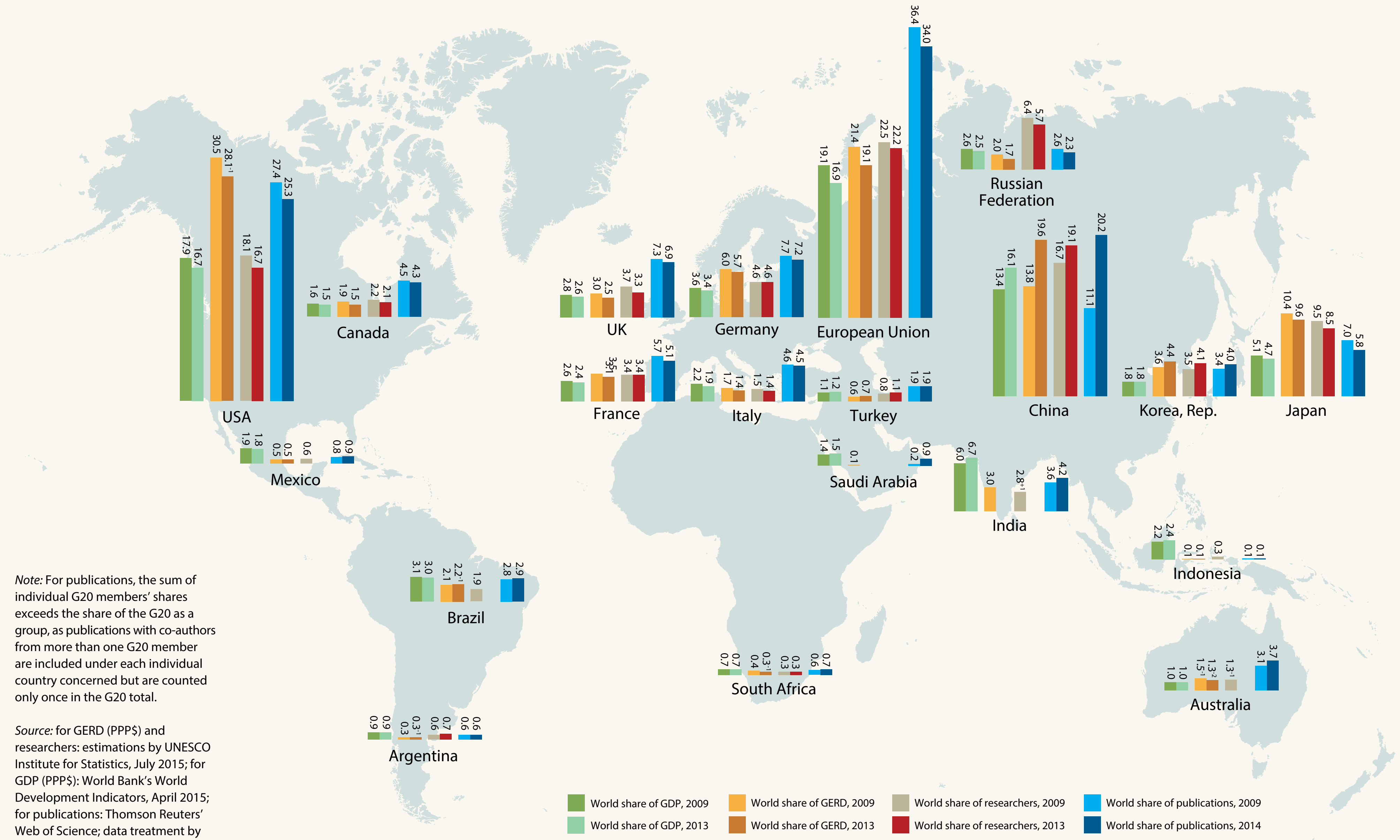
Global shares of triadic patents, 2002 and 2012 (%)



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	2014
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 macro-economic 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, even if countries are at very different stages: 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 staring 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 for 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 of 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 3% 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

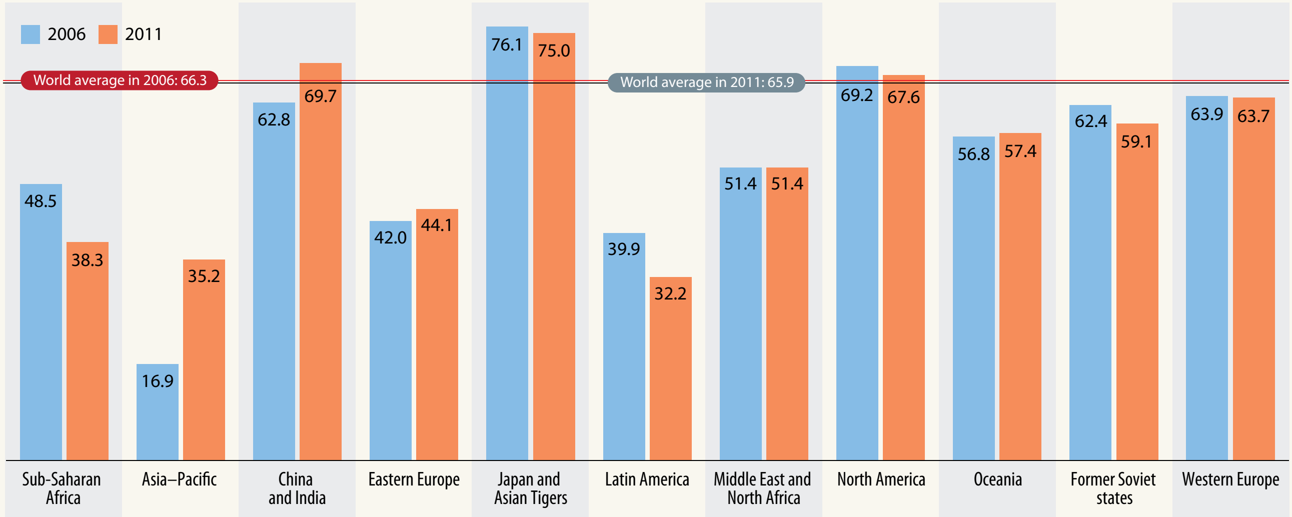
Another difference between the 'culture' of public and private science and technology concerns the degree of mobility. Private science is increasingly mobile, public science is not. Here, we are not referring to individual researchers working in the public and private sectors, who tend to see mobility 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%

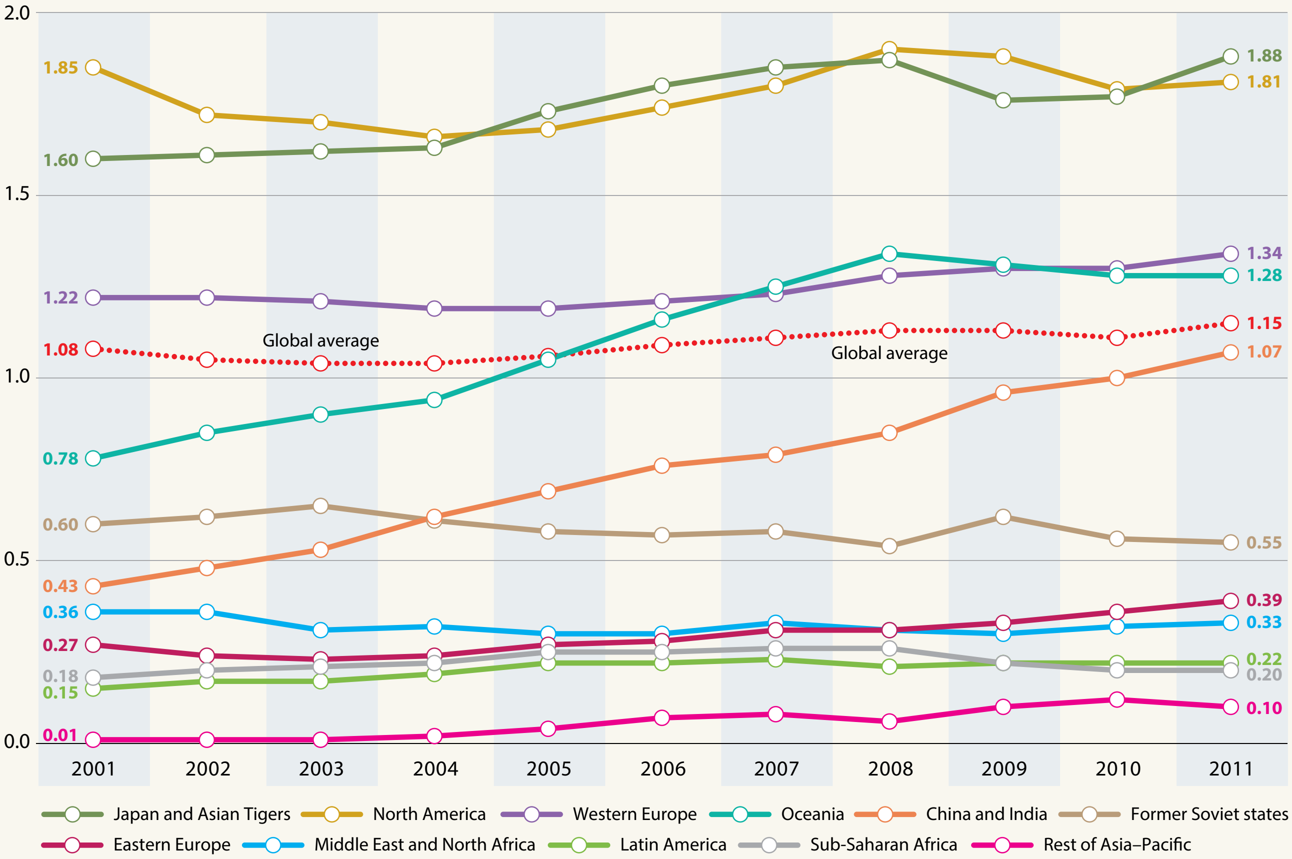
Global average for business R&D as a share of GDP in 2001

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%

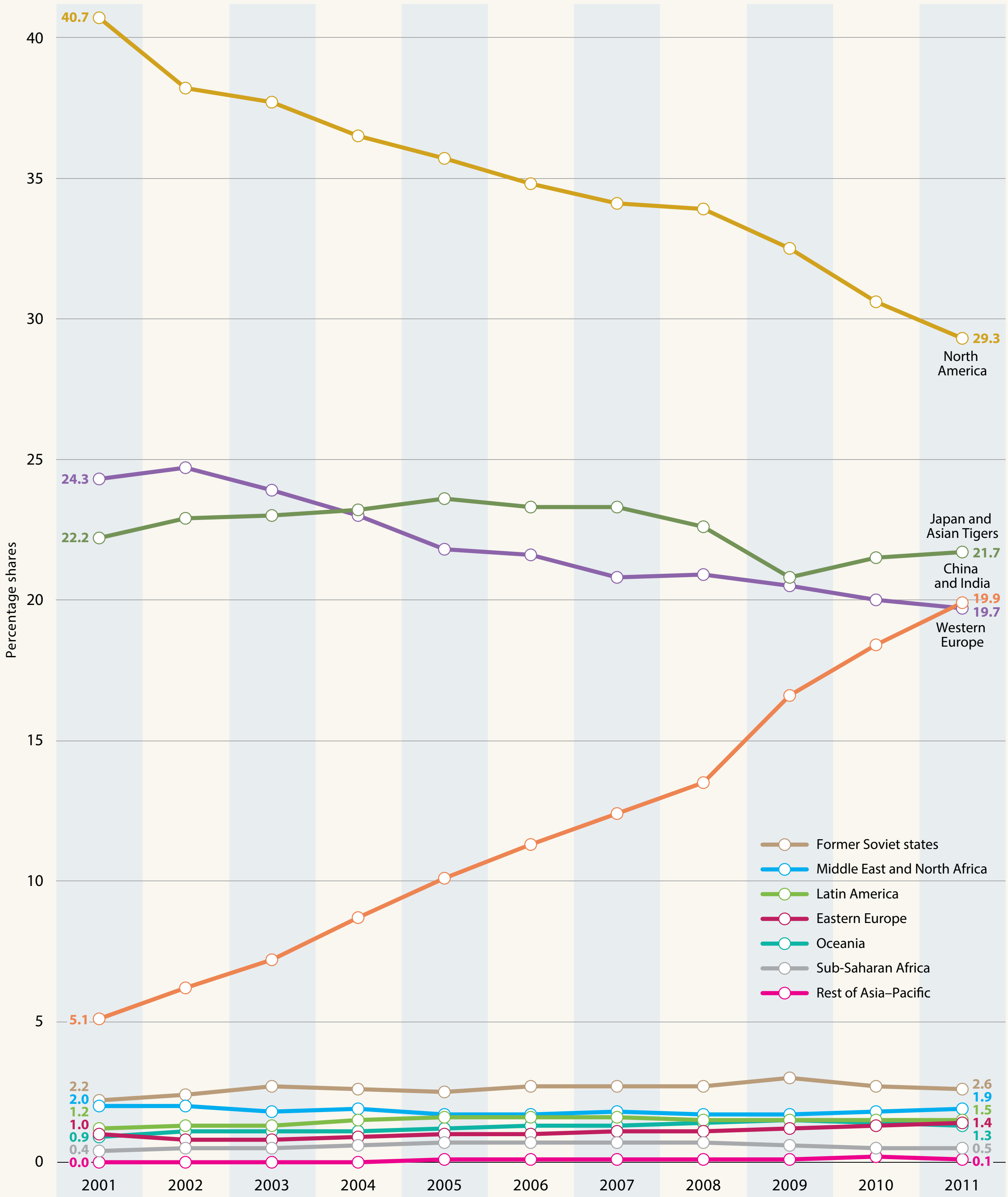
China and India's share of global business R&D in 2001

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%.

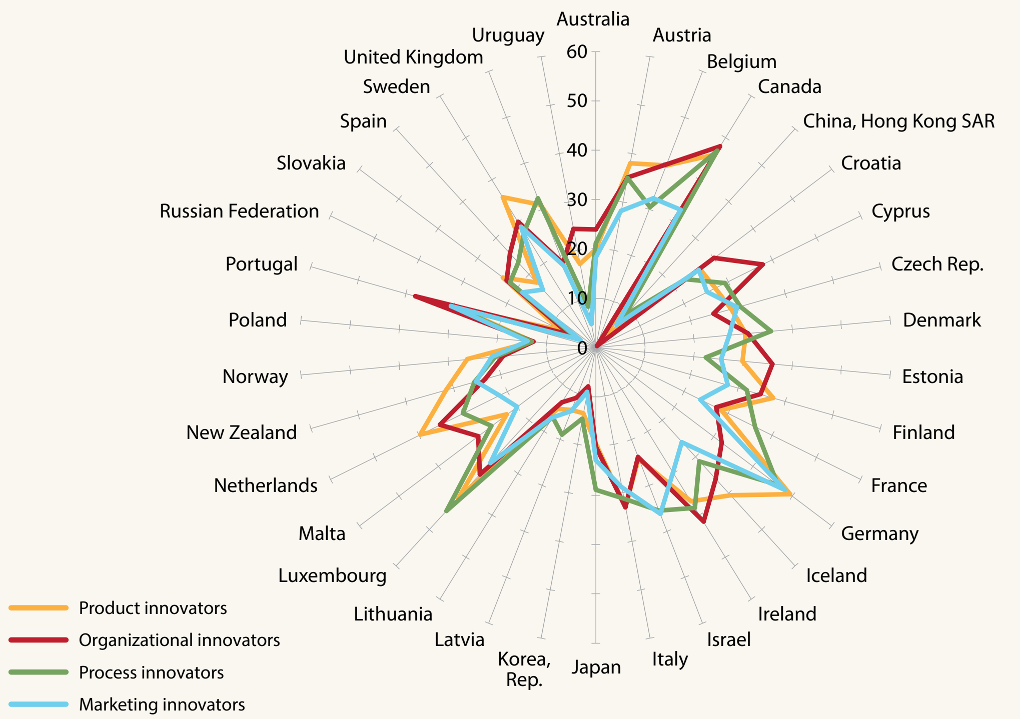
In the BRICS countries, product innovators prevail in South Africa and the Russian Federation, whereas China and India present similar shares of both types of innovators (Figure 2.3). In Brazil, the share of firms implementing process innovation is remarkably higher than the share implementing product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

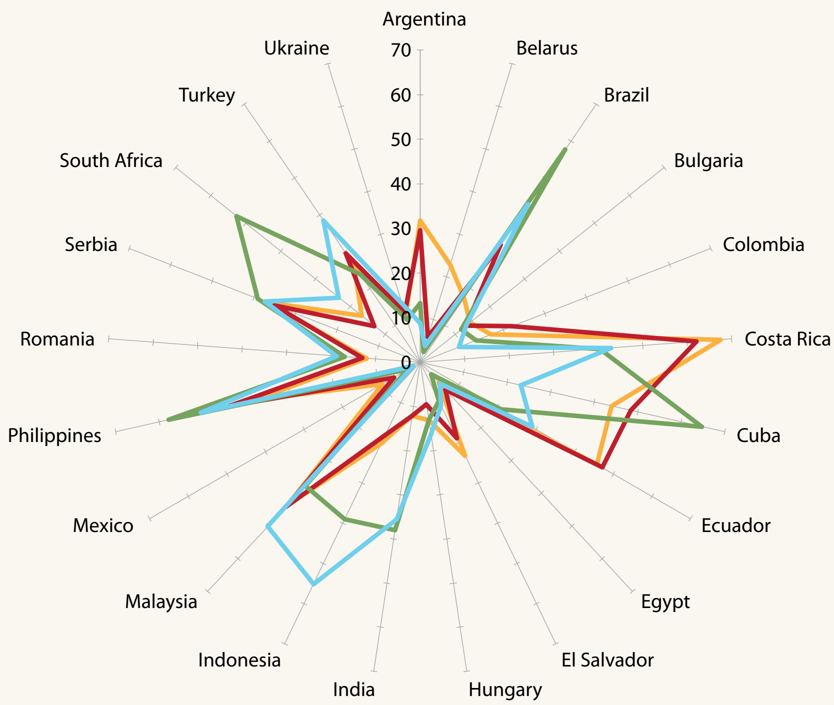
Figure 2.2: **Types of innovator around the world**

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.

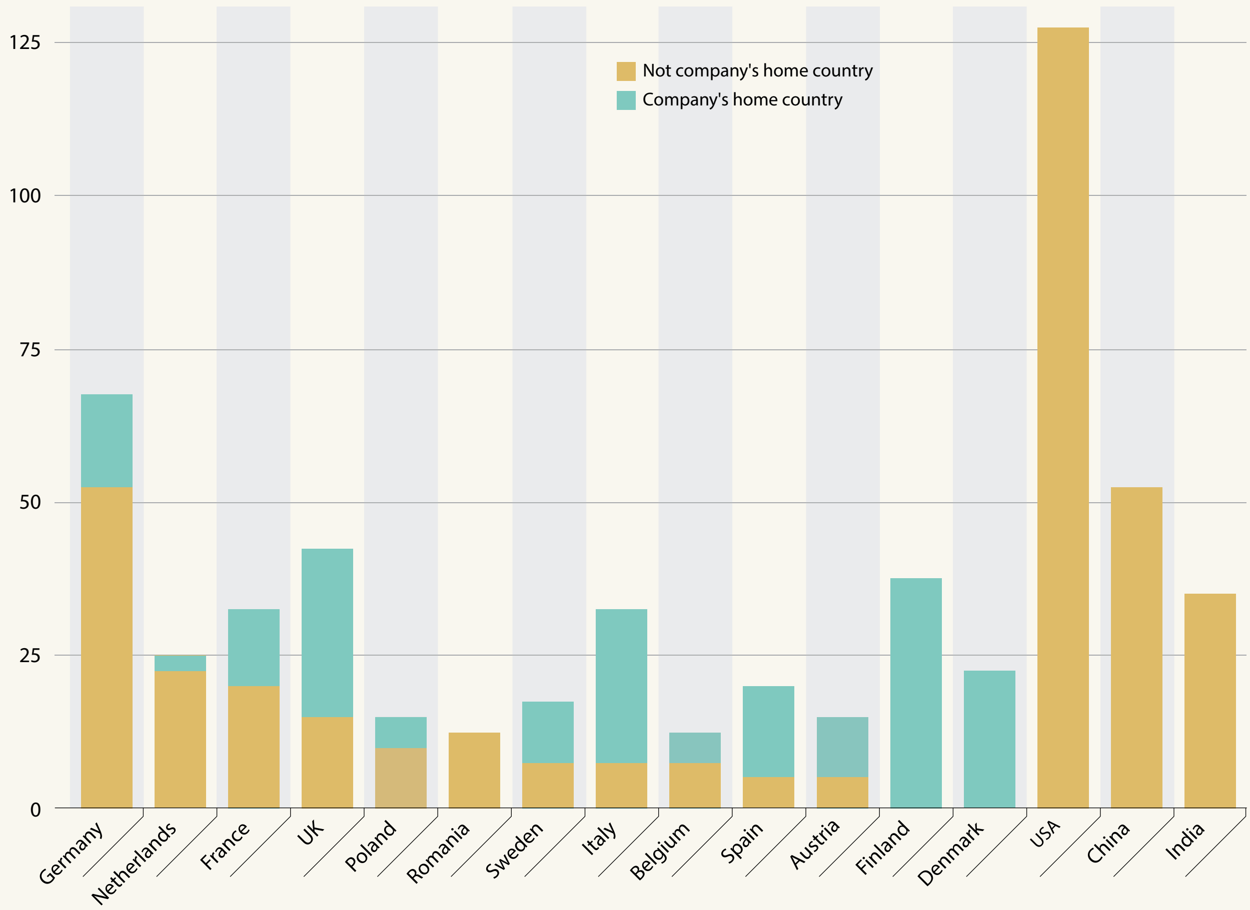
Within the EU, the quality of R&D personnel and knowledge-sharing opportunities with universities and public organizations are considered the most important criteria. Other important factors are proximity to other company sites (for Belgium, Denmark, Germany, France, Italy, Finland and Sweden) and the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

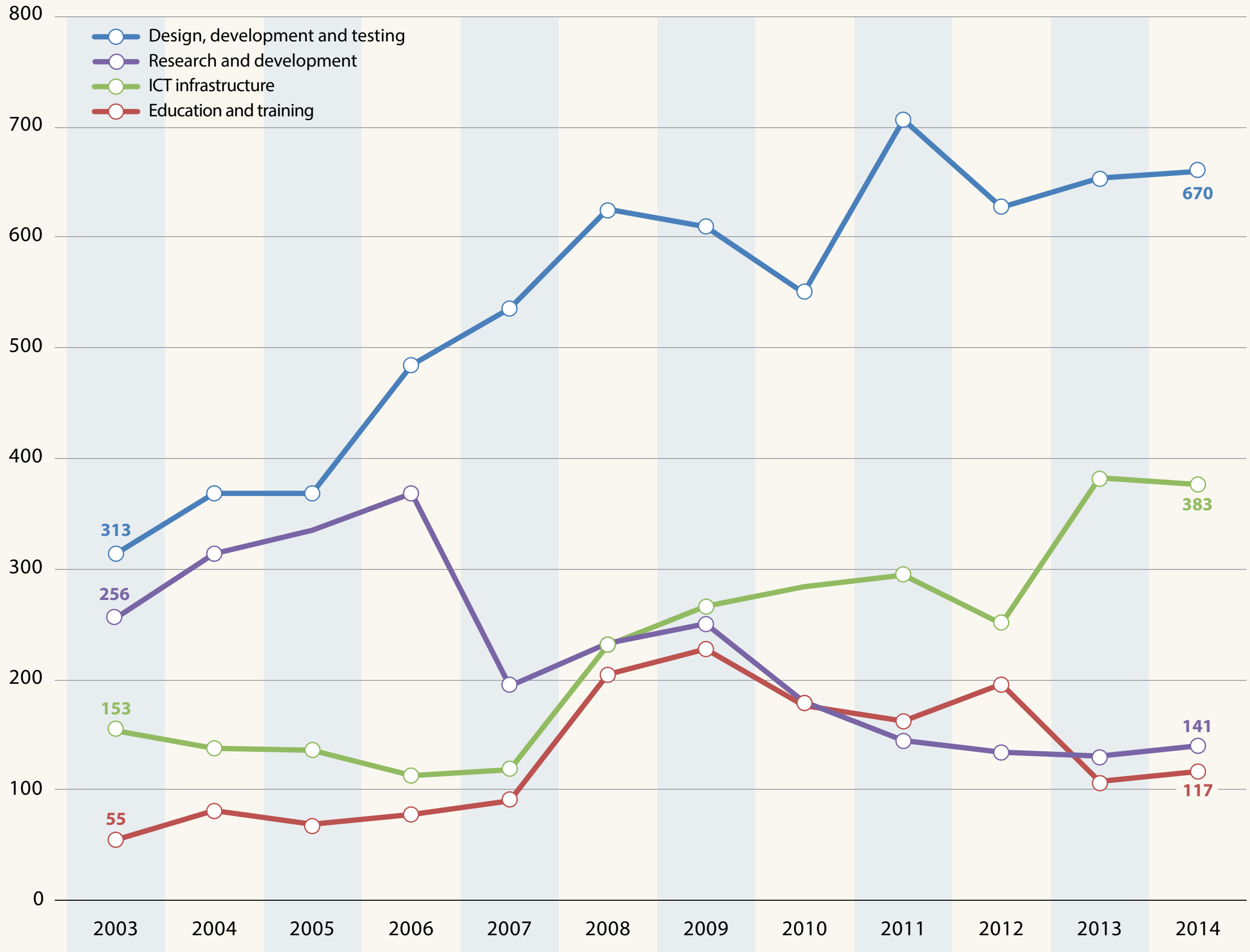
Source: (text and Figure 2.4): Executive Summary from: Joint Research Centre Institute for Prospective Technological Studies (2014) *The 2014 EU Survey on Industrial R&D Investment Trends.* See: http://iri.jrc.ec.europa.eu/survey14.html

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 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	

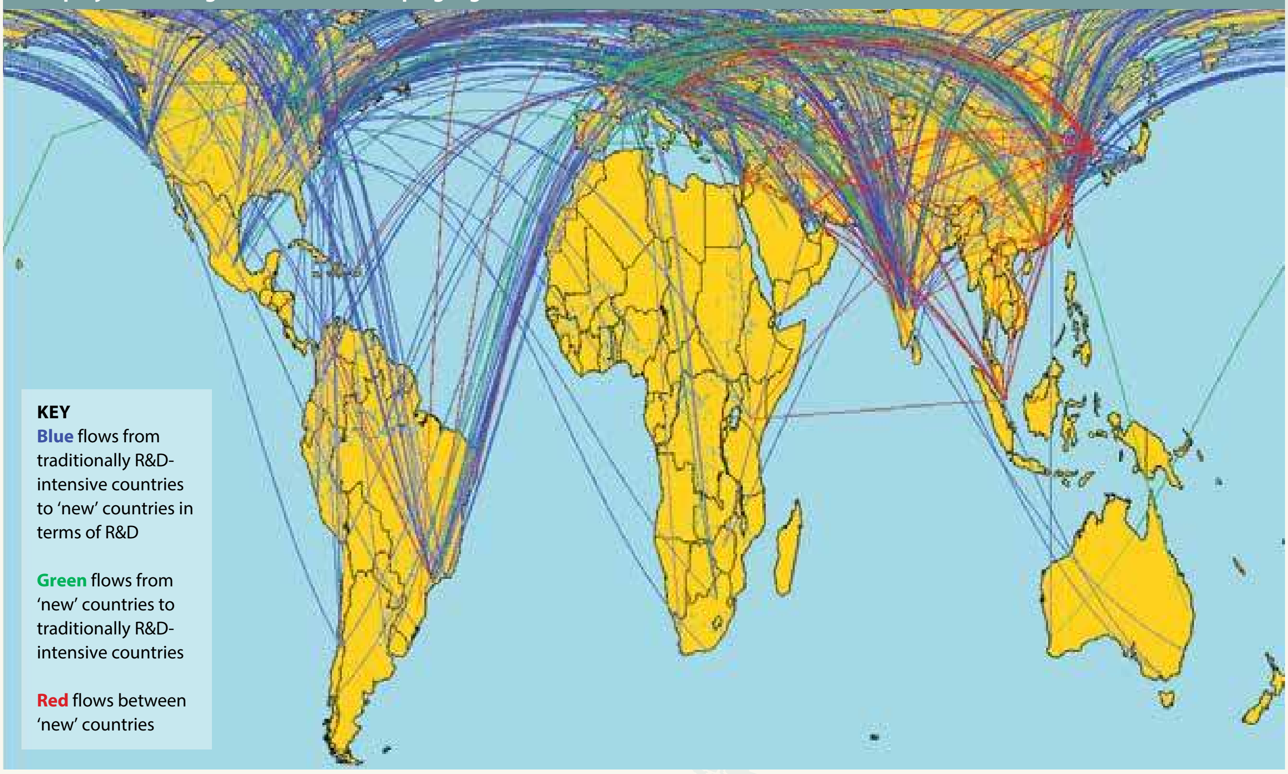
4.3%

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	

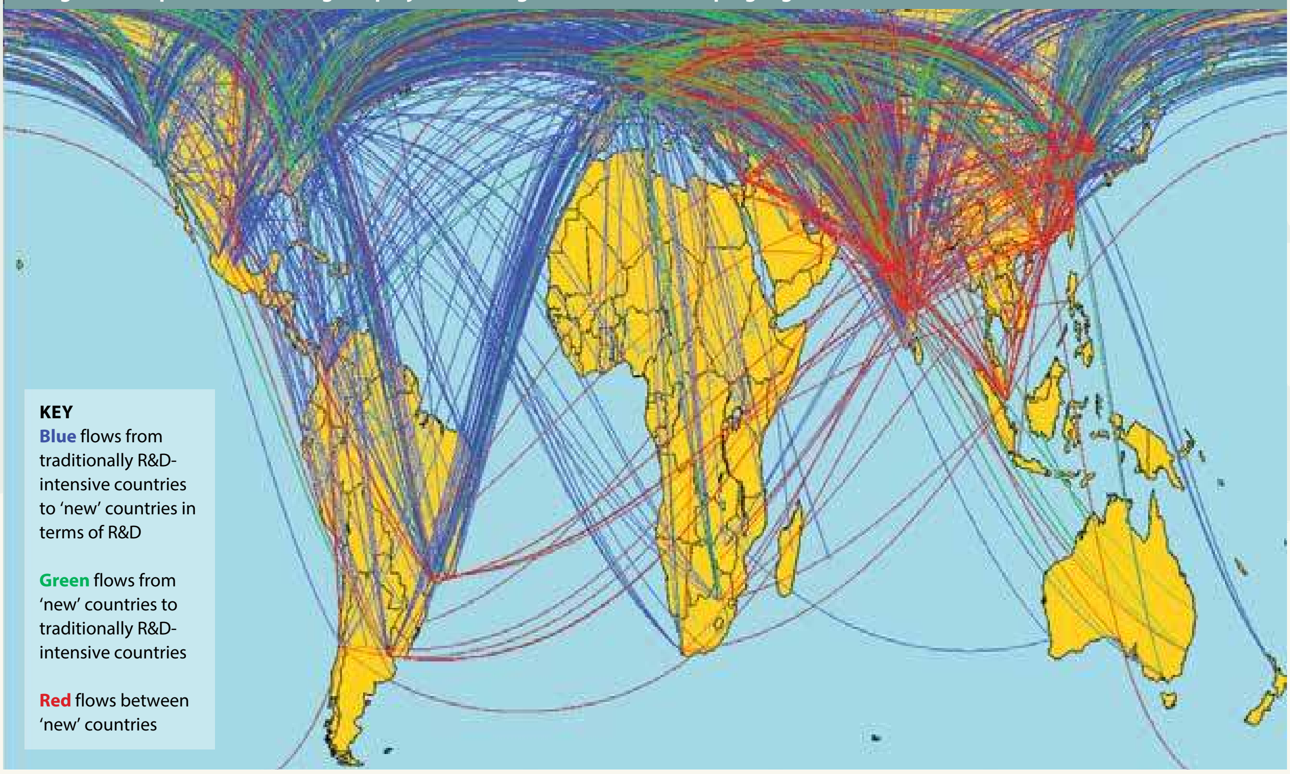
1.1%

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 projects in education	Destination of FDI projects 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
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	

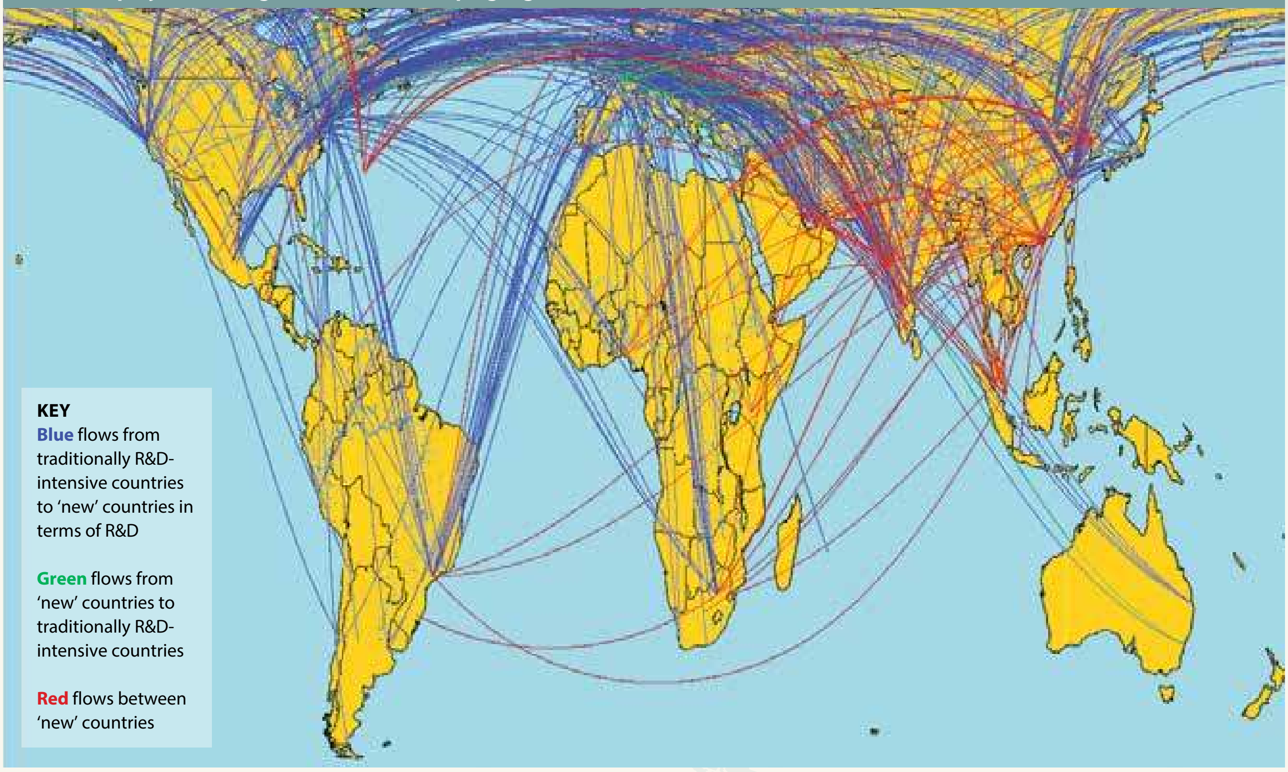
5.9%

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



KEY
Blue flows from traditionally R&D-intensive countries to 'new' countries in terms of R&D

Green flows from 'new' countries to traditionally R&D-intensive countries

Red flows between 'new' countries

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 projects in design, development and testing										
	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	

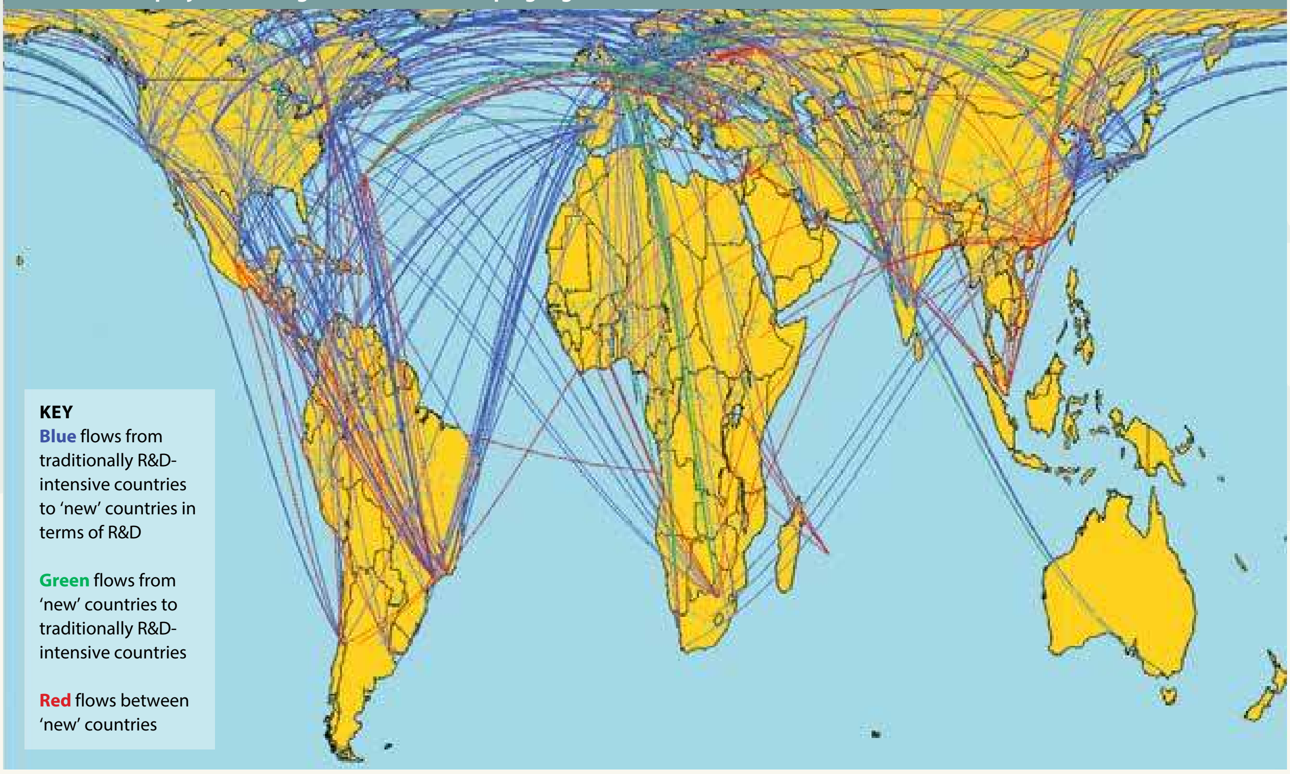
7.2%

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.

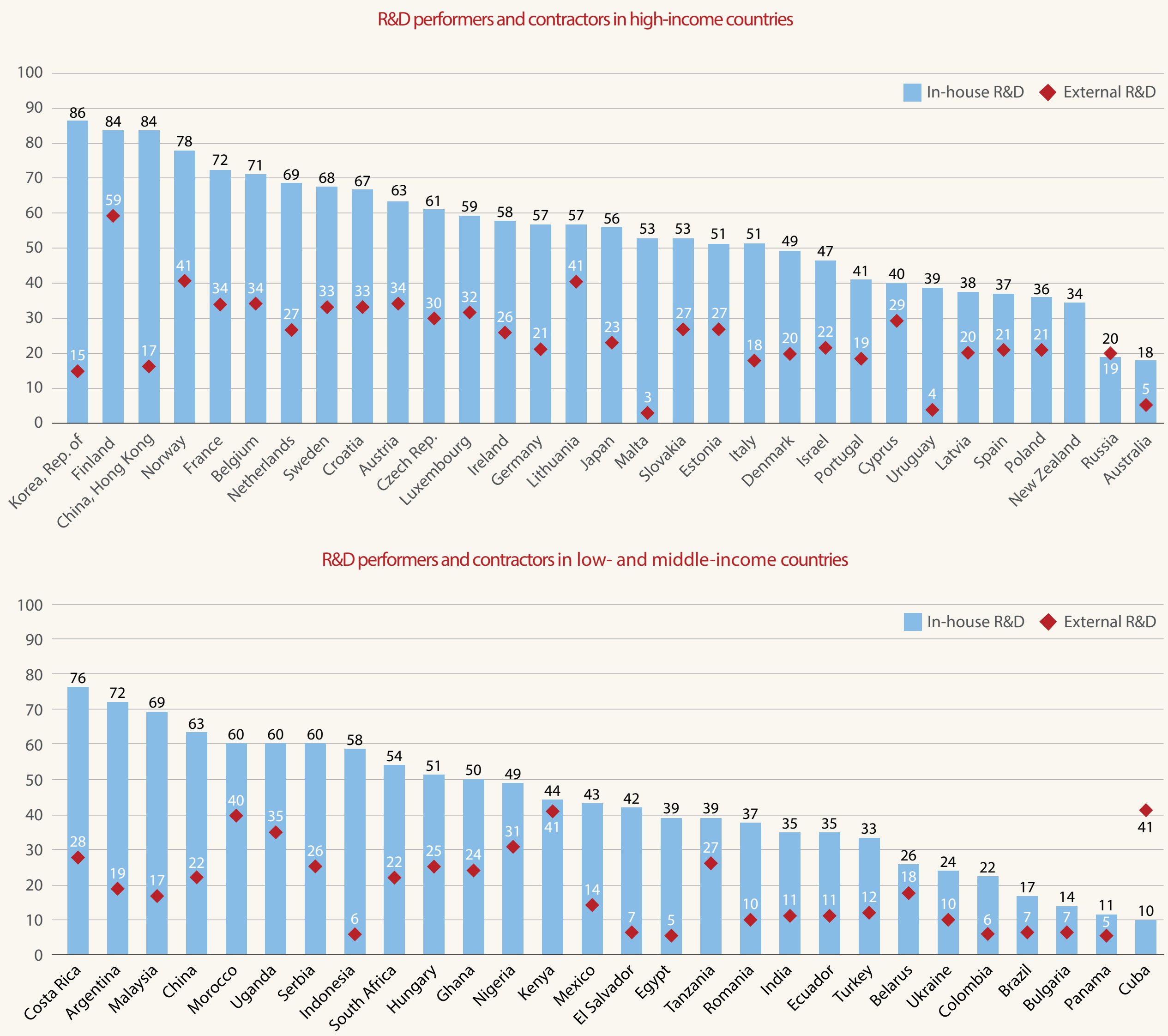
In the EU's Community Innovation Survey, which is followed by many countries worldwide, the harmonized questionnaire asks about engagement in in-house and outsourced (or external) R&D but also other activities related to innovation, such as the acquisition of machinery, equipment and software and the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

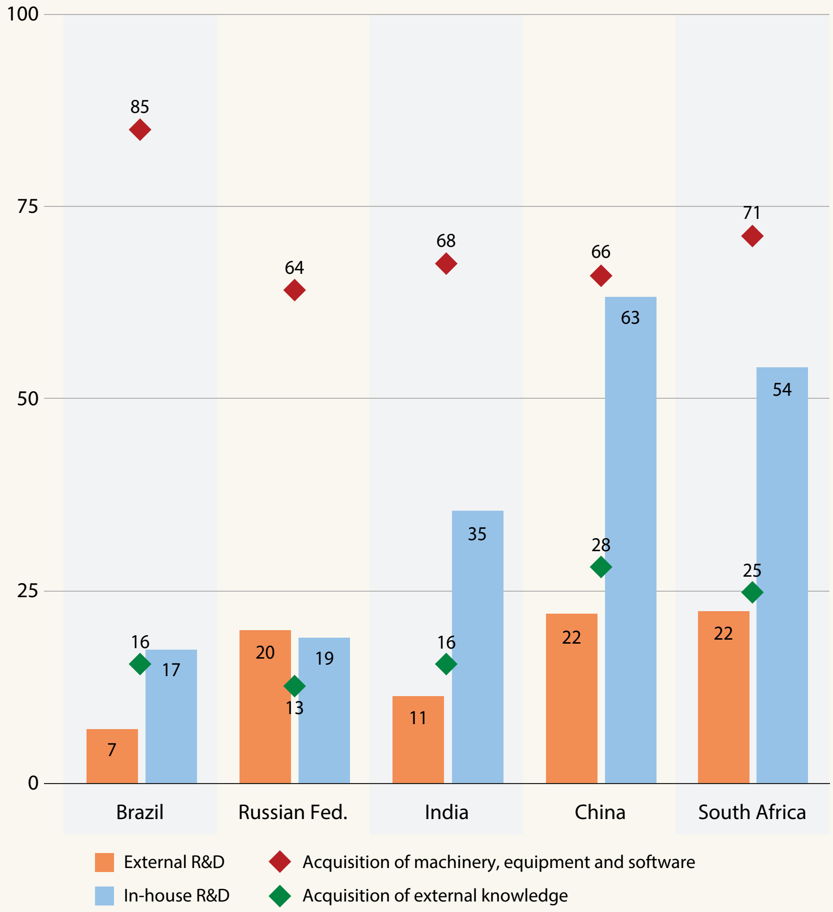
Among BRICS countries, China is the country with the highest share of firms engaging in the acquisition of external knowledge. In China, about 30% of firms engaged in innovation purchase existing know-how and licence patented and non-patented inventions or other types of external knowledge.

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 Russia 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**

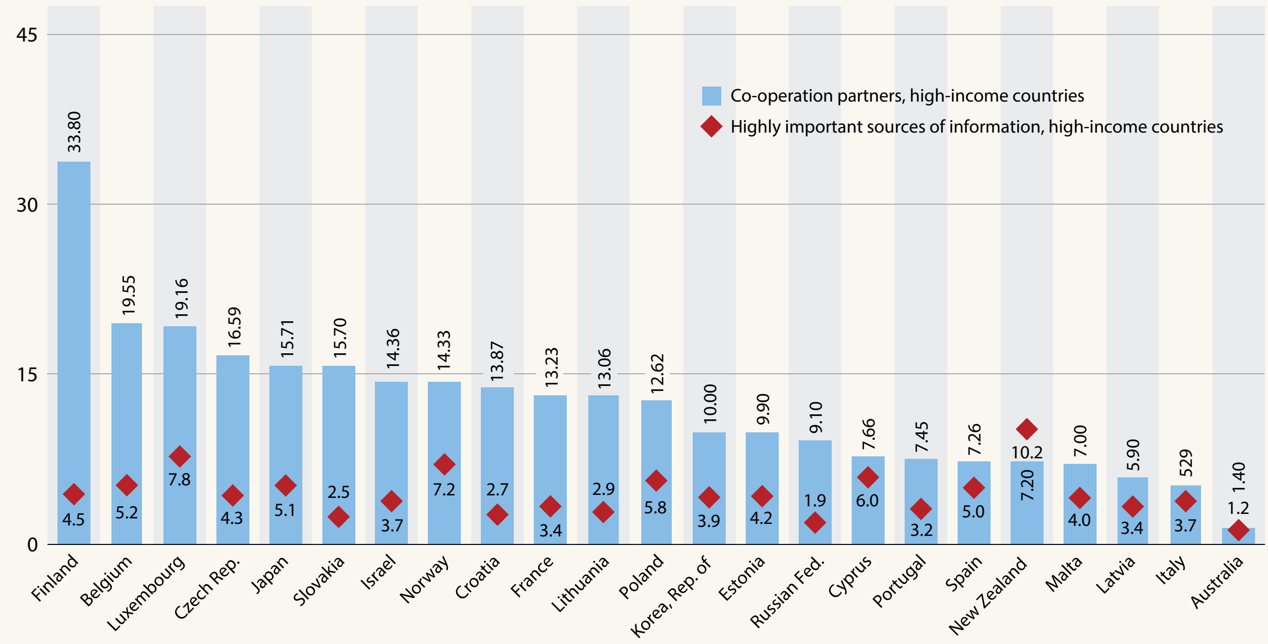
Share of innovation-active manufacturing firms (%)

	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.

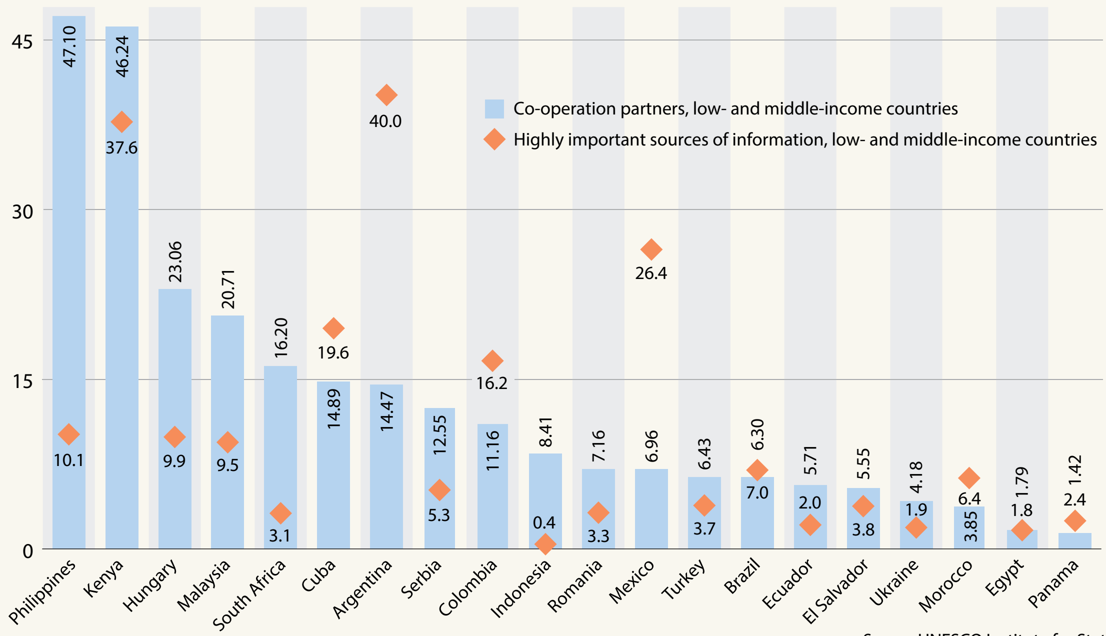
There is a wealth of evidence to support the claim that diaspora knowledge networks can transform the local and international environment for innovation. As far back as the 1960s and 1970s, the Korean and Taiwanese diaspora were persuaded to leave California's Silicon Valley to establish science parks 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

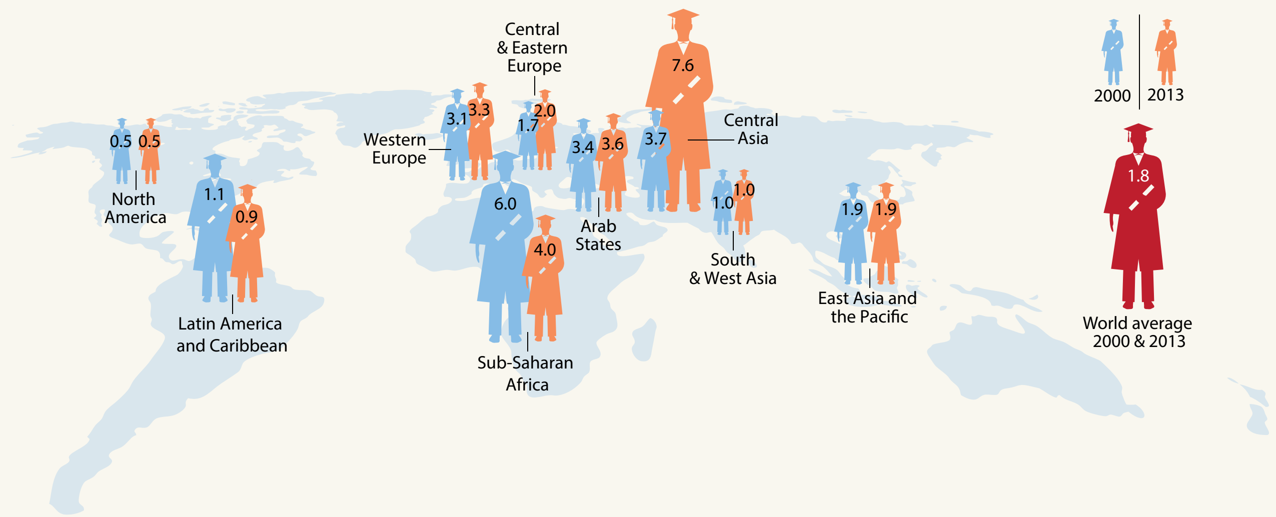
Here, we shall be analysing trends in the cross-border migration of university students and doctorate-holders. Over the past two decades, the number of students pursuing higher education abroad has more than doubled from 1.7 million (1995) to 4.1 million (2013). Students from the Arab States, Central 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 (%)

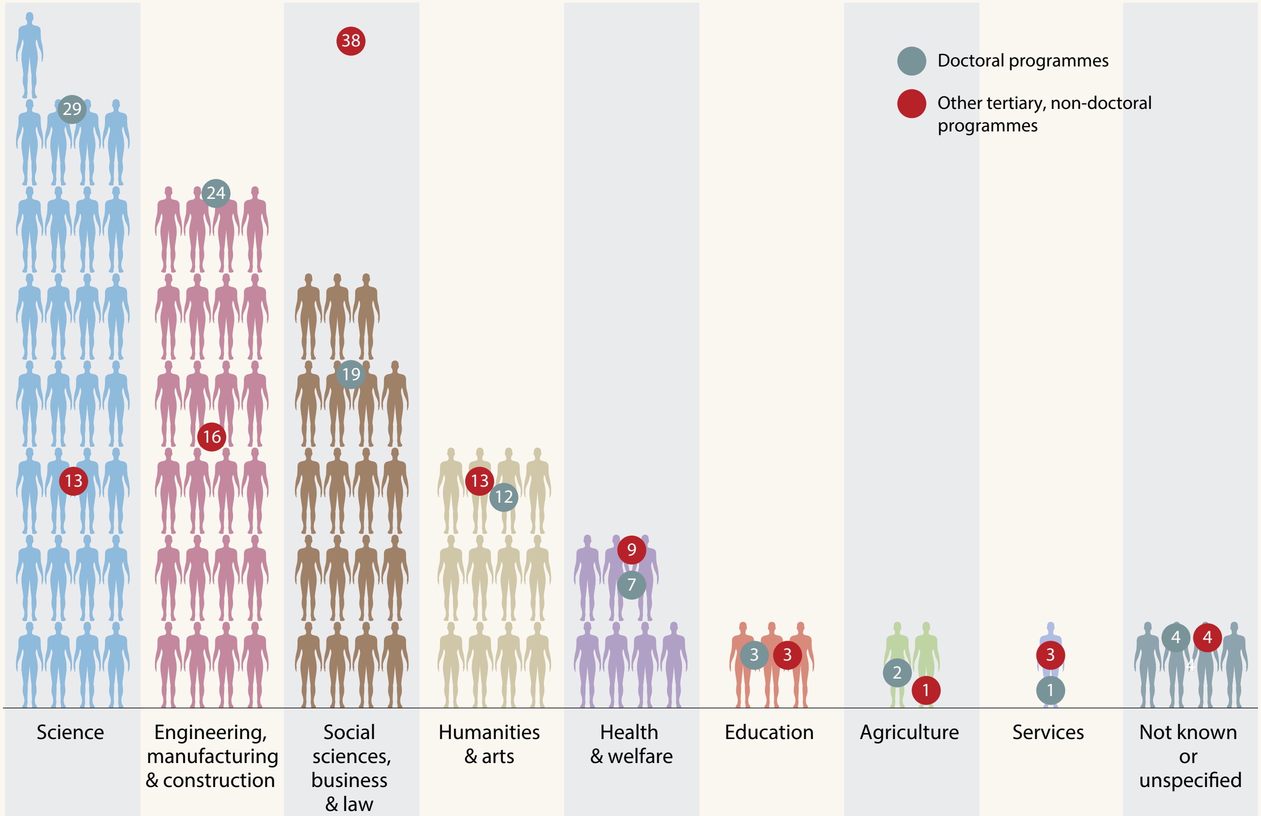


Note: The outbound mobility ratio is the number of students from a given country (or region) enrolled in tertiary programmes abroad, expressed as a percentage of total tertiary enrolment in that country (or region).

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).

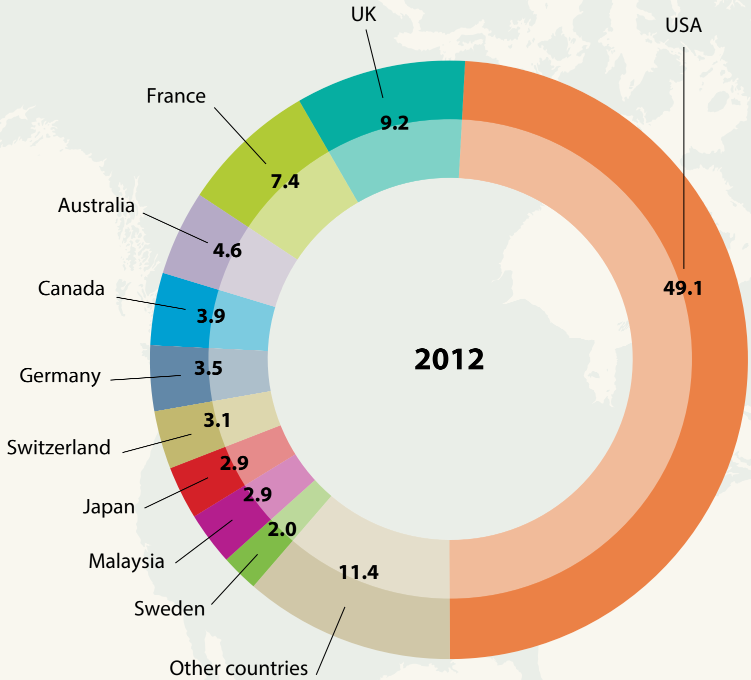
There is a marked variation in the inbound mobility rate of doctoral students: three in ten students in the USA are from overseas, compared to more than four in ten in the UK and France (Figure 2.12). The rate is even higher in Luxembourg, Liechtenstein and Switzerland, where more than half of doctoral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

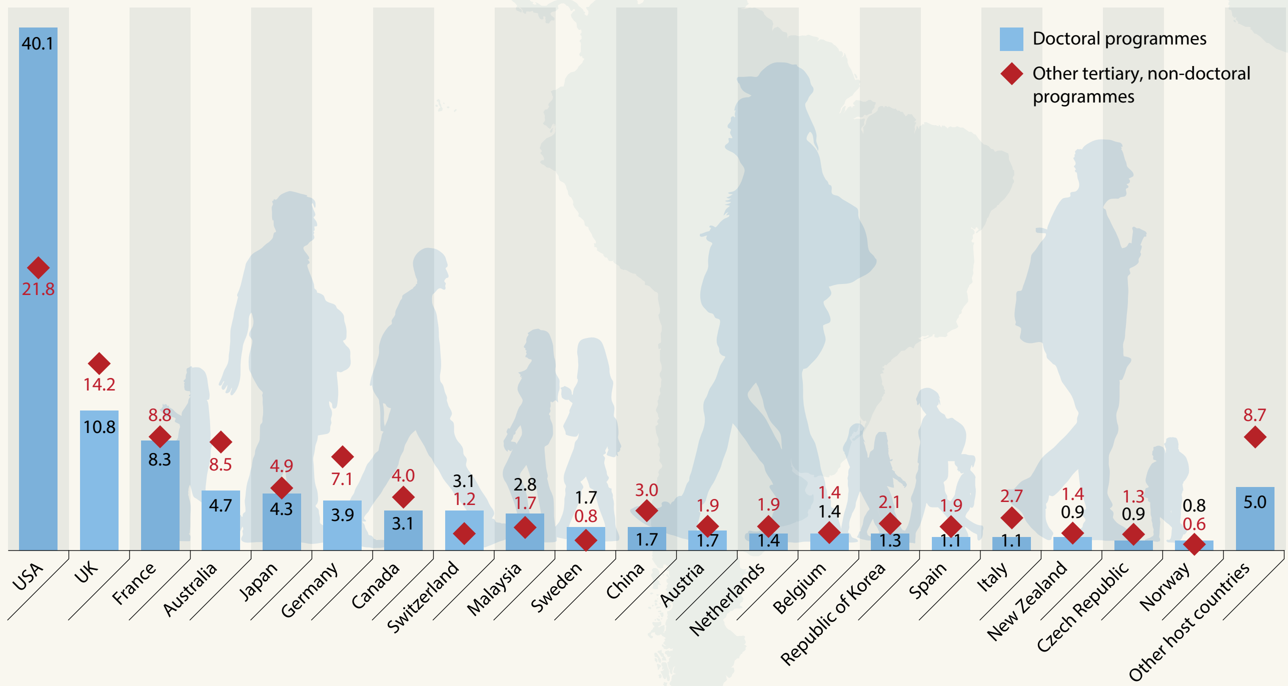
Share of international doctoral students enrolled in science and engineering programmes in the UK

7.4%

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

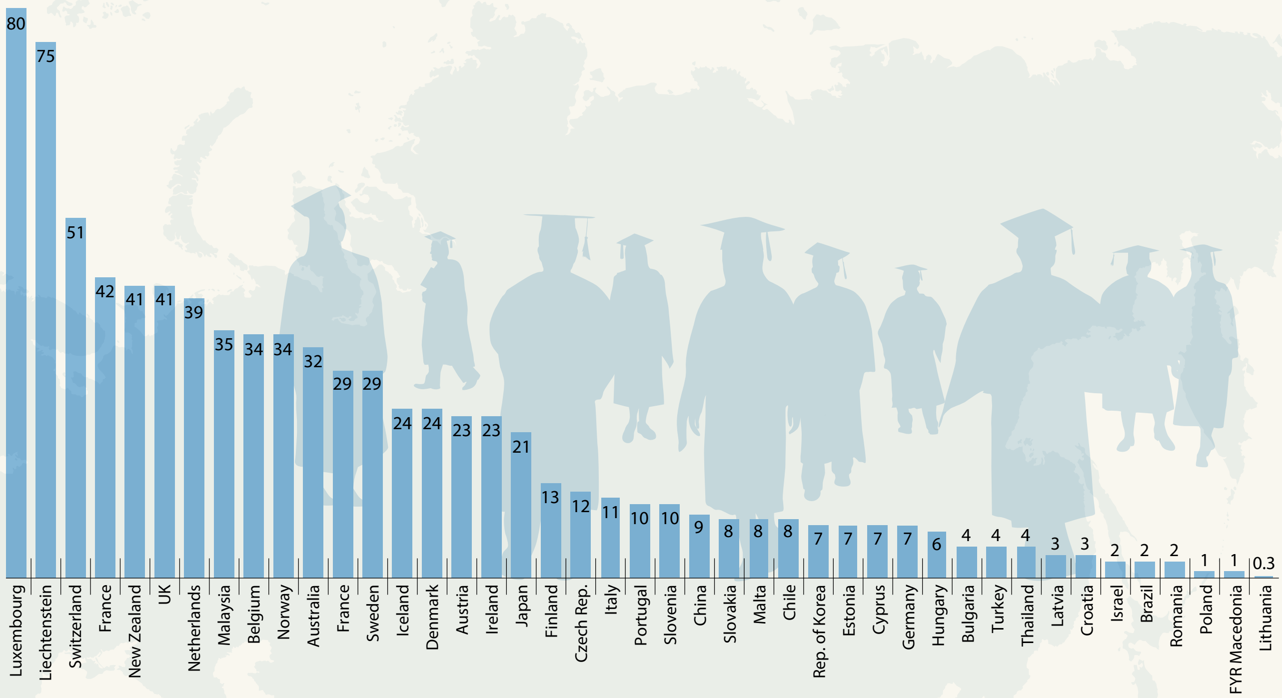
The USA hosts four out of ten international doctoral students

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

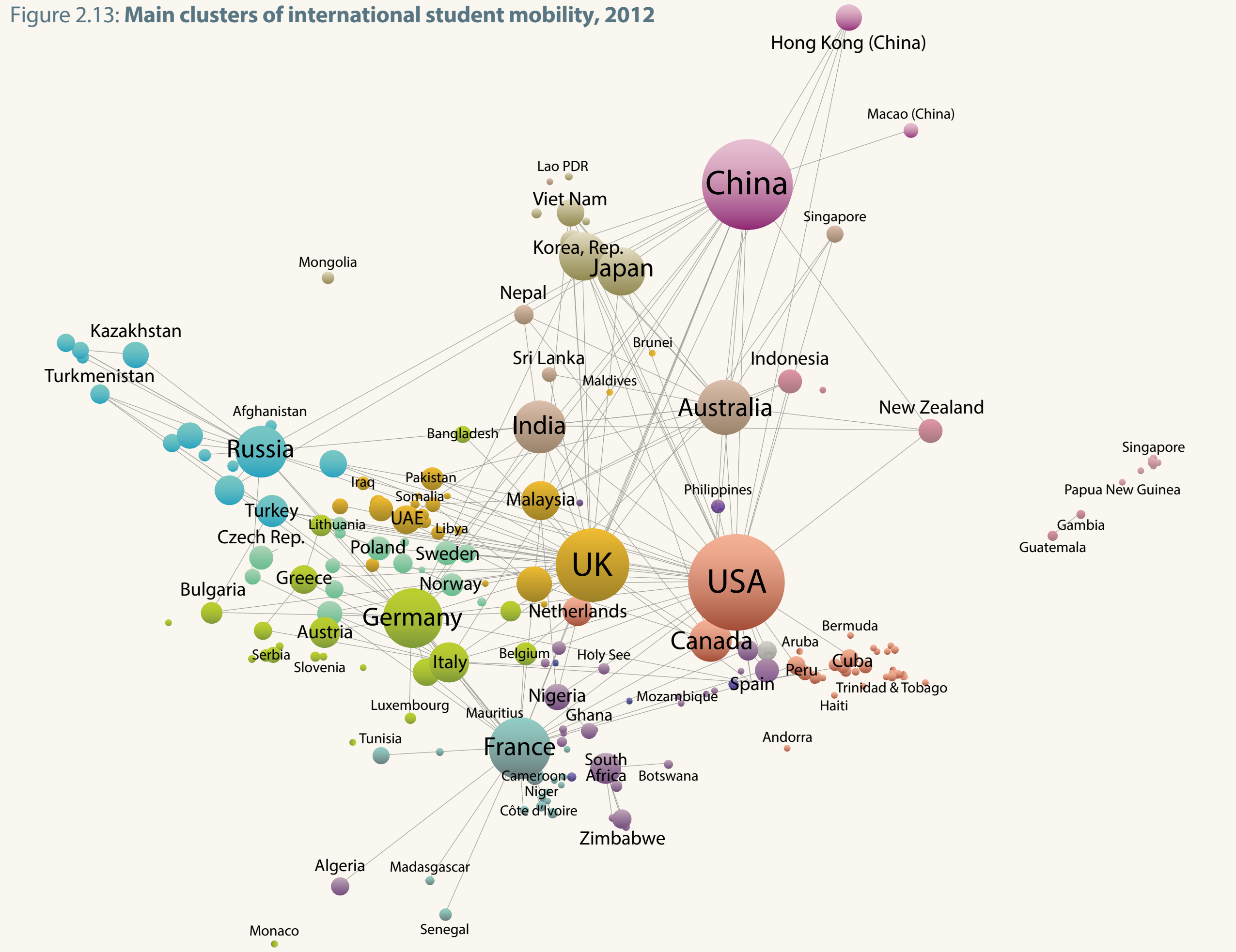
* The number of students from a given country enrolled in doctoral programmes abroad, expressed as a percentage of total doctoral enrolment in that country

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

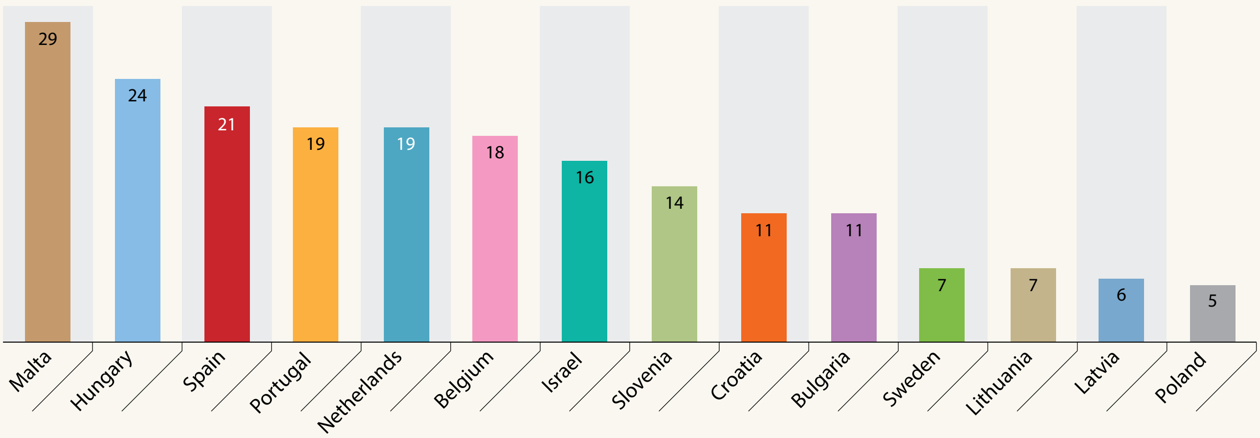
The careers of doctorate-holders survey reveals that, on average, between 5% and 29% of citizens with a doctorate have gained research experience abroad for three months or longer in the past 10 years (Figure 2.14). In Hungary, Malta and Spain, the proportion is over 20%, whereas in Latvia, Lithuania,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

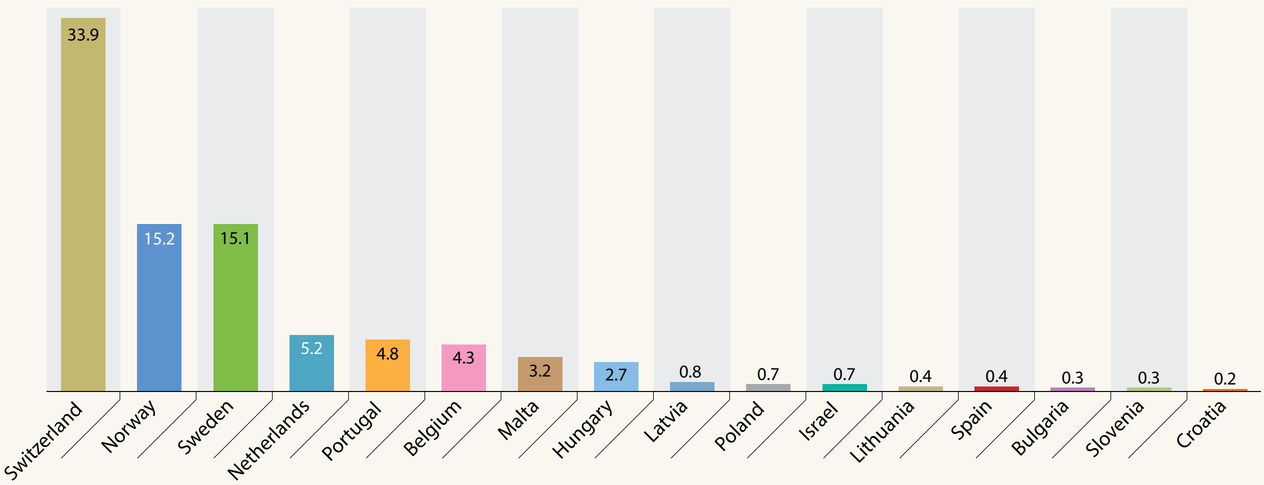
Figure 2.14: **Percentage of national citizens with a doctorate who lived abroad in the past ten years, 2009**



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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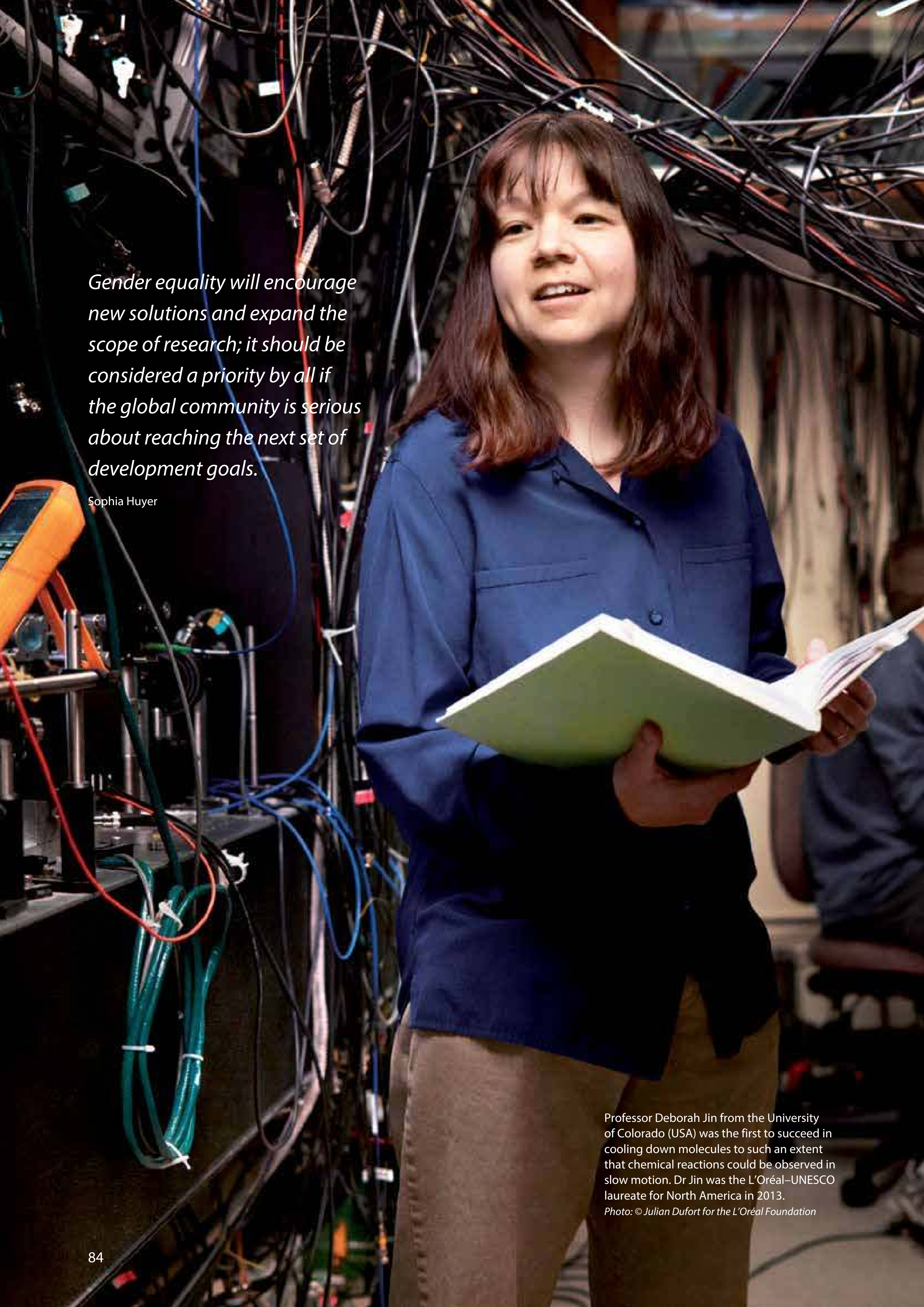


Gender equality will encourage new solutions and expand the scope of research; it should be considered a priority by all if the global community is serious about reaching the next set of development goals.

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

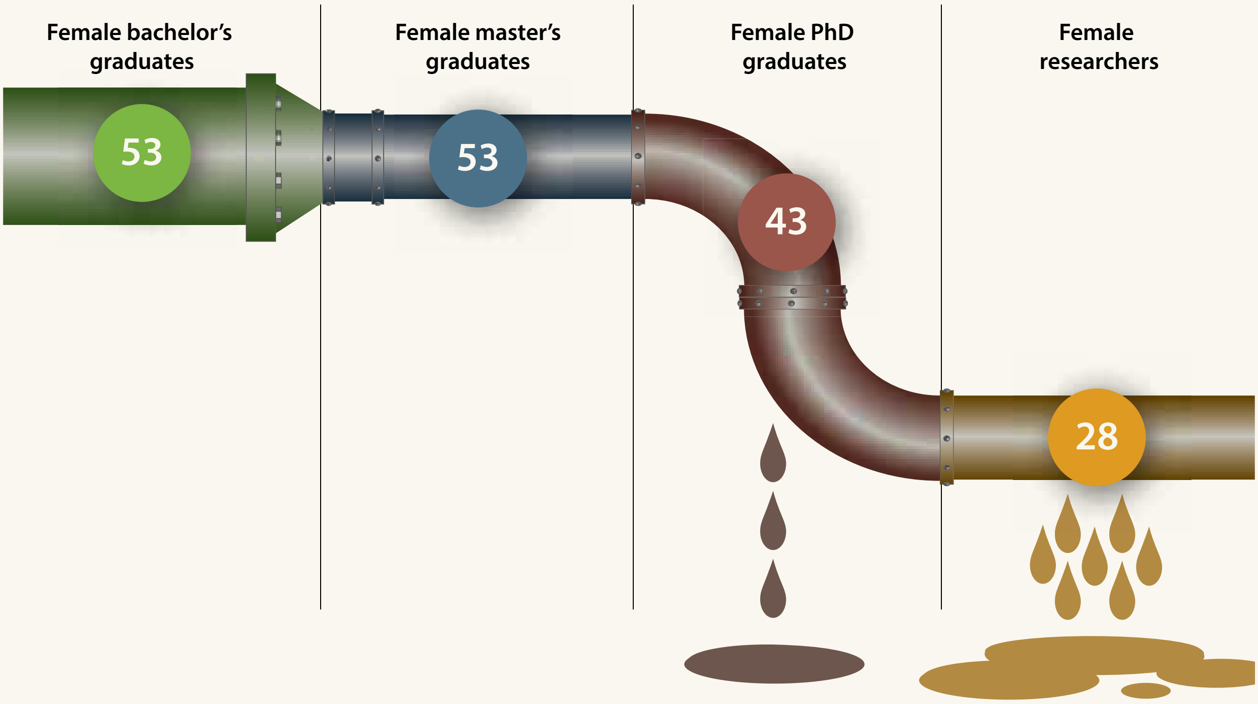
When it comes to women's participation in research overall, globally, we are seeing a leaky pipeline. Women are actively pursuing bachelor's and master's degrees and even outnumber men at these levels, since they represent 53% of graduates, but their numbers drop off abruptly at PhD level. Suddenly, 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).

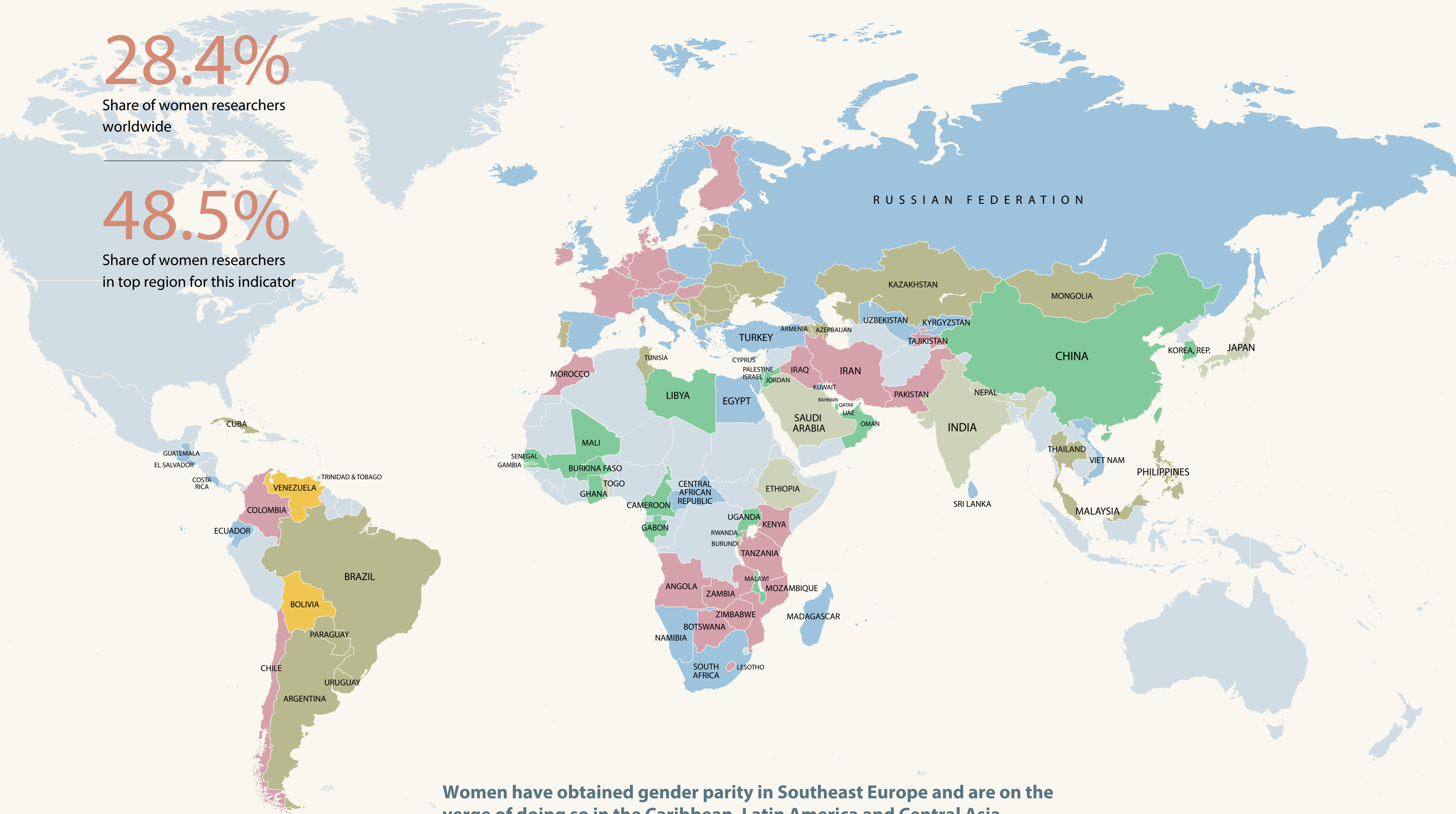
Although data for most countries are limited, we know that women made up 14% of university chancellors and vice-chancellors at Brazilian public universities in 2010 (Abreu, 2011) and 17% of those in South Africa in 2011 (Figure 3.3). In Argentina, women make up 16% of directors and vice-directors of 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 16.7). 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
Macedonia, FYR	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

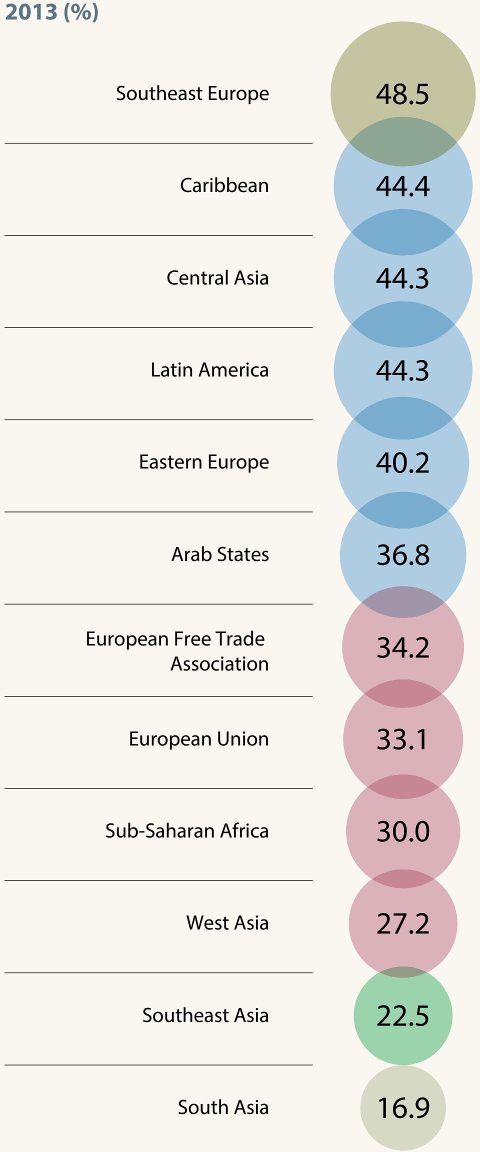
Source: UNESCO Institute for Statistics, August 2015

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



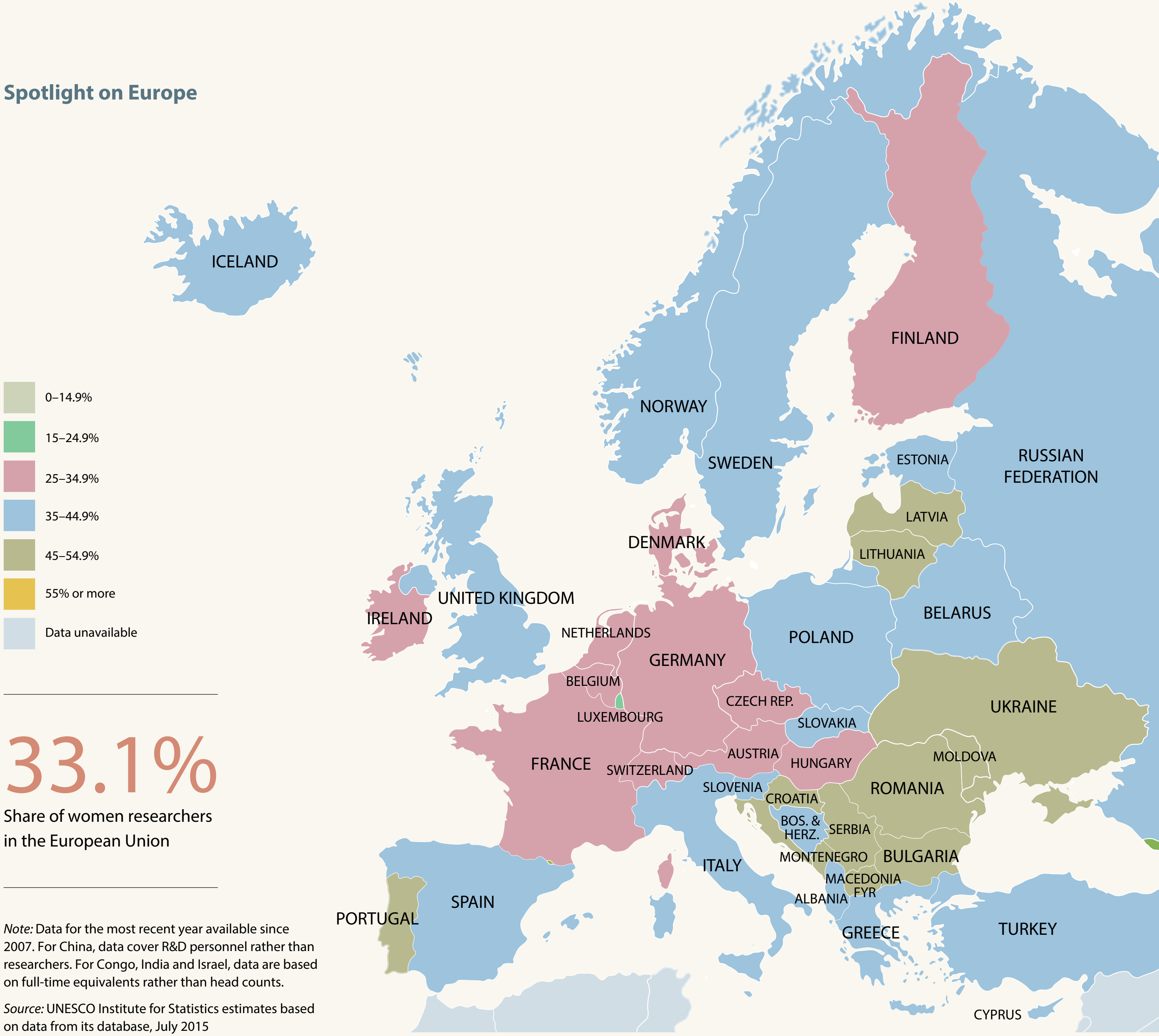
Women have obtained gender parity in Southeast Europe and are on the verge of doing so in the Caribbean, Latin America and Central Asia

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



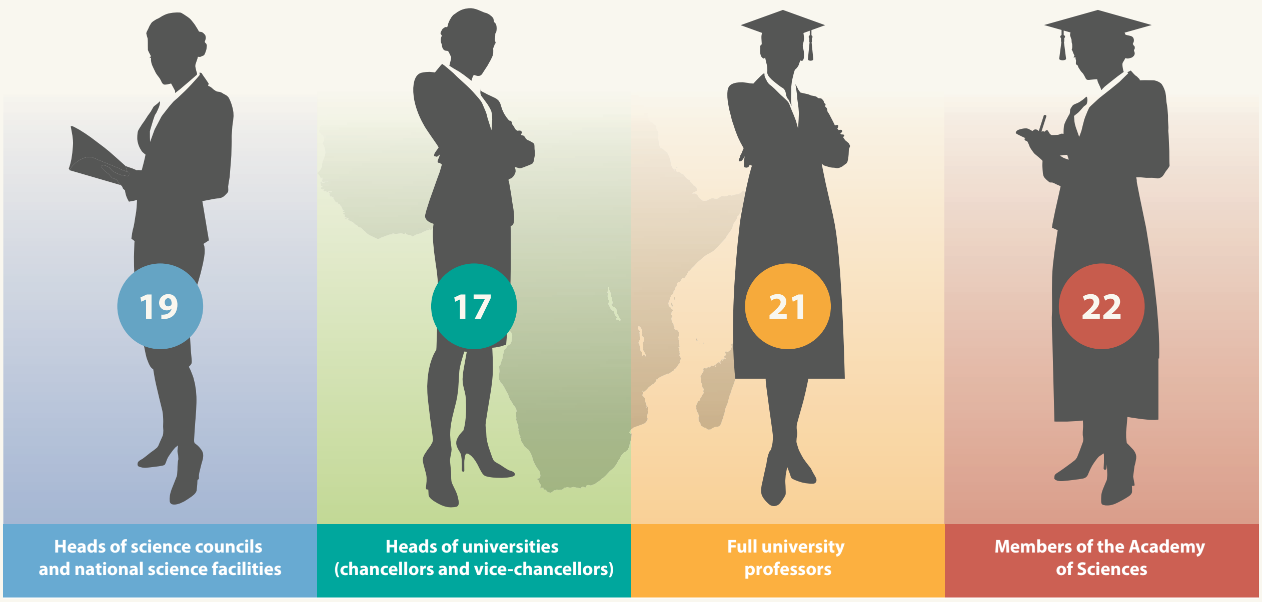
33.1%

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
Macedonia, FYR	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, Brunei Darussalam 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.

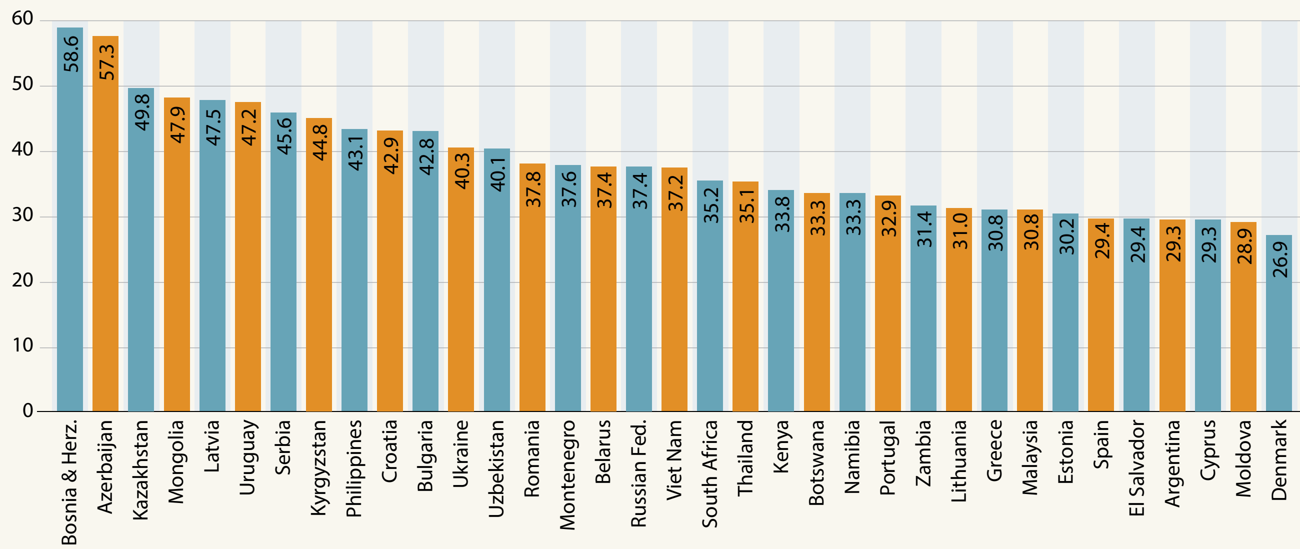
Female researchers in the region are primarily employed in government research institutes, with some countries also seeing a high participation of women in private non-profit organizations and universities. With the exception of Sudan (40%) and Palestine (35%), fewer than one in four researchers in the 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 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 over 70% 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

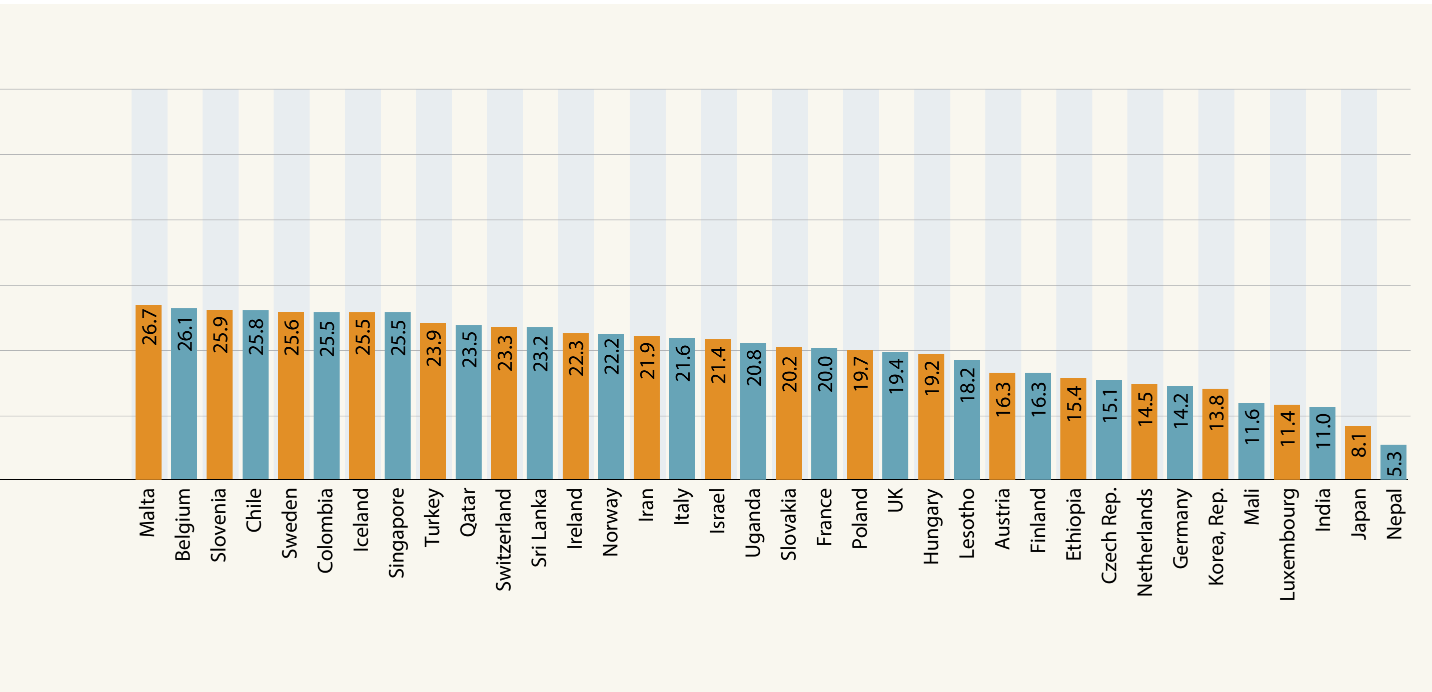
Just under one in three (30%) researchers in sub-Saharan Africa is a woman. Much of sub-Saharan Africa is seeing solid gains in the share of women among tertiary graduates in scientific fields. In two of the top four countries for women's representation in science, women graduates are part of very small 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

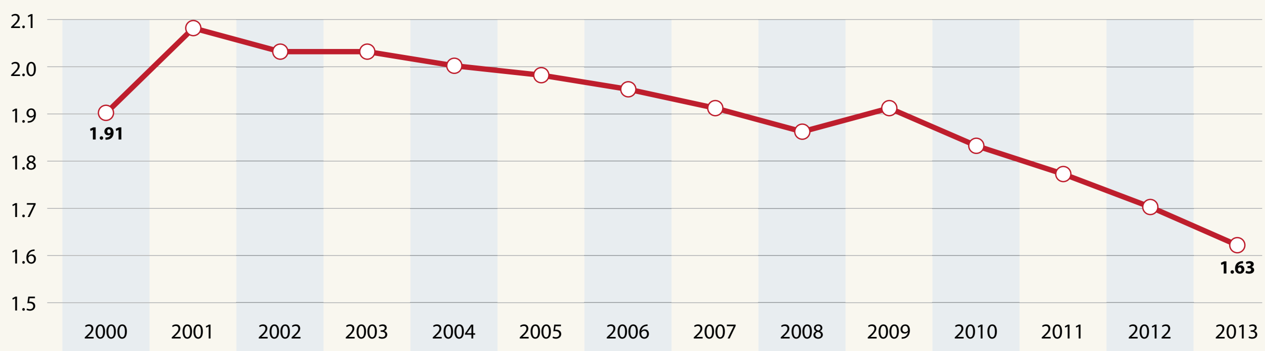
The government's incremental approach to policy-making over the past decade has translated into a lack of bold moves to stimulate funding for science and innovation. The organizational ecology of science and technology (S&T) has undergone some change, with a growing focus on economic returns from investment 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

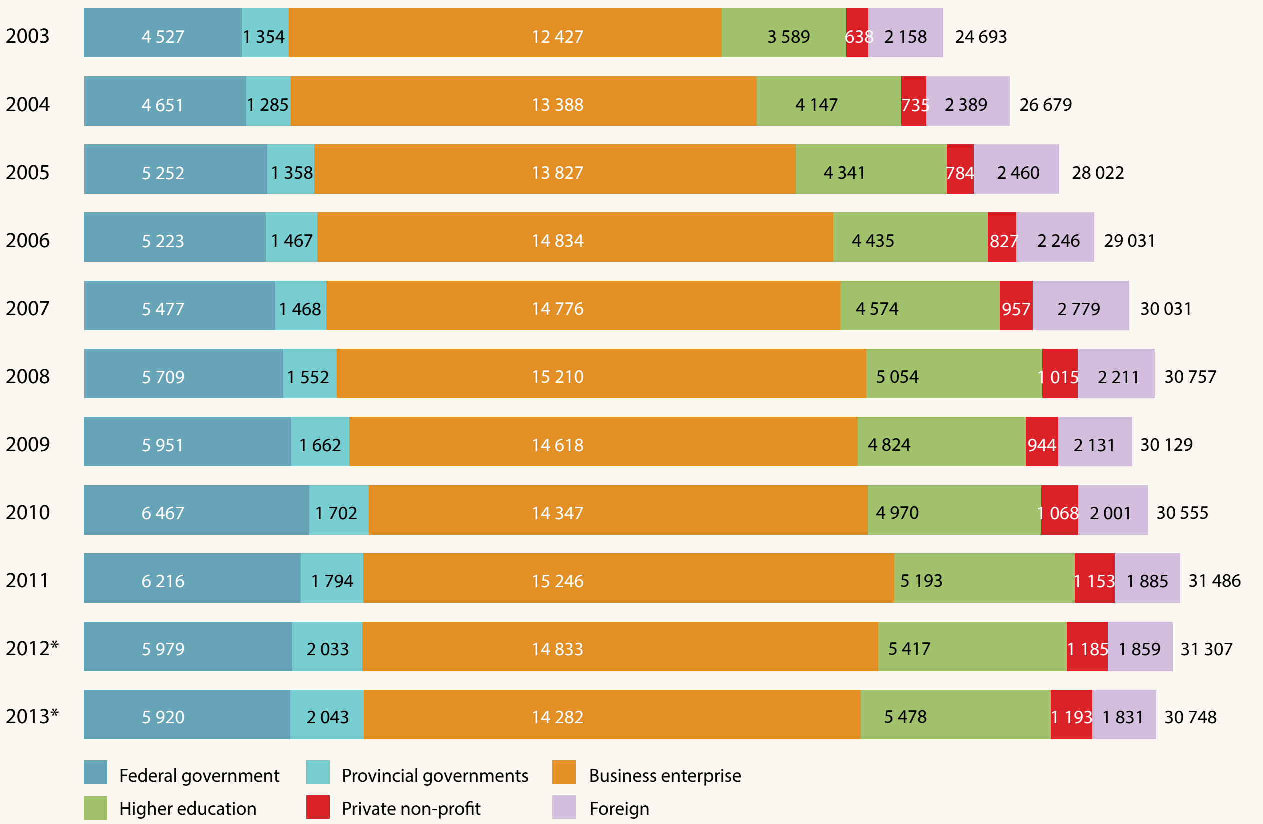
Canada's R&D effort at its lowest level for a decade

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.

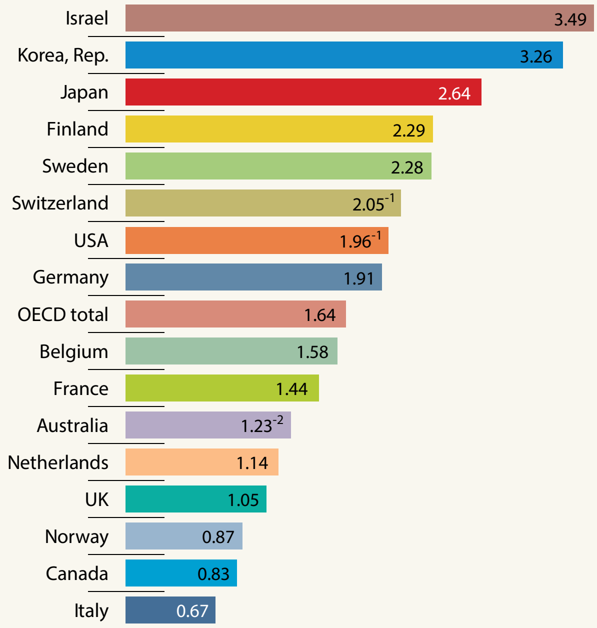
A 6.9% decline in federal funding of R&D is the main contributor to a stagnant year for Canadian R&D in 2014, according to the latest data from Statistics Canada. The agency released a brief report in January 2015 which projected

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 understand reasons, although four key industries display considerable strength (CCA, 2013b):

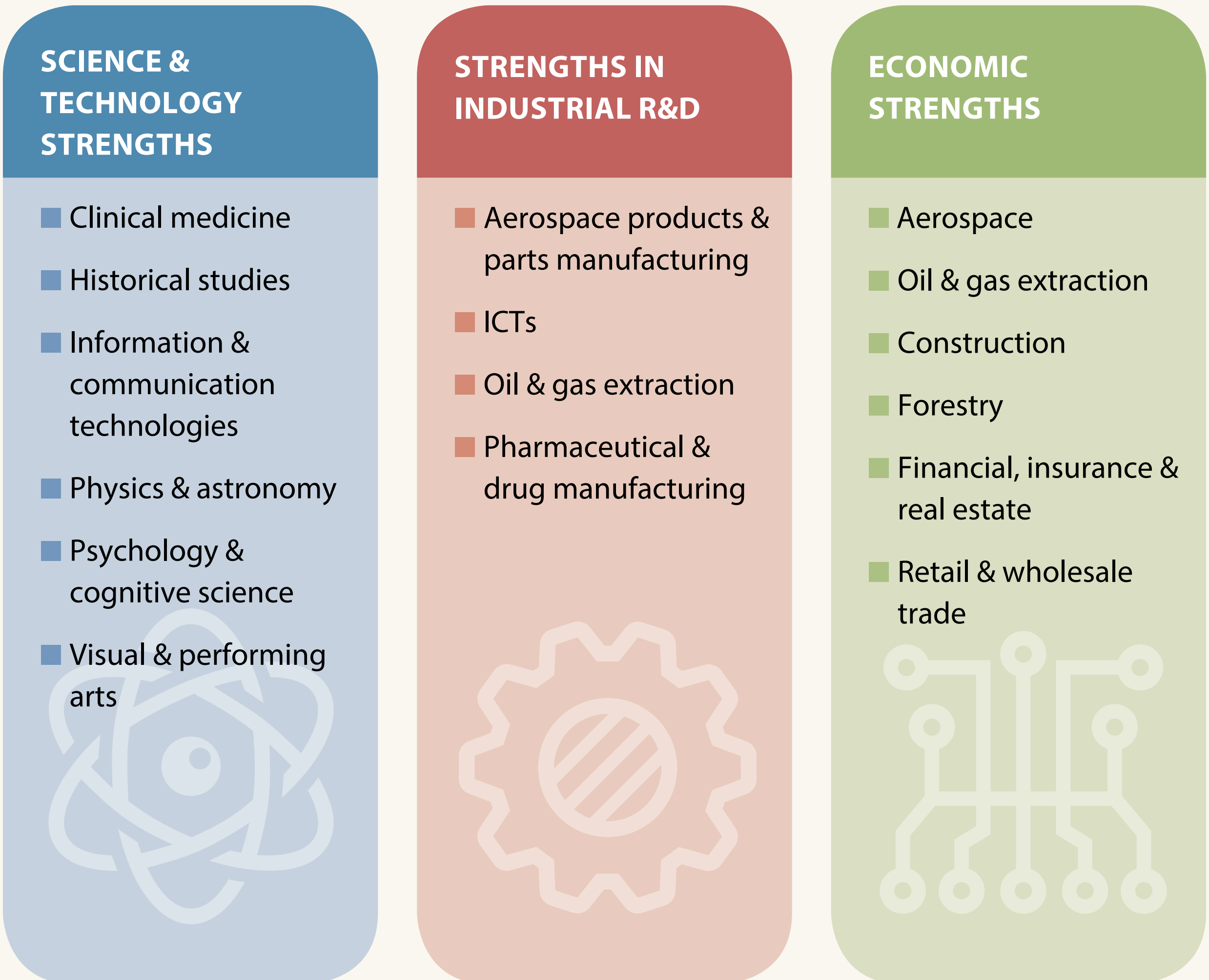
- aerospace products and parts manufacturing;
- information and communication technologies (ICTs);
- oil and gas extraction; and
- pharmaceutical drug manufacturing.

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**



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]

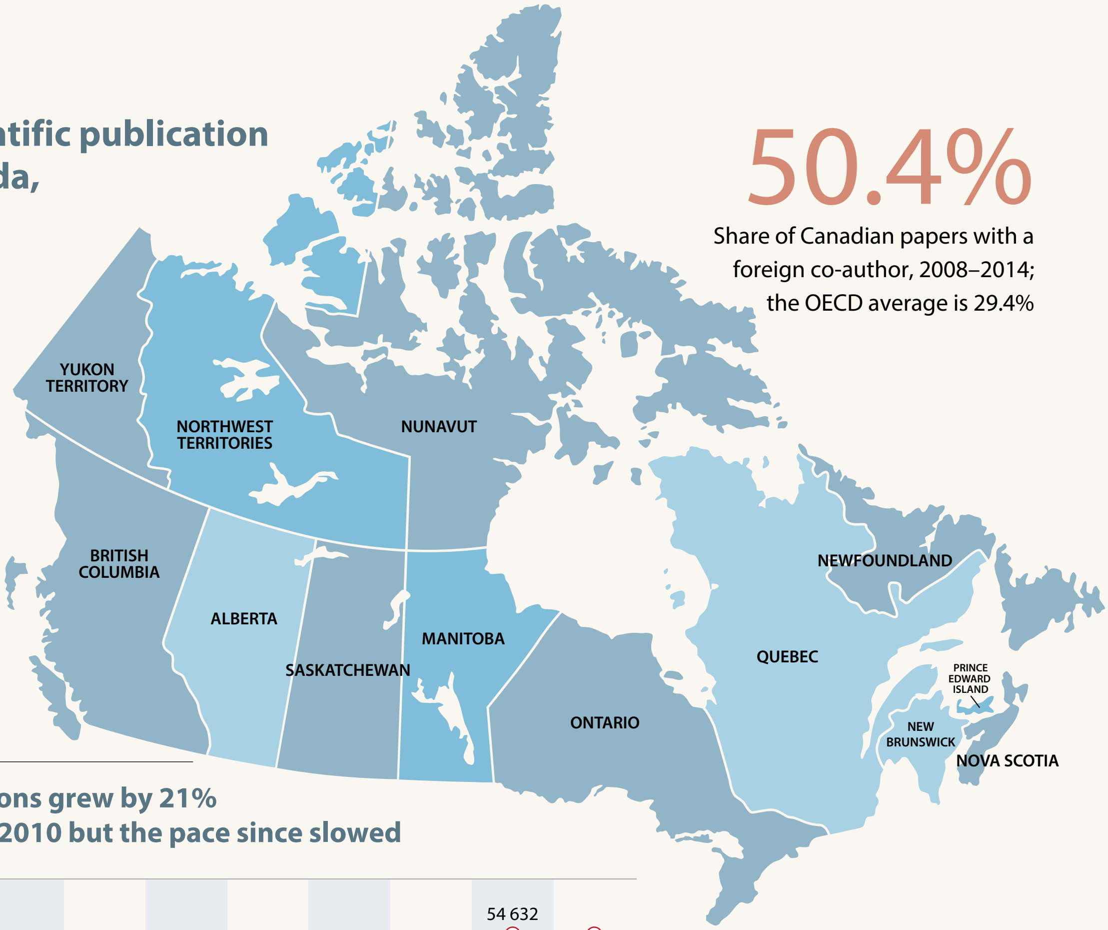
The Canada–Eureka partnership gives Canadian companies greater access to European markets. Eureka is a pan-European intergovernmental initiative designed to support the competitiveness of European companies by fostering market-oriented R&D via international collaboration. The partnership agreement was 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 in India; 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, ISPCanada closed its office in April 2015.

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



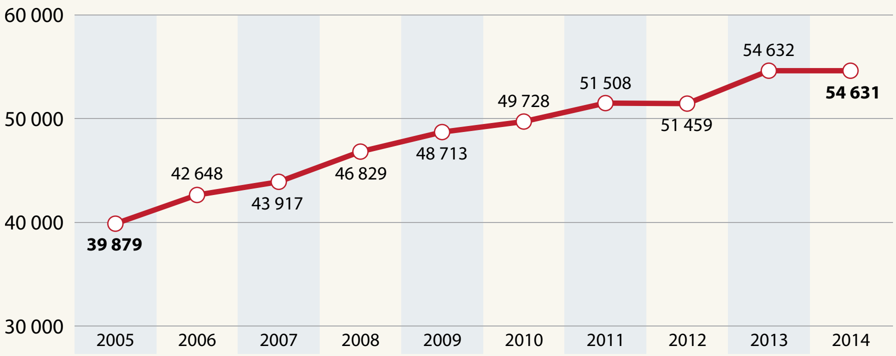
1.25

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

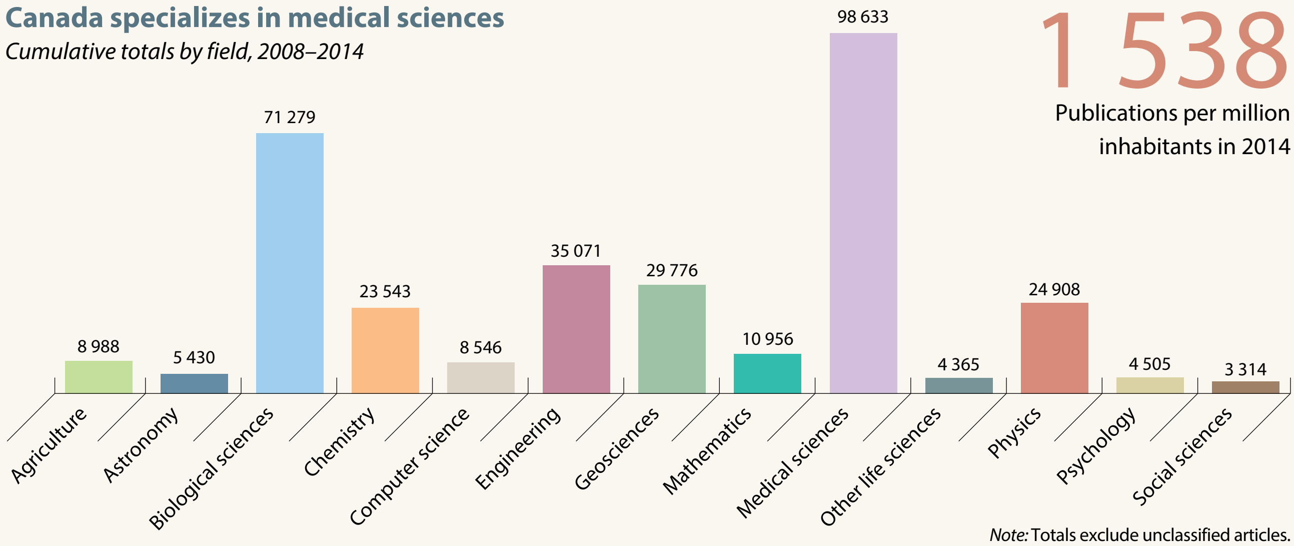


13.1%

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.

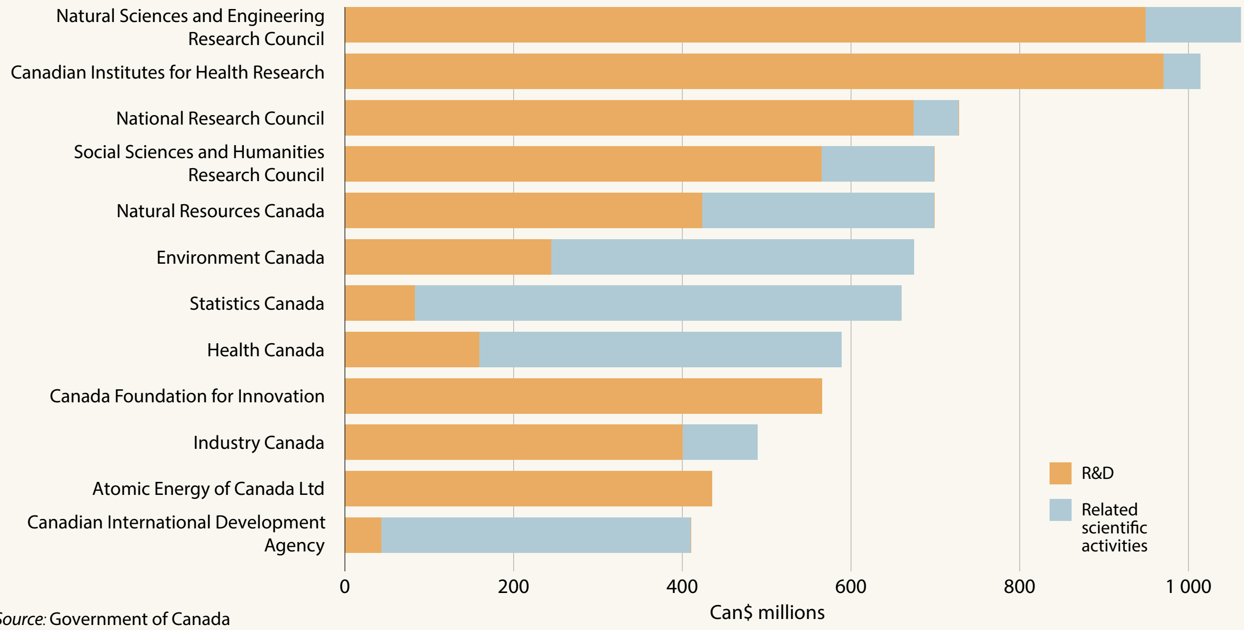
7. Invitations to participate in the online survey of federal scientists were sent to 15 398 PIPSC members – scientists, researchers and engineers – engaged in scientific work in over 40 federal departments and agencies. Of these, 4 069 (26%) responded (PIPSC, 2014).

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

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:

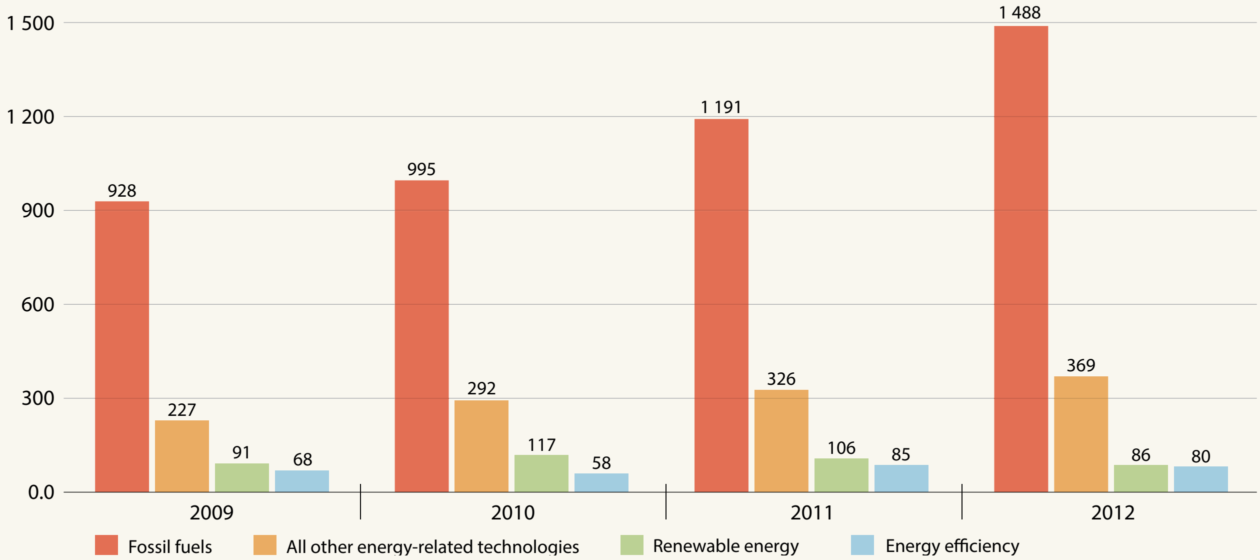
- the Sustainable Development Tech Fund has used CAN$ 684 million allocated by the federal government to support 269 projects that address climate change, air quality, clean water and clean soil;
- the NextGen Biofuels Fund supports the establishment of first-of-a-kind large demonstration-scale facilities 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, 2012). 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.

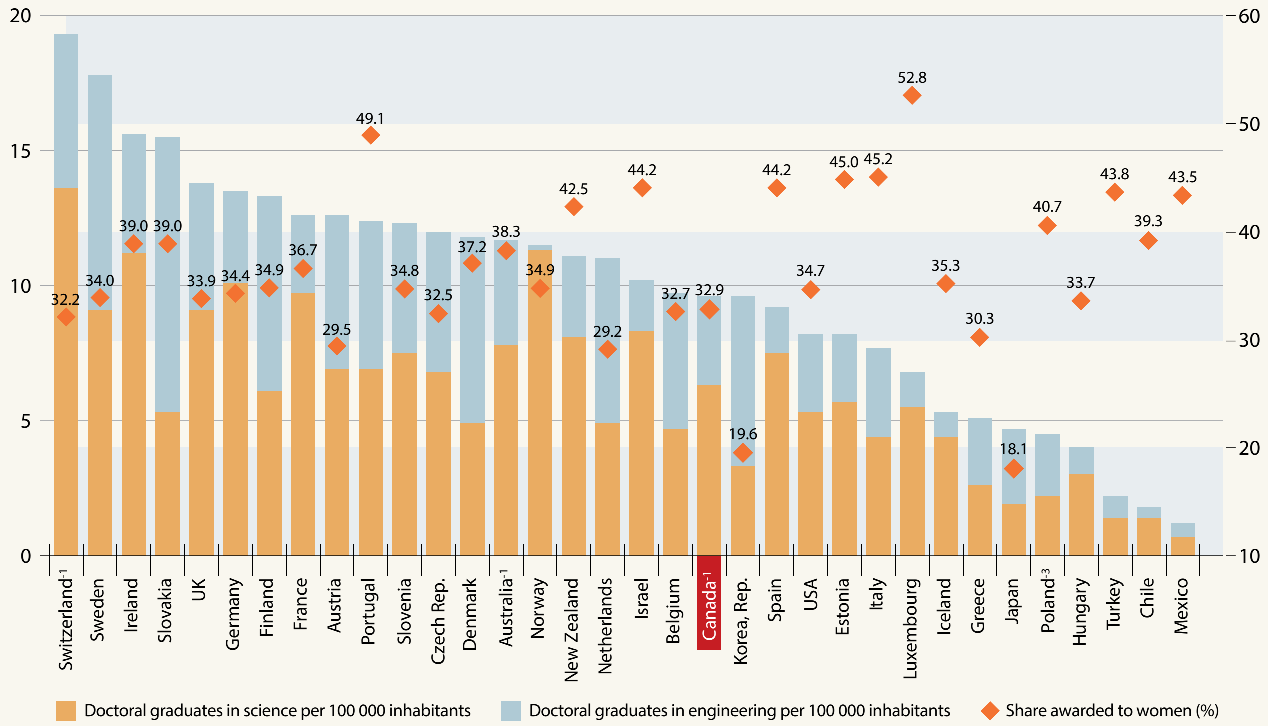
While education remains almost exclusively a provincial matter, responsibility for R&D is undefined constitutionally. As a result, different levels of government intervene with various policy instruments, leading to varying outcomes.

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**

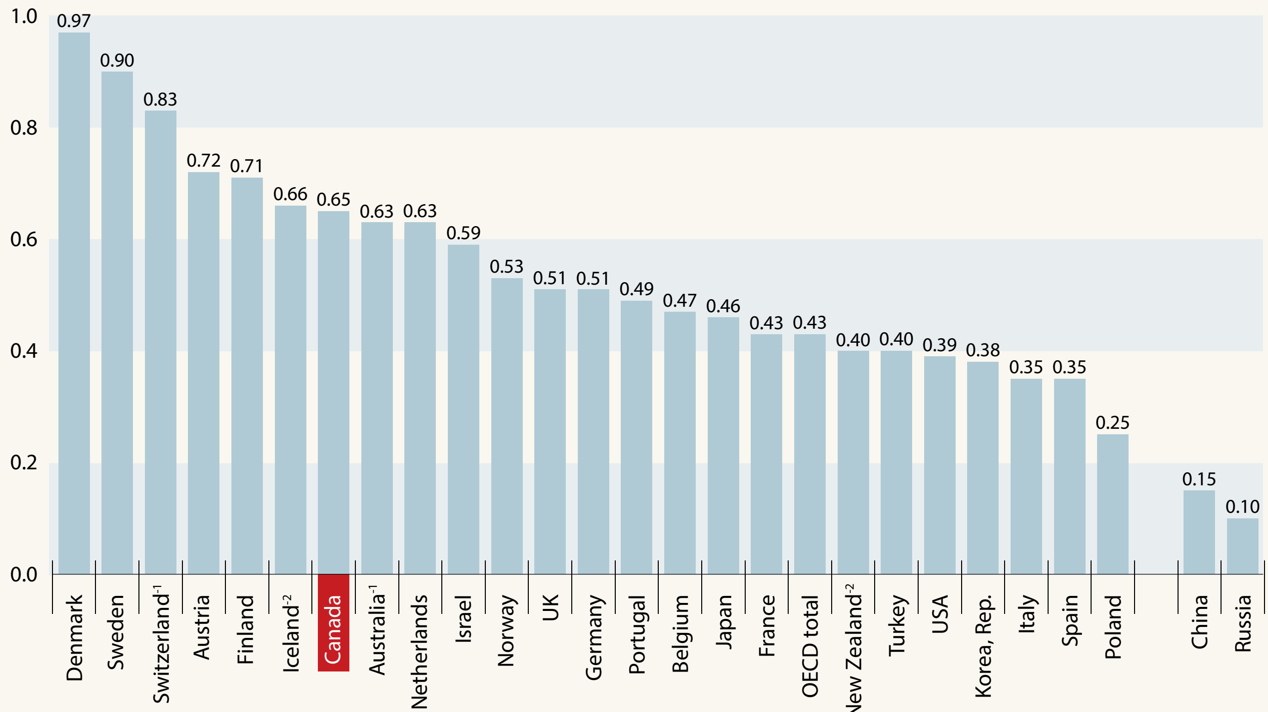


-n = data are for *n* years before reference year

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.

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.

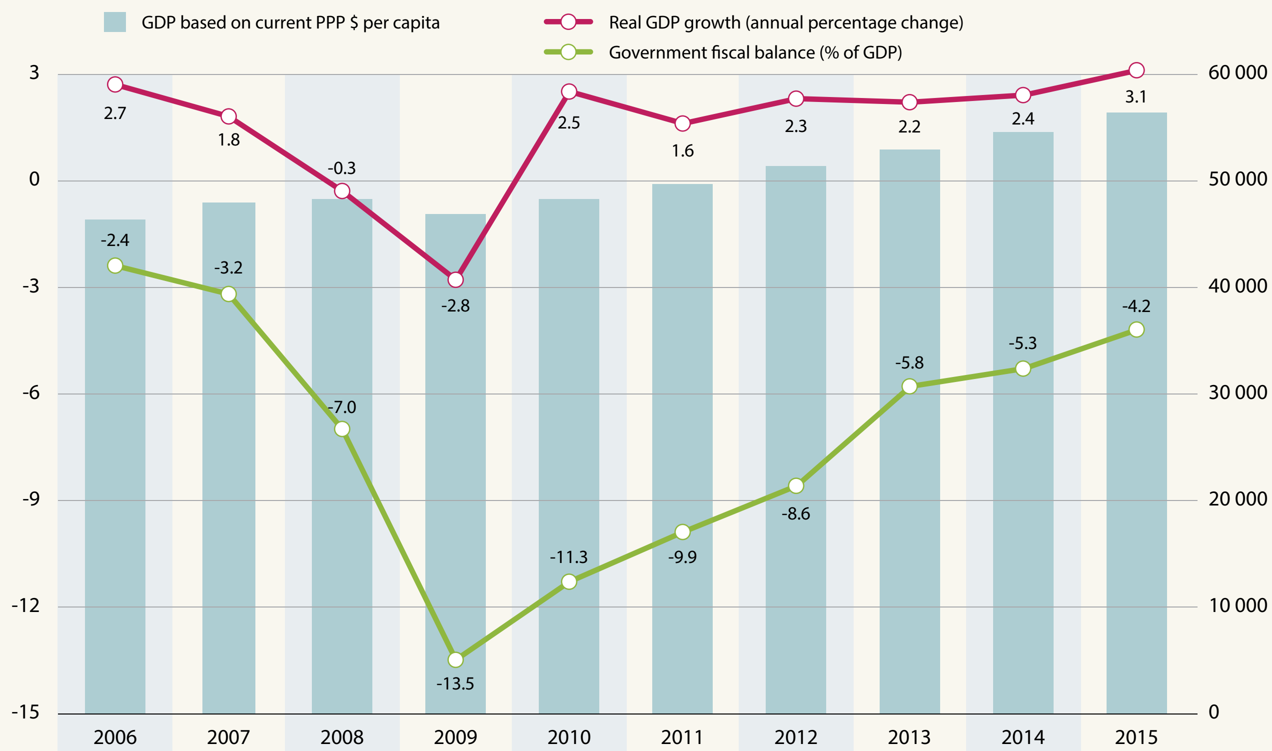
1. According to the US National Bureau of Economic Research, the USA was in recession from December 2007 to end June 2009.

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**

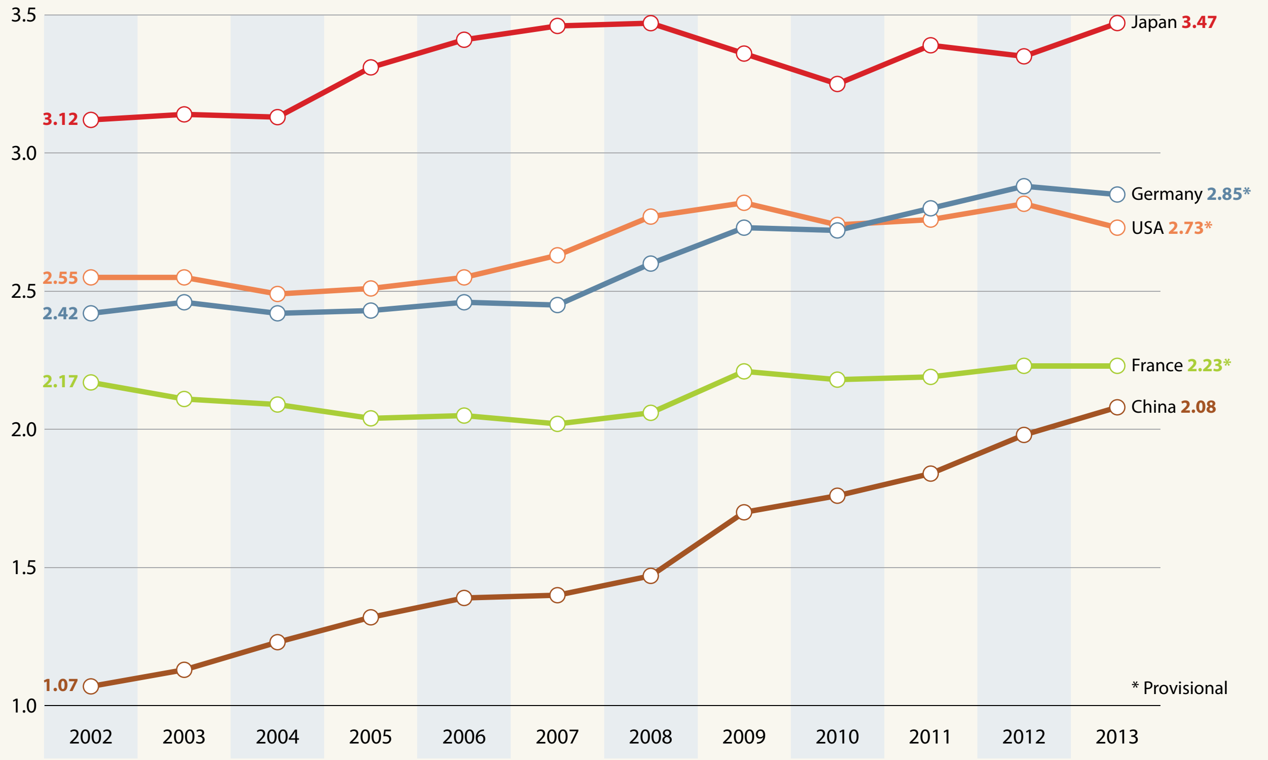


Note: Data for 2015 are estimates. General government fiscal balance is also known as net lending/borrowing. The fiscal balance covers both the federal and state governments.

Source: IMF Data Mapper online, August 2015

Figure 5.2: **GERD/GDP ratio in the USA, 2002–2013 (%)**

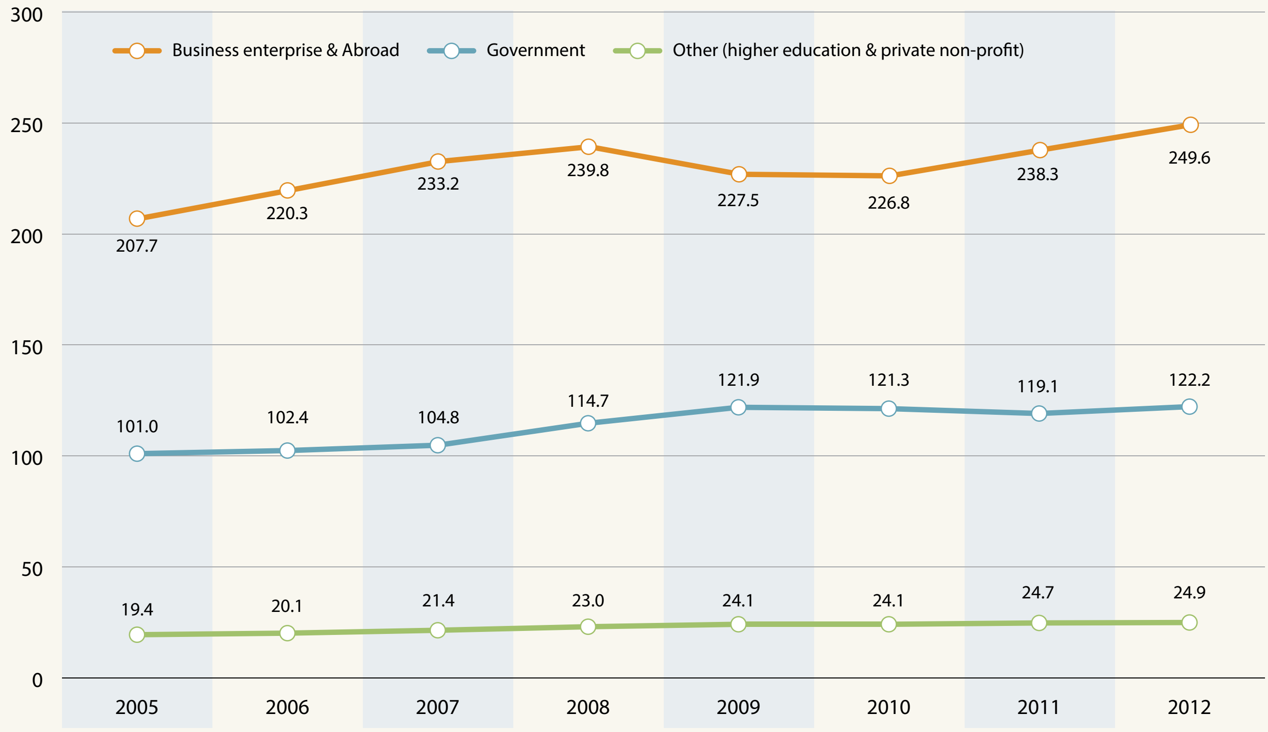
Other countries are given for comparison (%)



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 him 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 Advancing 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 Accelerated 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.

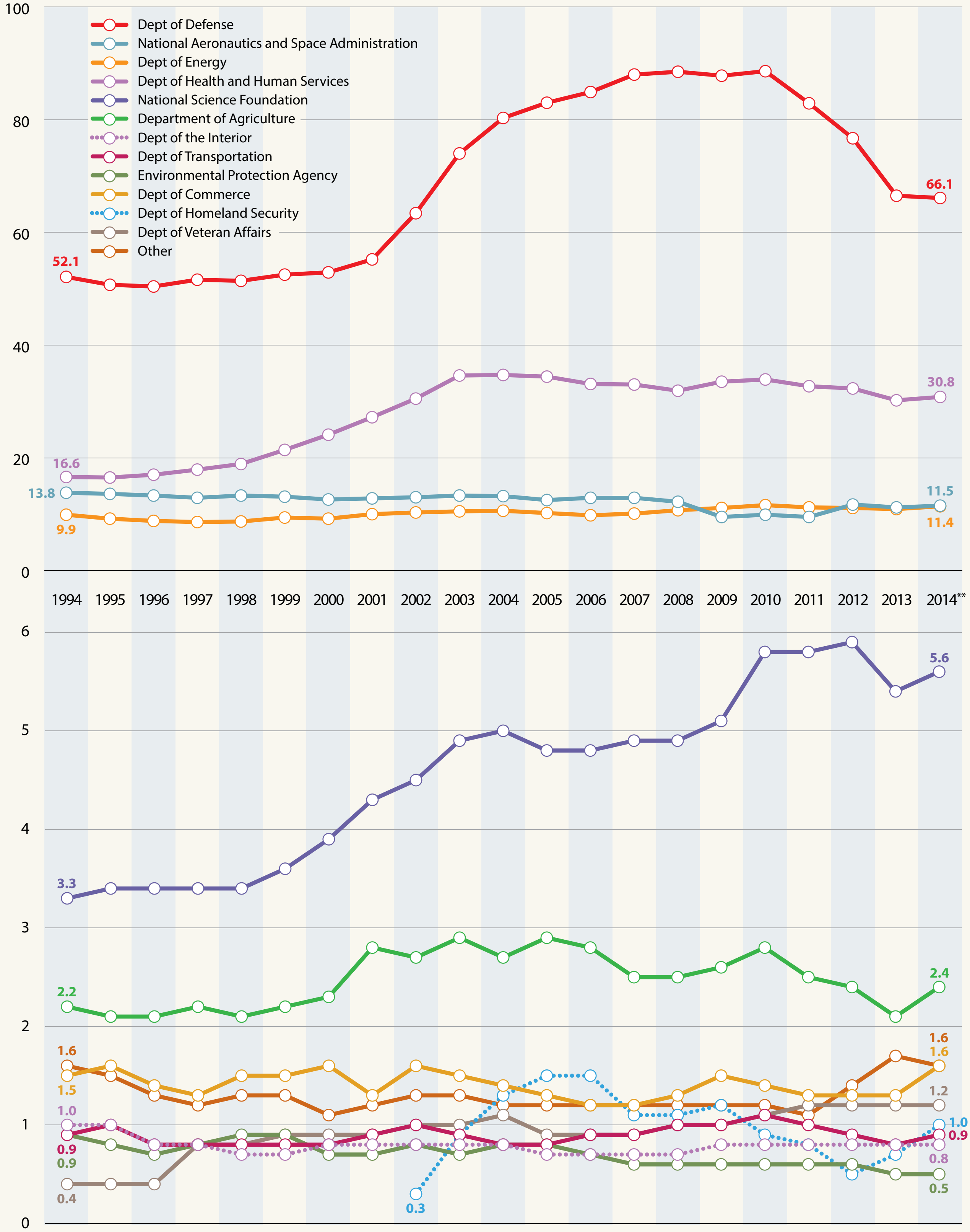
Non-defence federal R&D contracts were slightly above US$ 10 billion in 2014, a drop of 6% over the previous year. Hunter suggested that this trend was due to a combination of decreasing federal budgets for specific research and the budget sequester instigated by Congress in 2013, which has enacted US $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%.

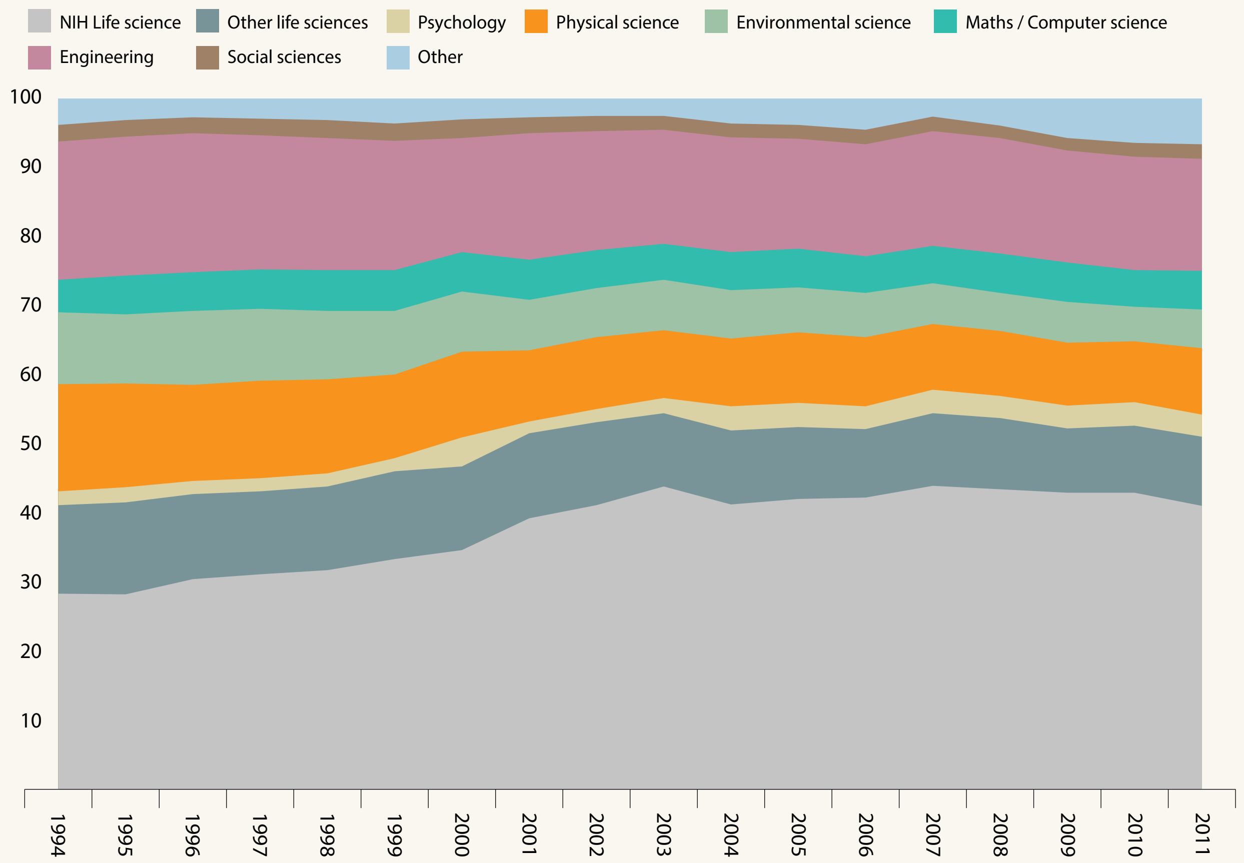
Furthermore, the average age of a researcher obtaining an NIH grant[4] for the first time is now 42 years. This raises the question of whether institutions are in a position to promote young faculty or give them tenure, as obtaining grants tends to be a pre-requisite for obtaining tenure. After reviewing 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.

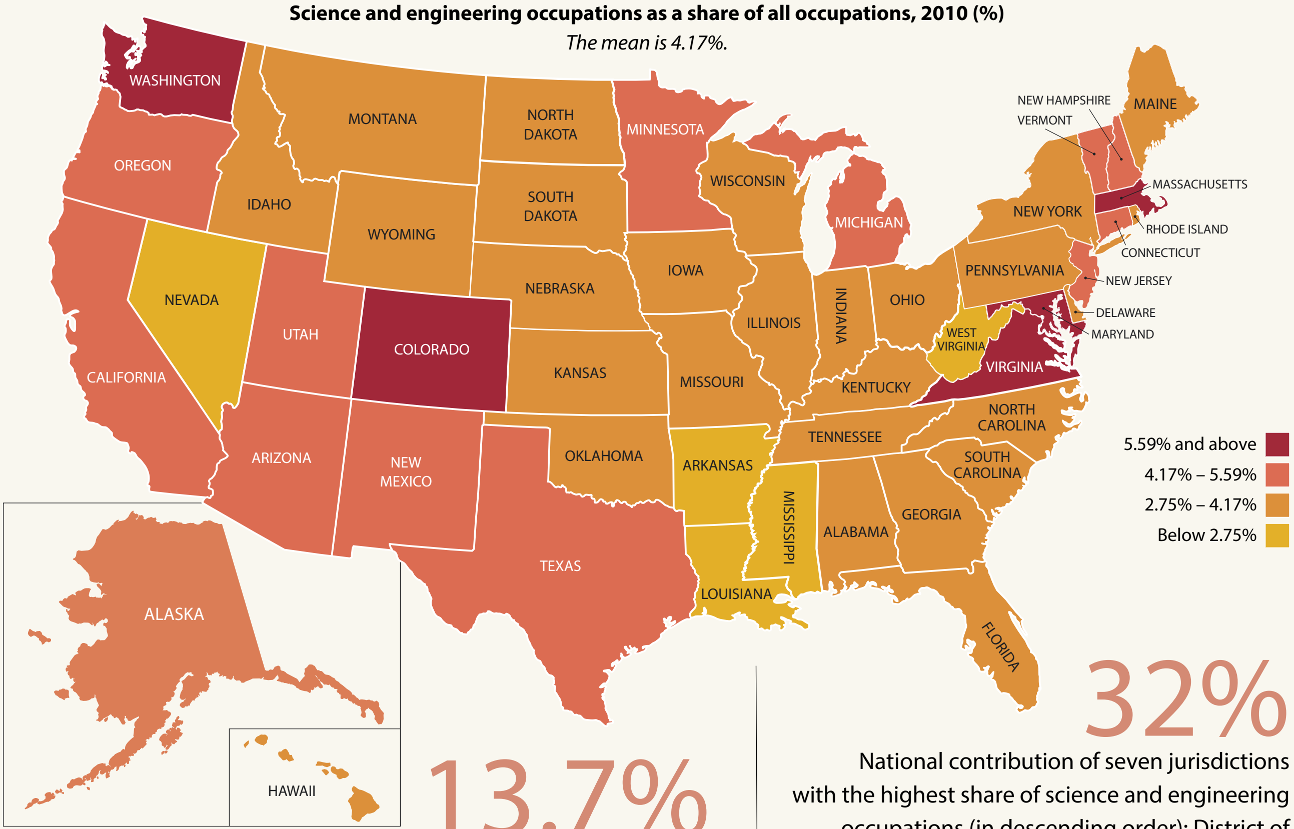
6. By 2015, the Chinese economy had overtaken the USA in terms of purchasing power parity (GDP in international dollars) but was still far from doing so in terms of GDP at market prices and exchange rates.

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%

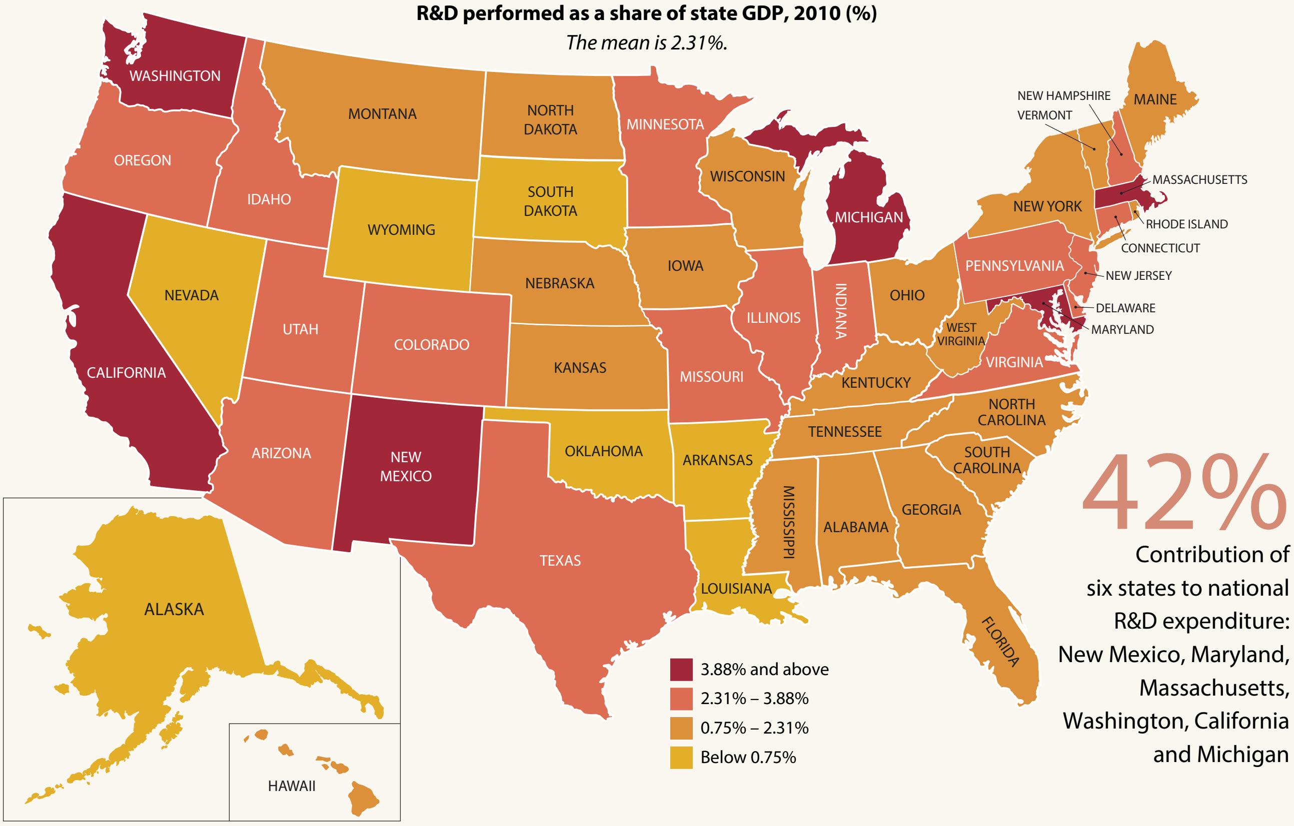
California's share of national science and engineering occupations, the top US state for this indicator

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

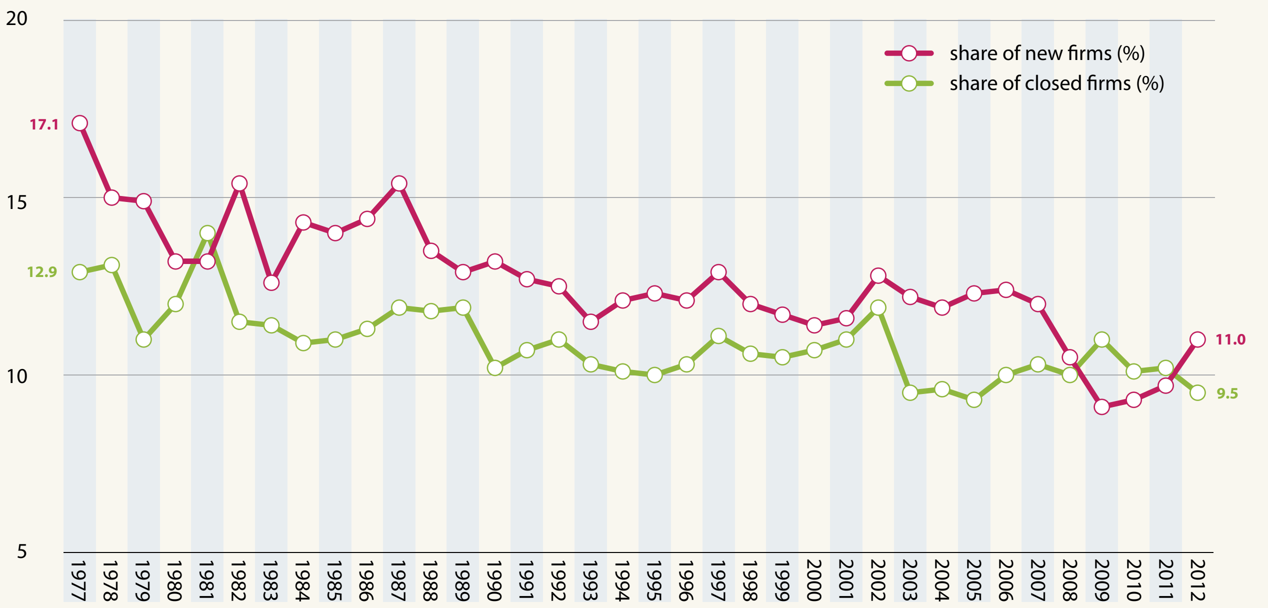
The recession has been bad for US business research spending. From 2003 to 2008, this type of expenditure had followed a generally upward trajectory. In 2009, the curve inverted, as expenditure fell by 4% over the previous year then again in 2010, albeit by 1–2% this time. Companies in high-opportunity 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, 61% 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: 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.

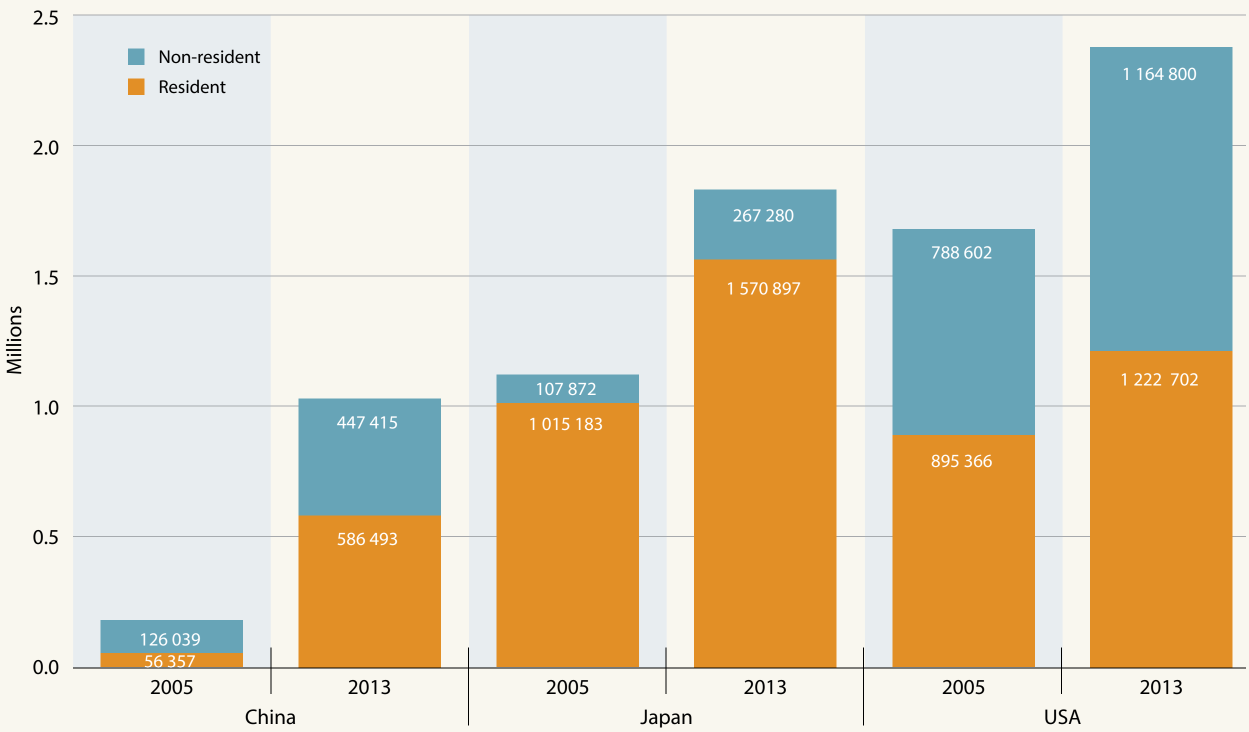
The small sensors that facilitate this connectivity are also being applied in industry and health care. Since it relies on service contracts for much of its revenue, General Electric is currently investing in sensor technology to collect more information about the performance of its aeroplane engines 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**

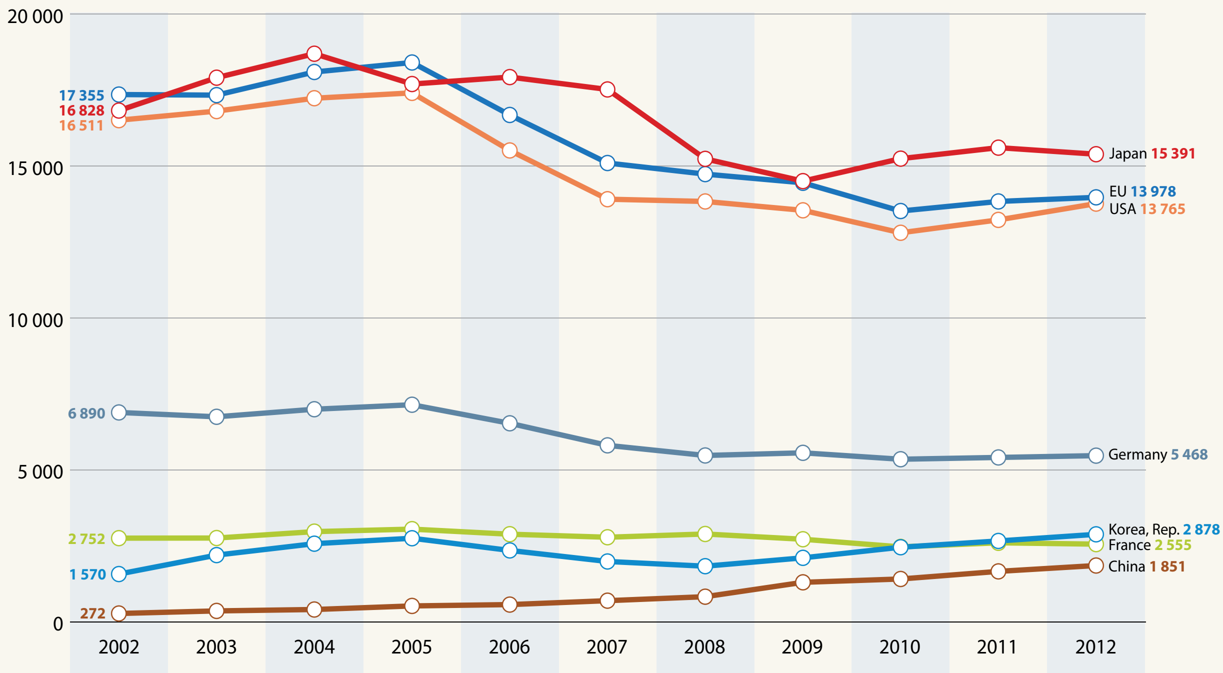
Other major economies are given for comparison



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

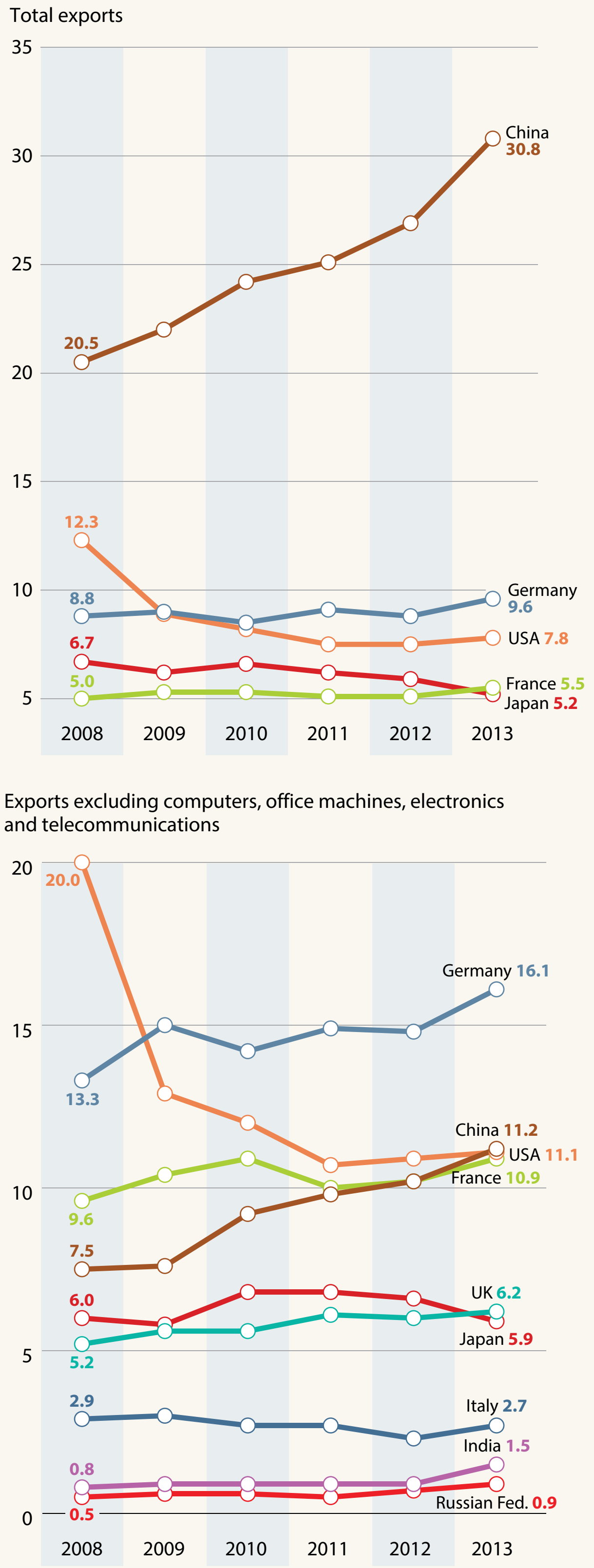


Note: Triadic patents are filed by the same inventor for the same invention in the USA, Europe and Japan.

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.

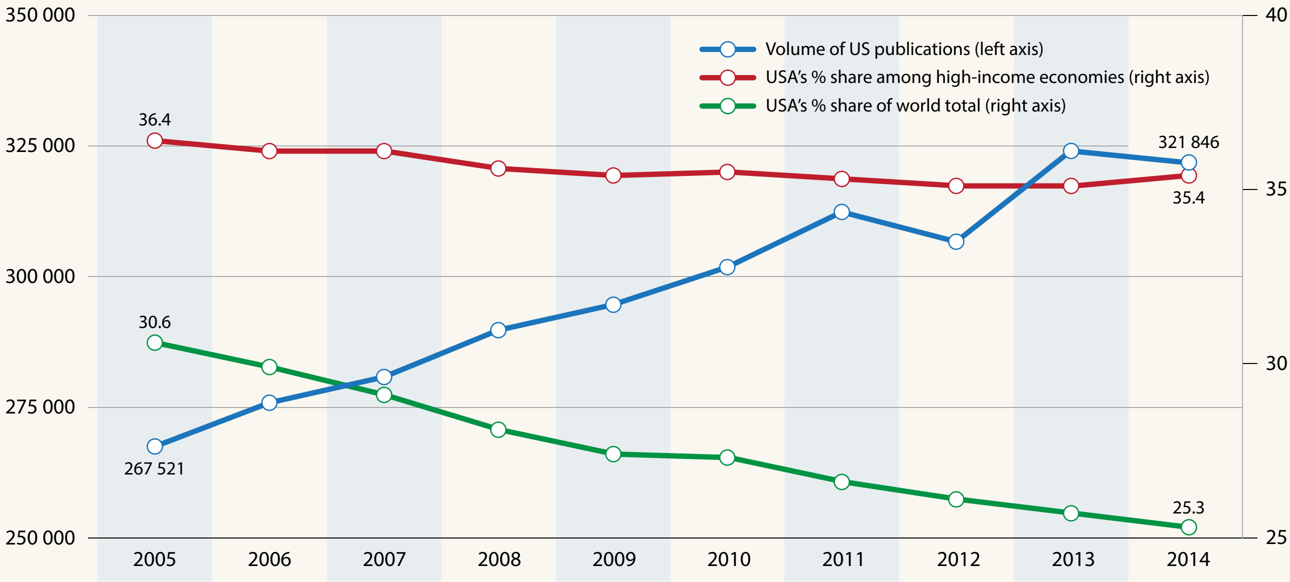
Too many researchers competing for academic posts

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

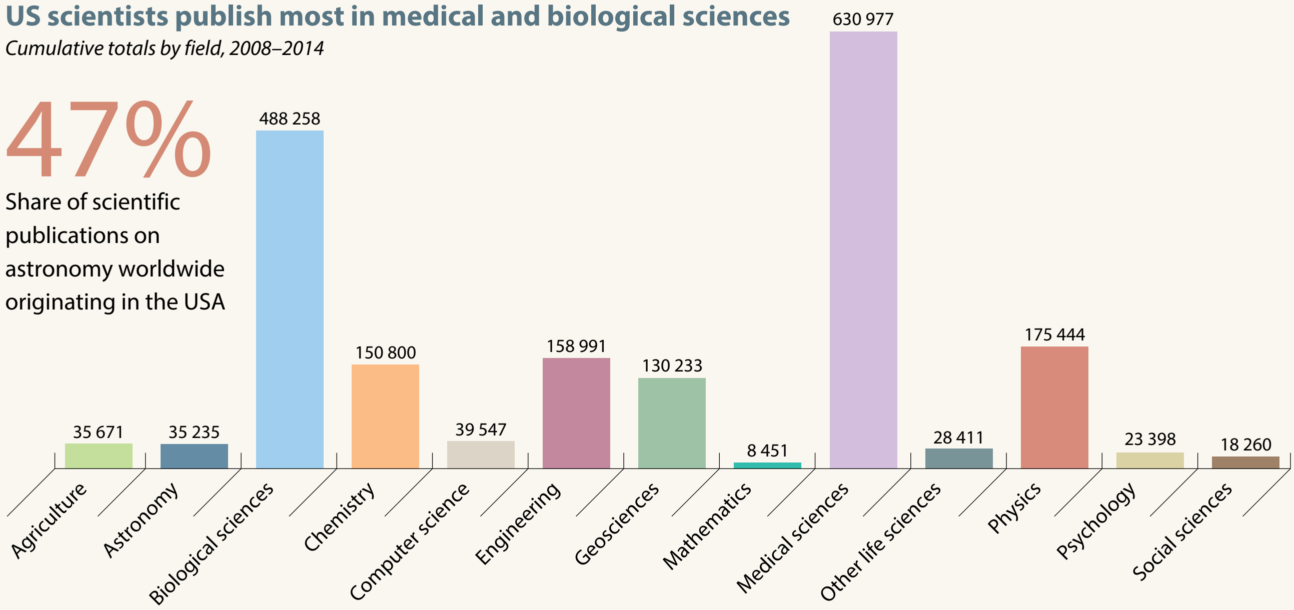
14.7%
Share of US papers among 10% most cited papers, 2008–2012; the OECD average is 11.1%

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 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).

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.

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.

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).

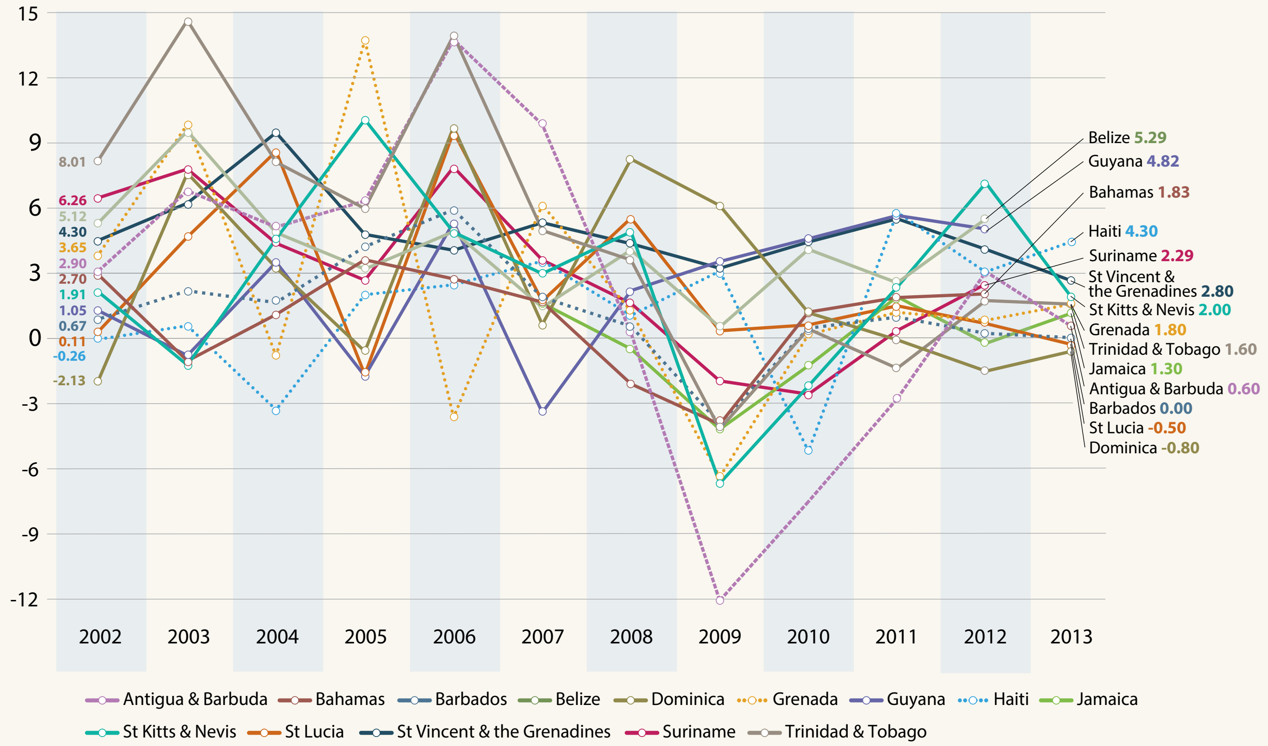
2. The region lost about 3.5% of GDP after the failure of the CL Financial Group in January 2009; this group of insurance companies had invested in real estate and other vulnerable assets in a weak regulatory environment. The group was active in all the CARICOM countries but Haiti and Jamaica. It was 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$)	Unemployment rate, 2013 (%)	Inflation, consumer prices, 2013 (%)	Debt to GDP ratio, 2012 (%)	Remittances, 2013 (US$ 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.

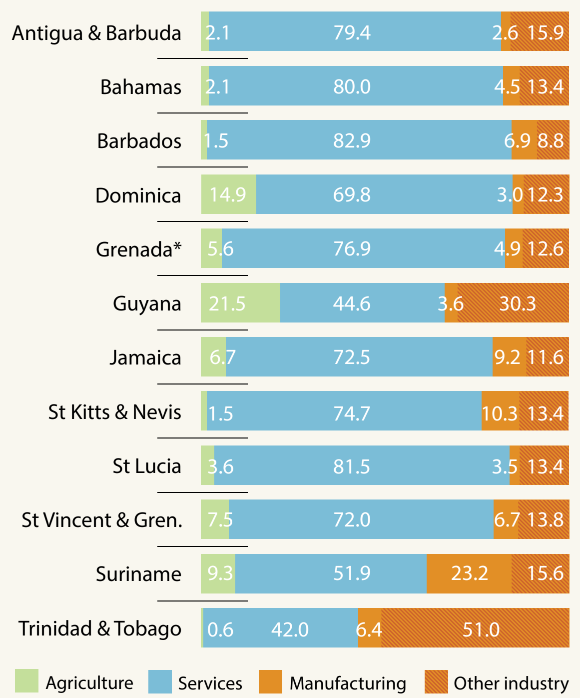
The CCCCC has produced an implementation plan for 2011–2021 and carried out work to assess and build capacity in climate change mitigation and resilient development strategies. This work has been supported by the region's specialists, who have produced models for climate change and mitigation processes 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**

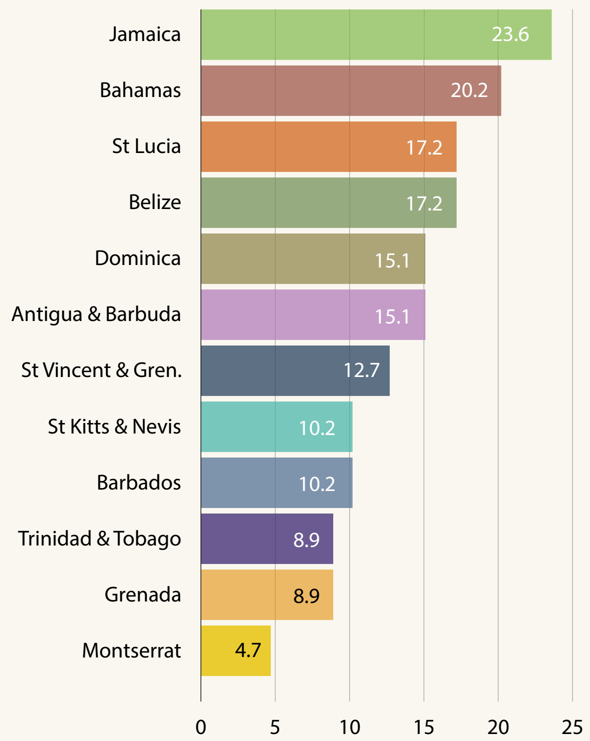


*For Grenada, data are for 2011.

Note: Data are unavailable for Haiti and Montserrat.

Source: World Bank; World Development Indicators, September 2014

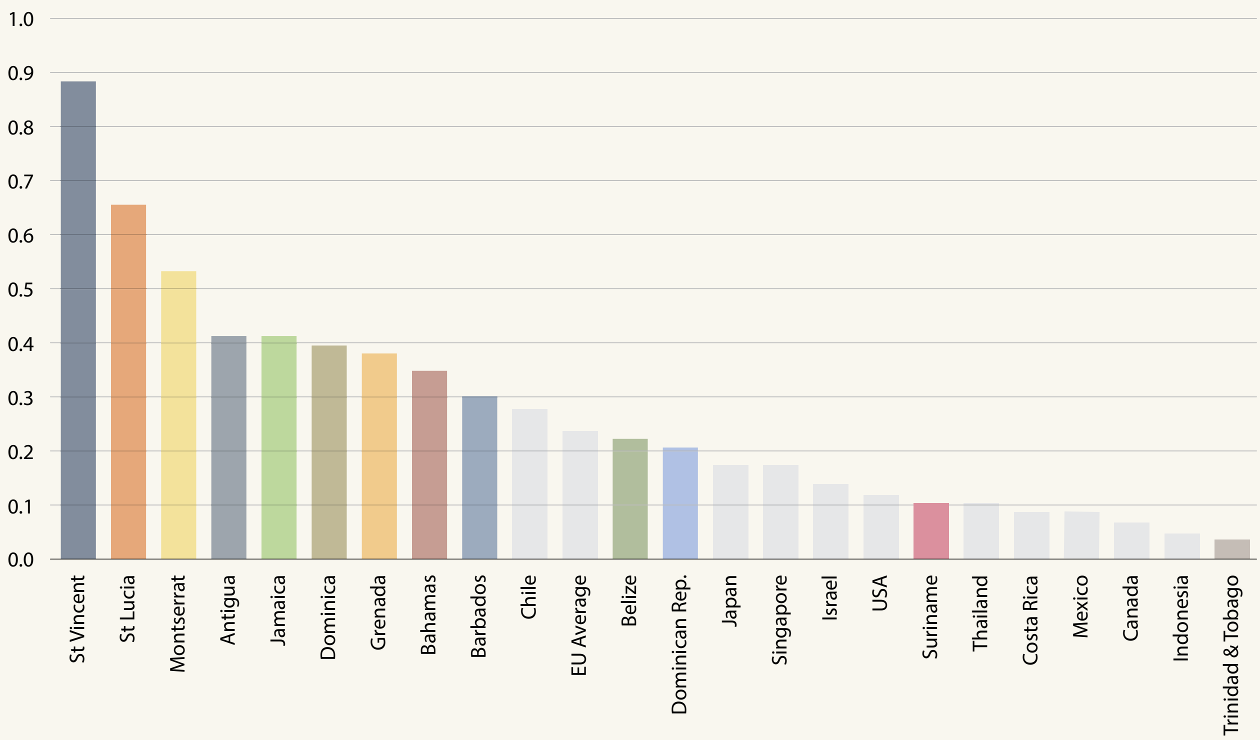
Figure 6.3: **Probability of a hurricane striking Caribbean countries in a given year, 2012 (%)**



Source: IMF (2013)

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].

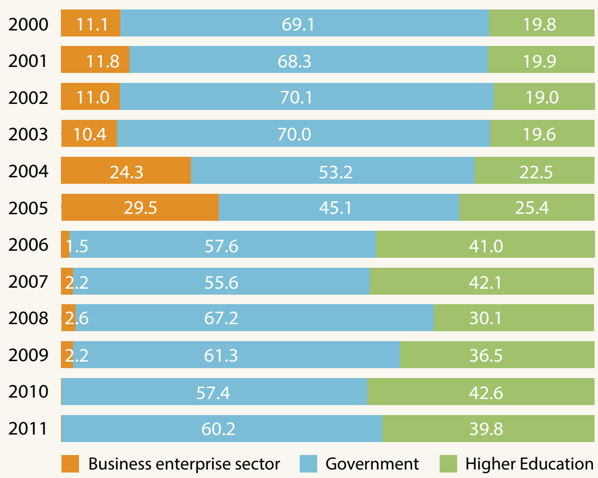
The UNESCO Institute for Statistics has also published several guides for developing countries, most recently the *Guide to Conducting an R&D Survey for Countries Starting to Measure R&D*[9] (2014). In 2011, the UNESCO Institute for Statistics ran a training workshop in Grenada to help CARICOM countries 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.

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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.

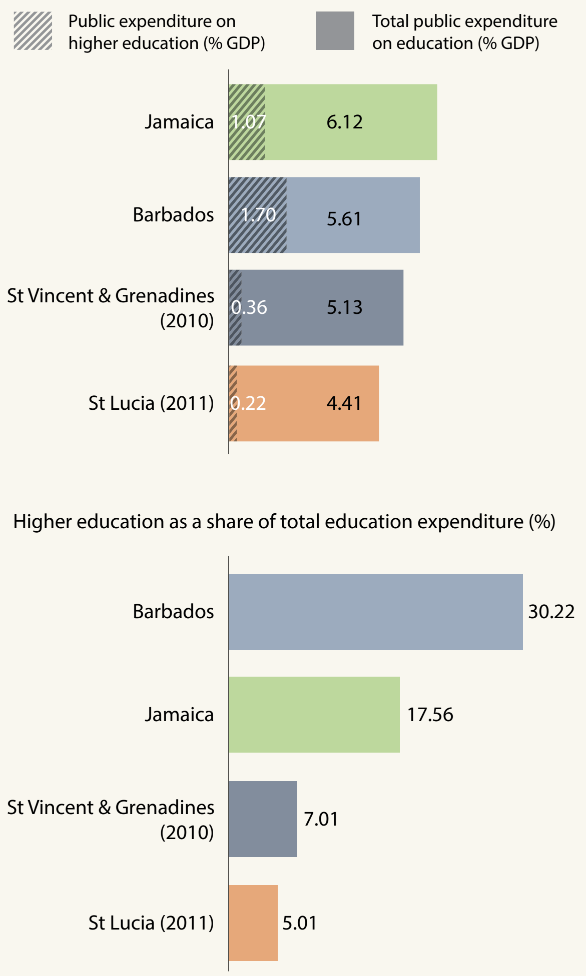
Better co-ordination should avoid duplication

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.

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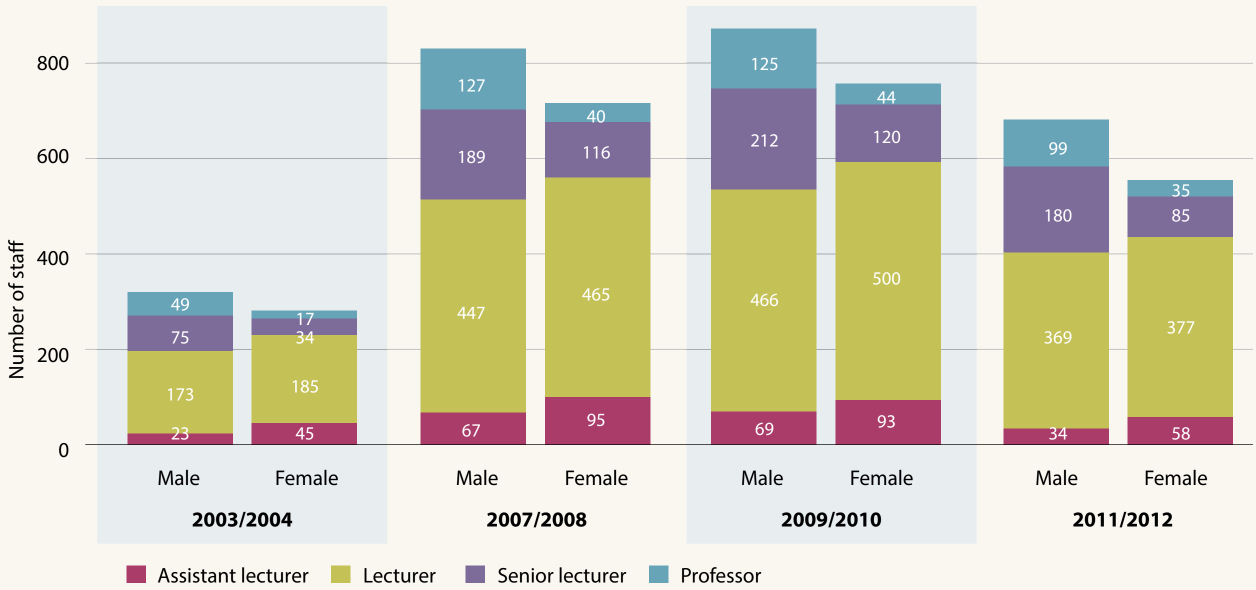
13. See: www.cariri.com

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.

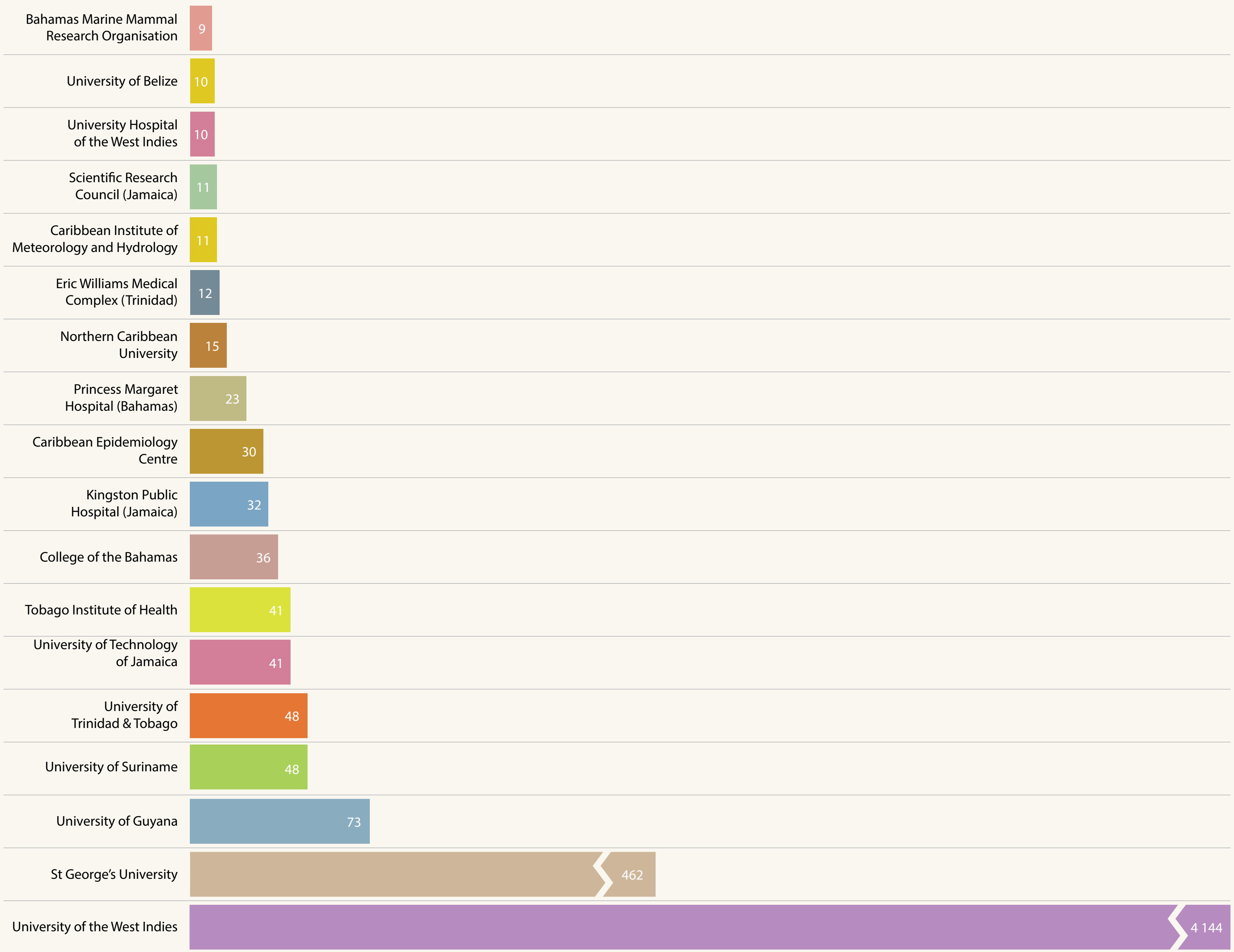
The Tropical Medicine Research Institute has built a research culture of a high standard by offering mentorship opportunities to young promising researchers (through postdoctoral positions) and competent support staff, such as research nurses, physicians, statisticians and equipment technologists. Very 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

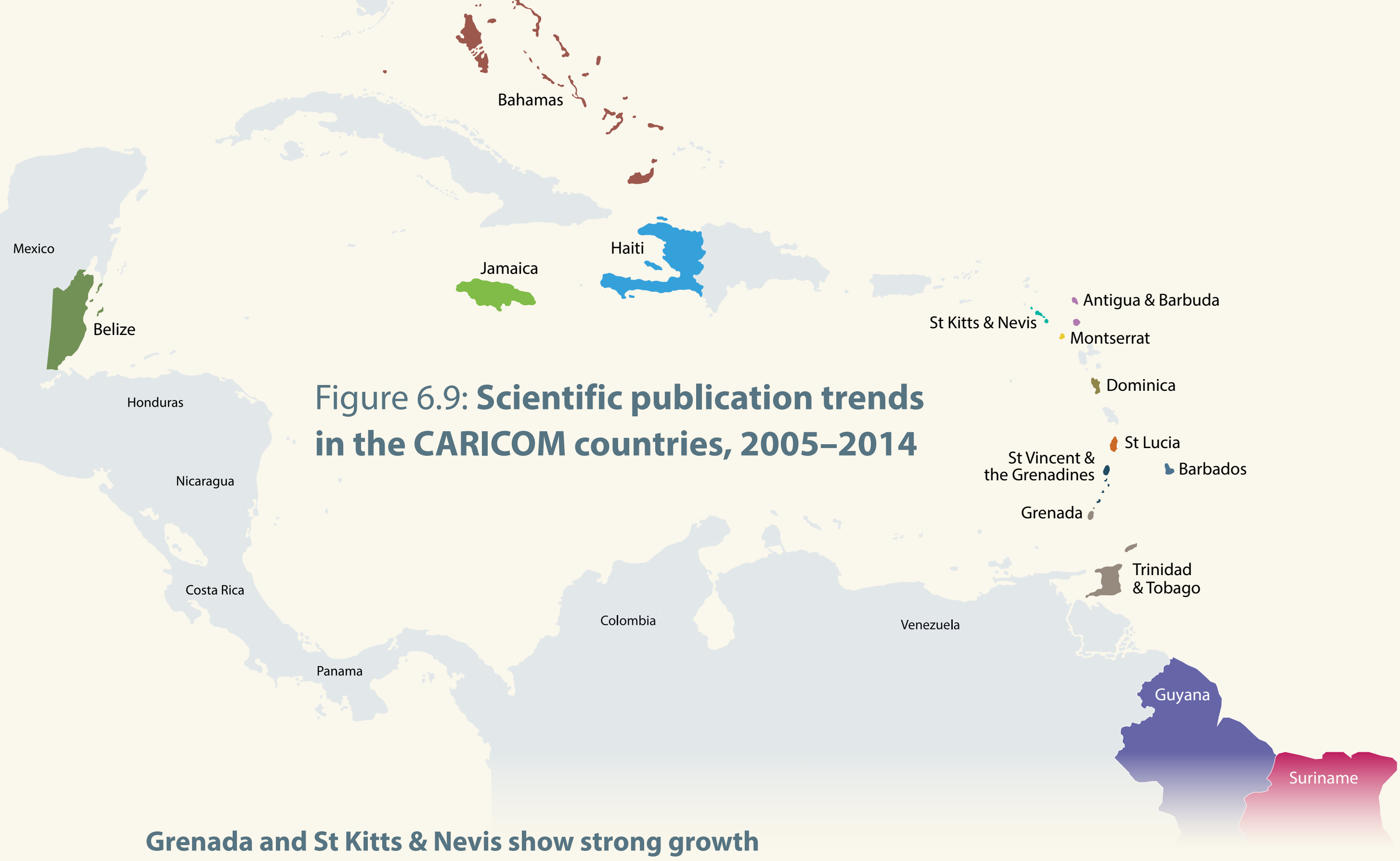
Private indigenous research companies are also emerging, such as the Bio-tech R&D Institute (Box 6.2). Cariscience has admitted the institute as a member at a time when some university departments are finding it a challenge to meet the criteria for membership. This is an important development in the 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.

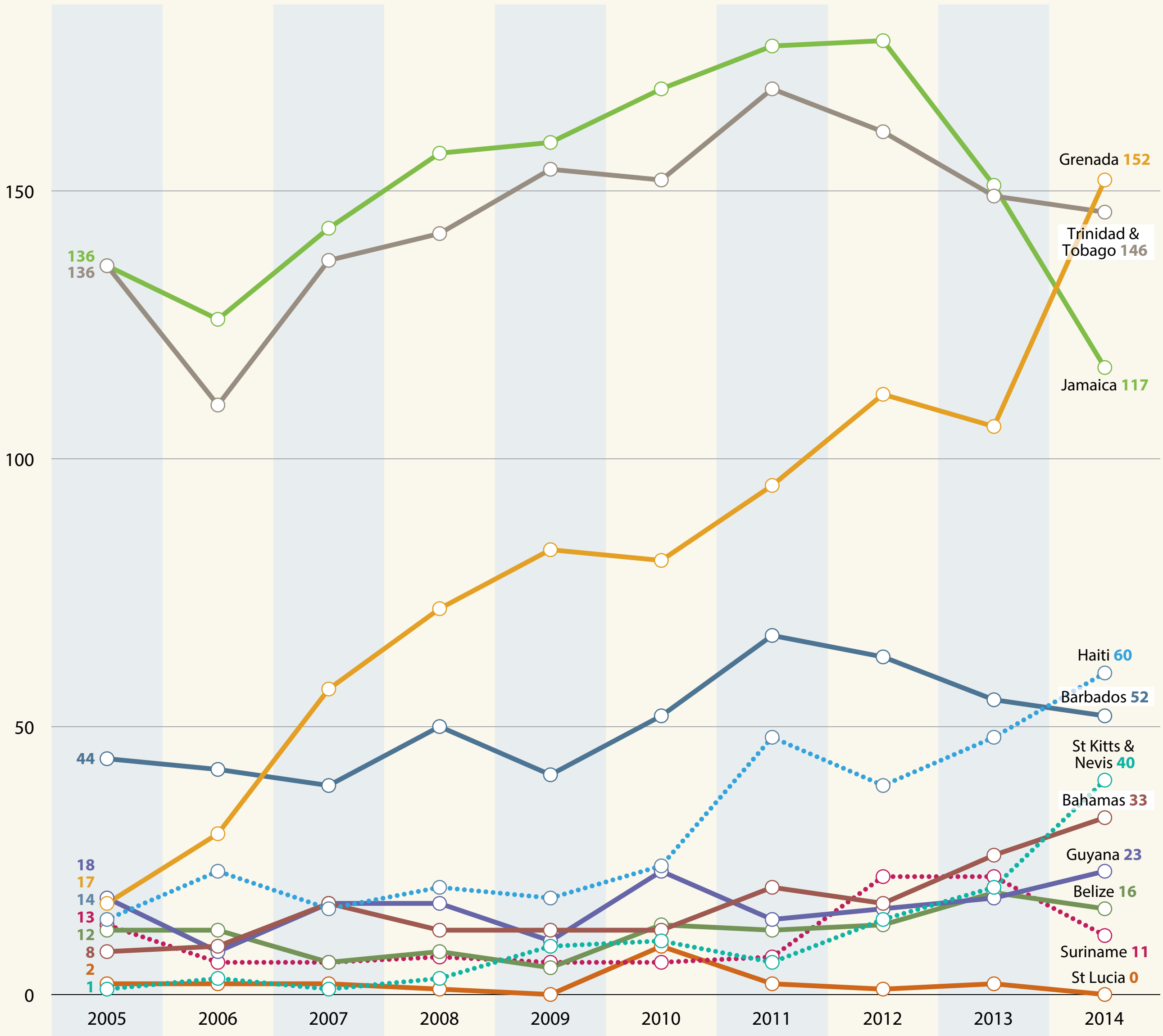
15. US Patent numbers: 8 597 874; 8 129 102; and 7 709 815: www.uspto.gov

Figure 6.9: **Scientific publication trends in the CARICOM countries, 2005–2014**



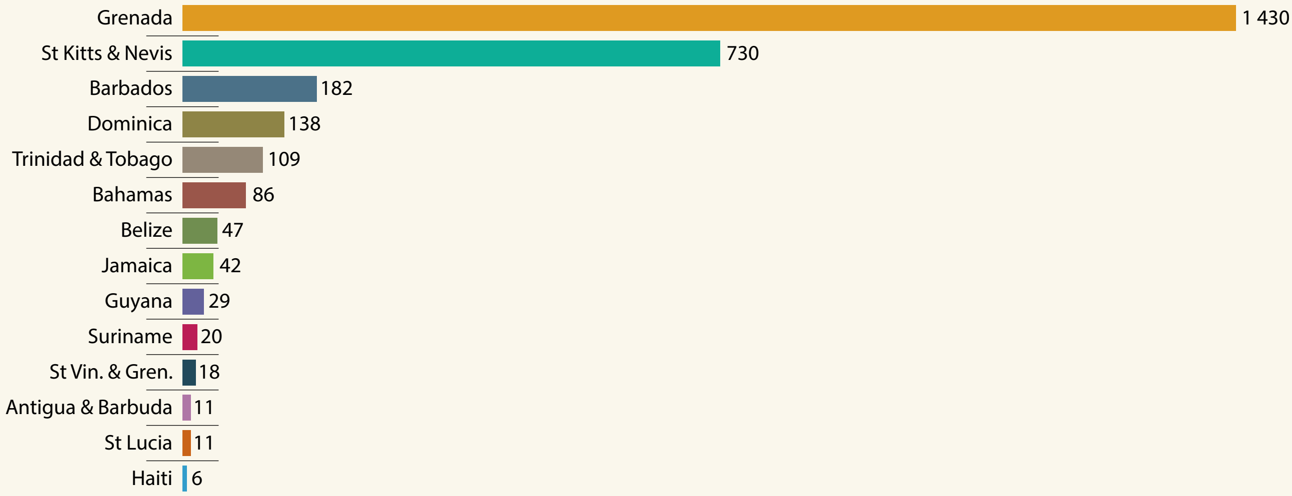
Grenada and St Kitts & Nevis show strong growth

Countries with more than 15 publications between 2008 and 2014



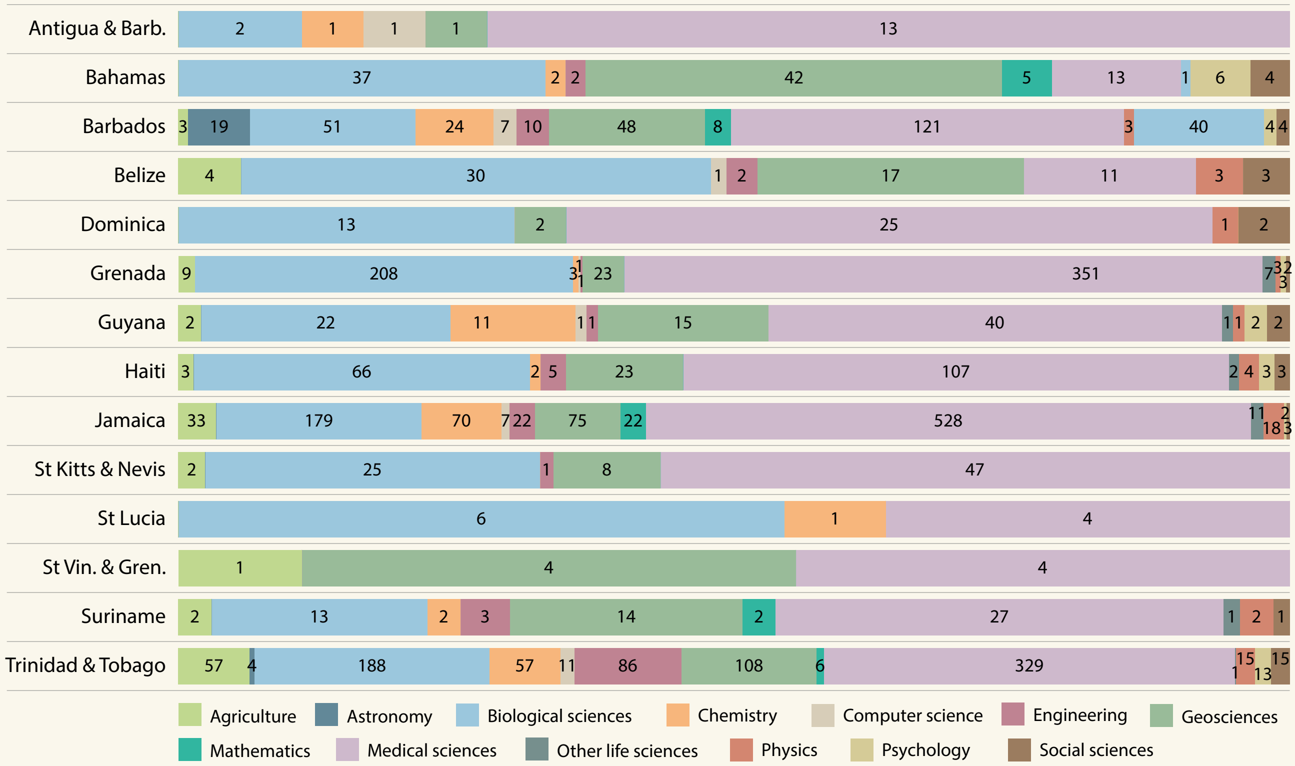
Grenada has the most intensive output

Scientific publications per million inhabitants in 2014



CARICOM countries publish most in health, led by Grenada and Jamaica

Cumulative totals, 2008-2014



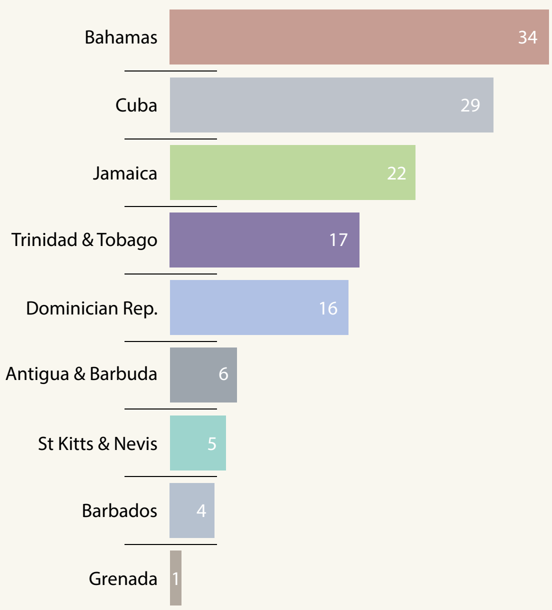
Jamaica and Trinidad & Tobago are close partners

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

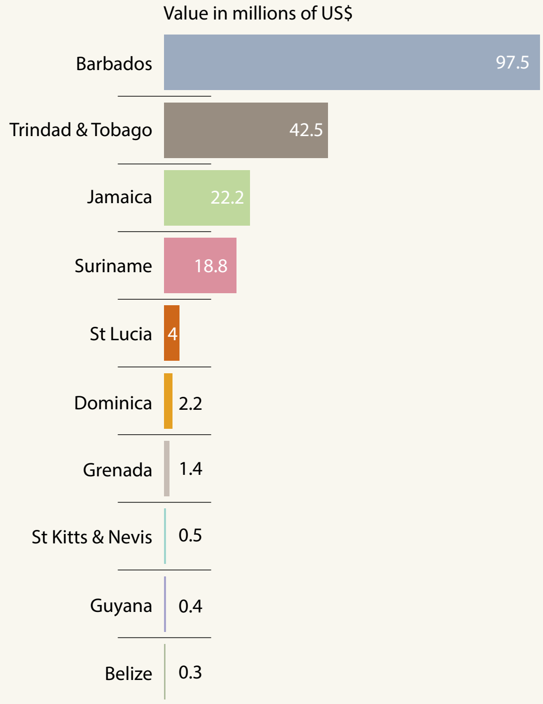
Figure 6.10: **USPTO patents granted to Caribbean countries, 2008-2013**



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).

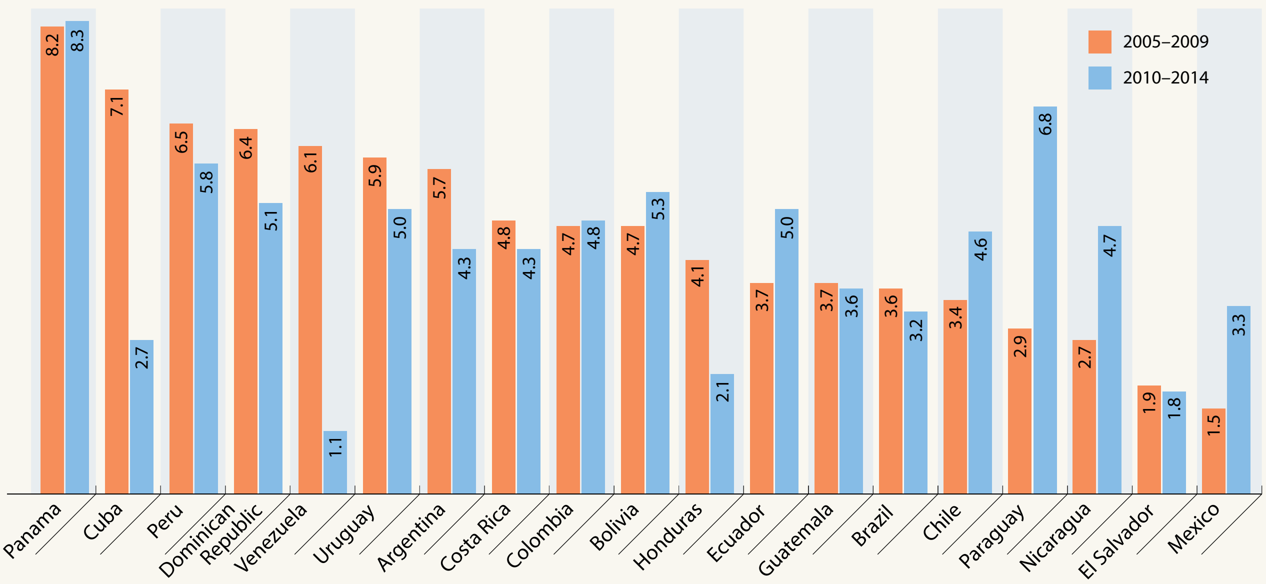
The Latin American economy grew by just 1.1% in 2014, meaning that GDP per capita actually stagnated. Preliminary figures for the first quarter of 2015 suggest an ongoing slowdown in activity since the decade-long commodities boom wound down in 2010 (see also Figure 7.1); some of the region's larger 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.

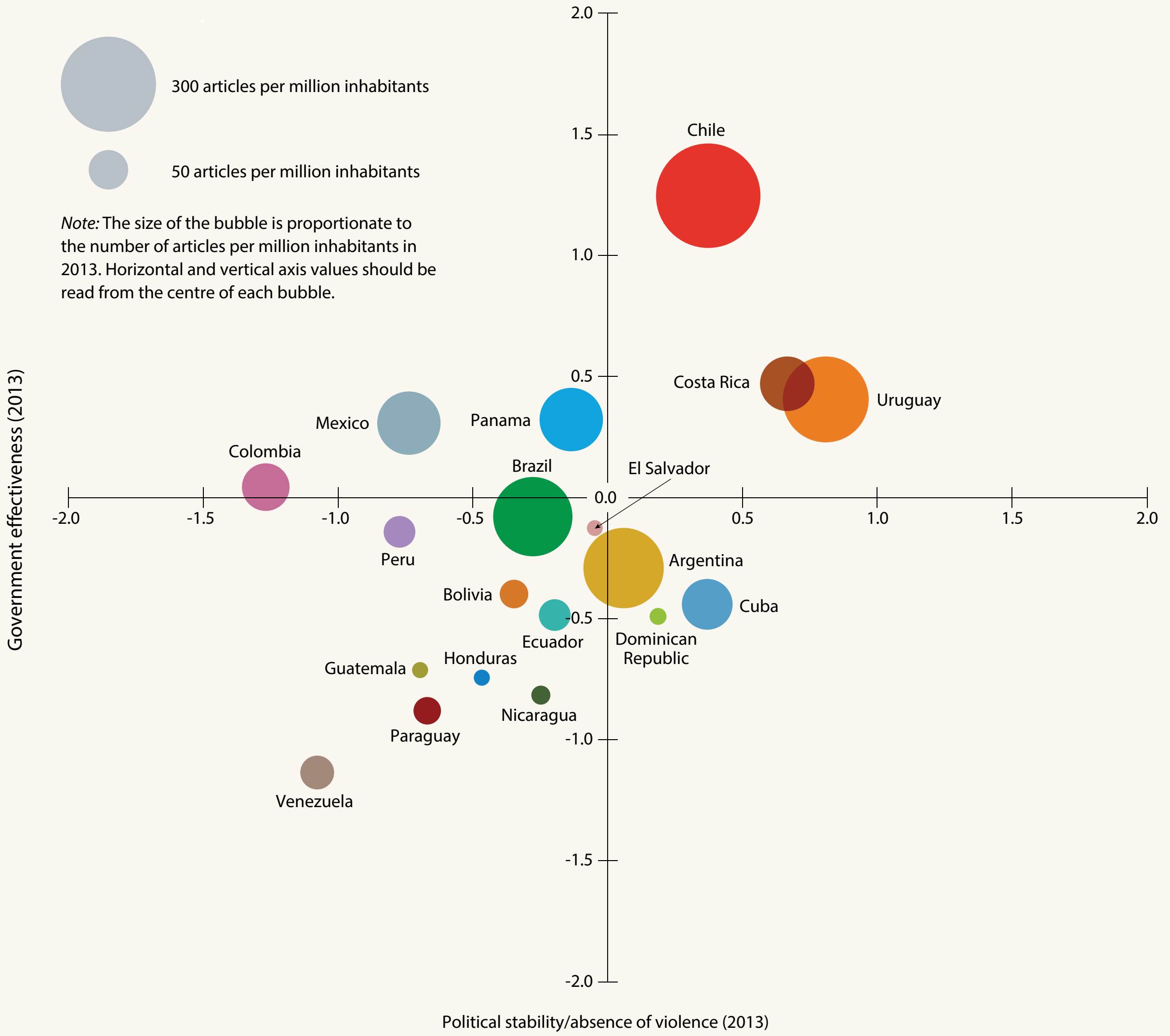
Source: World Bank's World Development Indicators, September 2015

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).

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.

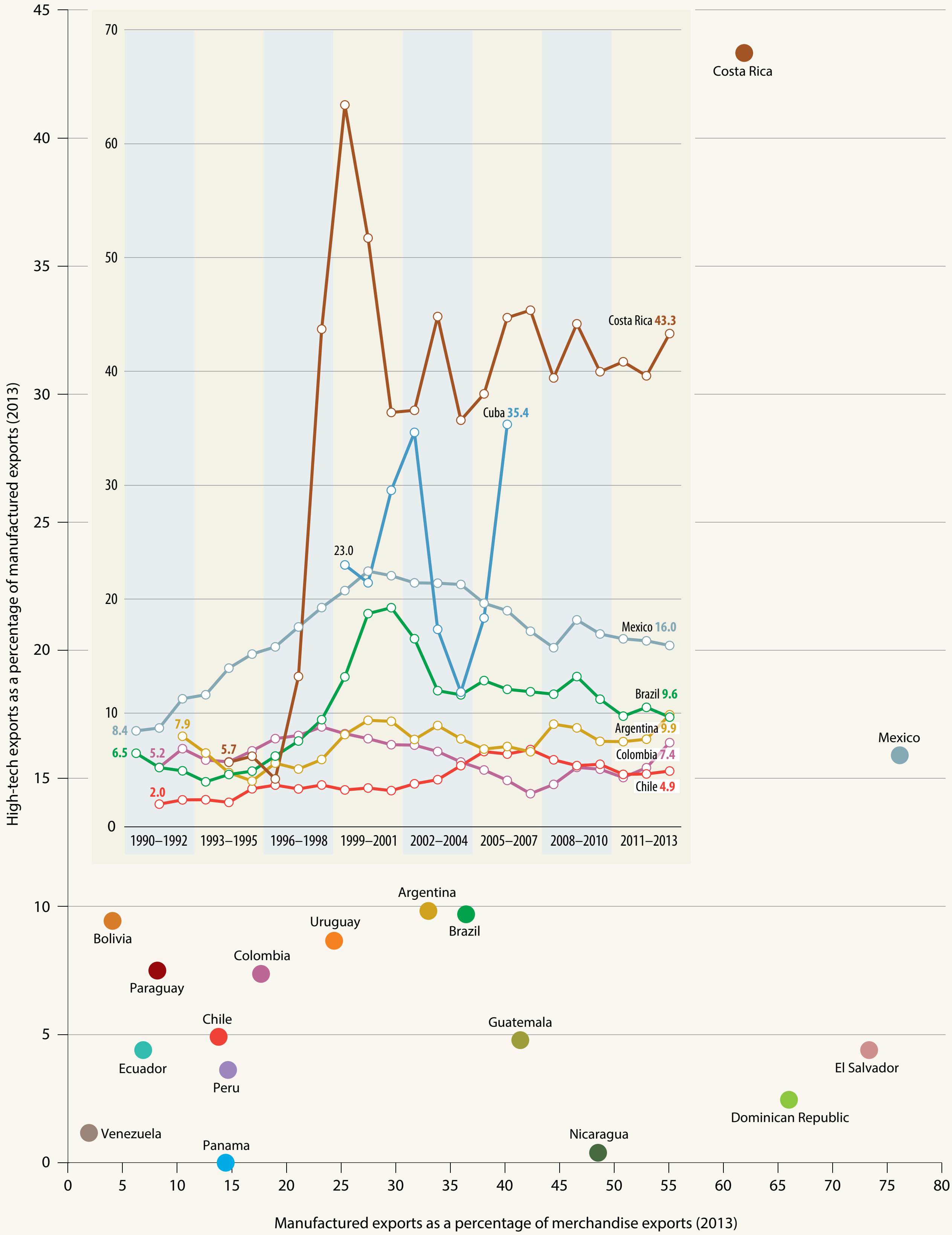
Only in Costa Rica and, to a lesser degree, Mexico, do certain high-tech exports drive economic growth to an extent comparable with developing European economies (Figure 7.3). Moreover, there has been a decline in the high-tech component of manufactured exports from Mexico (and Brazil) since 2000. In 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.

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.

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 objectives and goals												
	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 than 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%

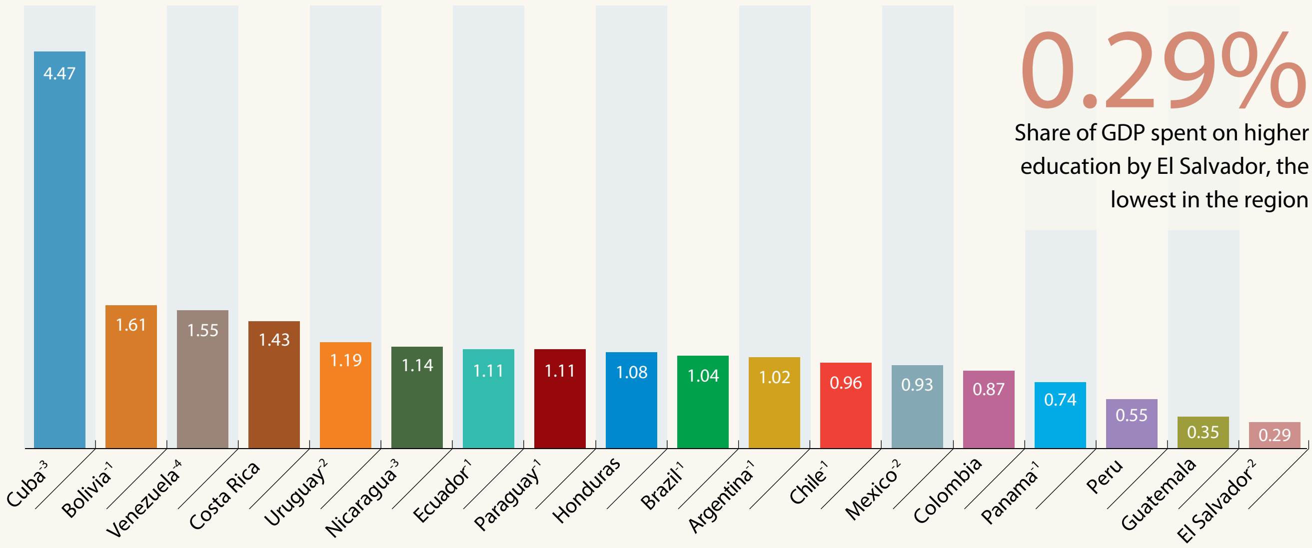
Share of GDP spent on higher education by Cuba, the highest in the region

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

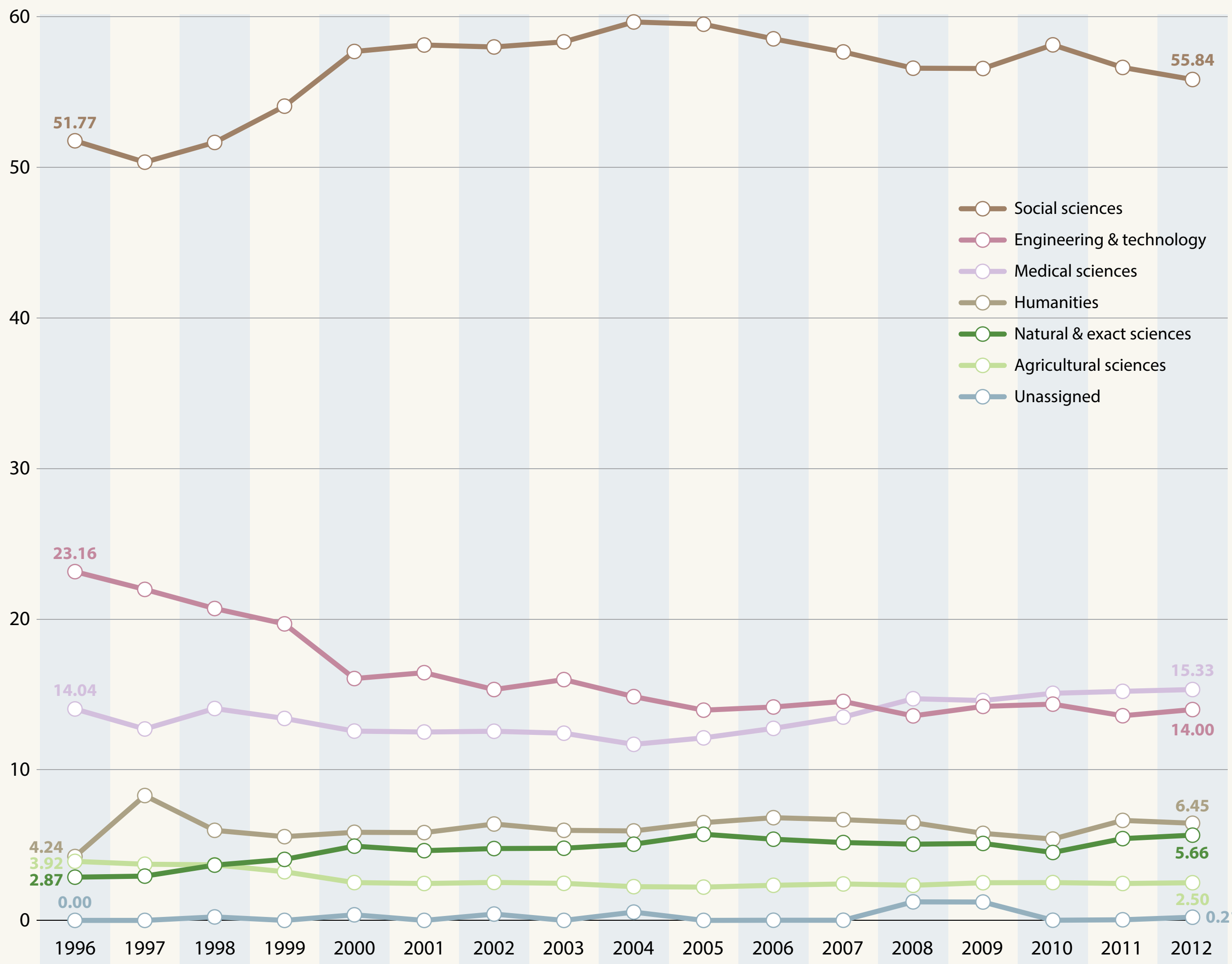
Expenditure on higher education as a share of GDP, 2013 or closest year (%)



+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

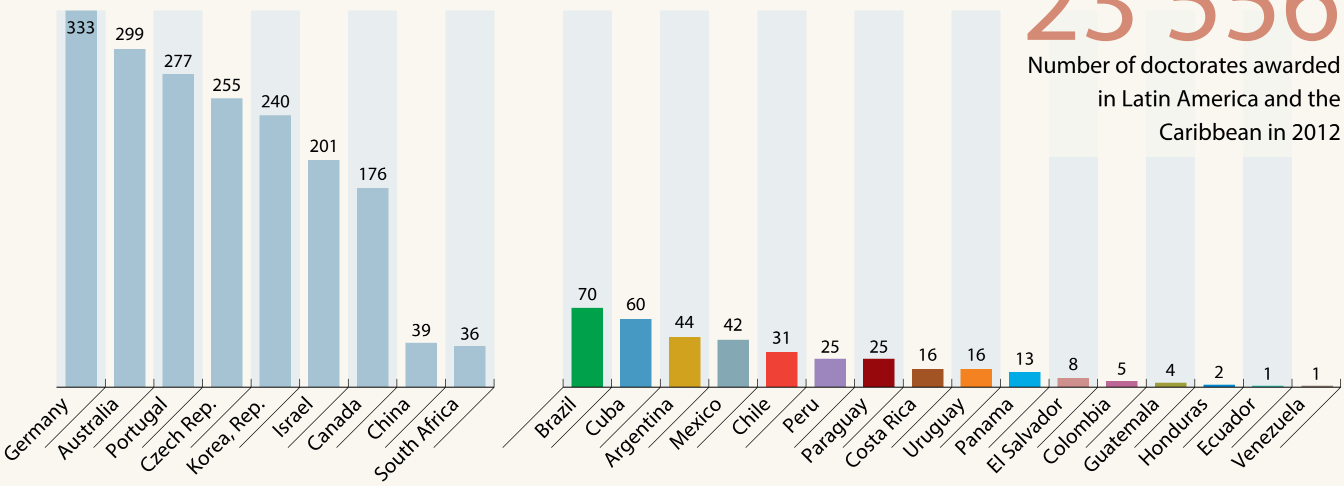
Distribution of bachelor's degrees by field of study, 1996–2012 (%)



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

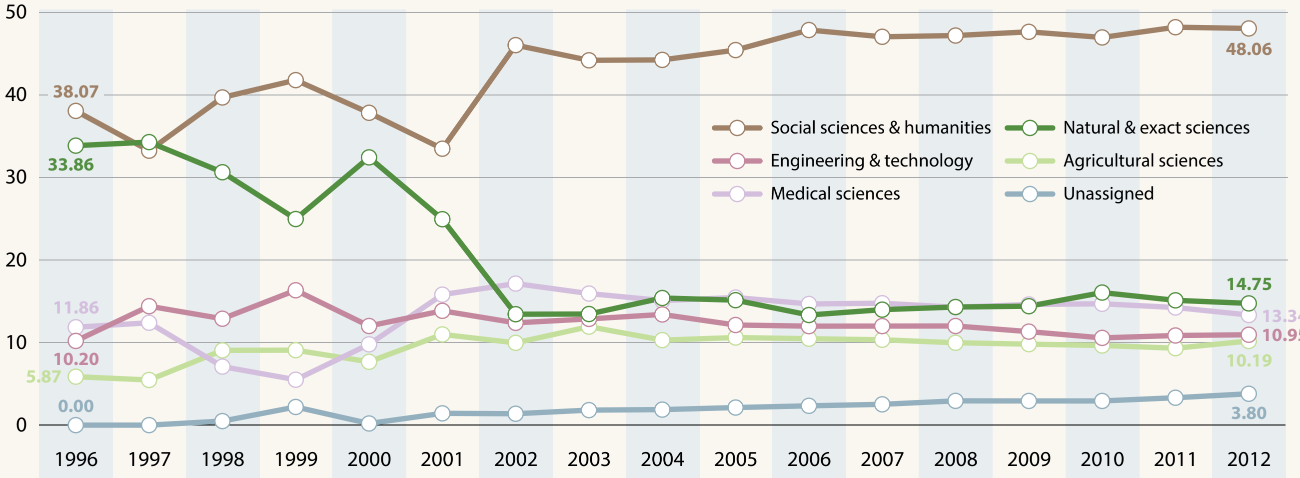


23 556

Number of doctorates awarded in Latin America and the Caribbean in 2012

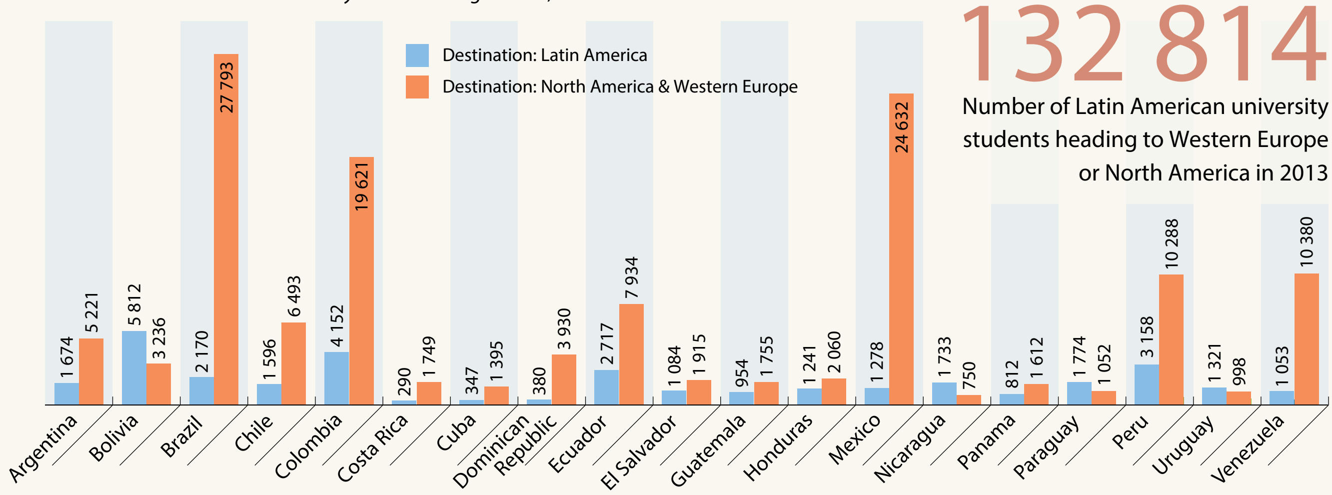
The share of PhD graduates in natural sciences has not recovered since this indicator plunged a decade ago

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.

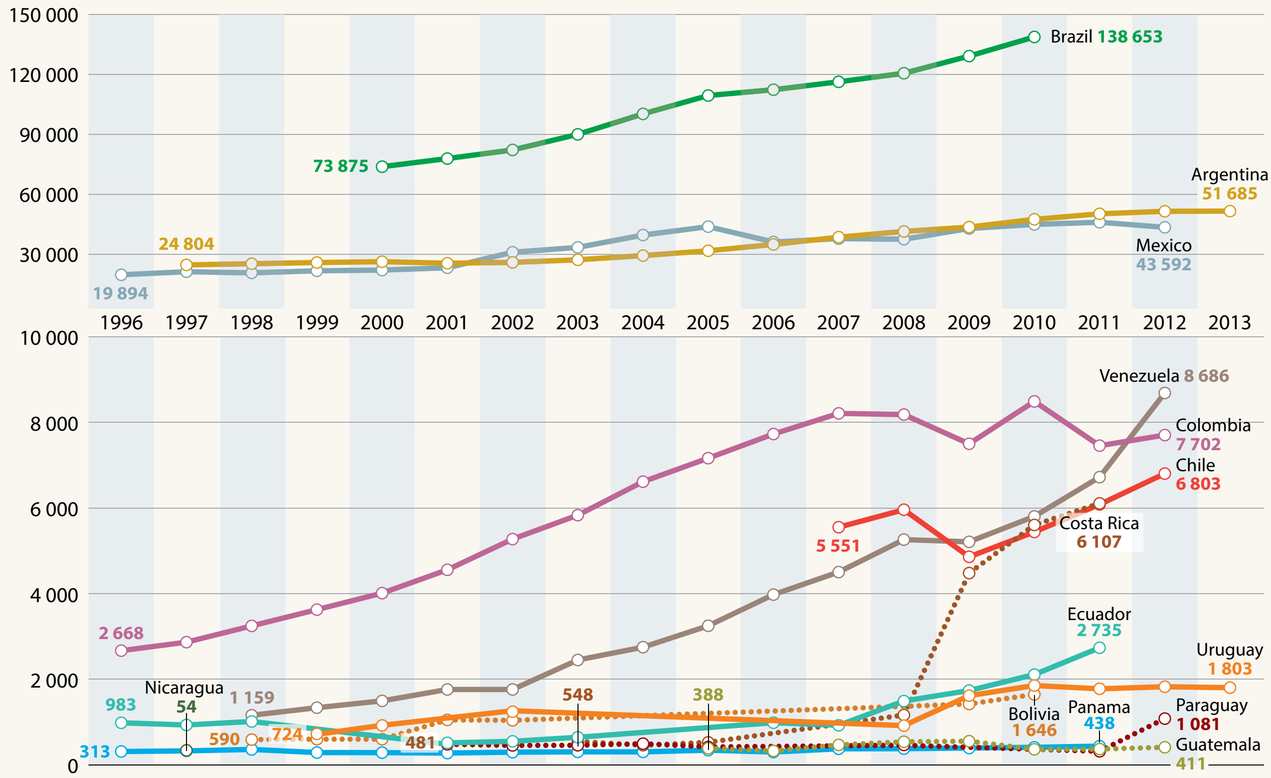
Internal experts recruited from within the company serve as the main body of instructors.

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

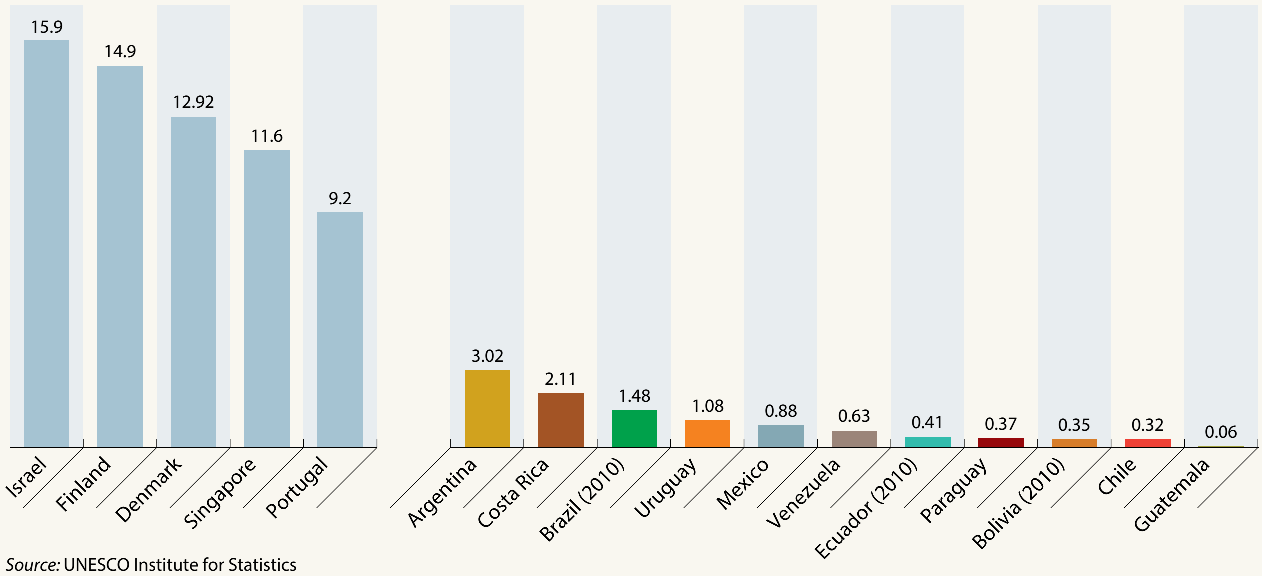
Source: compiled by author

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.

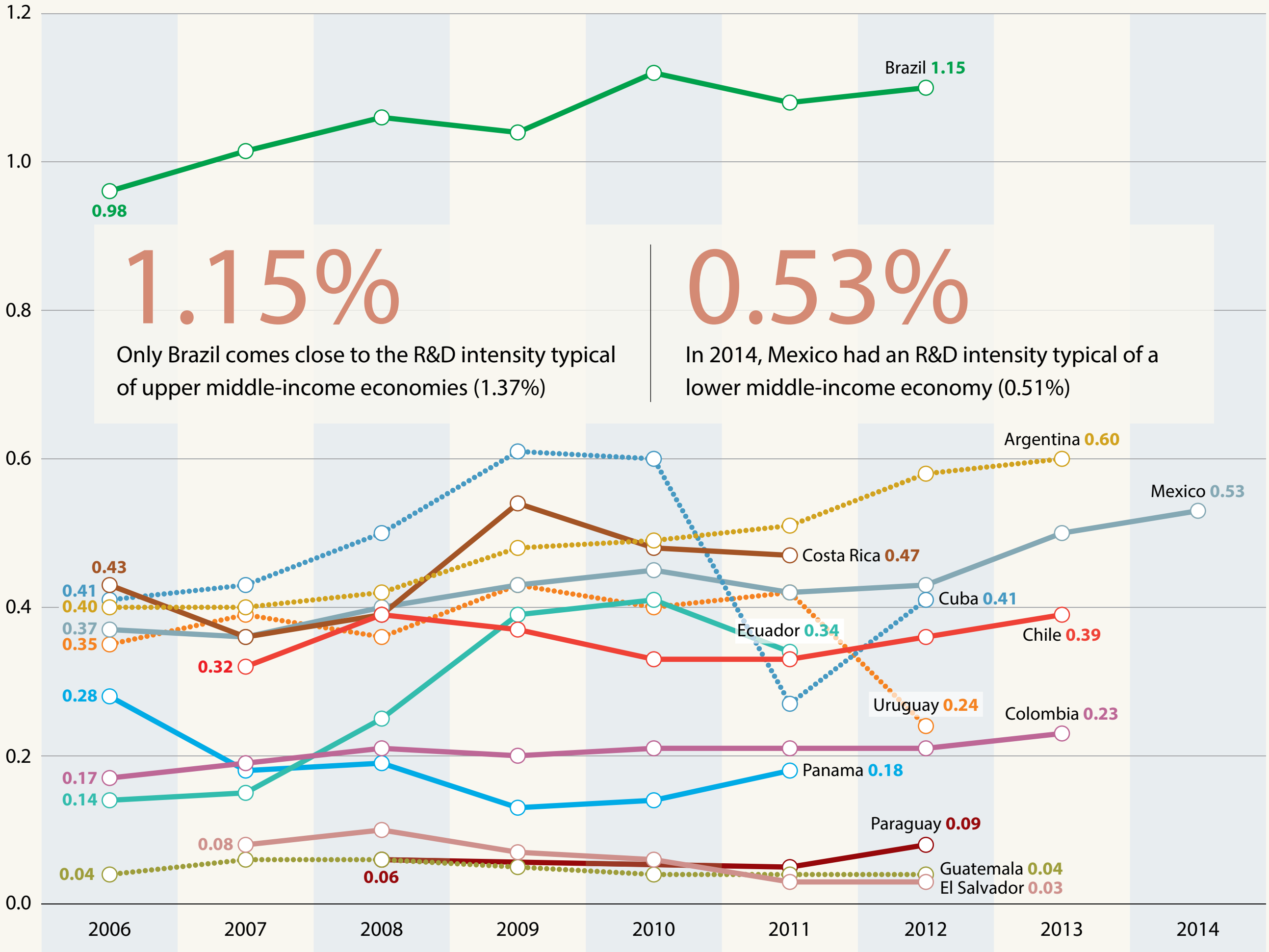
A breakdown of R&D expenditure by socio-economic objective is only available for a handful of countries. In 2012, Argentina and Chile allocated one-third of this expenditure to engineering and technology, a sizeable share for emerging economies. Both prioritized industrial and agricultural production 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

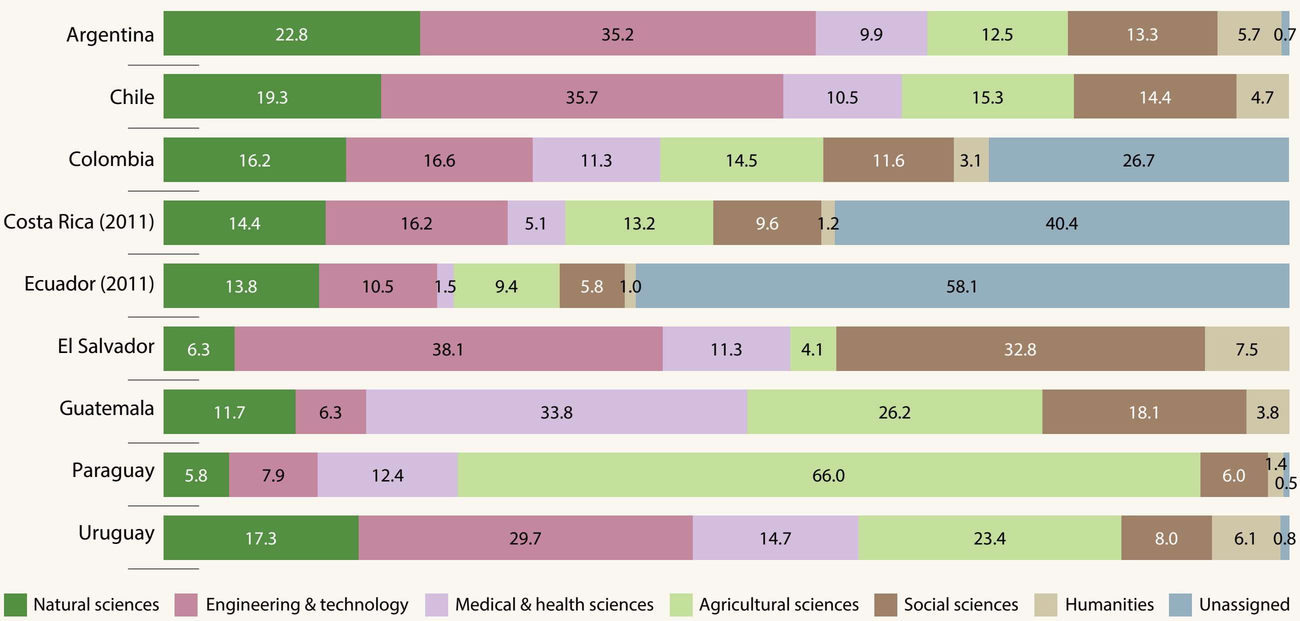
GERD as a share of GDP, 2006–2014 (%)



Note: Data are unavailable for Honduras, Nicaragua, Peru and Venezuela. Data are only available for Bolivia for 2009 (0.15%).

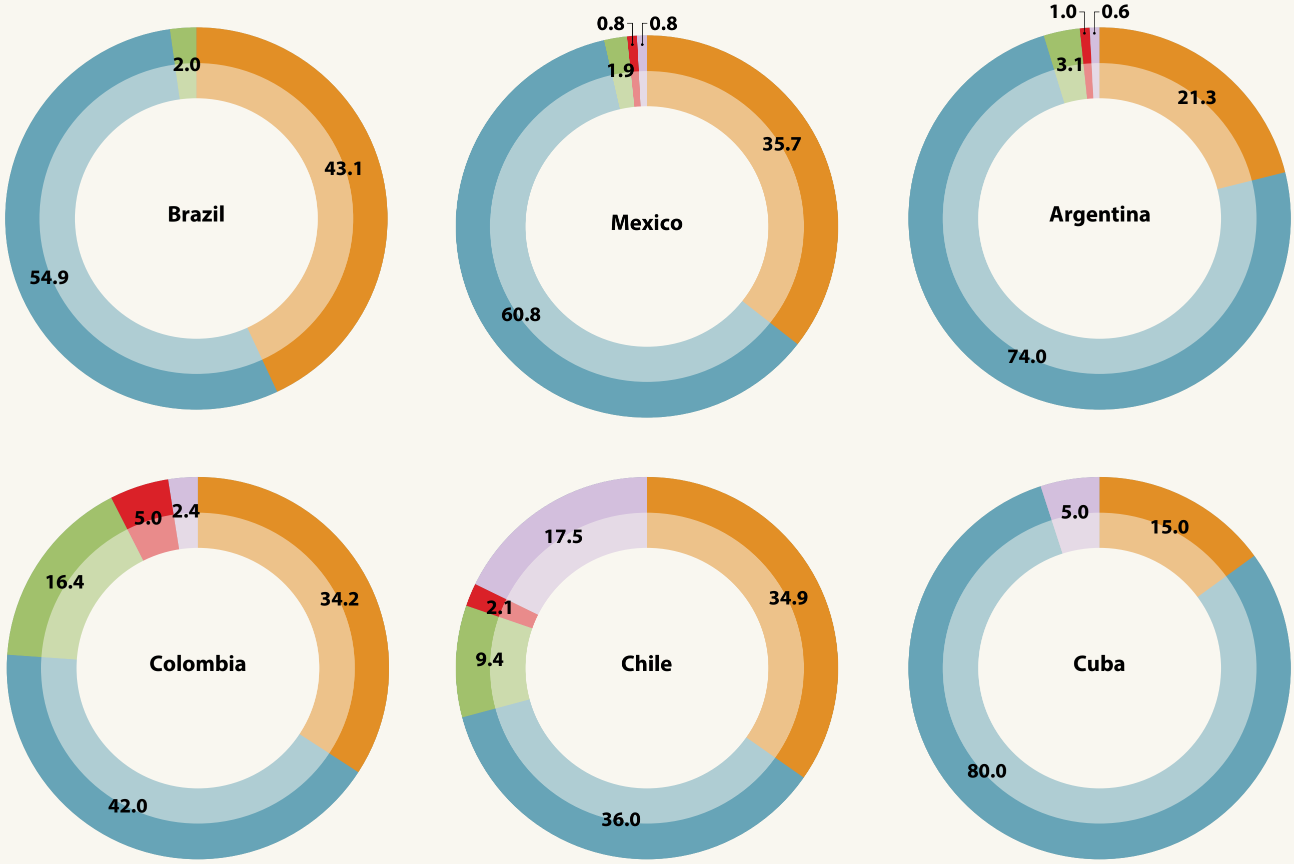
Agricultural sciences account for two-thirds of Paraguay's R&D expenditure

GERD by field of science, 2012 (%)

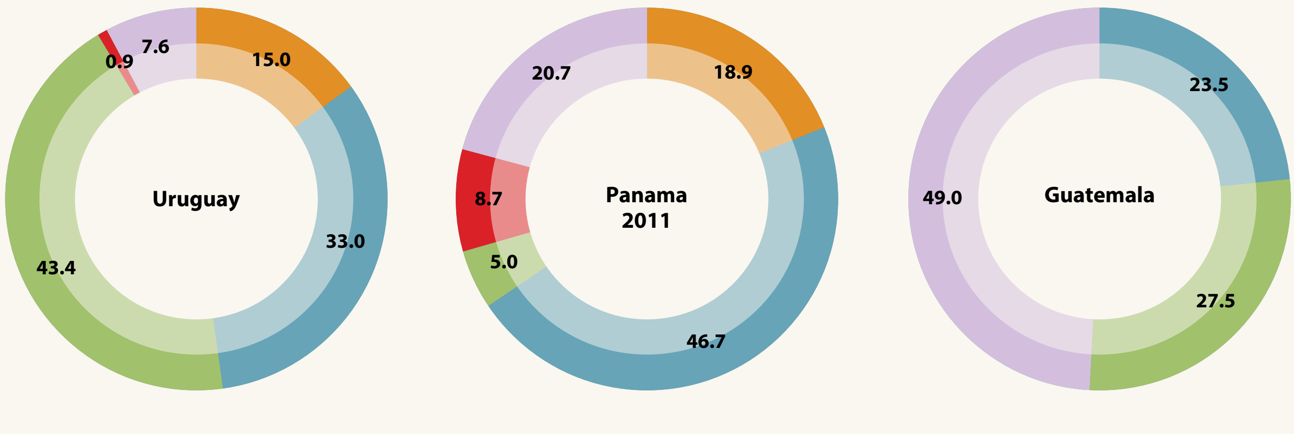


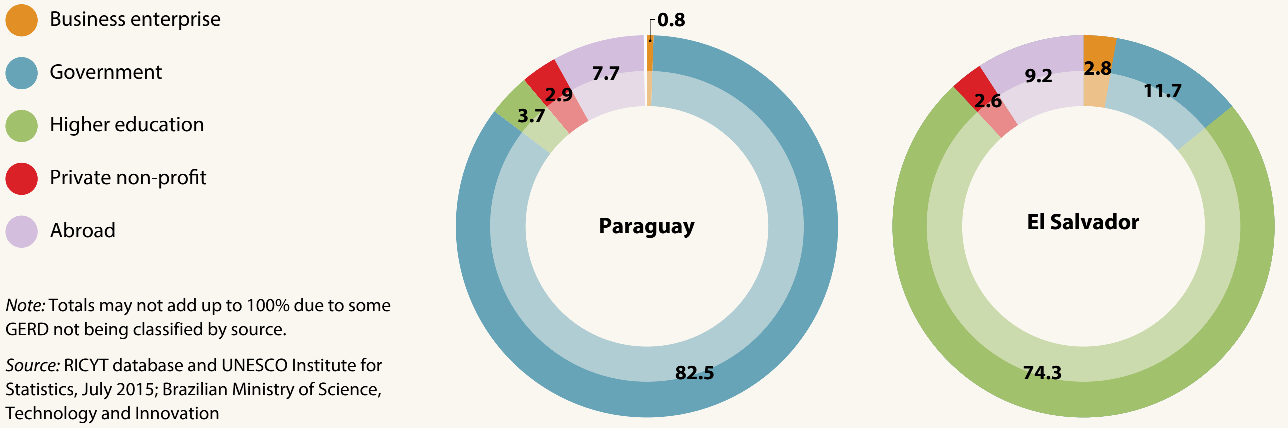
Brazil and Mexico have the highest share of business-funded R&D in Latin America

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

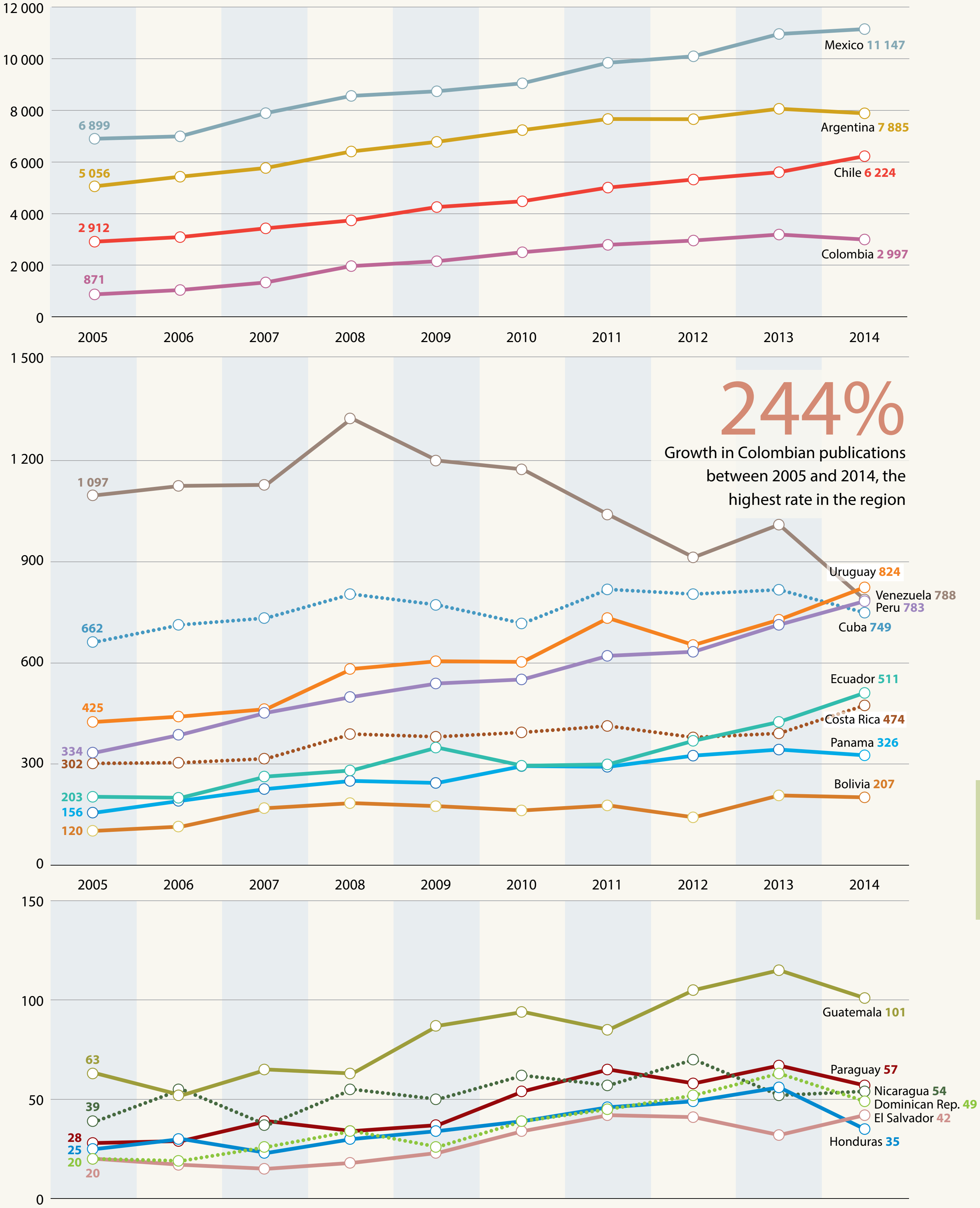
Figure 7.8: **Scientific publication trends in Latin America and the Caribbean, 2005–2014**

4.0% Latin America and the Caribbean's world share of publications in 2005

5.2% Latin American 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

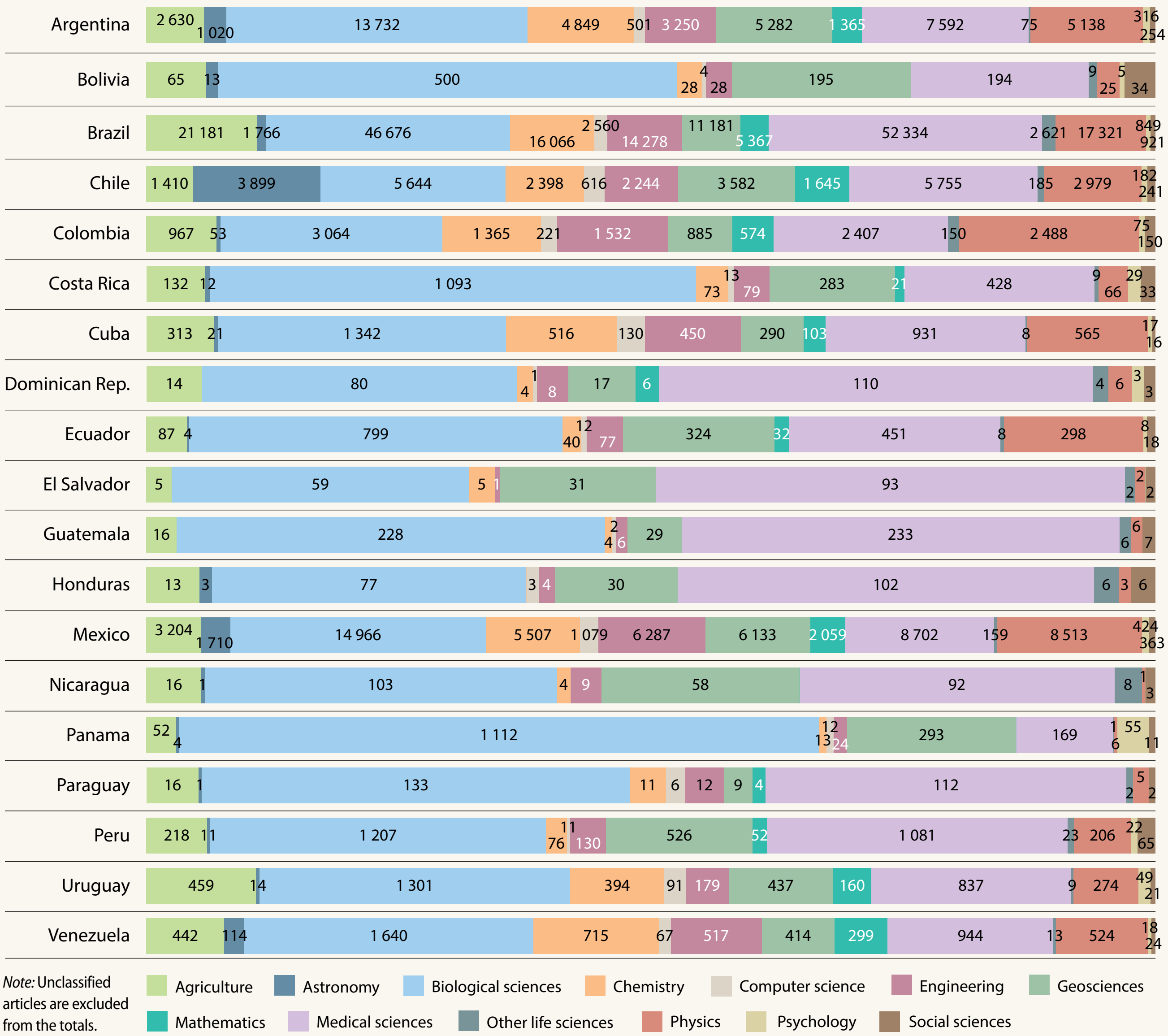


Chapter 7

Figure 7.8 *(continued)*

Life sciences dominate research in Latin America and the Caribbean

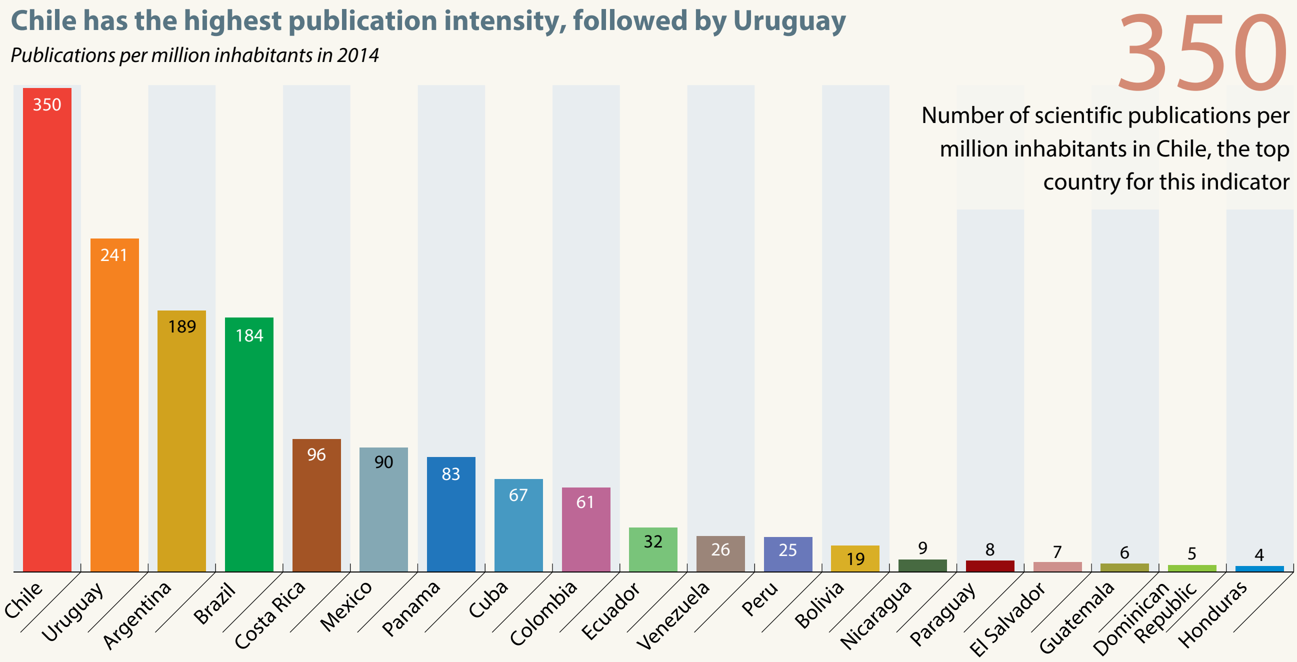
Cumulative totals by field, 2008–2014



Note: Unclassified articles are excluded from the totals.

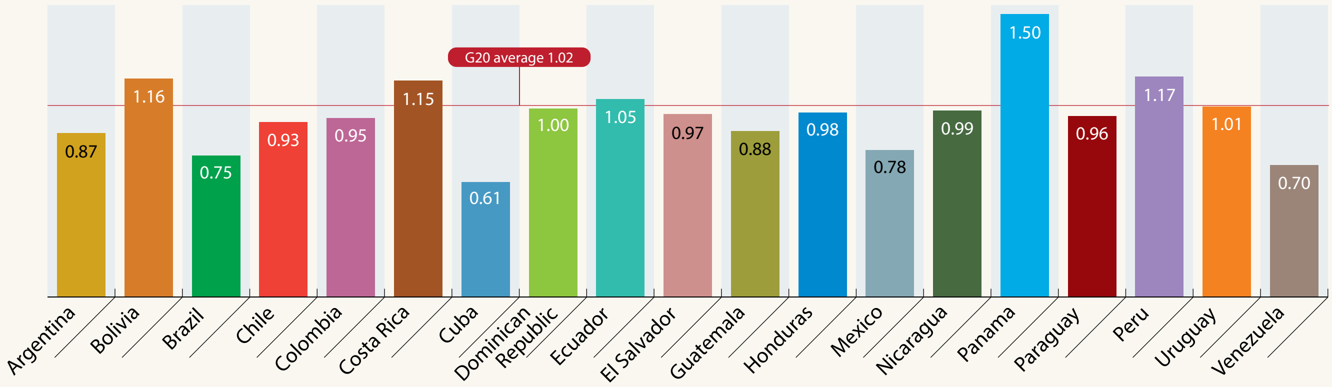
Chile has the highest publication intensity, followed by Uruguay

Publications per million inhabitants in 2014



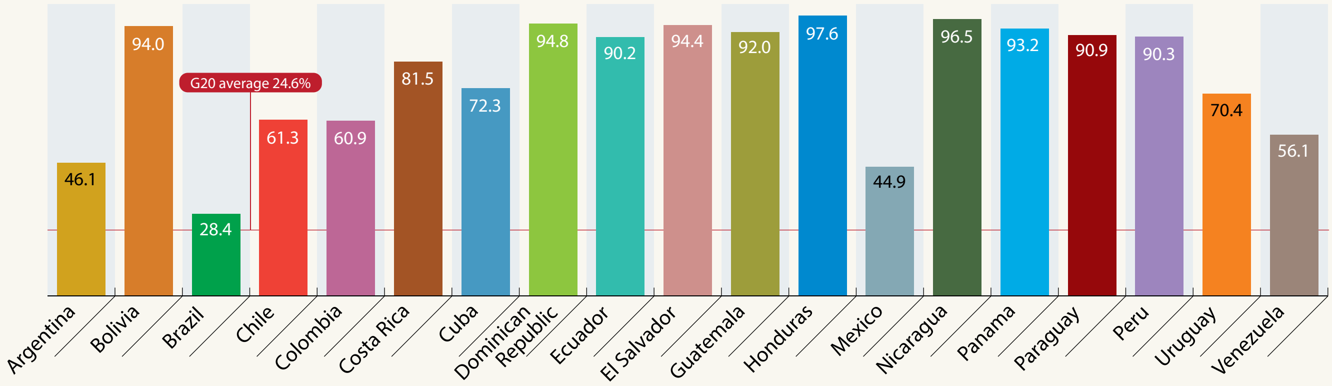
Countries with modest output have the highest average citation rate

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 the 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), 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.

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

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 ethnical 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).

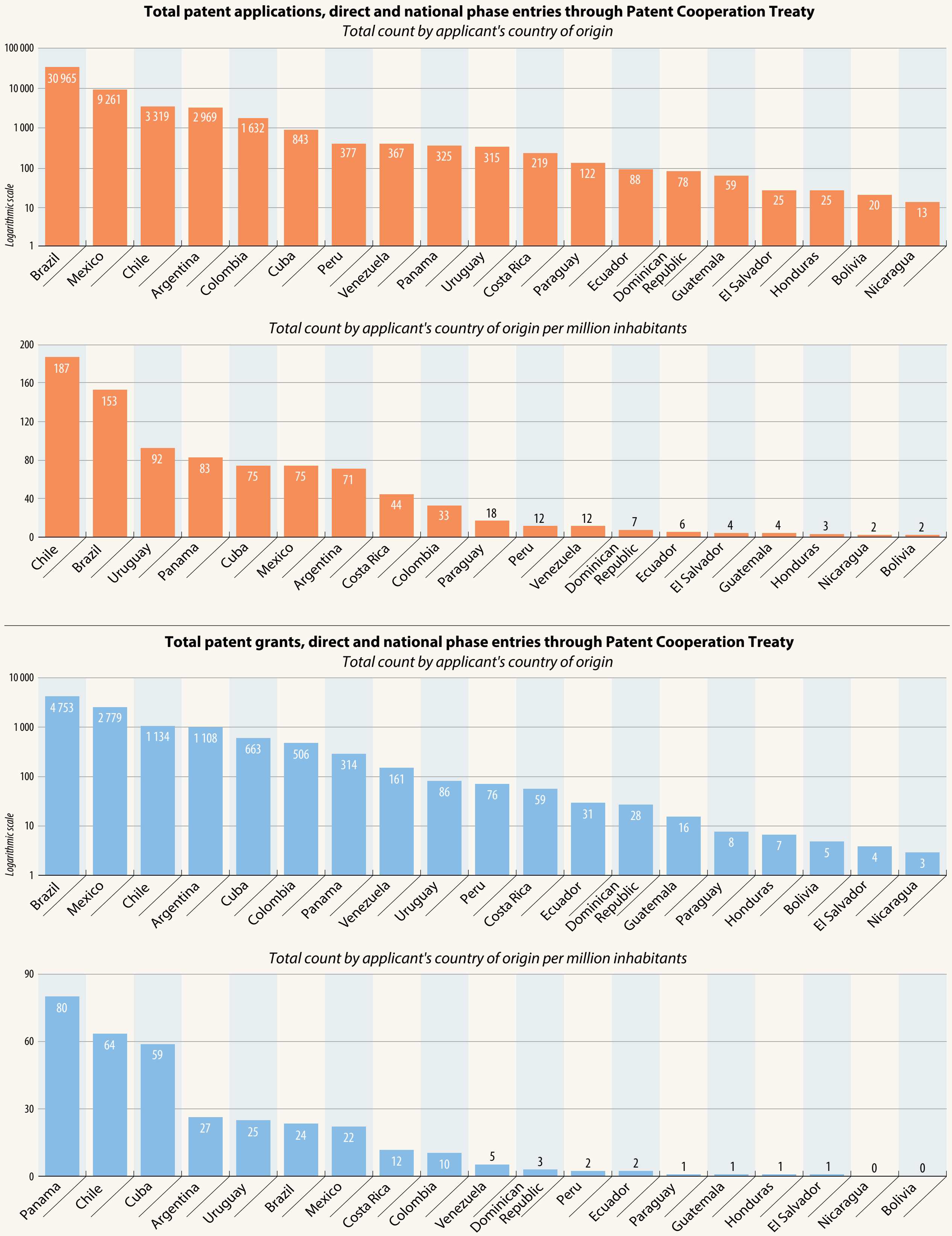
In 2013, the Mexican National Council for Science and Technology (CONACYT) stated that, within its strategic areas of growth, 'innovation will be oriented towards benefiting the less fortunate, with indigenous groups to receive special attention'. CONACYT subsequently announced a Call for Research into 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: Whirpool 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 (Prosocia) 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 Científíco 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

Chapter 7

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).

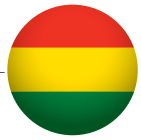
In 2012, the Ministry of Science, Technology and Productive Innovation (MINCYT) launched the *National Science, Technology and Innovation Plan: Innovative Argentina 2020*. The plan prioritizes the most scientifically underdeveloped regions by assigning 25% of all new posts at the National Scientific 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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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.

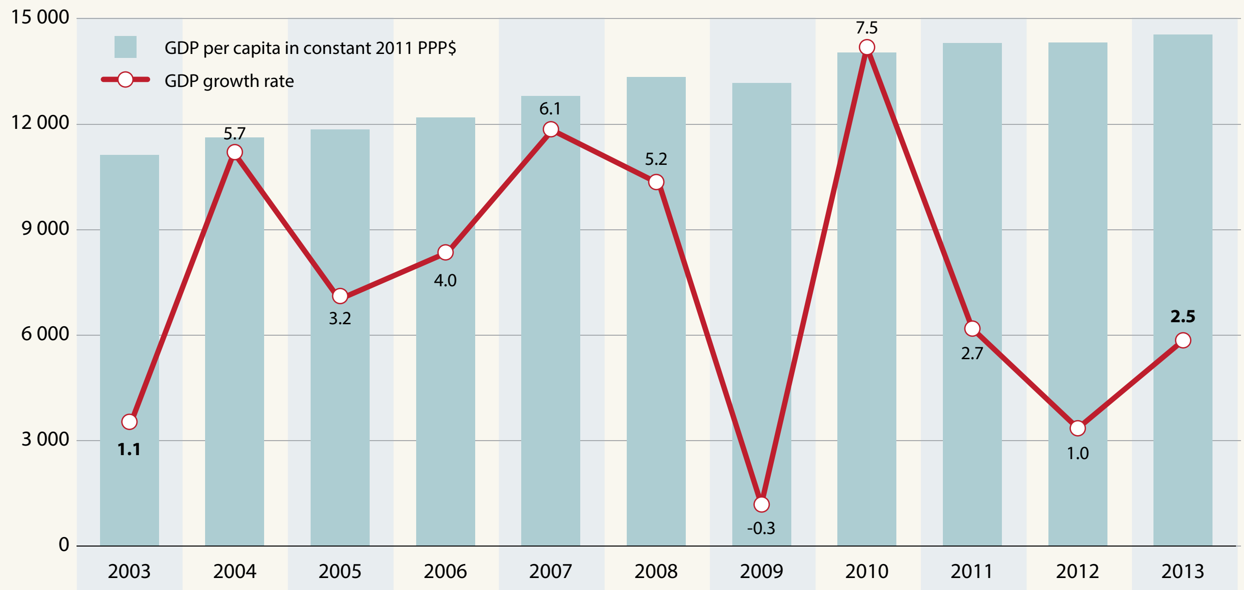
Social inclusion progressing more slowly

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 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.

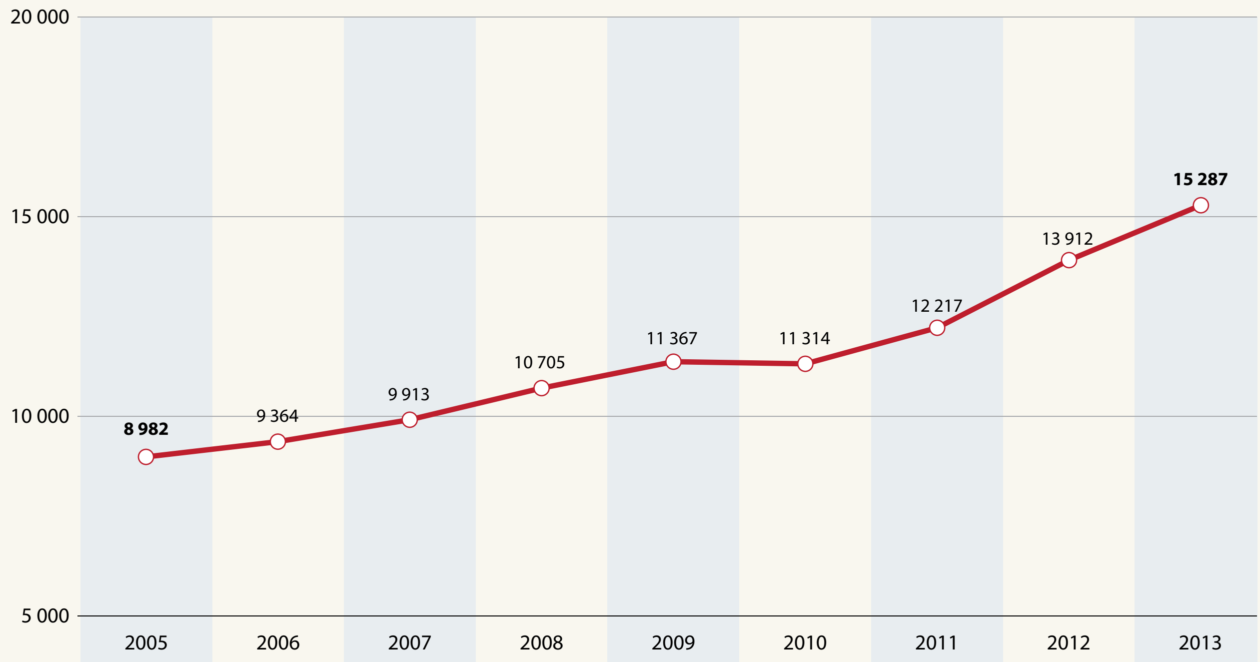
The programme also seeks to attract young researchers from abroad who might wish to settle in Brazil or establish partnerships with Brazilian researchers in the programme's priority areas, namely:

- 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).

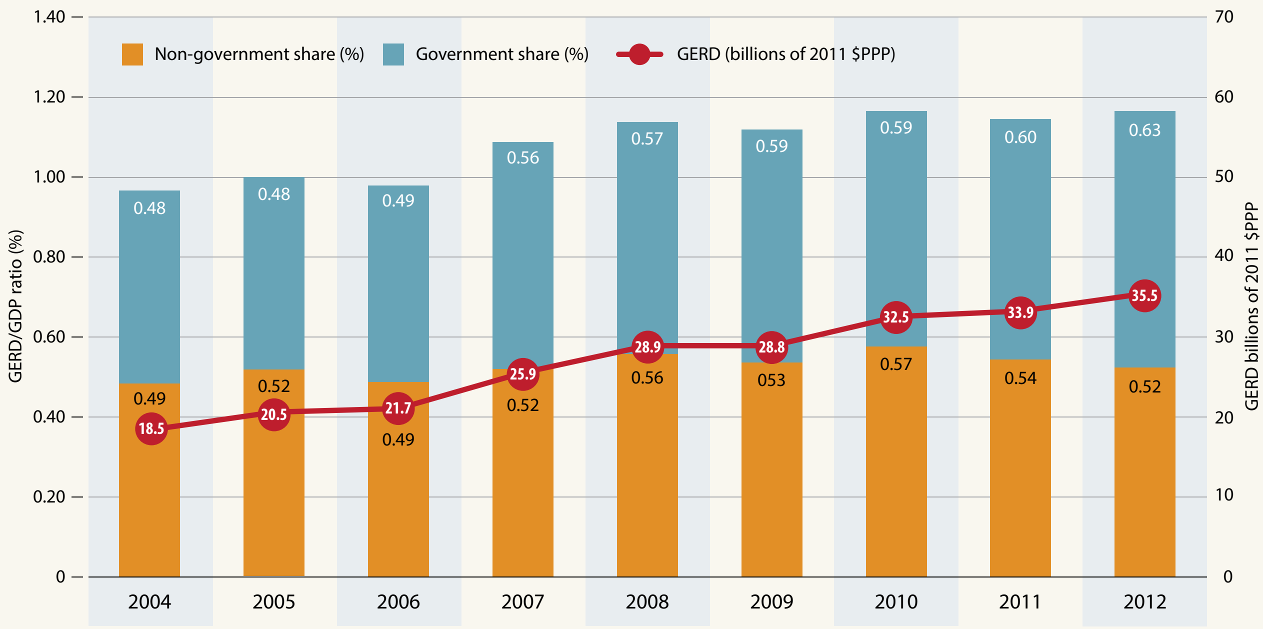
The gap between Brazil and advanced economies is much greater when it comes to human resources in R&D (Figure 8.5). Also striking is the sharp decline in the share of research personnel employed by the business sector in recent years (Figure 8.6). This is contrary to the trend observed in most developed 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

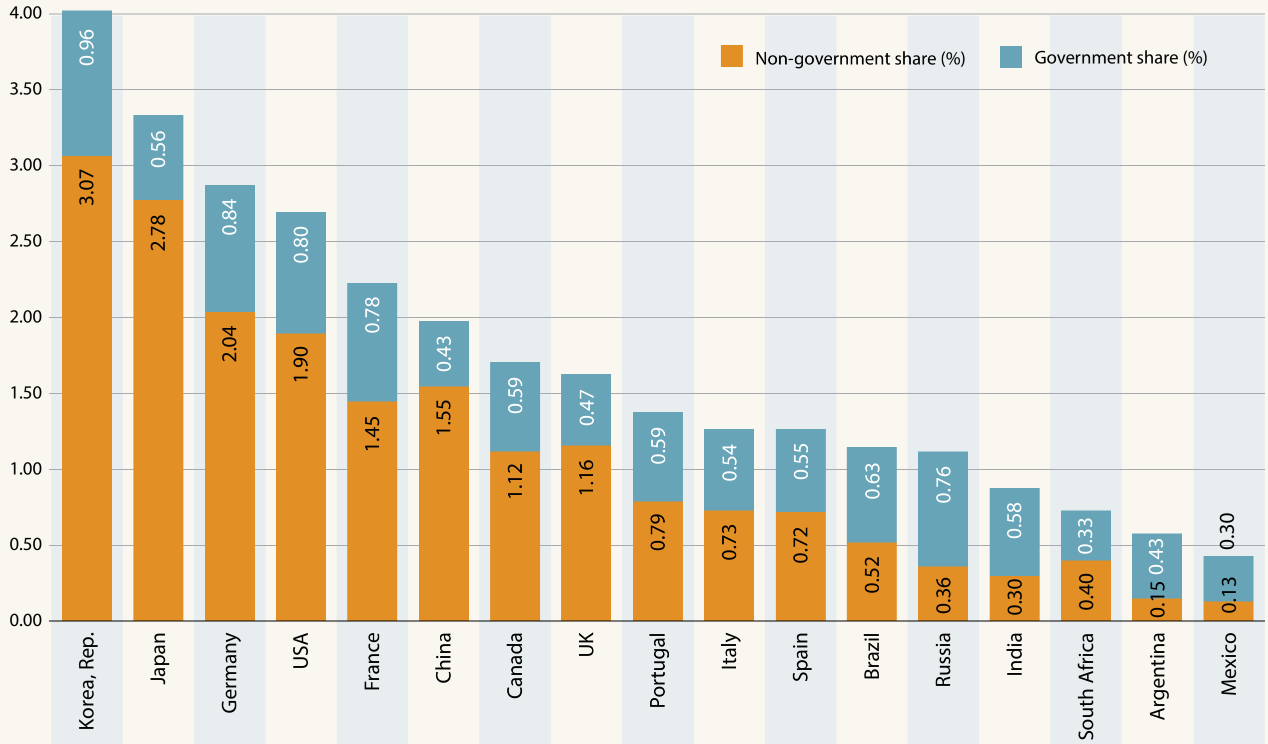


Note: The great majority of non-government funding comes from business enterprises. Private universities accounted for just 0.02–0.03% of GERD between 2004 and 2012. Figures 8.3 and 8.4 are based on updated GDP data for Brazil available as of September 2015 and may thus not match other indicators indexed 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 (%)**

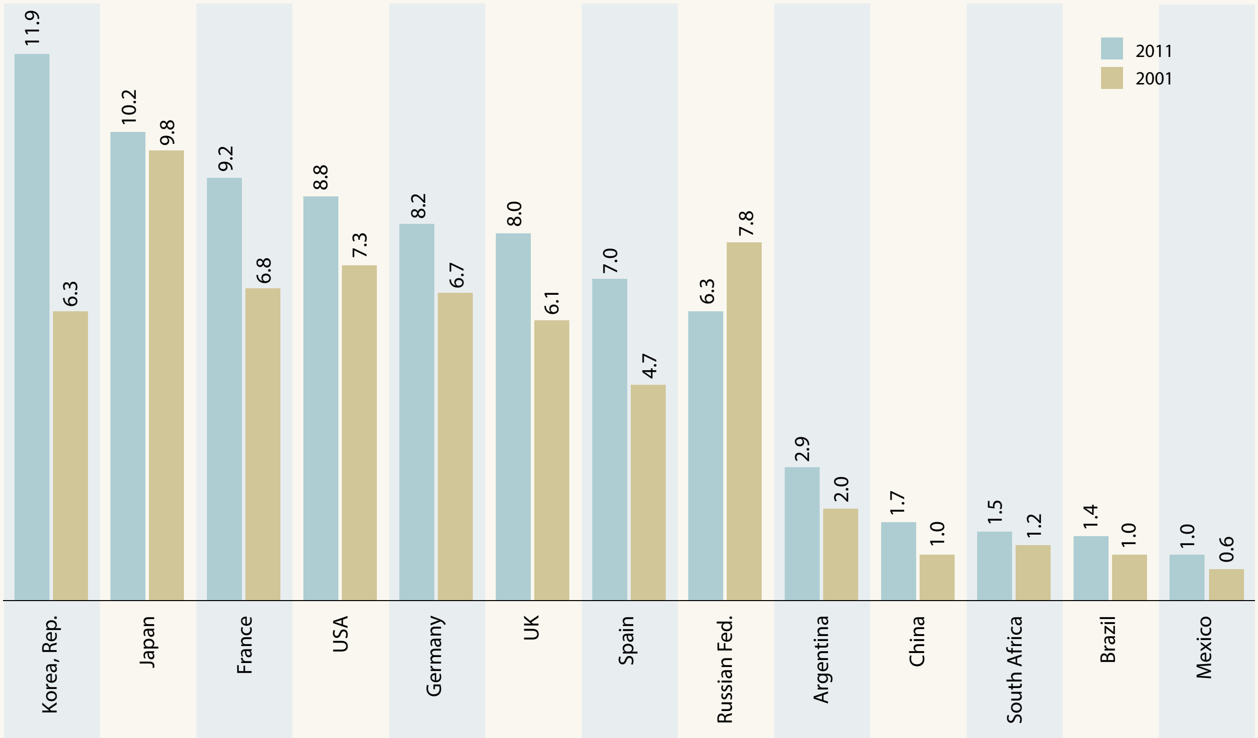
Other countries are given for comparison



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 (%)**

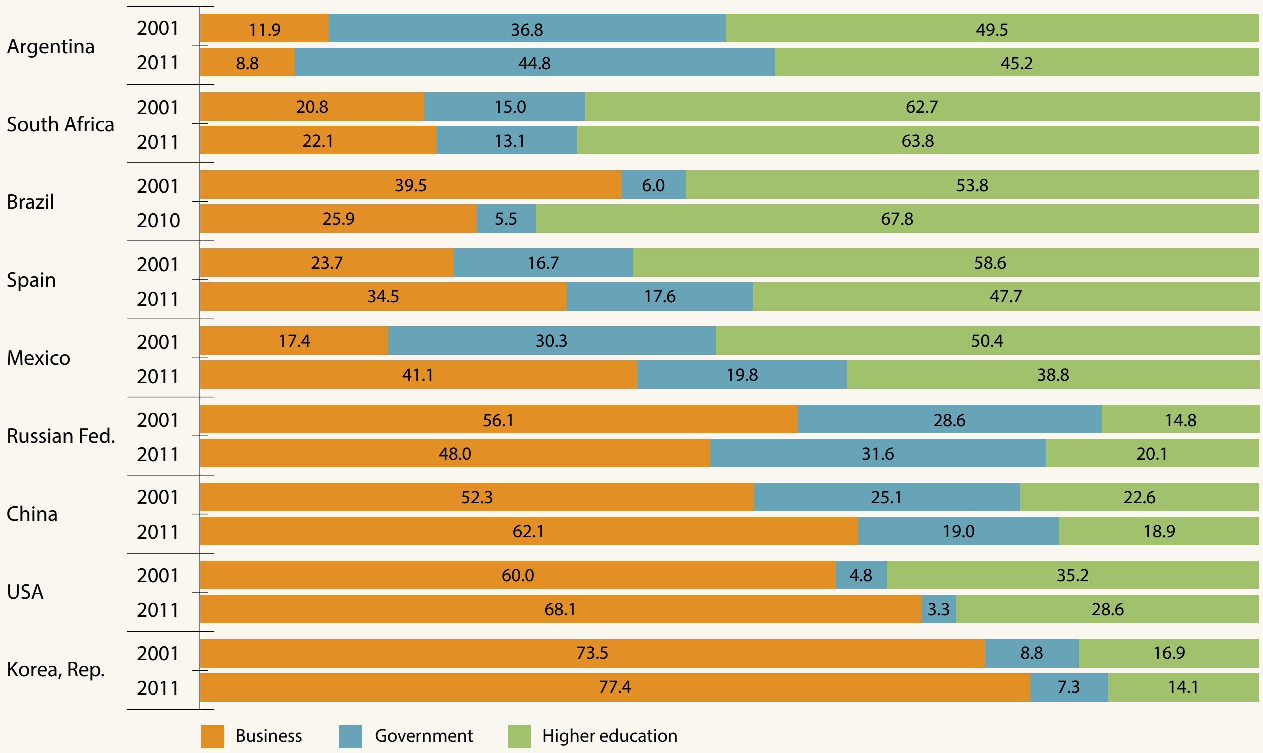
Other countries are given for comparison



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 and information 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.

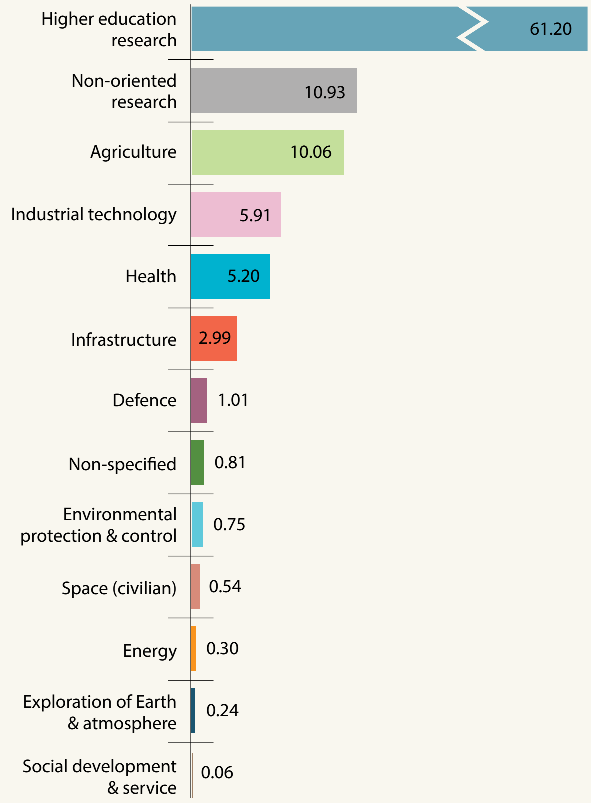
With some exceptions, the distribution of government spending on R&D in 2012 is similar[8] to that in 2000. After a sharp increase in industrial technology from 1.4% to 6.8%

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

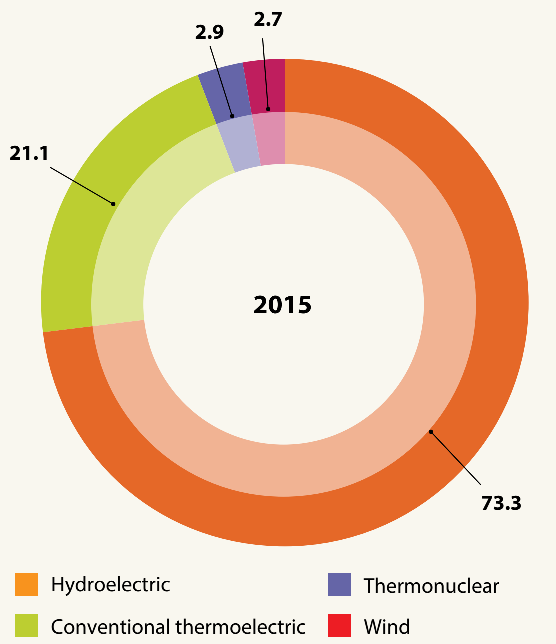
Intensive use of thermoelectric power plants operating on fossil fuels has compensated for much of the loss, since the share of new sources of renewable energy, such as solar and wind, in the energy mix remains small. Moreover, although Brazil has made great strides in the use of bioethanol in transportation, 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.

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. 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.

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/

9. See: http://iopppublishing.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.

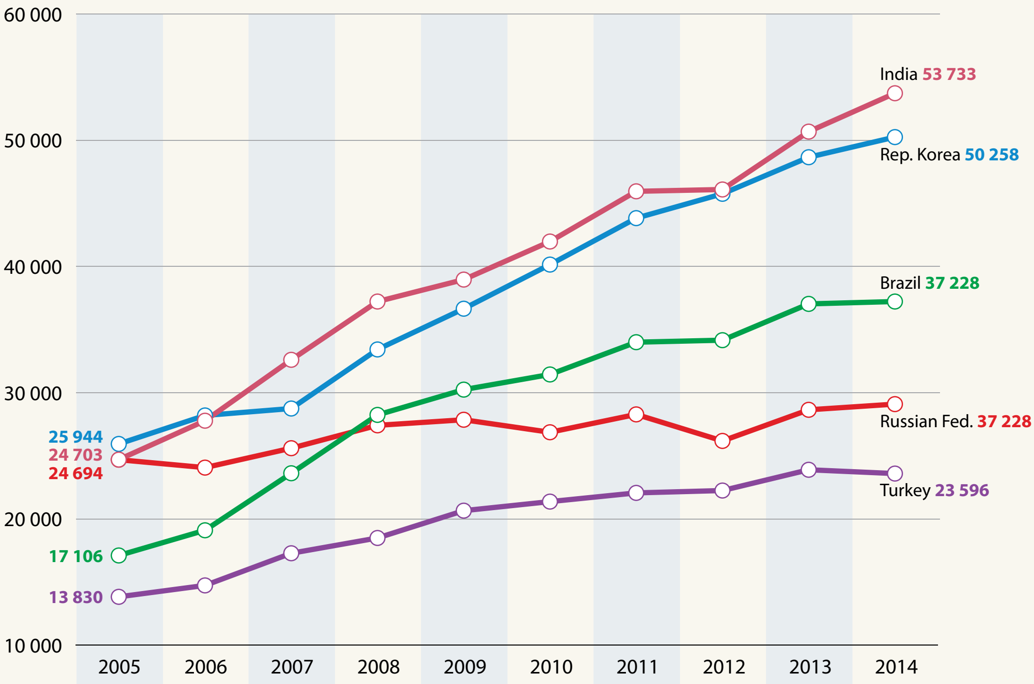
Patent applications to the Brazilian Patent Office (INPI) increased from 20 639 in 2000 to 33 395 in 2012, progressing by 62%. This rate pales in comparison with that of scientific publications over the same period (308%). Moreover, if one considers only patent applications by residents, the growth rate 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

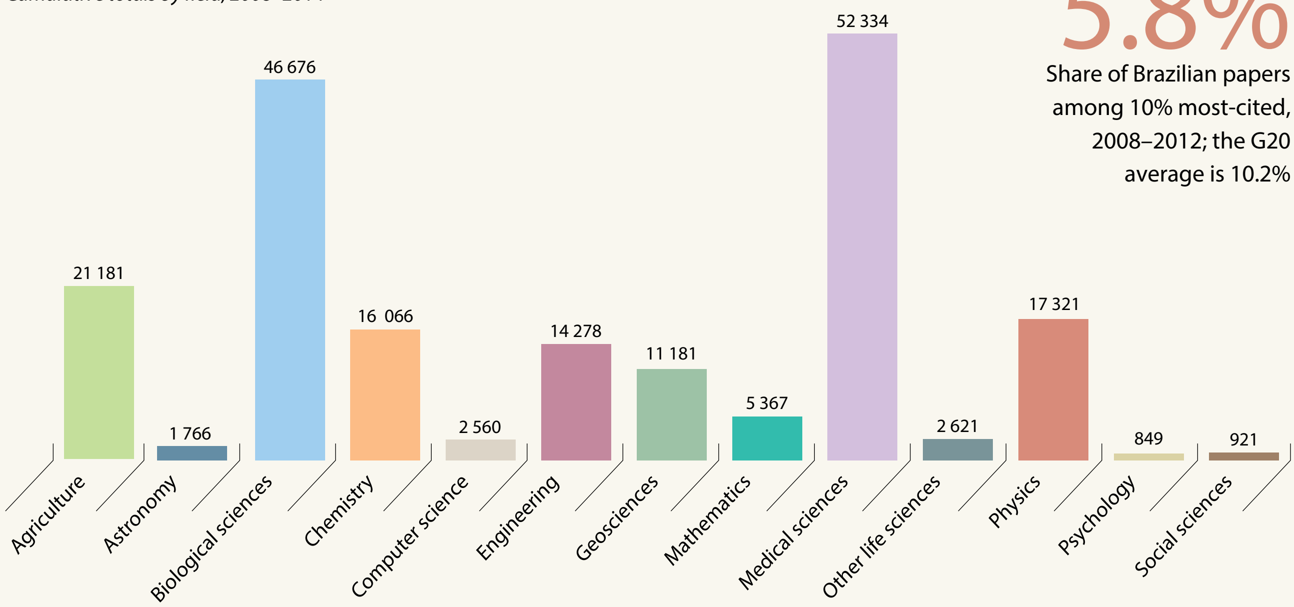
Publications per million inhabitants in 2014

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

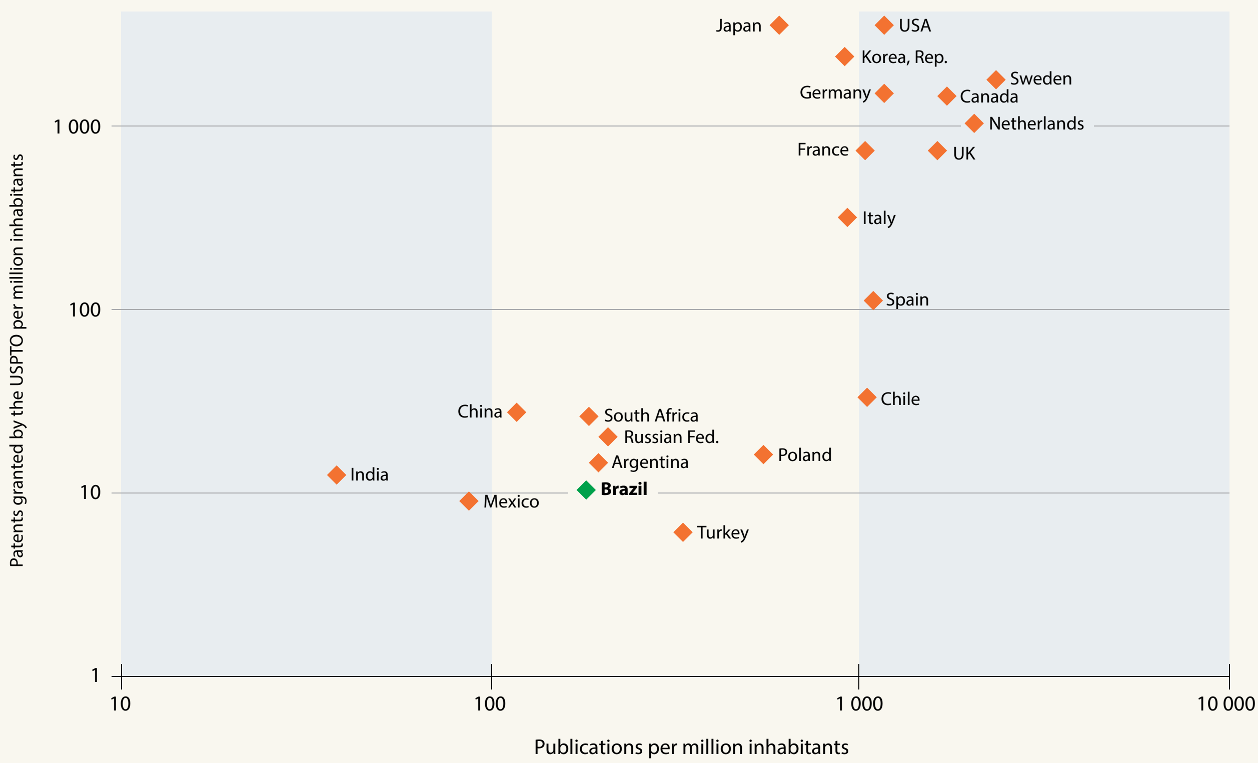
Table 8.1: **Invention patents granted to Brazilians by USPTO, 2004–2008 and 2009–2013**

	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).

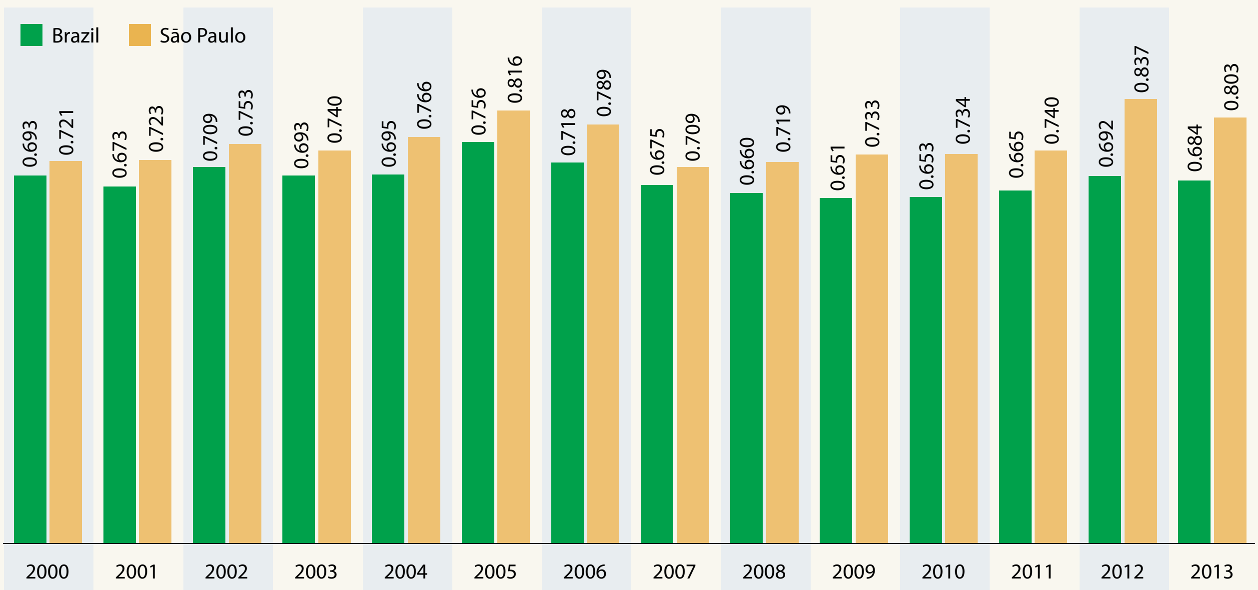
Two key factors explain São Paulo's success in scientific output: firstly, a well-funded system of state universities, including the University of São Paulo, University of Campinas (Unicamp) and the State University of São Paulo (Figure 8.12), all of which have been included in international university 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**

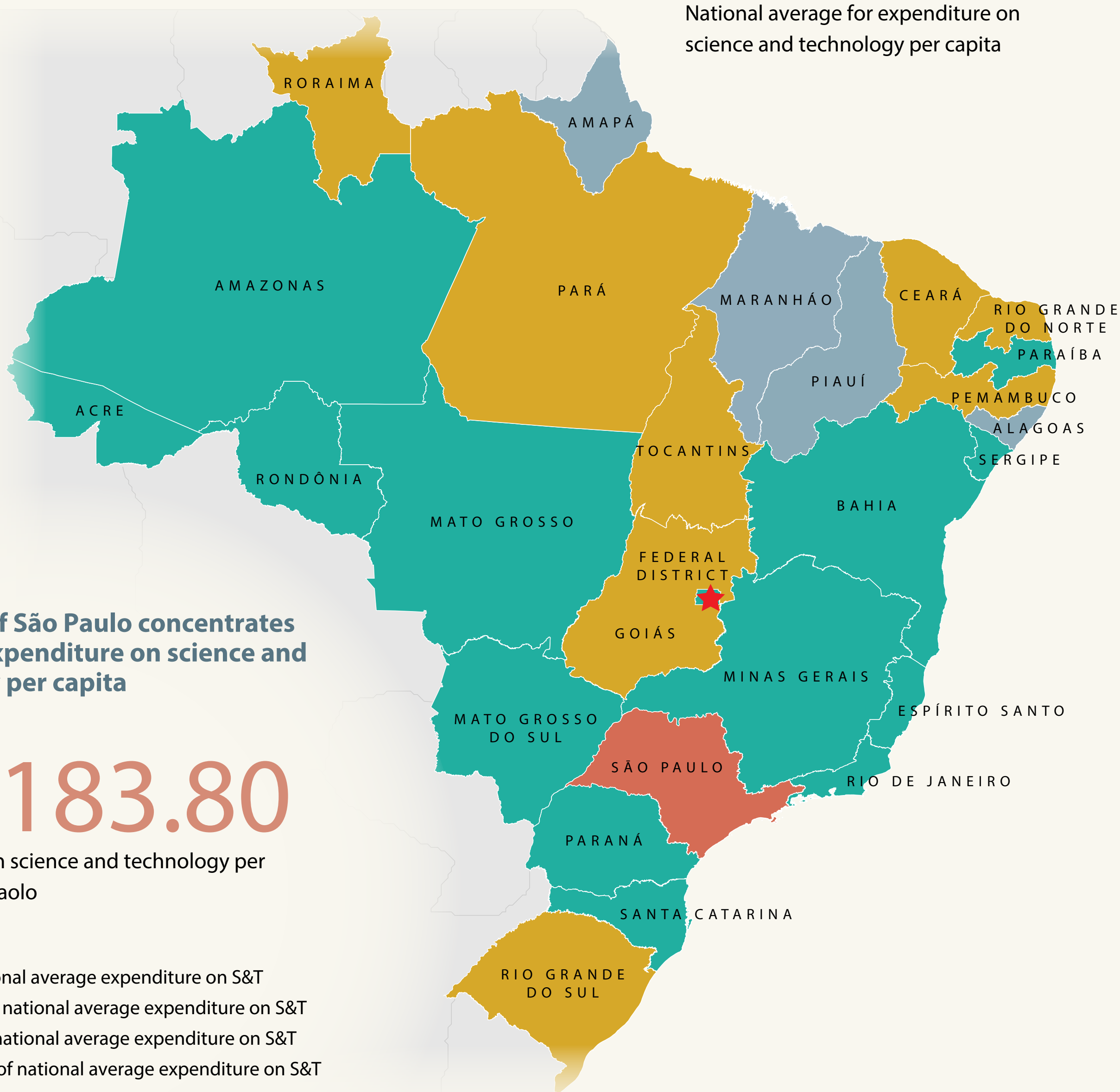


Source: InCites/Thomson Reuters, October 2014

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

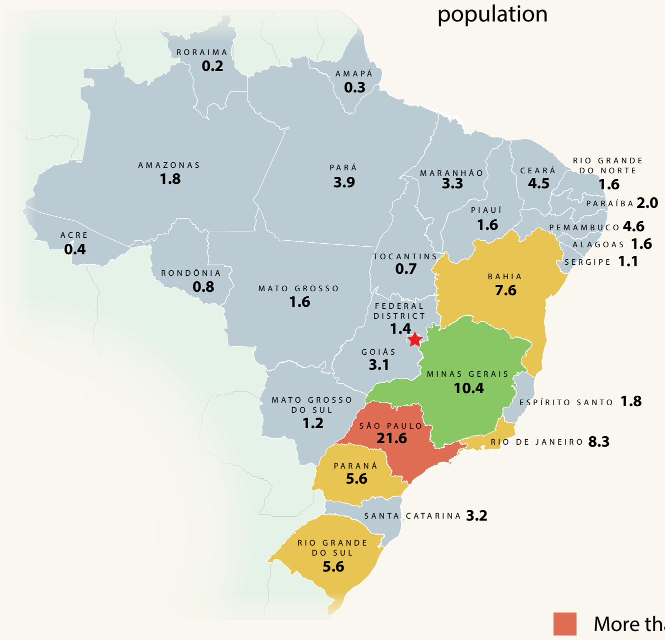
Research universities in Brazil

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%

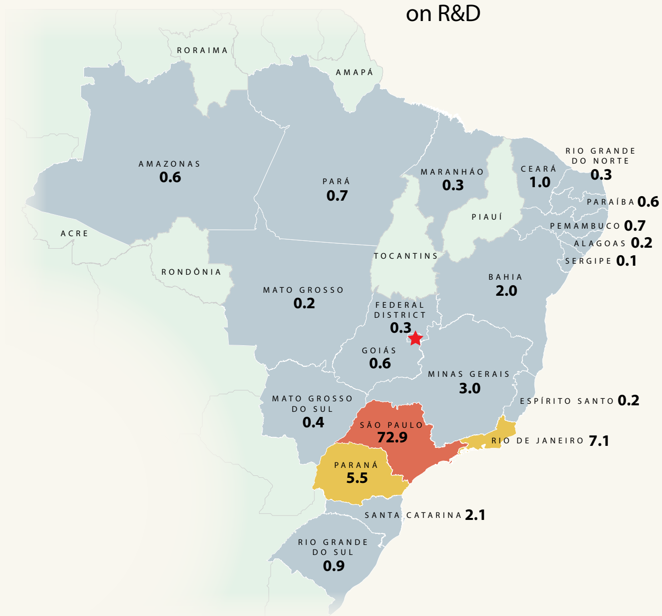
State of São Paulo's share of Brazilian population



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

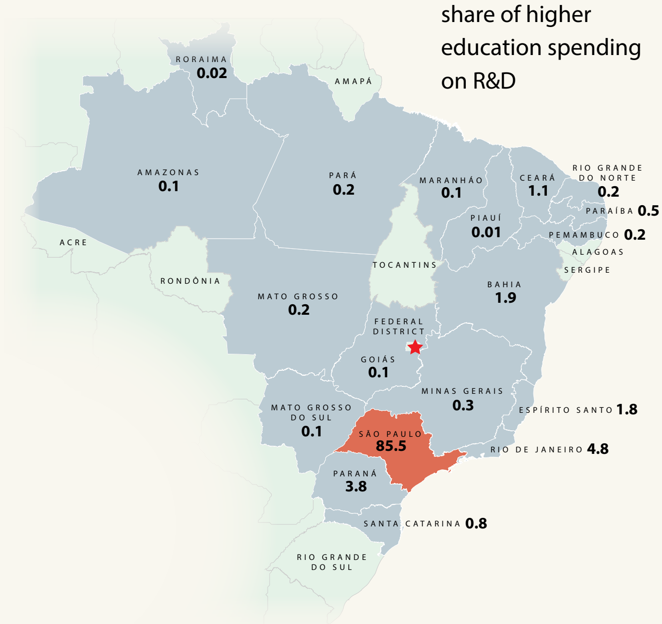
Data unavailable

Number of research universities

São Paulo dominates higher education spending on R&D

86%

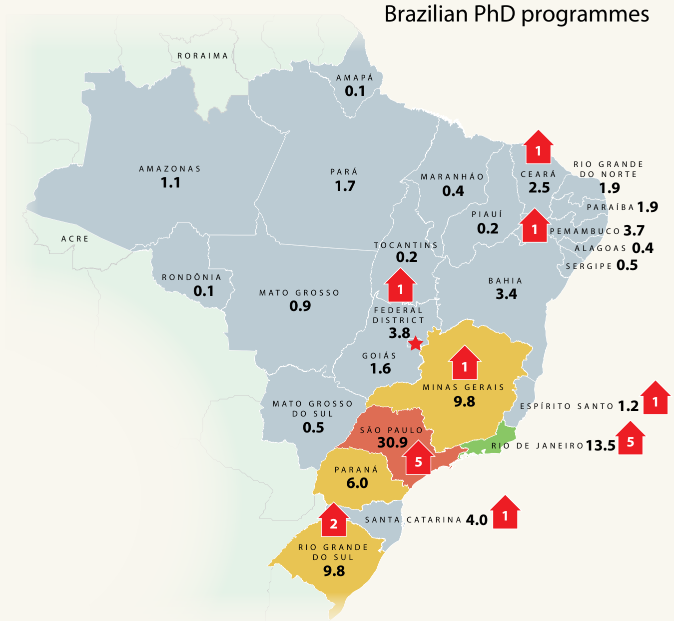
State of São Paulo's share of higher education spending on R&D



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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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 have the status of potential candidates.[1] 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. See also Chapter 10 on Southeast Europe and go to: http://ec.europa.eu/enlargement/countries/check-current-status/index_en.htm

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

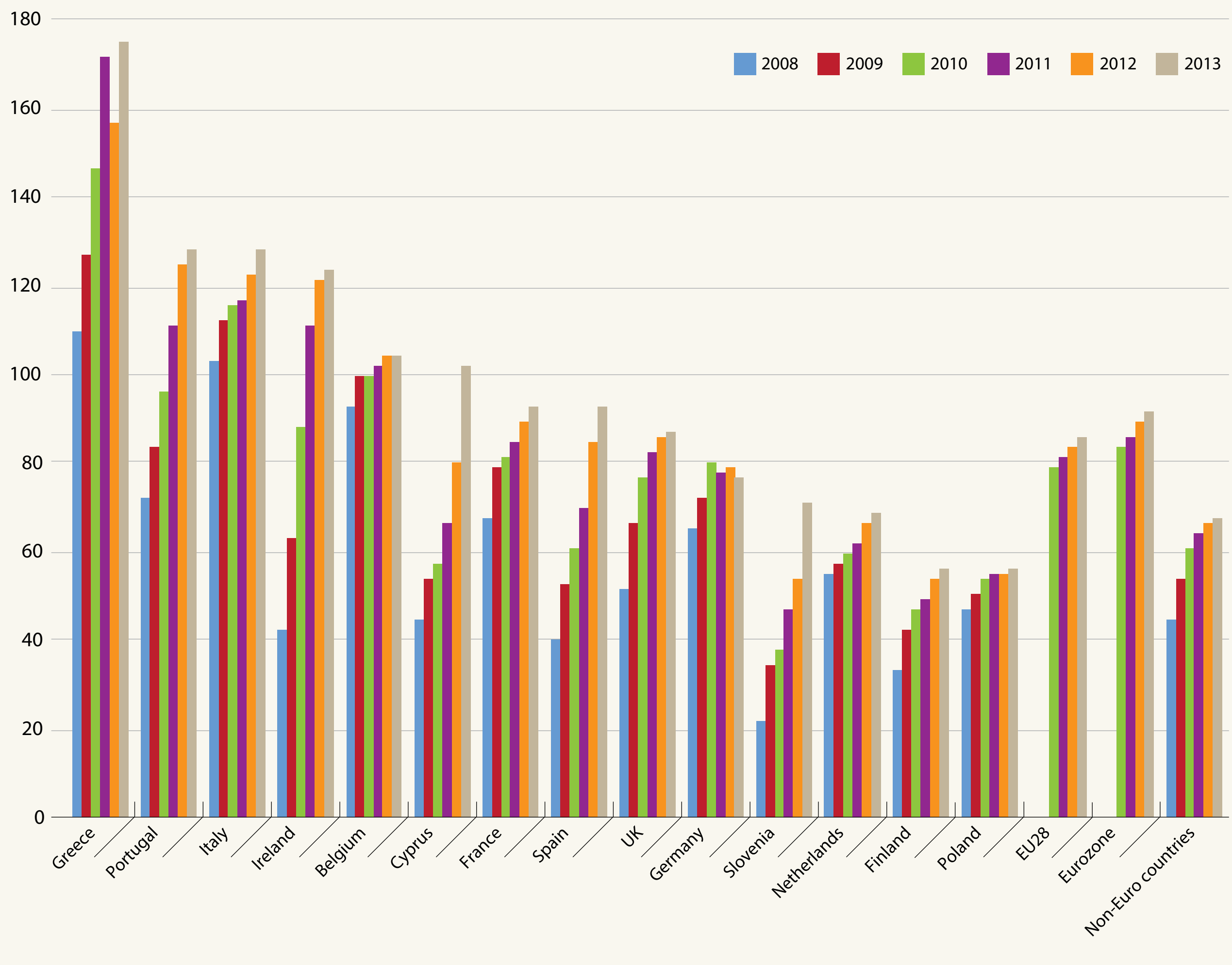
Source: Eurostat

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 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.

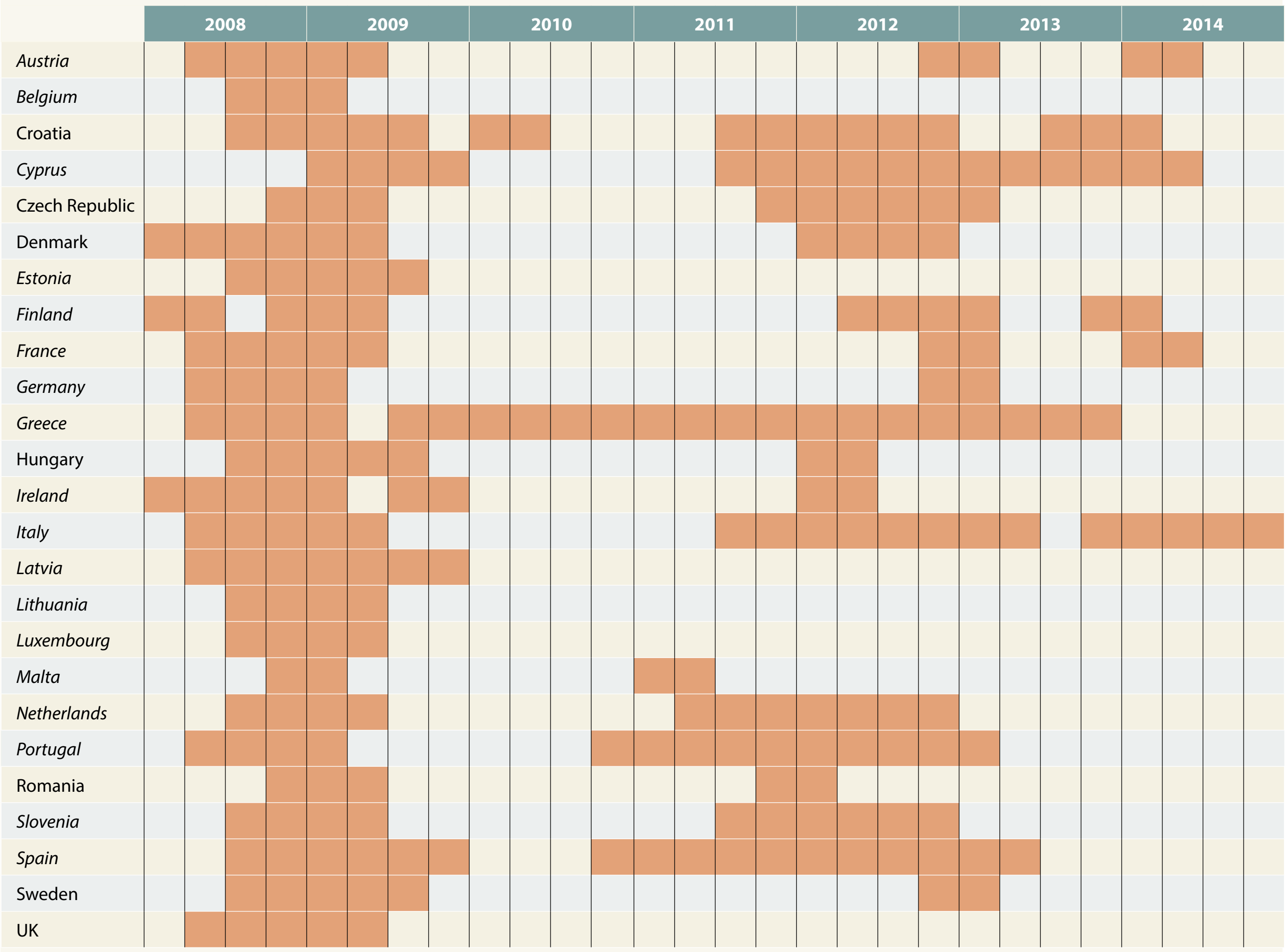
A serious debt crisis in the Eurozone

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 International Monetary 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 support 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.

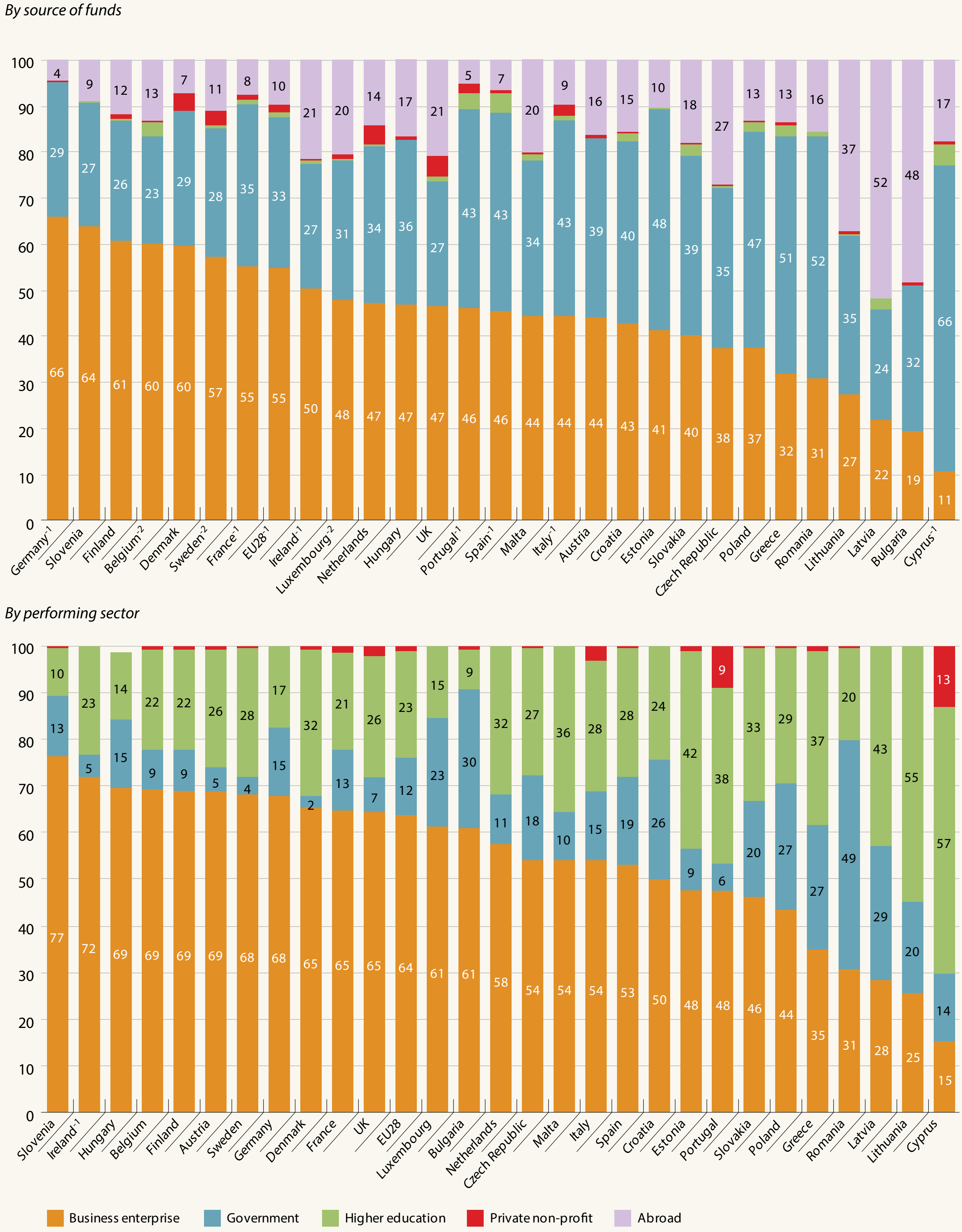
The EU is largely absent from the arena of internet-based companies active in new and emerging forms of innovation. According to Downes (2015), none of the 15 largest public internet companies today are European. Eleven are US-based and the remainder are Chinese. Indeed, the EU's attempts to replicate 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 (%)**

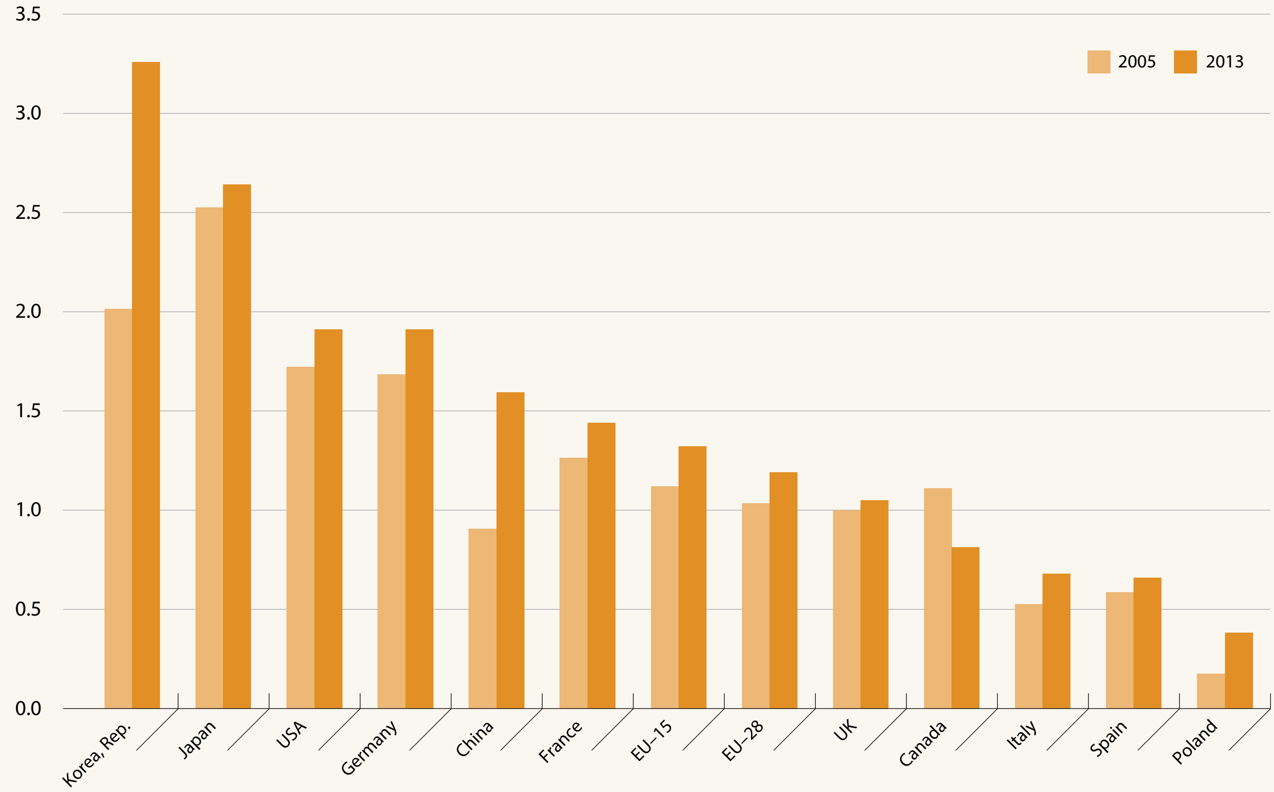


-*n* = data refer to *n* years before reference year

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
Fita	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 producers	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

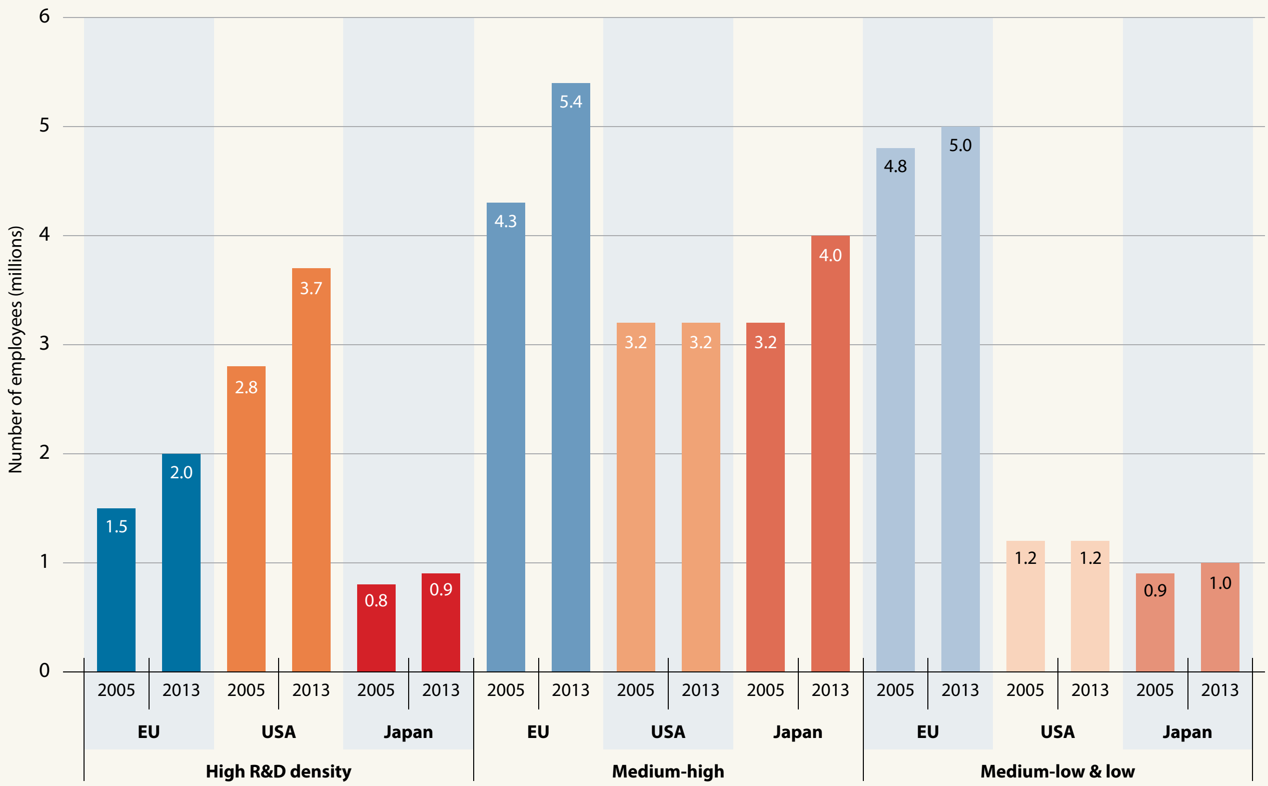
Table 9.6: **EU and US companies in selected R&D-intensive sectors, 2013**

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.

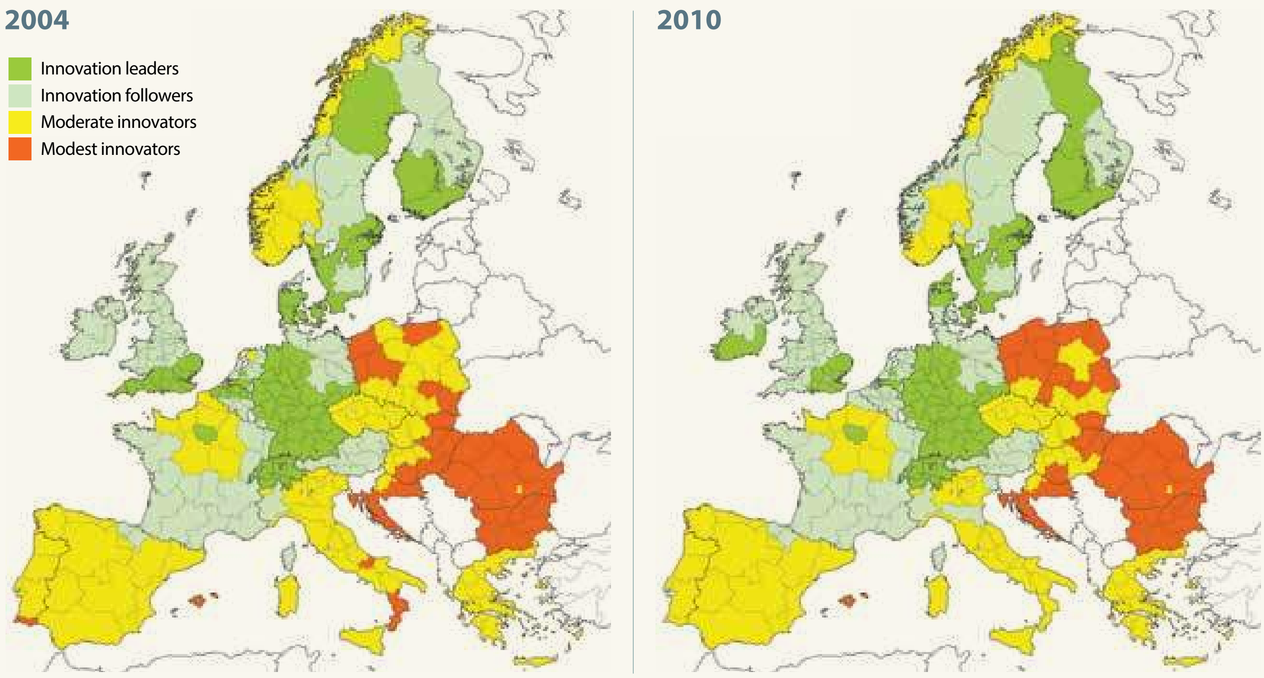
Source: Hernández *et. al* (2014), Figure S3

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 new 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 JRC	**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 of 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

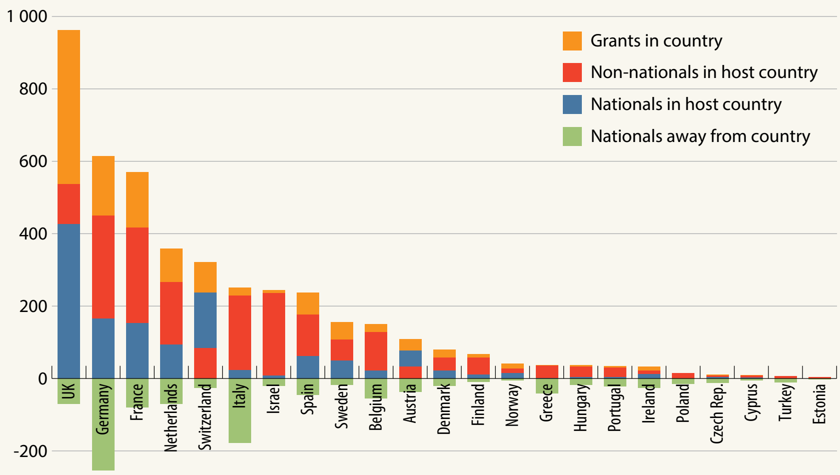
A scheme open to researchers everywhere

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*

Croatia and Romania performed about as well as the ten other 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 of Education and Science 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 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).

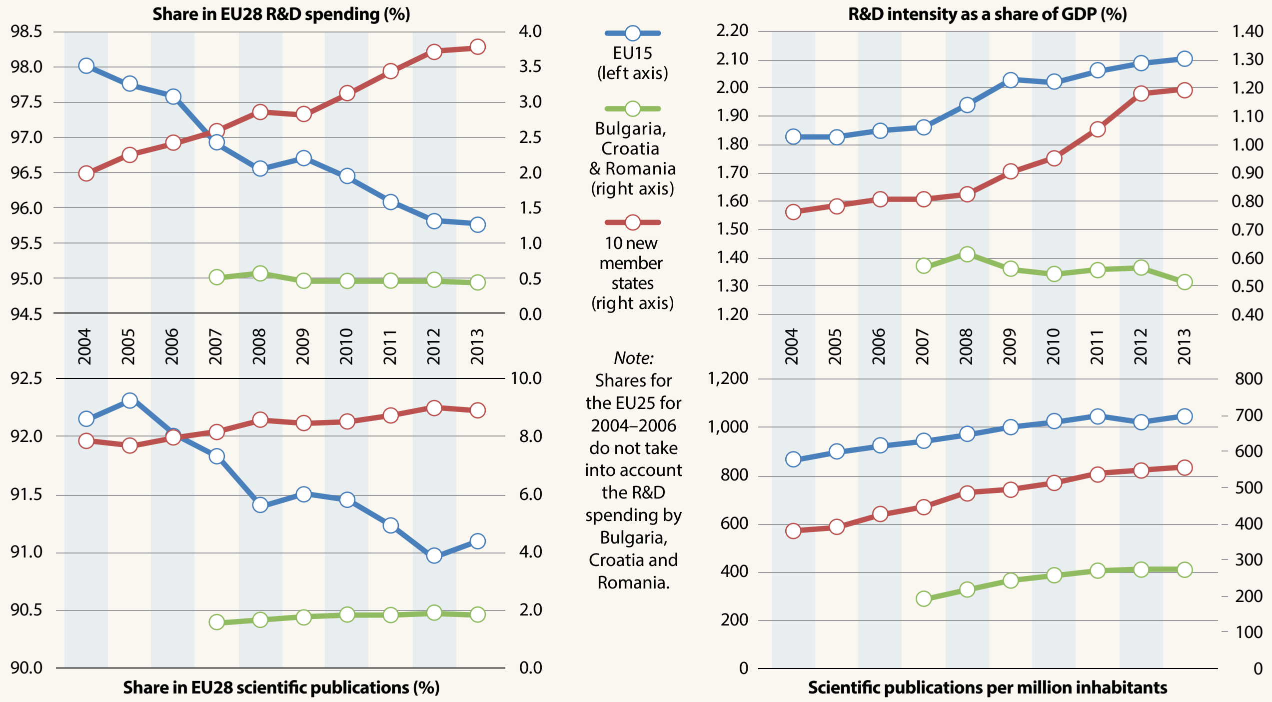
The EU intends for China to remain an important partner of Horizon 2020, even though China is no longer eligible for funding from the European Commission, meaning that EU

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

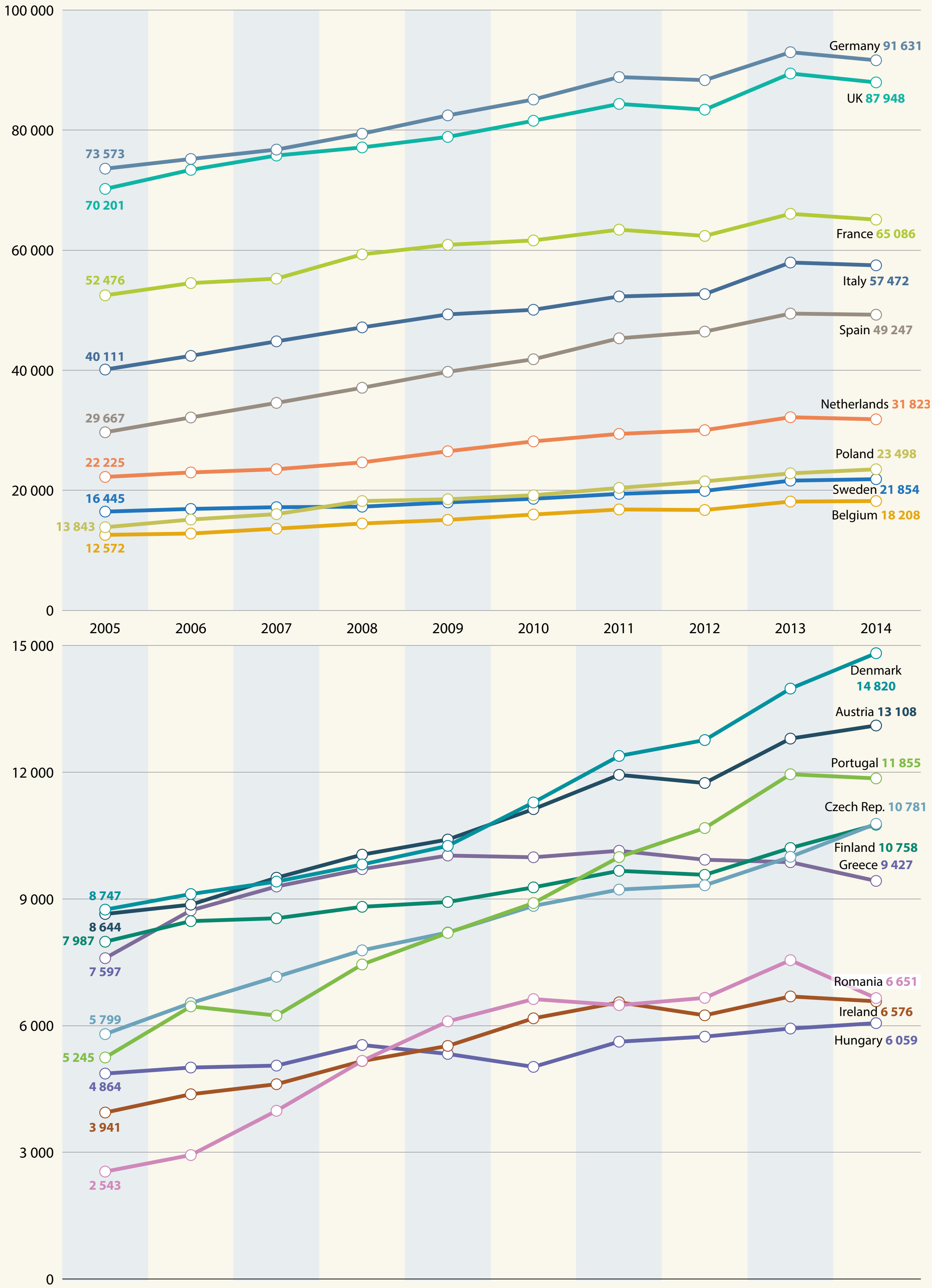
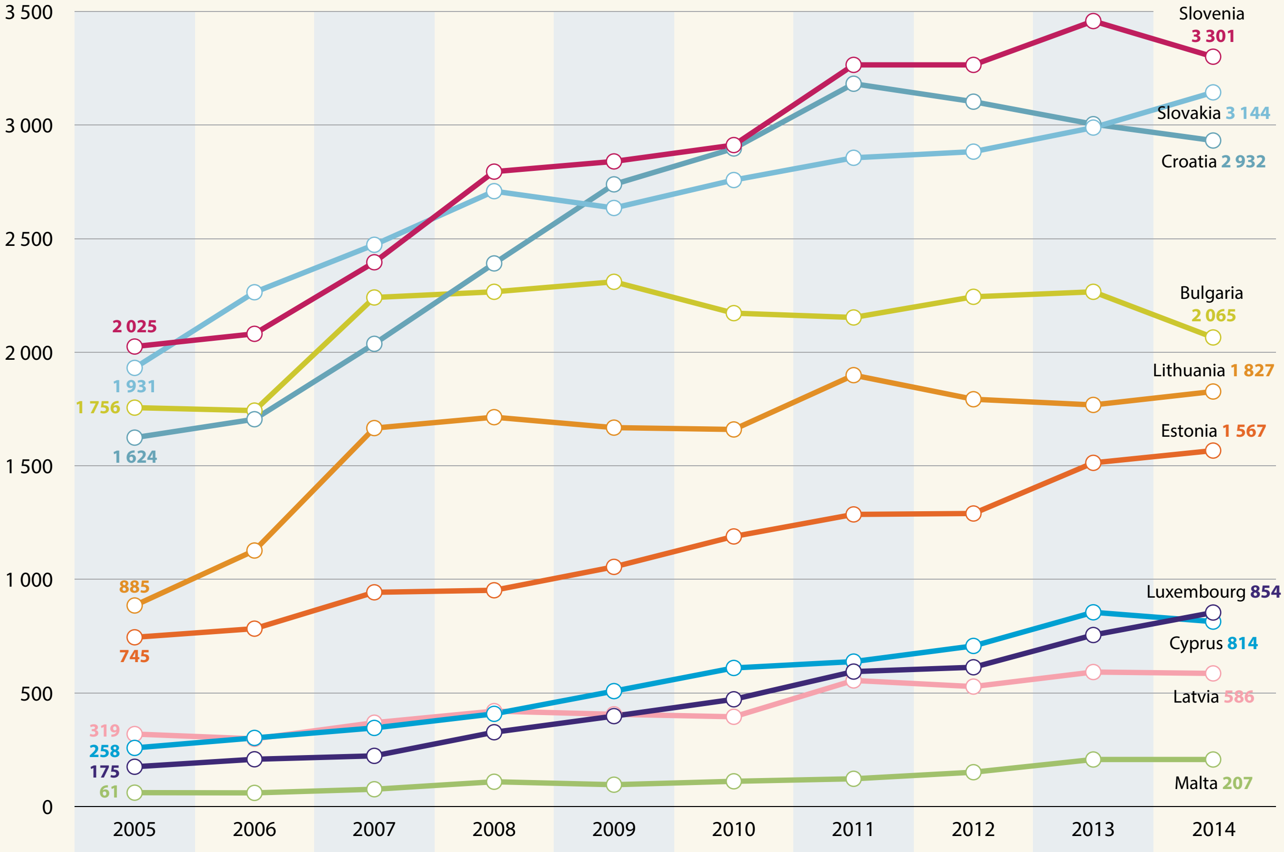
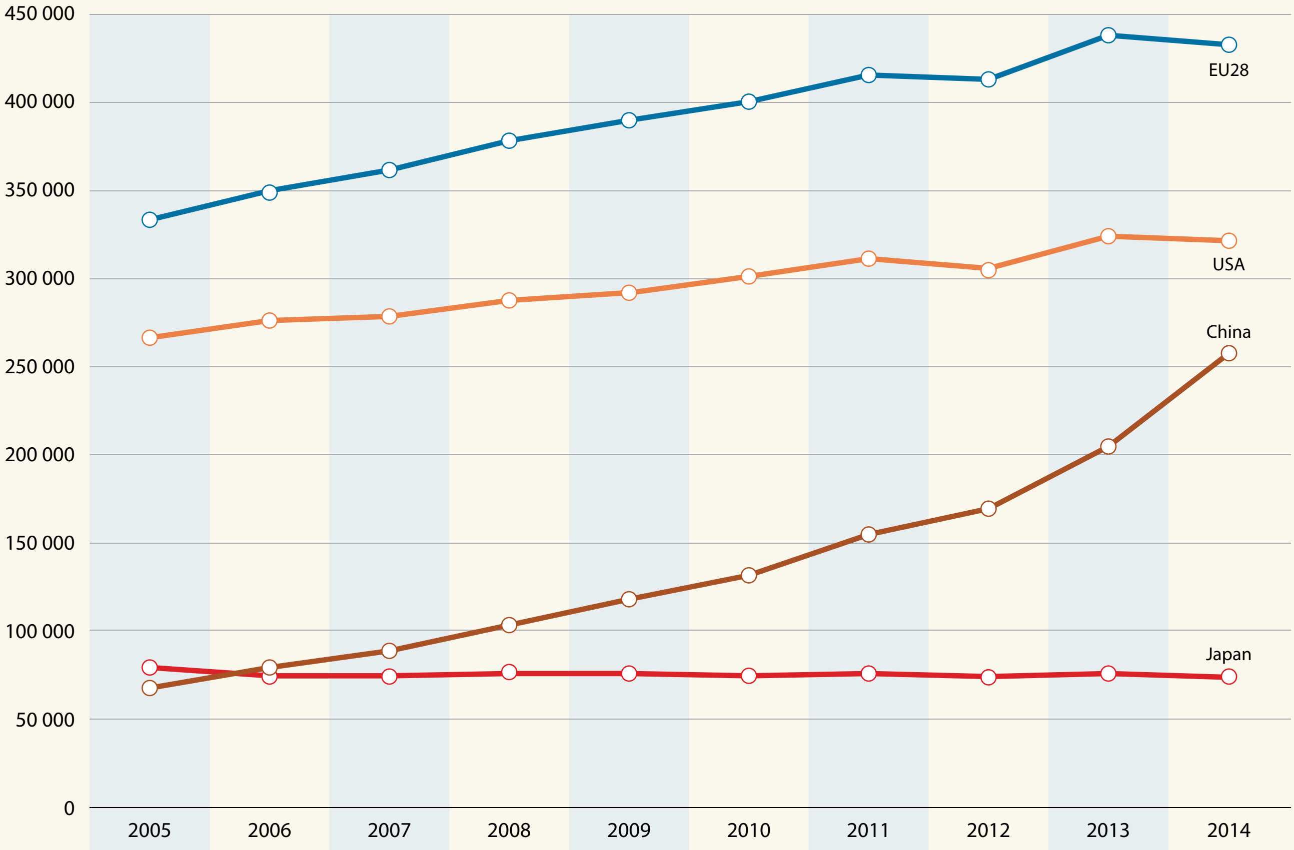


Figure 9.9 *(continued)*



With a 34% share of world publications in 2014, the EU is still the largest bloc for absolute authorship

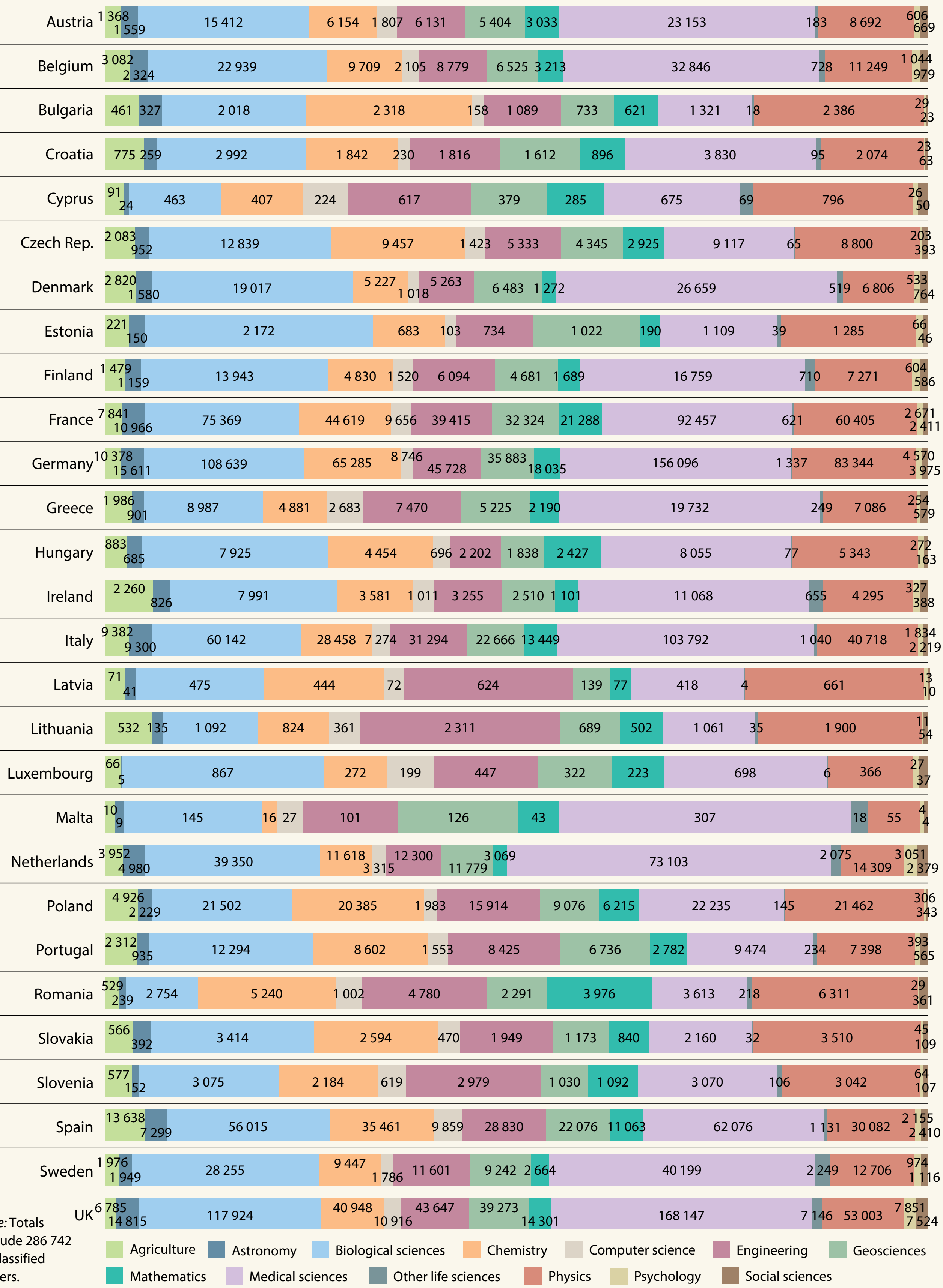


Chapter 9

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

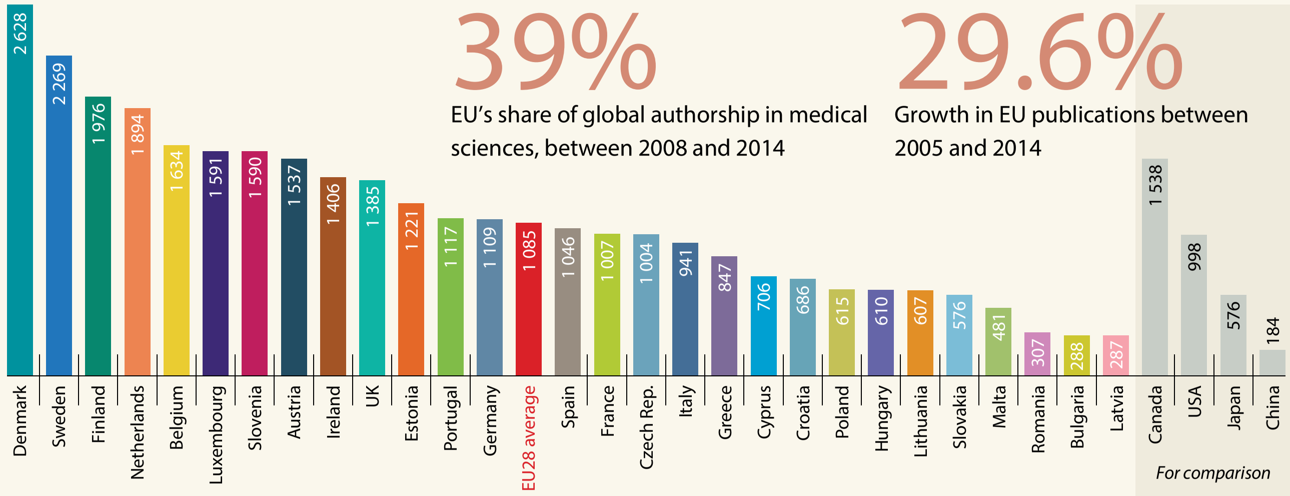


Note: Totals exclude 286 742 unclassified papers.

Figure 9.11: **Publication performance in the European Union, 2008–2014**

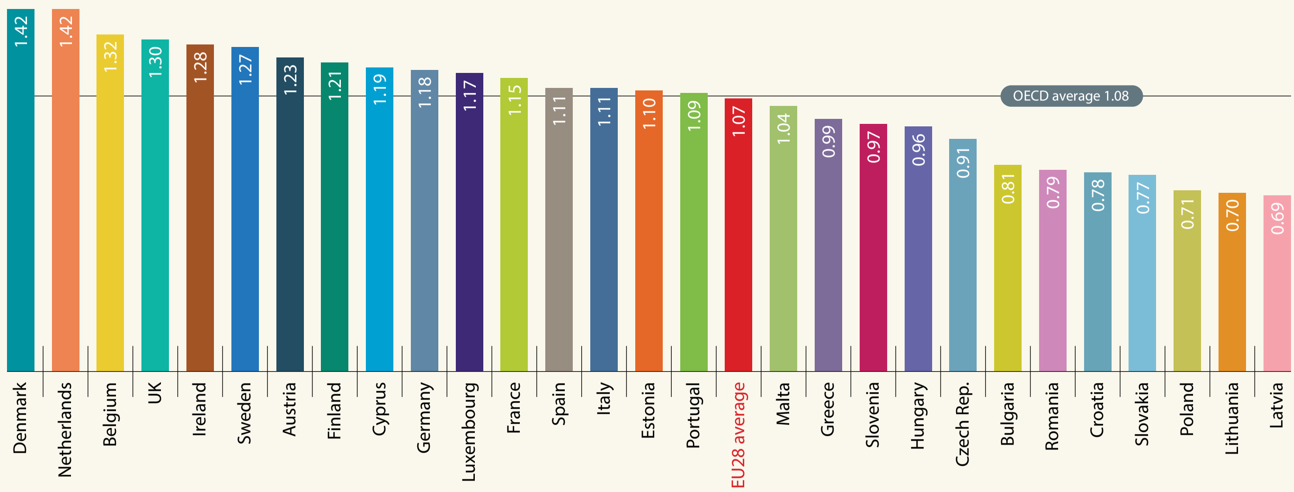
The Nordic EU members have the highest publication intensities

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

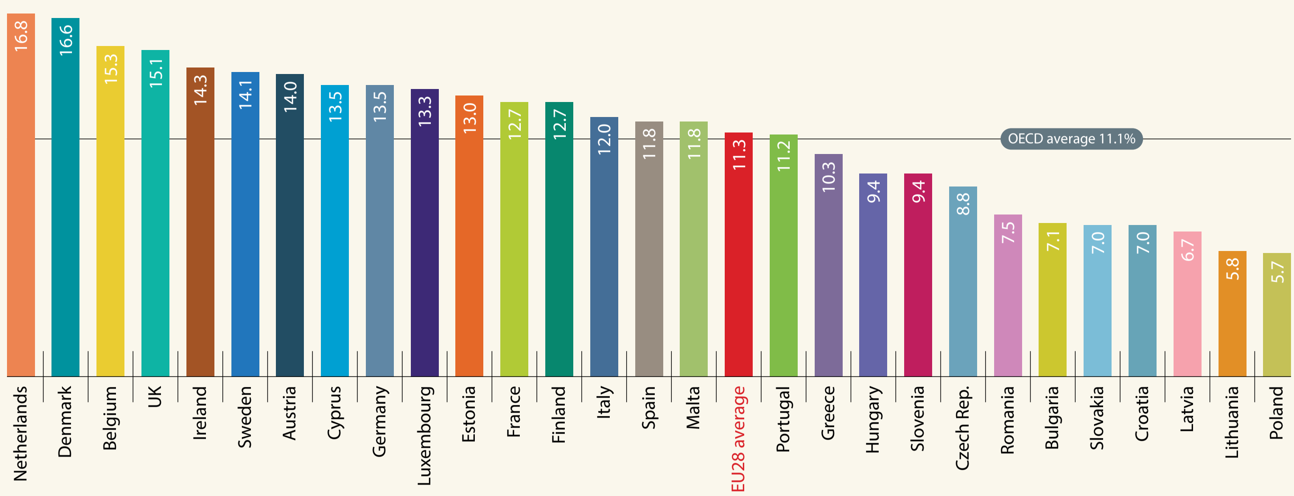
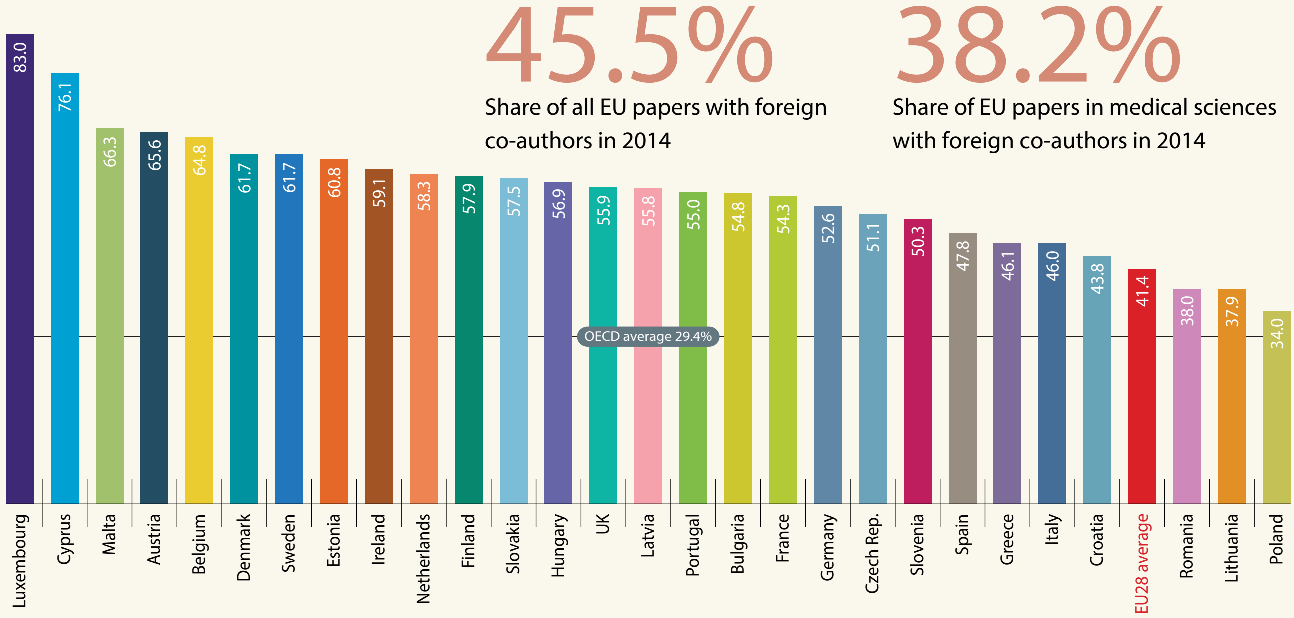


Figure 9.11 *(continued)*

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 Reuter's 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 company 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 (5 billion) than in 2003. A report published in 2013 by the Cour des comptes, France's watchdog for public finances, questioned the efficacity 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 county counts a large services sector, including financial services.

Policies focus on strengthening the UK's ability to innovate and commercialize new technologies. In 2013, investment in 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 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.

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.

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.

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
Macedonia, FYR	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 (%)**

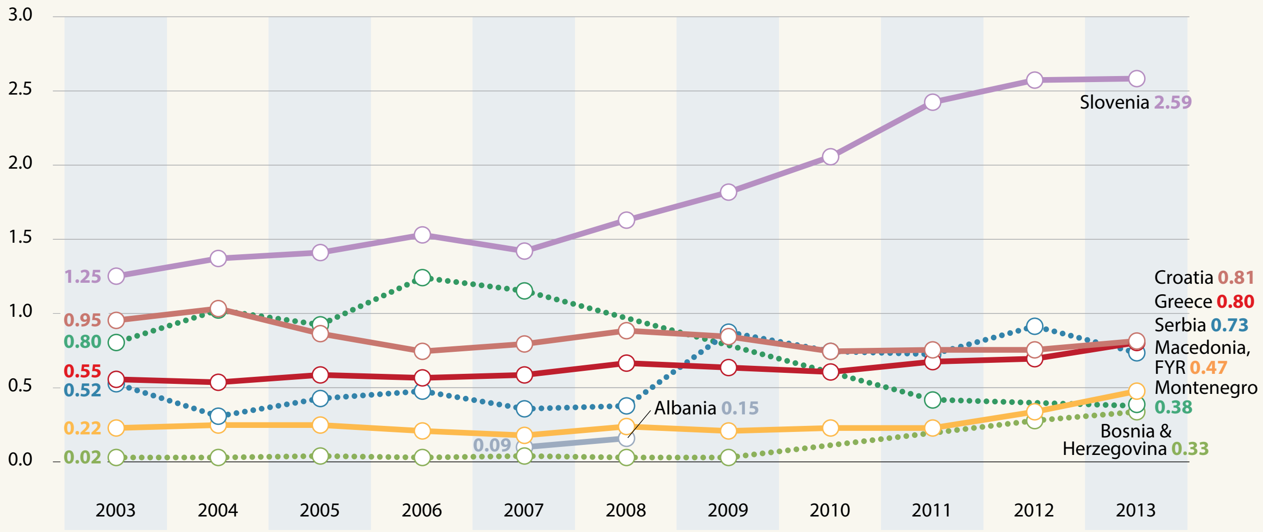
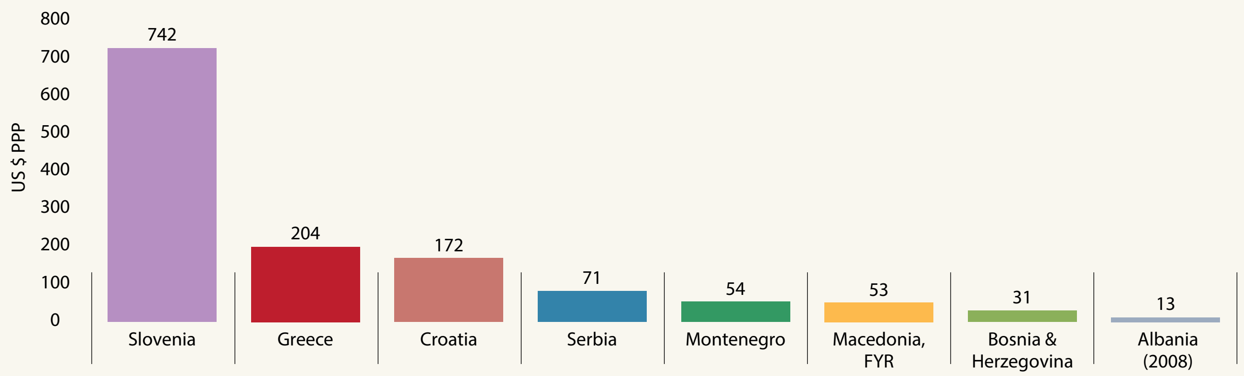
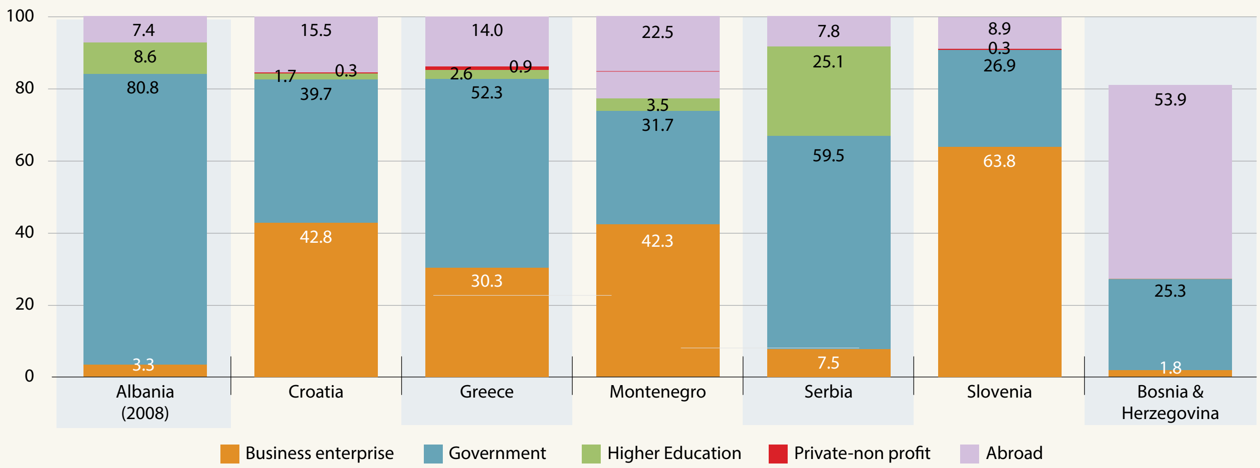


Figure 10.2: **GERD per capita in Southeast Europe, 2013 (%)**



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
Macedonia, FYR	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

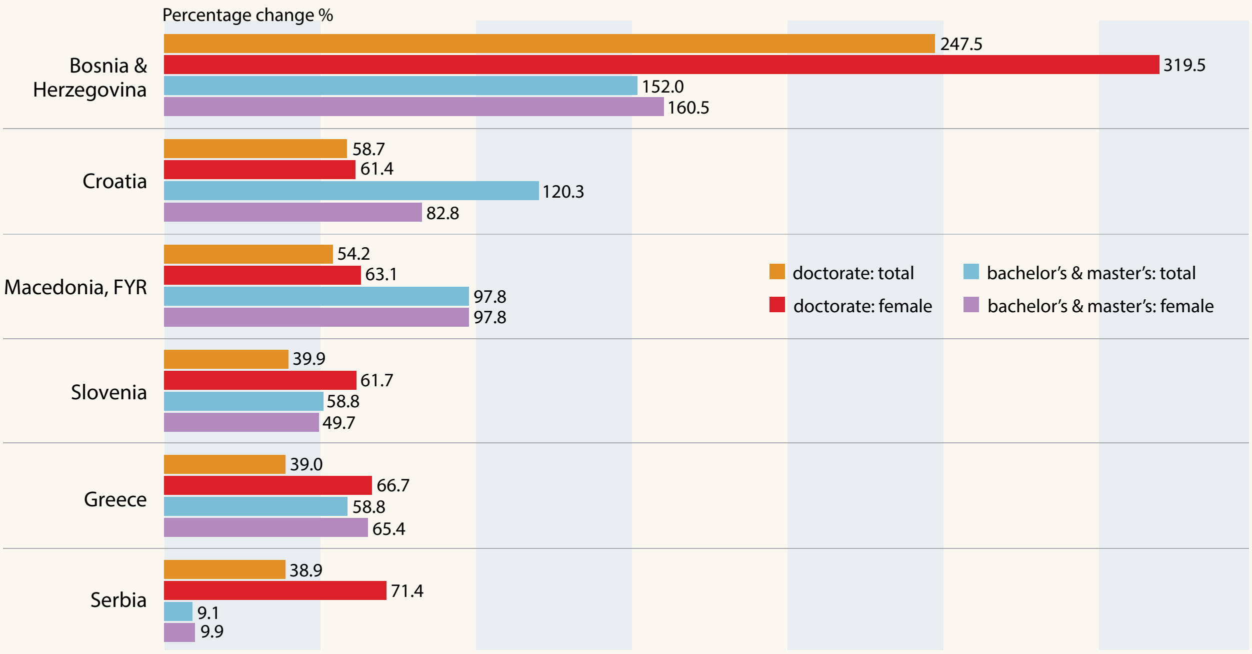
Table 10.3: **Capacity of Southeast Europe to retain and attract talent, 2014**

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
Macedonia, FYR	2.5	127	**Macedonia, FYR**	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*

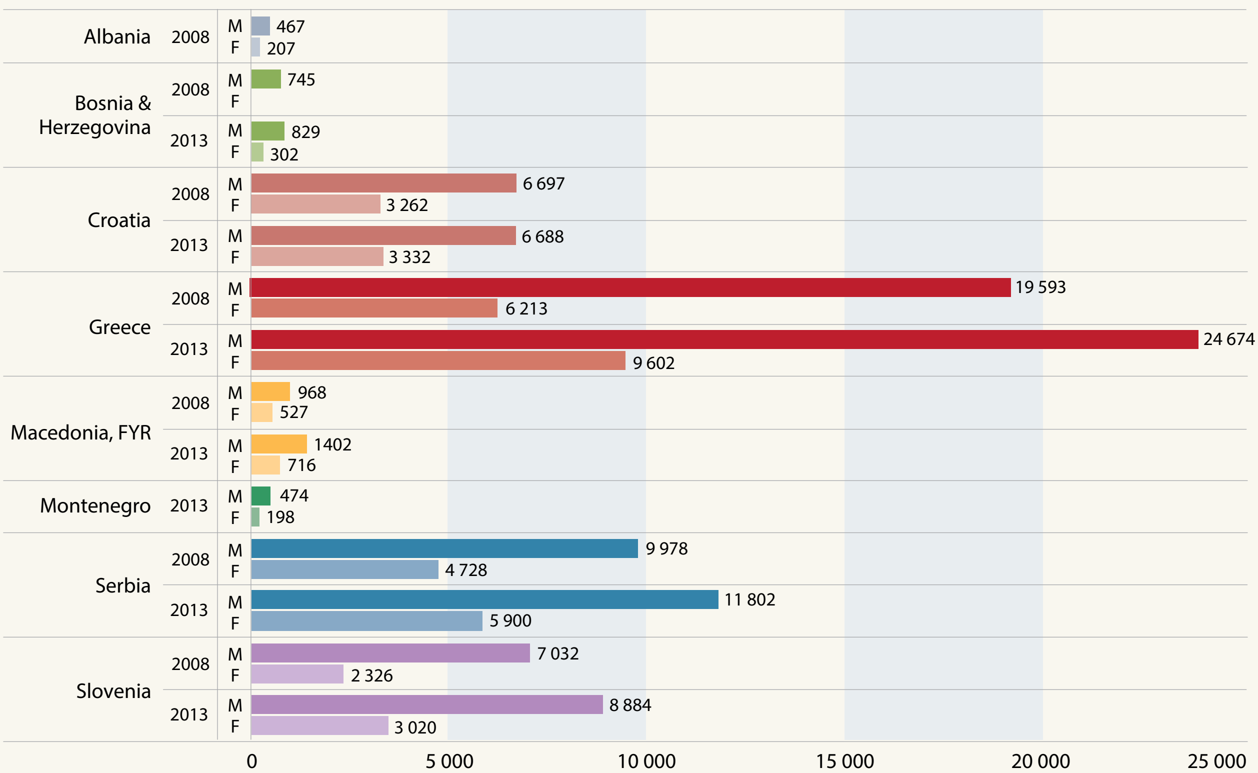
Figure 10.4: **Growth in number of tertiary graduates in Southeast Europe, 2005–2012**

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
Macedonia, FYR	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

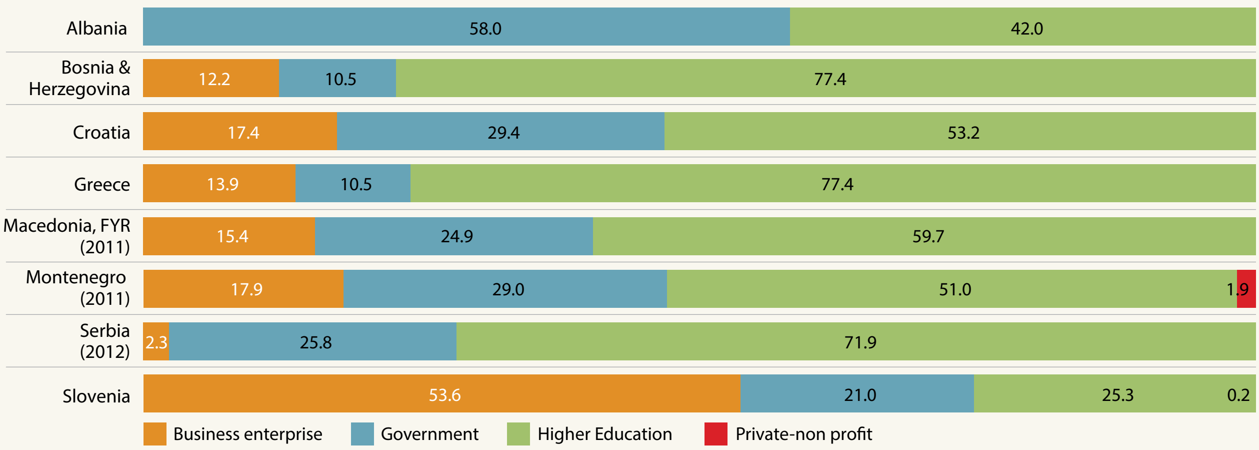
+n/-n = data refer to *n* years before or after reference year
Source: UNESCO Institute for Statistics, April 2015

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
Macedonia, FYR, 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

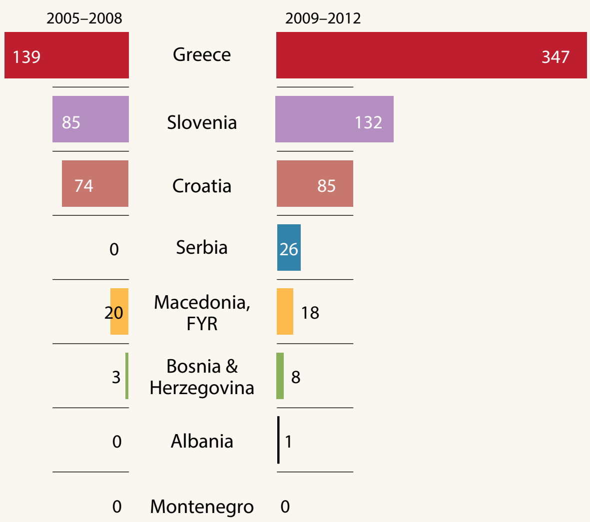
Source: UNESCO Institute for Statistics, April 2015

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**

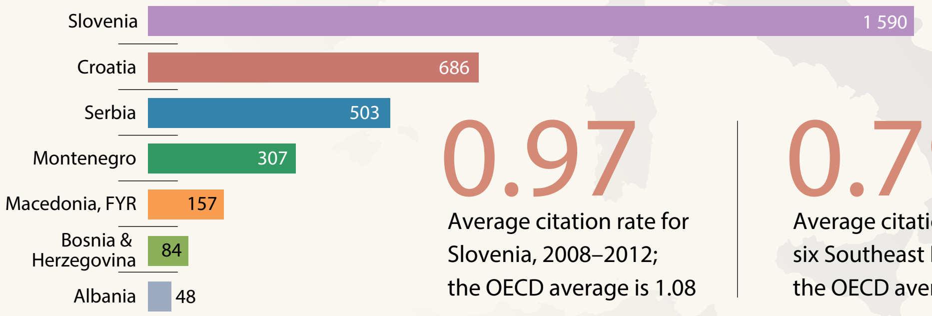
	Royalty payments and receipts (US$ per capita)		University–industry research collaboration 1 (low) – 7 (high)		Patents granted by USPTO per million inhabitants
	2006	2009	2007	2010	2002–2013
Albania	2.39	6.39	1.70	2.20	0.3
Bosnia & Herzegovina	–	4.87	2.40	3.00	3.9
Croatia	50.02	55.25	3.60	3.40	45.9
Greece	–	–	–	–	52.4
Macedonia, FYR	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



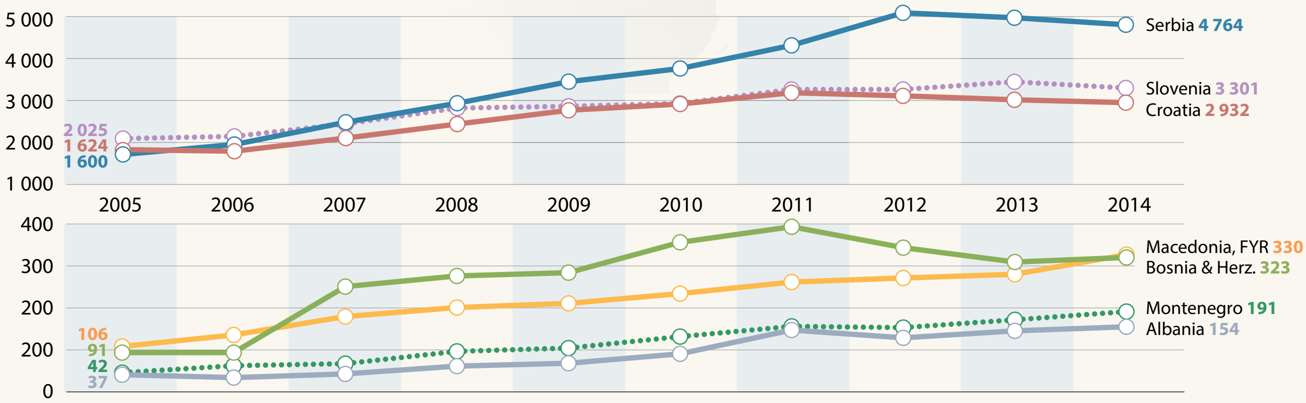
0.97

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

0.79

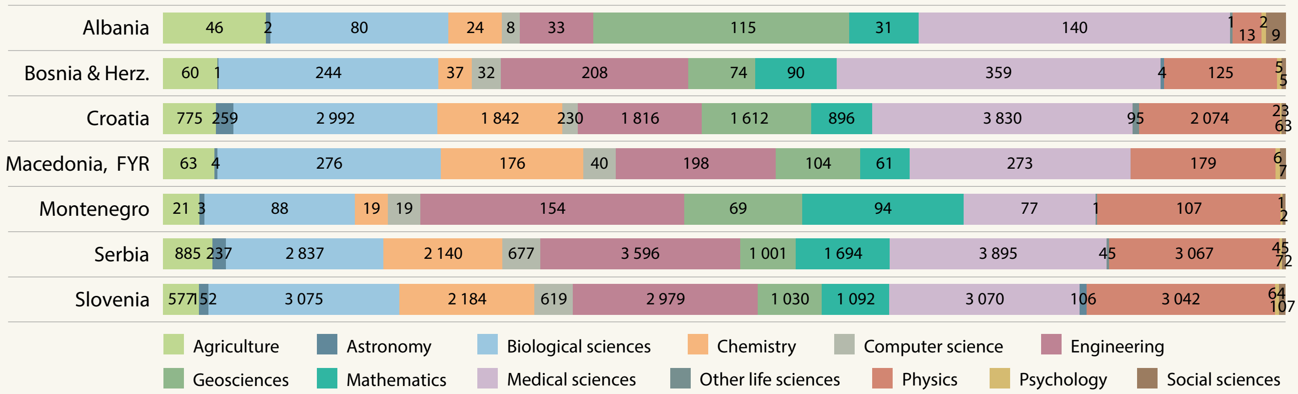
Average citation rate for the other six Southeast European countries; the OECD average is 1.08

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)
Macedonia, FYR	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 recession, 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.

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 *Innovation Strategy of the FYR of Macedonia 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, FYR 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, a Swiss psychiatrist and balloonist who initiated the Solar Impulse project, waves after the solar-powered aircraft Solar Impulse 2 arrives at Nanjing Lukou International Airport early Wednesday on April 22, 2015 in Nanjing, Jiangsu province of China. Solar Impulse 2, the first aircraft completely sustained by solar power, took off from Myanmar's second biggest city of Mandalay early Monday and after a 20-hour flight, the Solar Impulse 2 airplane touched down in south China's Chongqing Jiangbei International Airport and stayed at Chongqing, the fifth flight of a landmark journey to circumnavigate the globe powered solely by the sun, for twenty days.

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

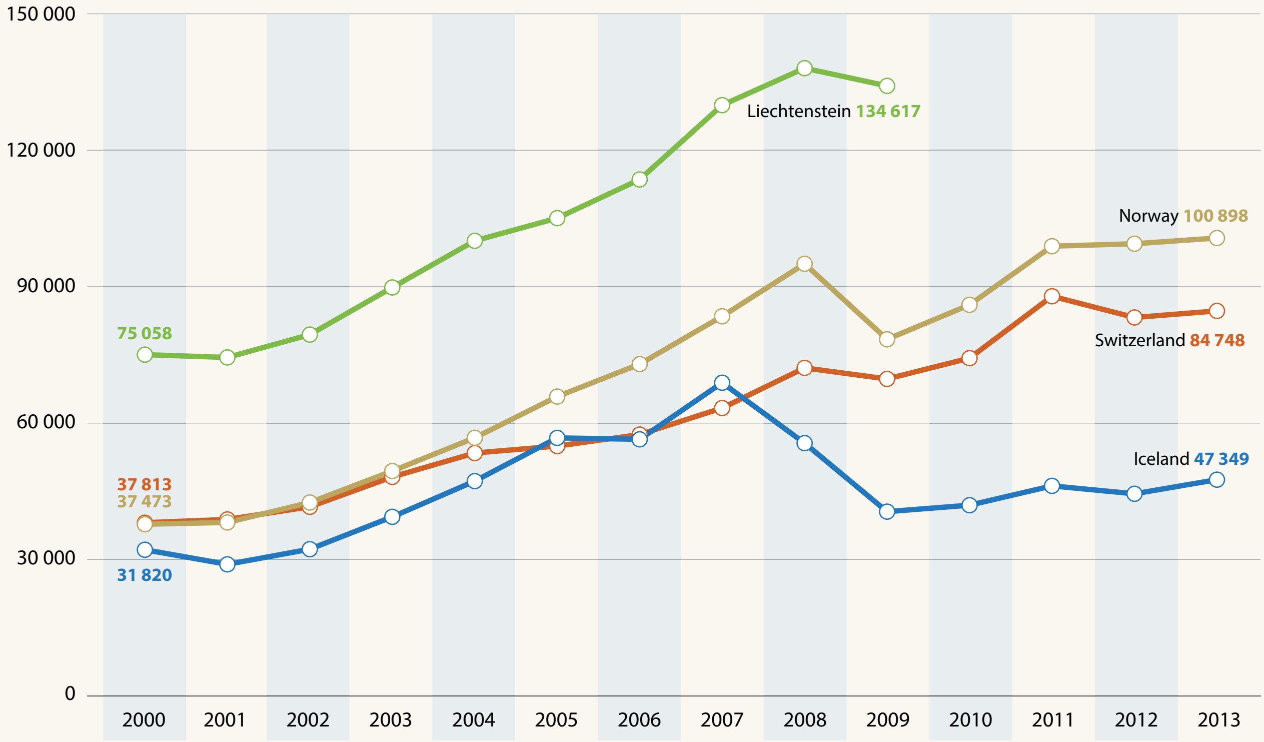
1. In January 2015, the Swiss franc soared by almost 30% against the euro, after the Swiss National Bank removed the cap it had imposed in 2011 to prevent such a scenario. Since then, the effect has softened to a 15–20% rise.

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:

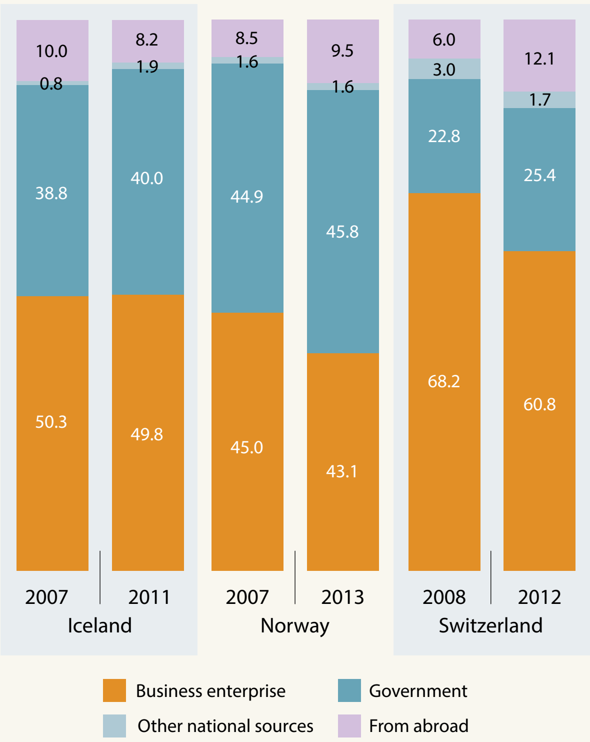
- two geographically remote countries with lengthy sea coasts (Iceland and Norway) and abundant natural resources, versus two inland nations (Liechtenstein and Switzerland) at the heart of Europe which are entirely dependent on the production of high-quality goods and services;
- two small countries (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 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).

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*

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

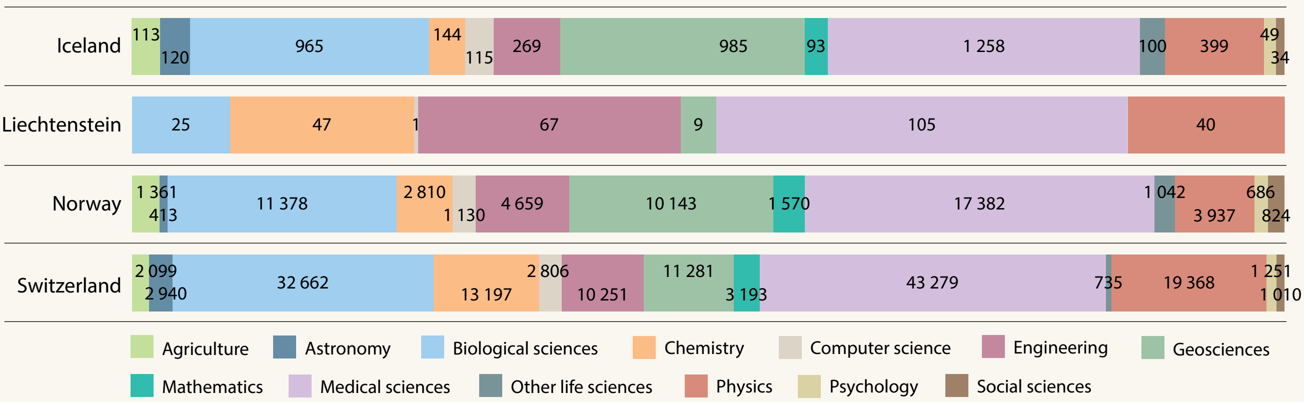
Norwegian publications per million inhabitants in 2014

3 102

Swiss publications per million inhabitants in 2014

Countries specialize in medical sciences, Switzerland stands out in physics

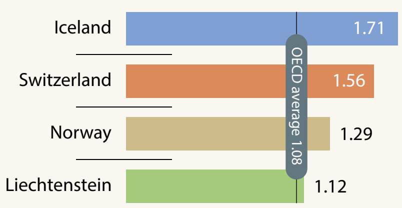
Cumulative totals by field, 2008–2014



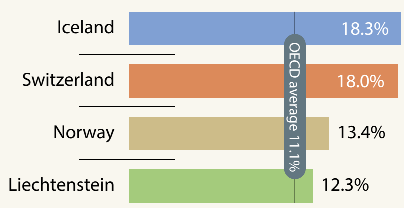
Note: The totals by field do not include unclassified publications, which are quite numerous for Switzerland (13 214), Norway (5 612) and Iceland (563). See the methodological note on p. 792.

All countries surpass the OECD average by far for key indicators

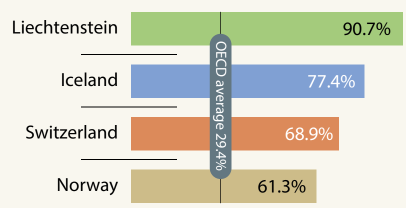
Average citation rate for publications 2008–2012



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)

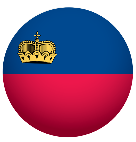
	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Iceland	USA (1 514)	UK (1 095)	Sweden (1 078)	Denmark (750)	Germany (703)
Liechtenstein	Austria (121)	Germany (107)	Switzerland (100)	USA (68)	France (19)
Norway	USA (10 774)	UK (8 854)	Sweden (7 540)	Germany (7 034)	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

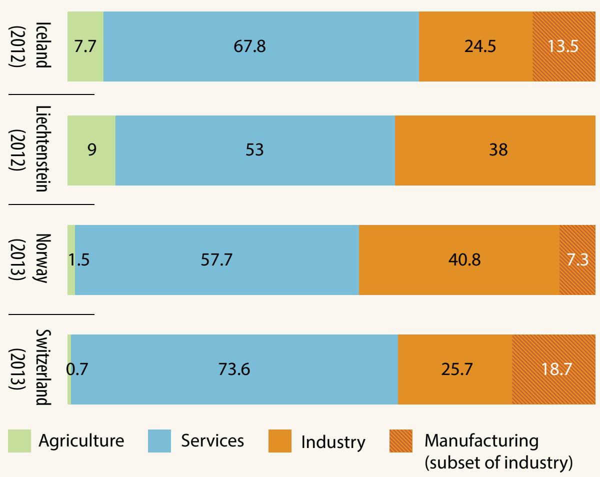
Knowledge not translating into innovation

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:

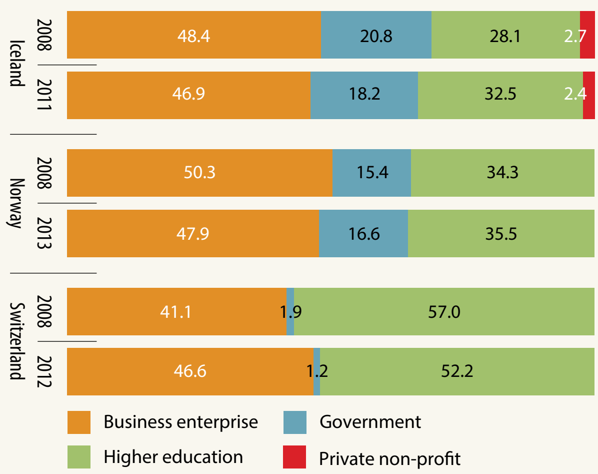
Figure 11.4: **GDP in EFTA countries by economic sector, 2013 or closest year (%)**



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).

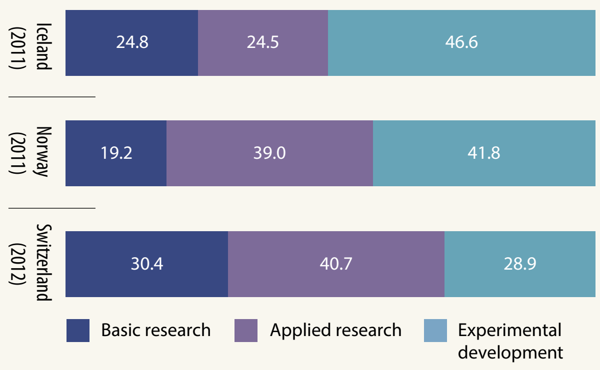
Longyearbyen, the world's most northerly city, hosts research bodies and infrastructure such as the:

- 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 Erӧcal 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**

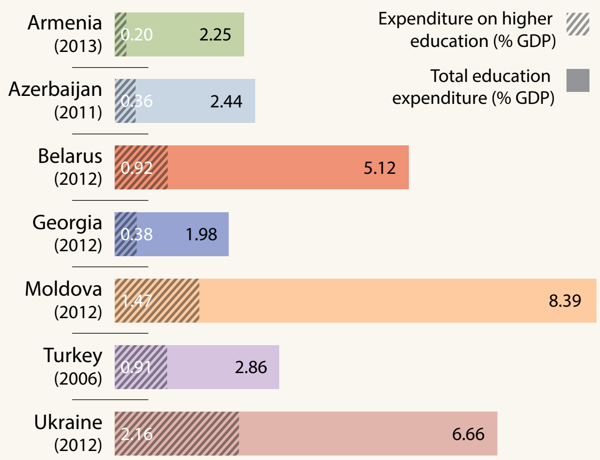
	Labour force with tertiary education		Gross enrolment ratio for tertiary education		PhD or equivalent graduates 2012 or closest year							
	Highest score 2009–2012 (%)	Change over five years (%)	Highest score 2009–2013 (% of age cohort)	Change over five years (%)	Total	Women (%)	Natural sciences	Women (%)	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.

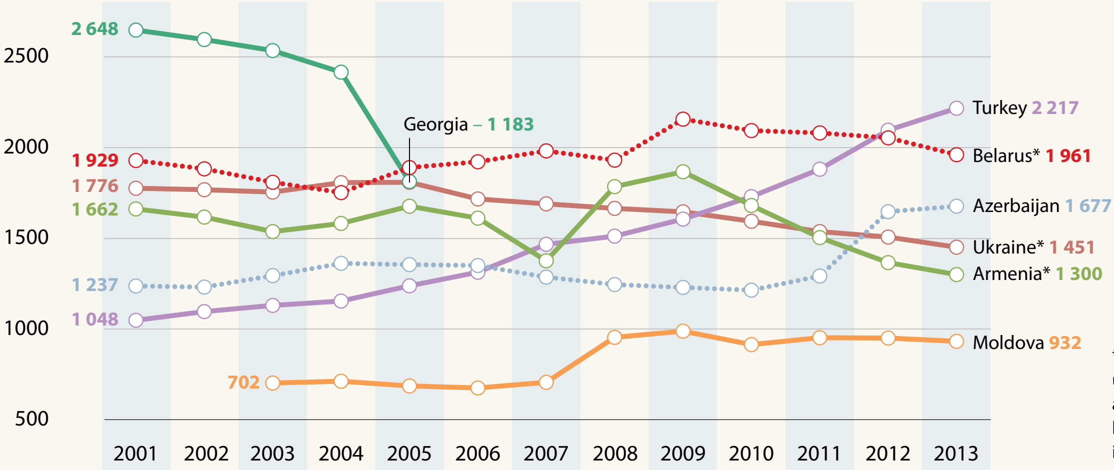
5. According to the *Statistical Yearbook: National Economy of the Ukrainian Soviet Socialist Republic, 1990,* published in Kiev in 1991

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

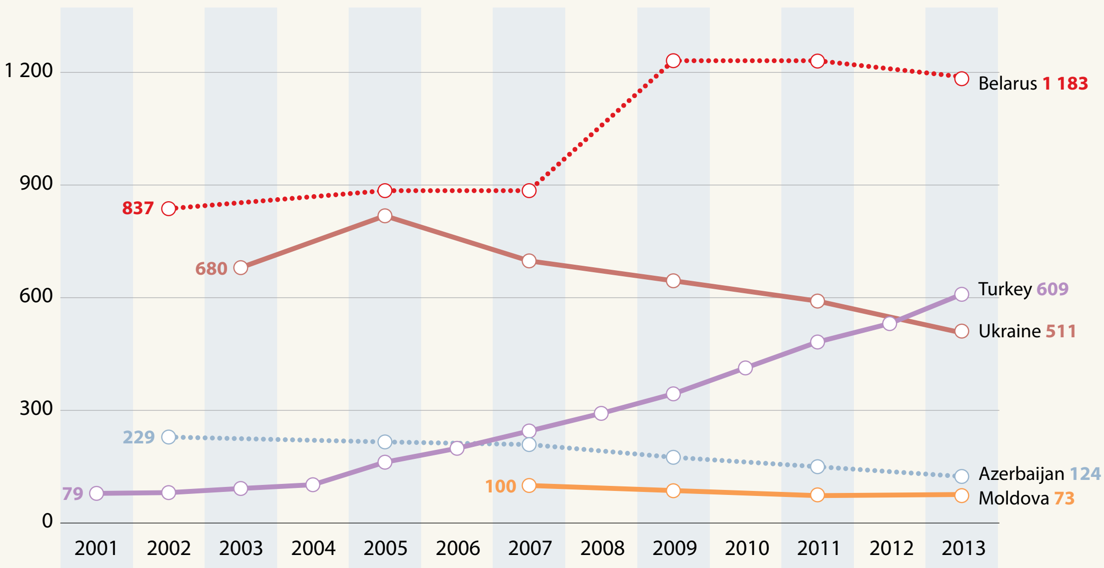
	Total		Natural sciences		Engineering		Medical sciences		Agricultural sciences		Social sciences		Humanities	
	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)	Total	Women (%)
Armenia*	3 870	48.1	2 194	46.4	546	33.5	384	61.7	45	66.7	217	47.0	484	60.5
Azerbaijan	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

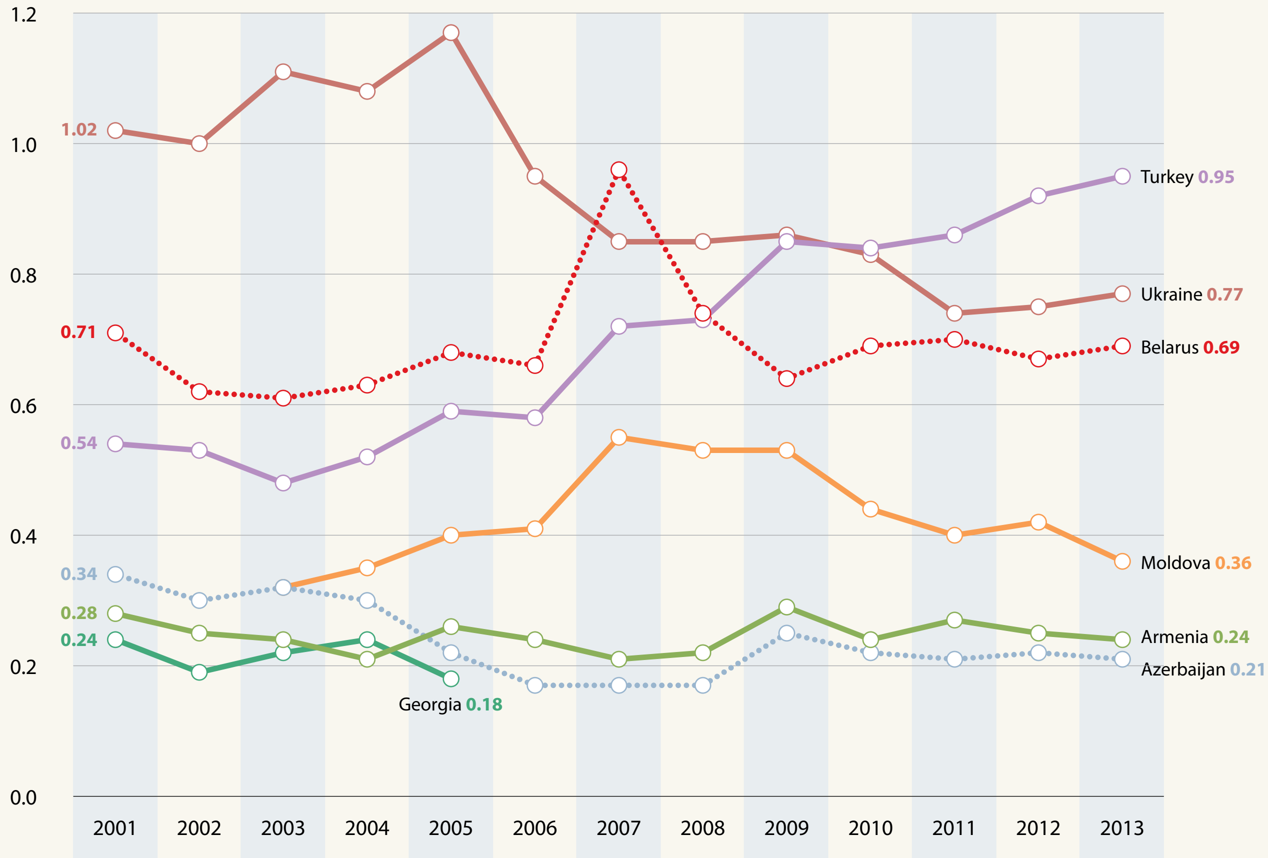
Researchers per million inhabitants by head count



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

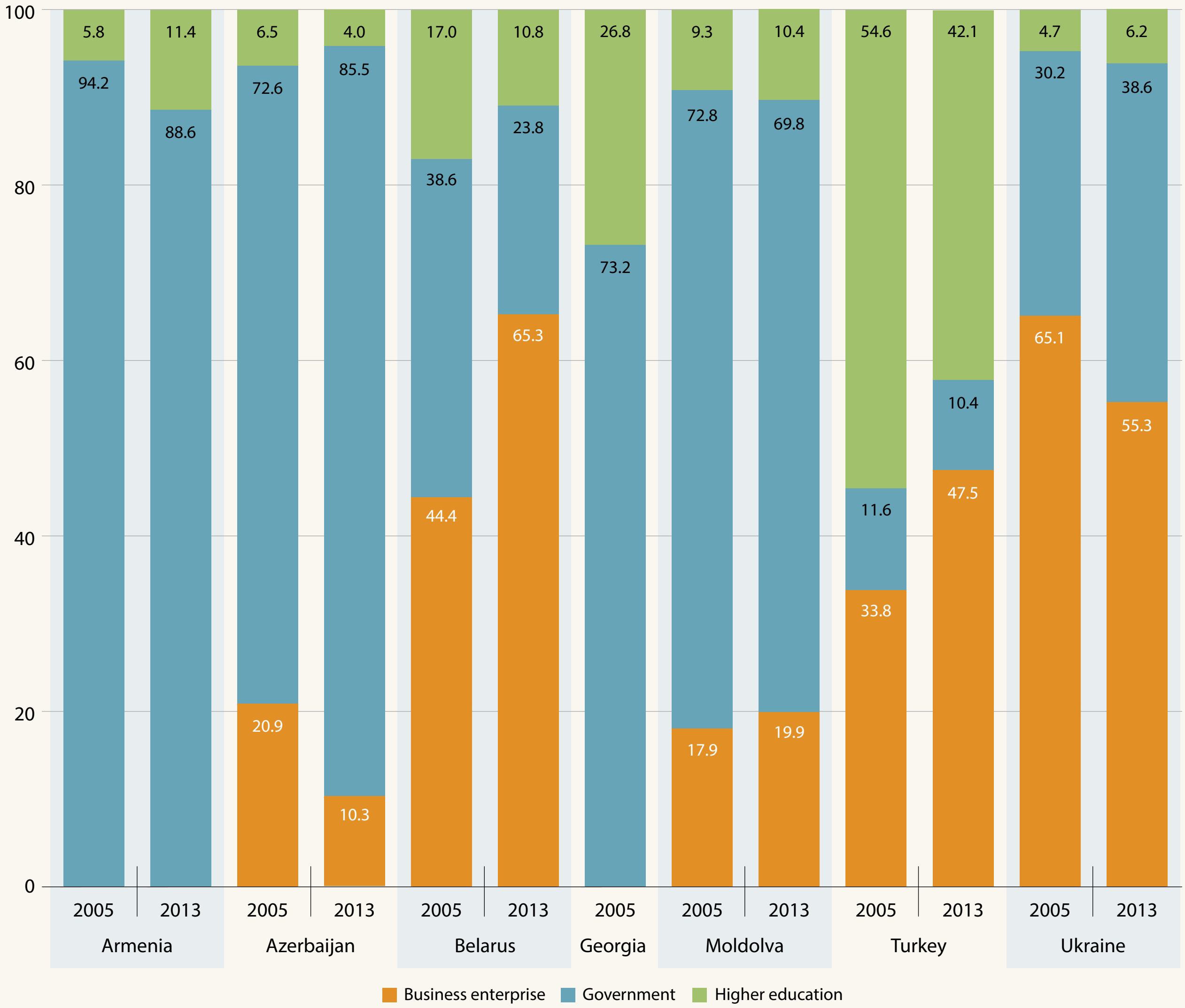
- On the whole, the legislative and institutional framework for intellectual property protection is in place in the Black Sea countries but there is room for improvement, especially for countries which are not members of the World Trade Organization (WTO[8]), both as concerns compliance with WTO's Agreement 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.

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**

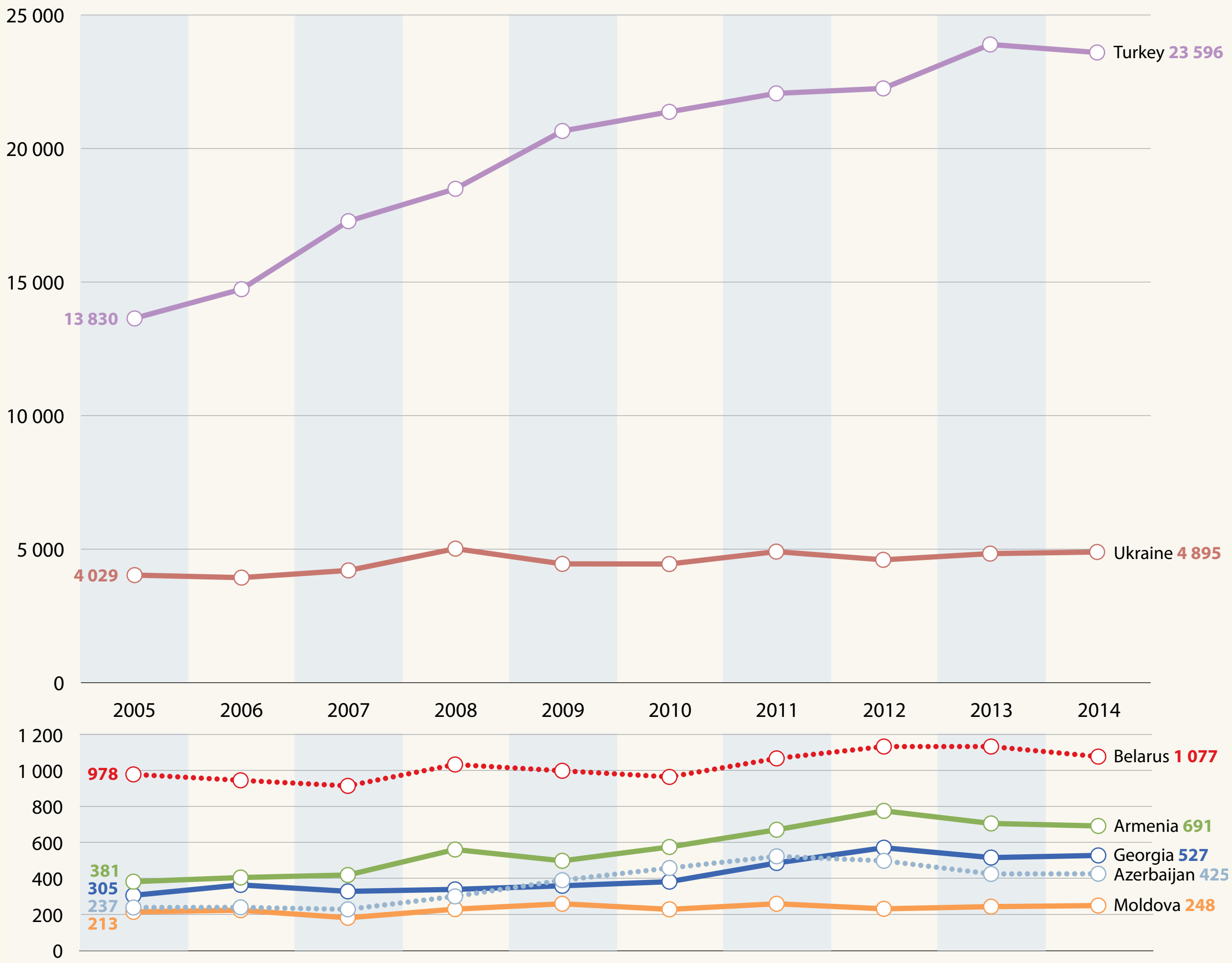
	National office applications						Patent applications to EPO		Patent applications to USPTO	
	Applications per billion PPP GDP, 2012			World rank			Total, 2001–2010	Ratio 2006–2010 to 2001–2006	Total 2001–2010	Ratio 2006–2010 to 2001–2006
	Utility model	Patents	Under the PCT	Utility model	Patents	Under 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)

Chapter 12

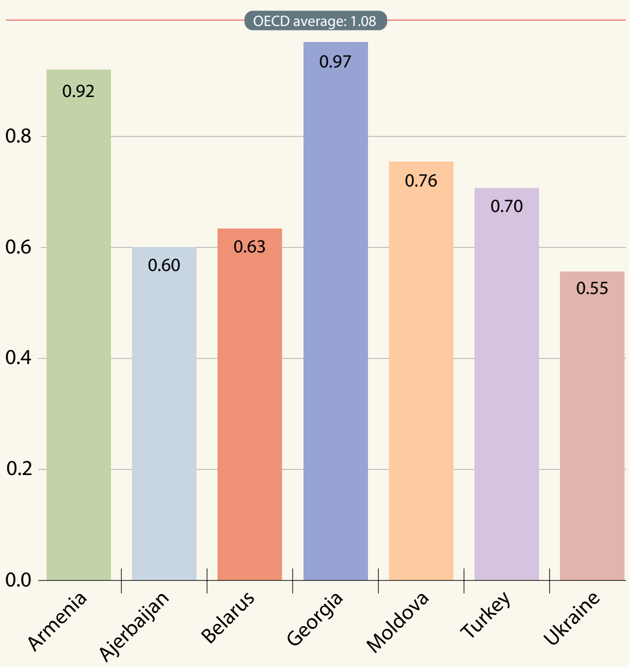
Figure 12.6: **Scientific publication trends in the Black Sea countries, 2005–2014**

Strong growth in publications in the smaller countries and Turkey



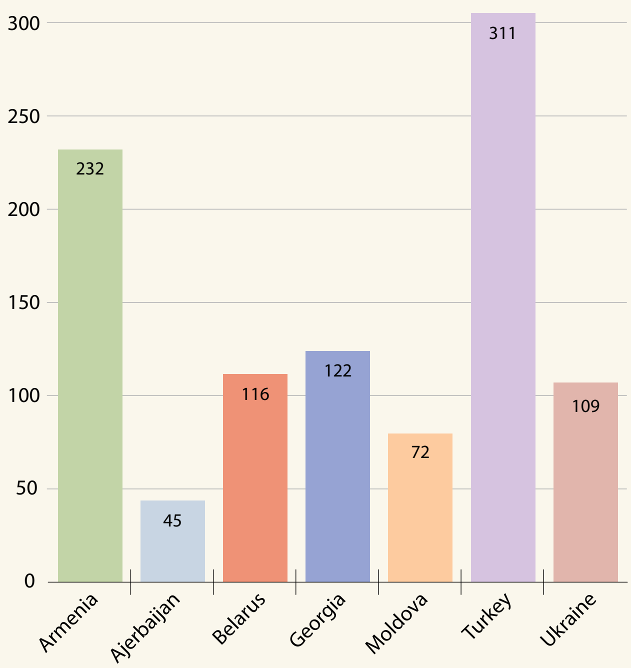
Georgia comes closest to the OECD average for the citation rate

Average citation rate, 2008–2012



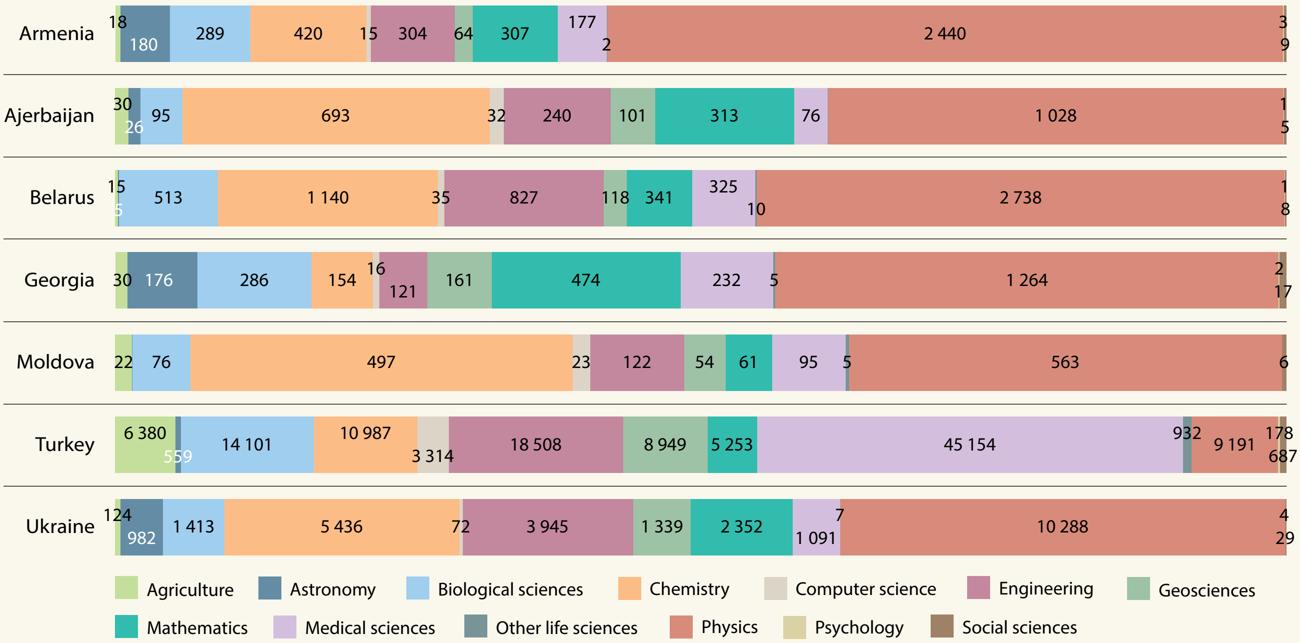
Turkey has the highest publication intensity, followed by Armenia

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



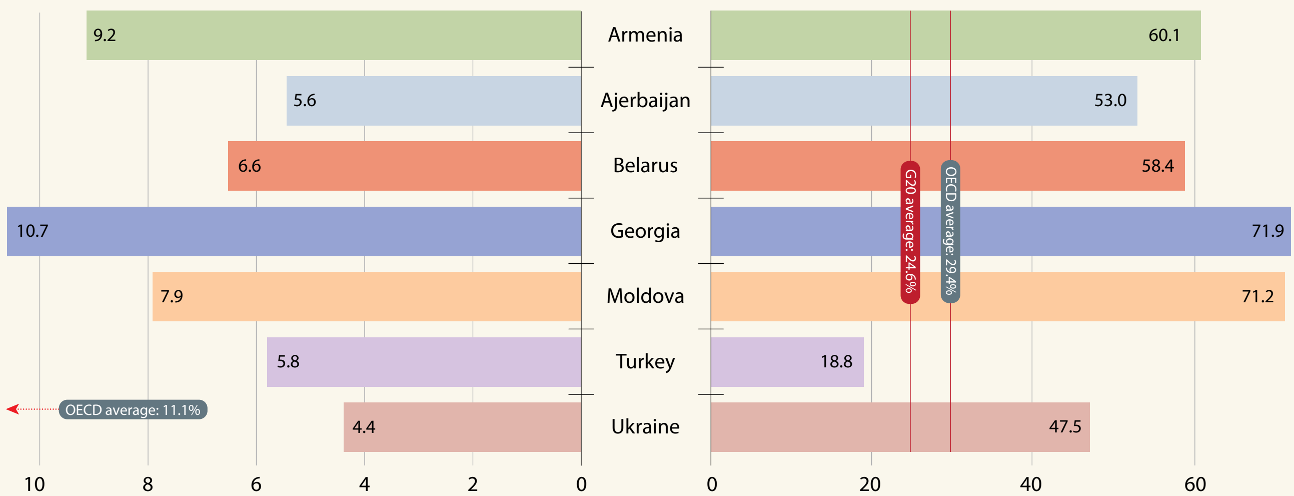
Note: : Some unclassified articles are excluded from these totals, including 28 140 for Turkey, 6 072 for Ukraine and 1 242 for Belarus.

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

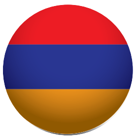
Main foreign partners, 2008–2014 (number of papers)

	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 of 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 the 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

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):

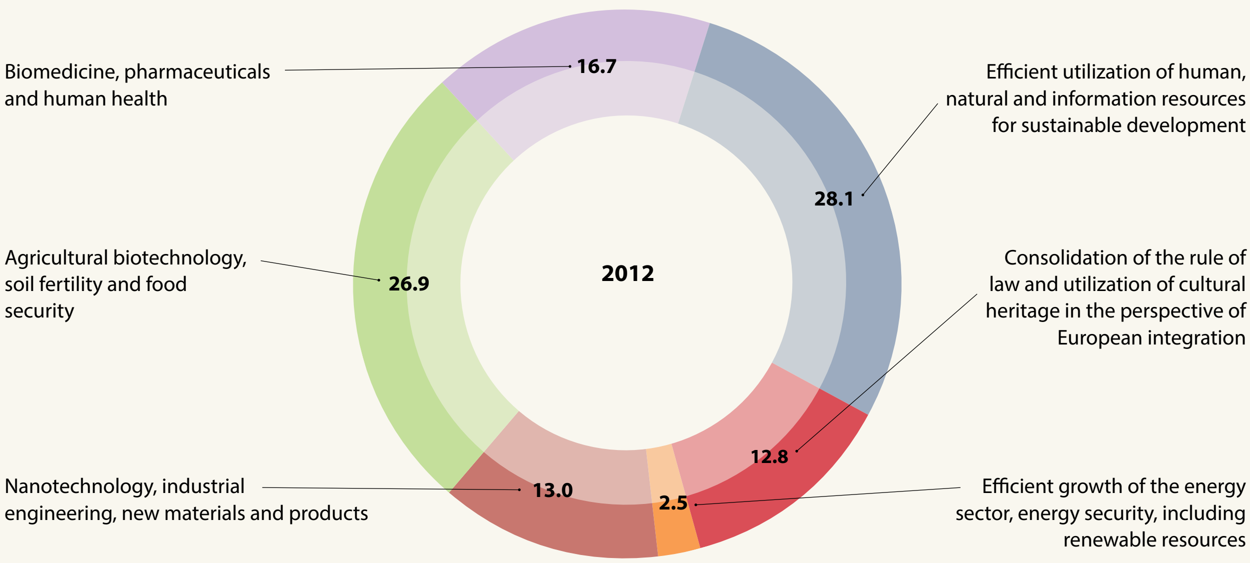
- Updating research equipment and the country's technical base;
- Designing targeted incentive schemes to encourage the young to embark on a research career, including stipends, grants and awards for young scientists, programmes for training abroad and so on;
- Greater participation in the European Research 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 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.

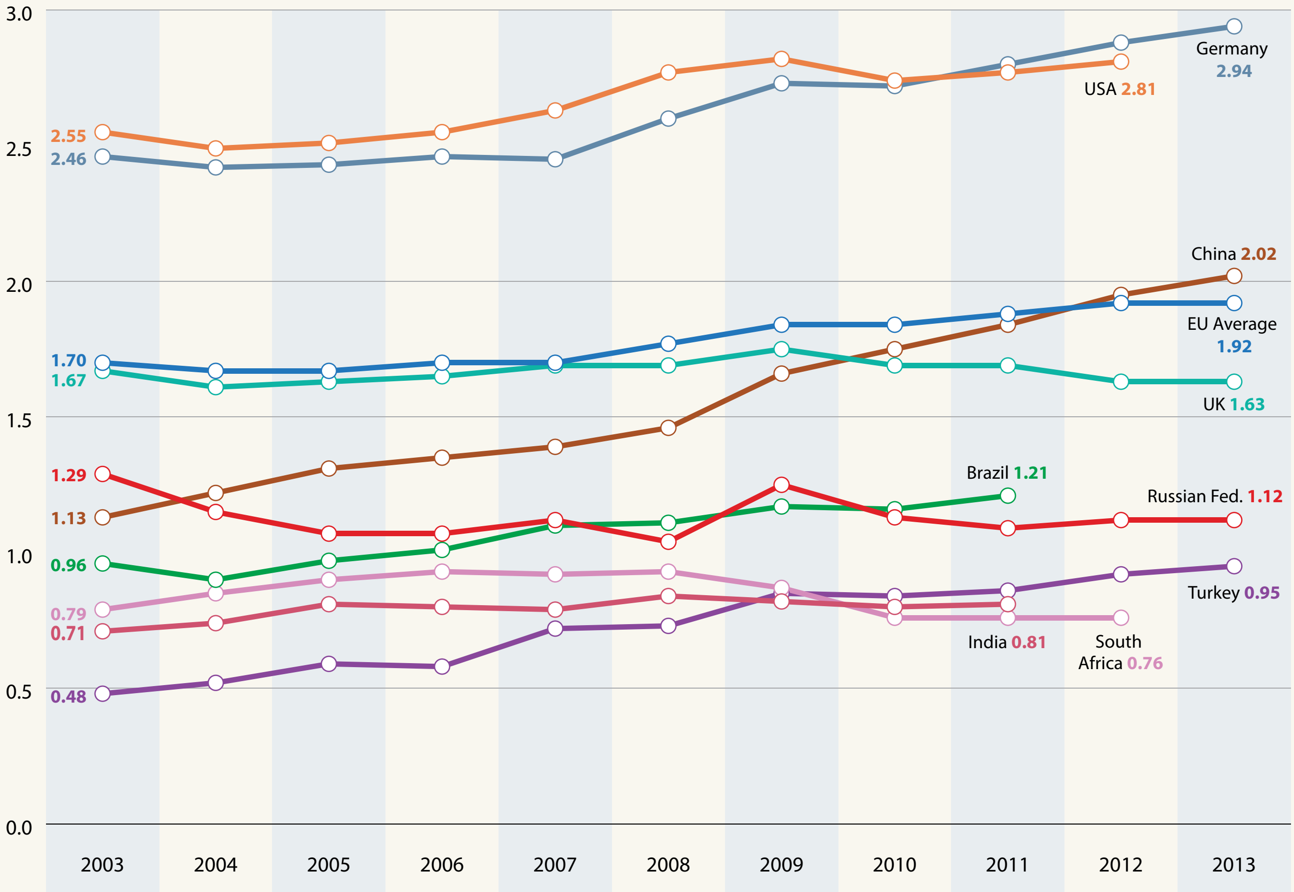
Figure 13.1: **Trends in GERD in the Russian Federation, 2003–2013**

1.29% Russian GERD/GDP ratio in 2003

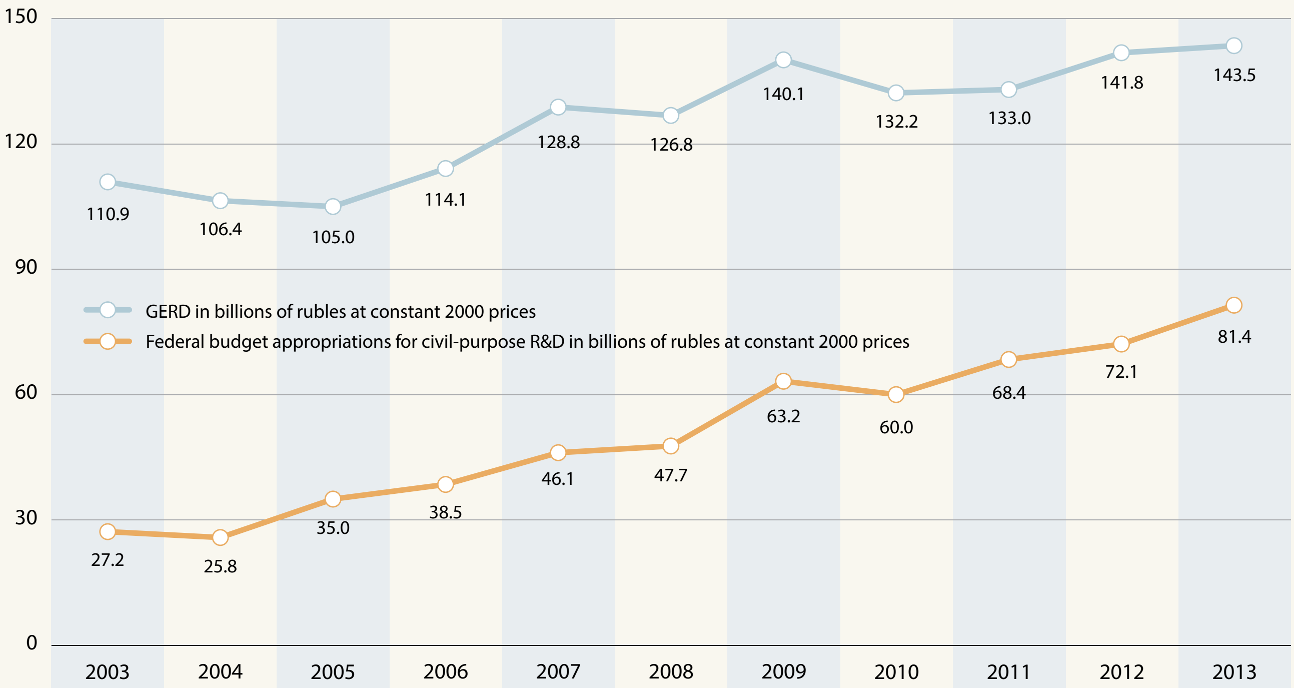
1.12% Russian GERD/GDP ratio in 2013

The Russian Federation's R&D intensity has not progressed over the past decade

Other countries are given for comparison

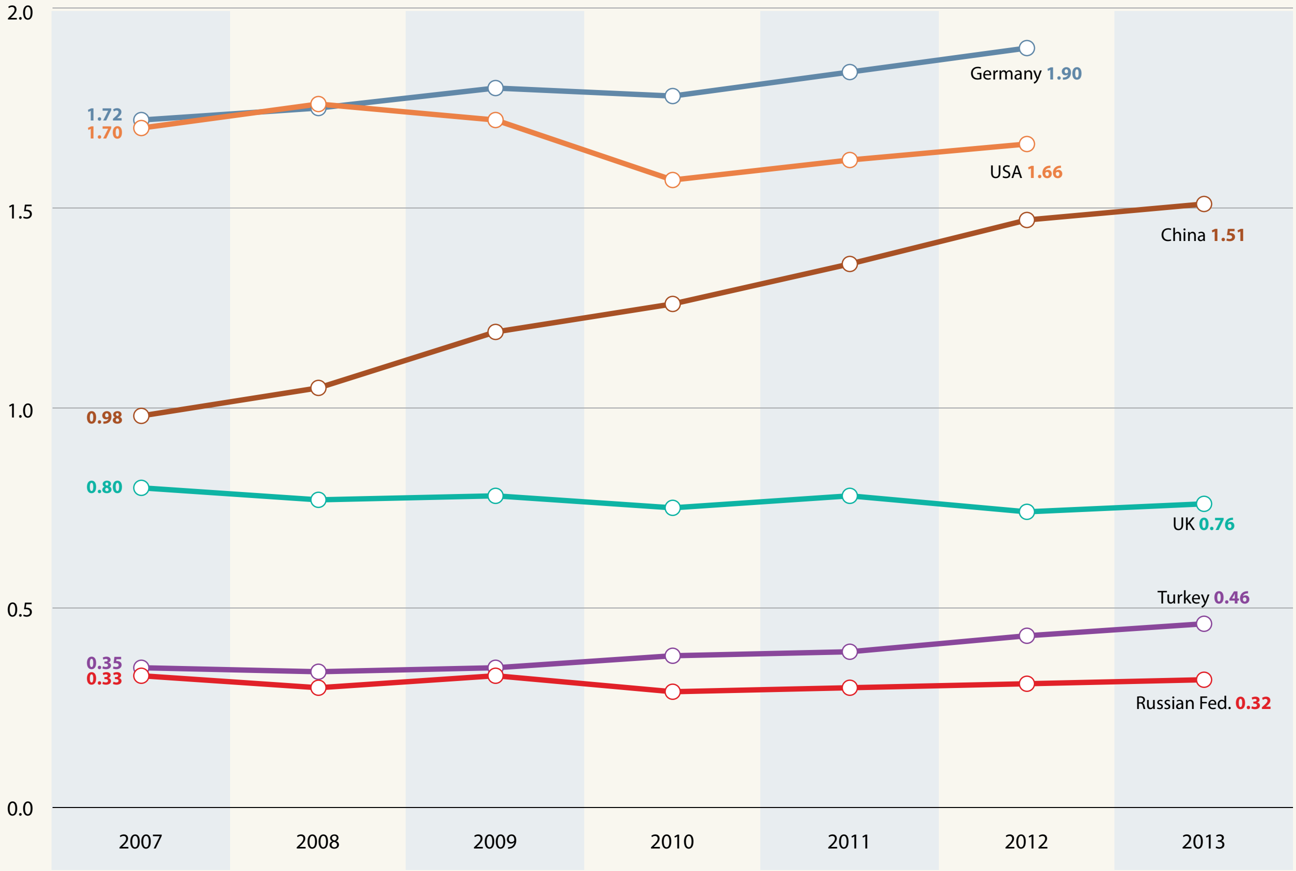


Federal budget allocations for civil-purpose R&D tripled between 2003 and 2013



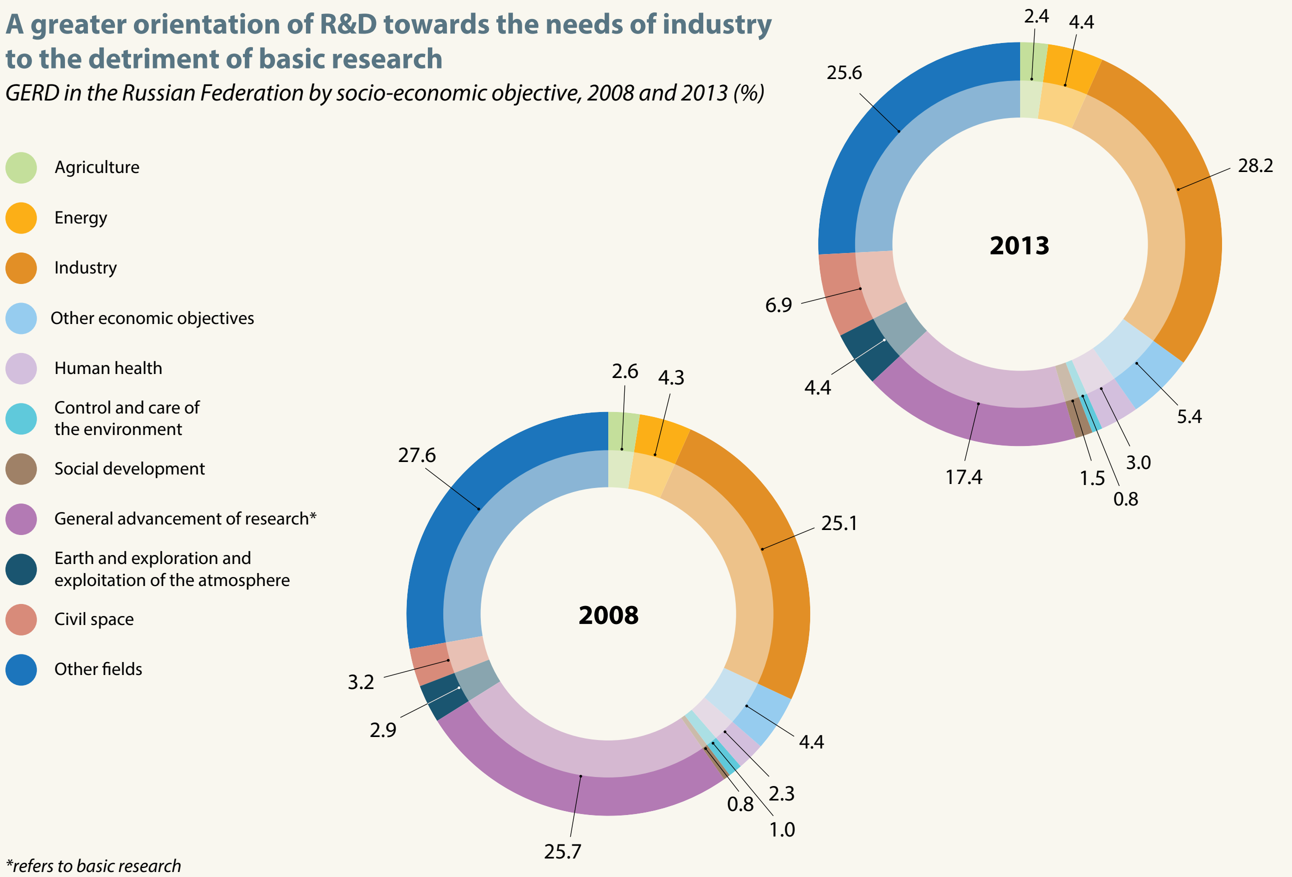
The low share of industry-financed R&D is a perennial concern

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.

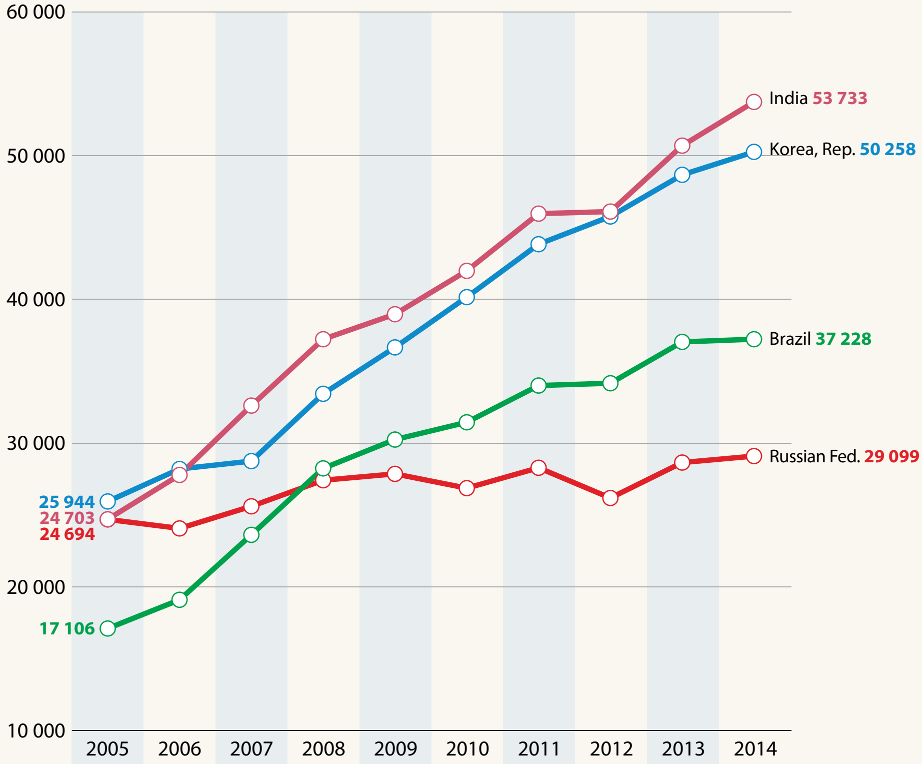
In 2013, there were 727 029 people engaged in R&D, a group encompassing researchers, technicians and support staff. Research personnel represented 1% of the labour force, or 0.5% of the total population. In absolute numbers, the Russian Federation figures among the world leaders for R&D personnel, coming only after the USA, Japan and China. However, there is

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

an imbalance in the dynamics and structure of R&D personnel. 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).

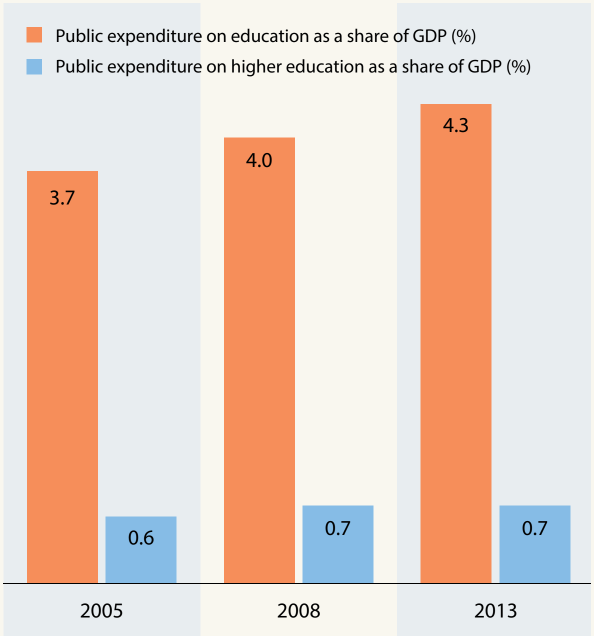
Training scientists becoming a core mission of research universities

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

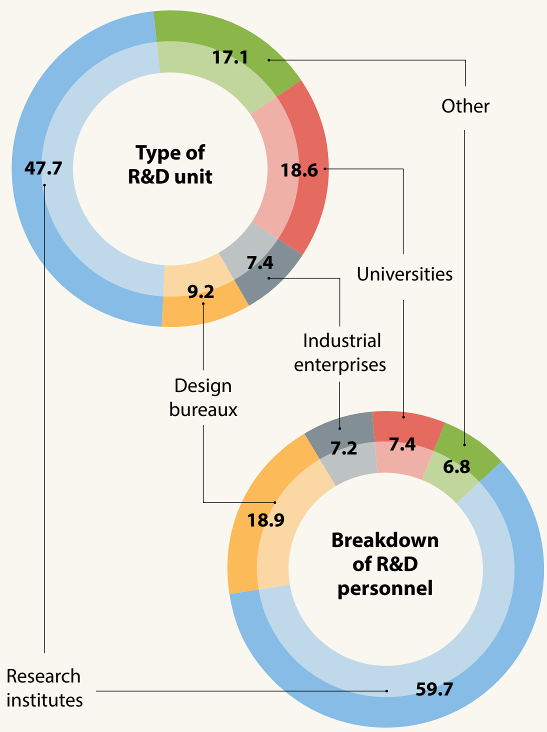
See also: http://economy.gov.ru/minec/press/interview/20141224

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. There are eight priority areas. Two 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 management 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).

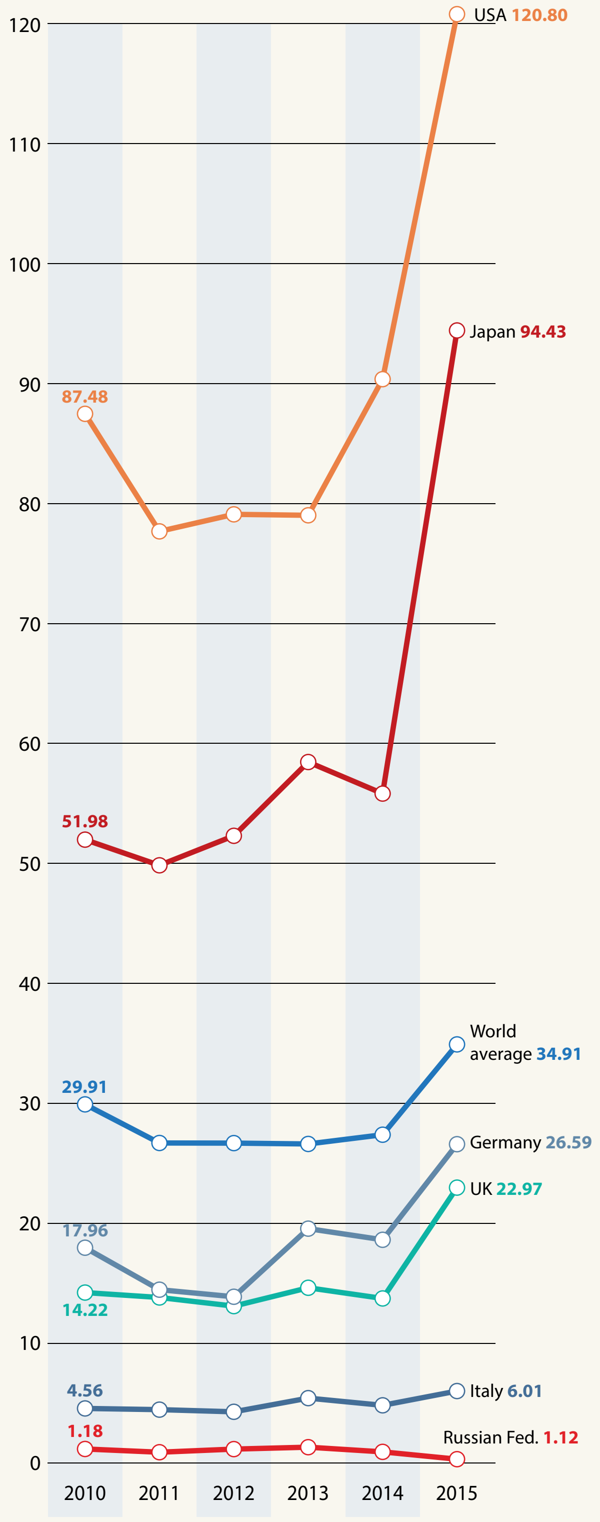
The advent of the State Roscosmos Corporation

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**

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, 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 an EU–Russian Federation Common Space of Education and Science

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 the a Common Space of Education and Science 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).

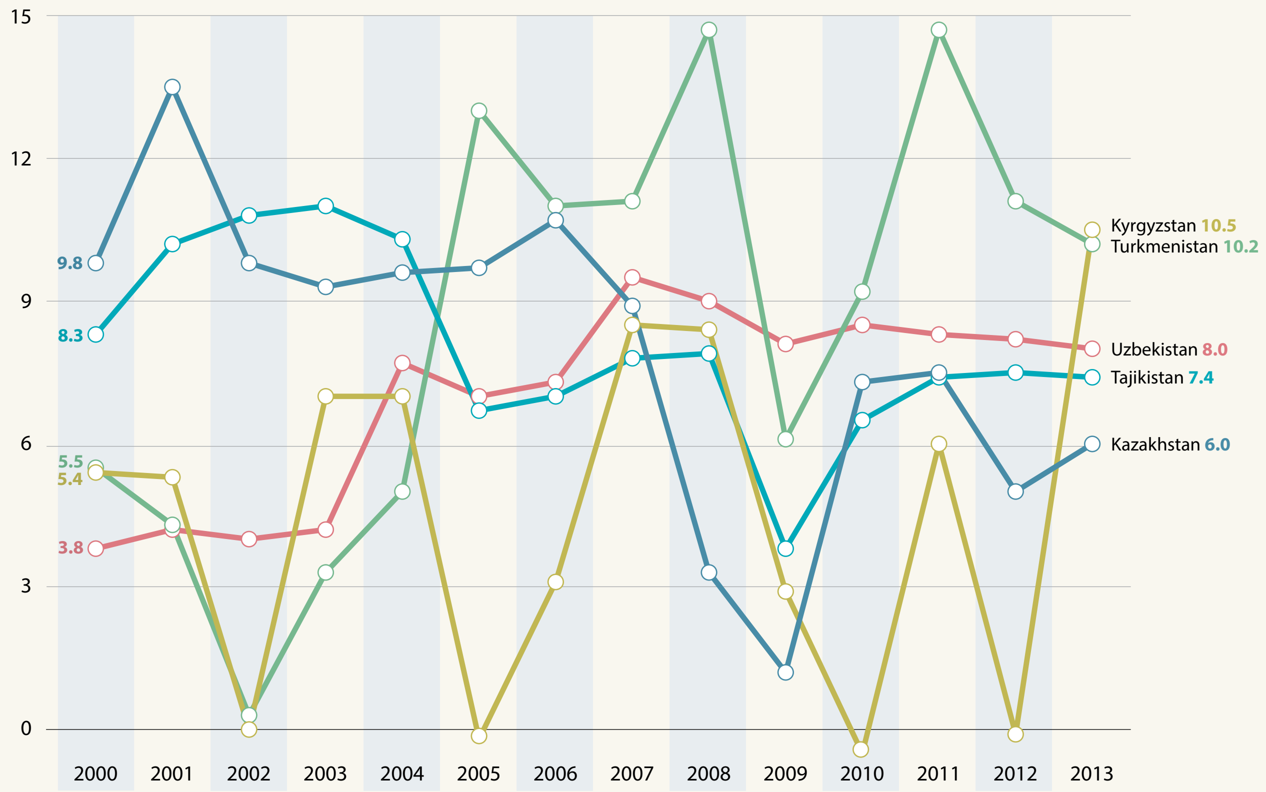
The republics which have fared best have surfed on the wave of the commodities boom. Kazakhstan and Turkmenistan have abundant oil and natural gas reserves and Uzbekistan's own reserves make it more or less self-sufficient. Kyrgyzstan, Tajikistan and Uzbekistan all have gold reserves and Kazakhstan has 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.

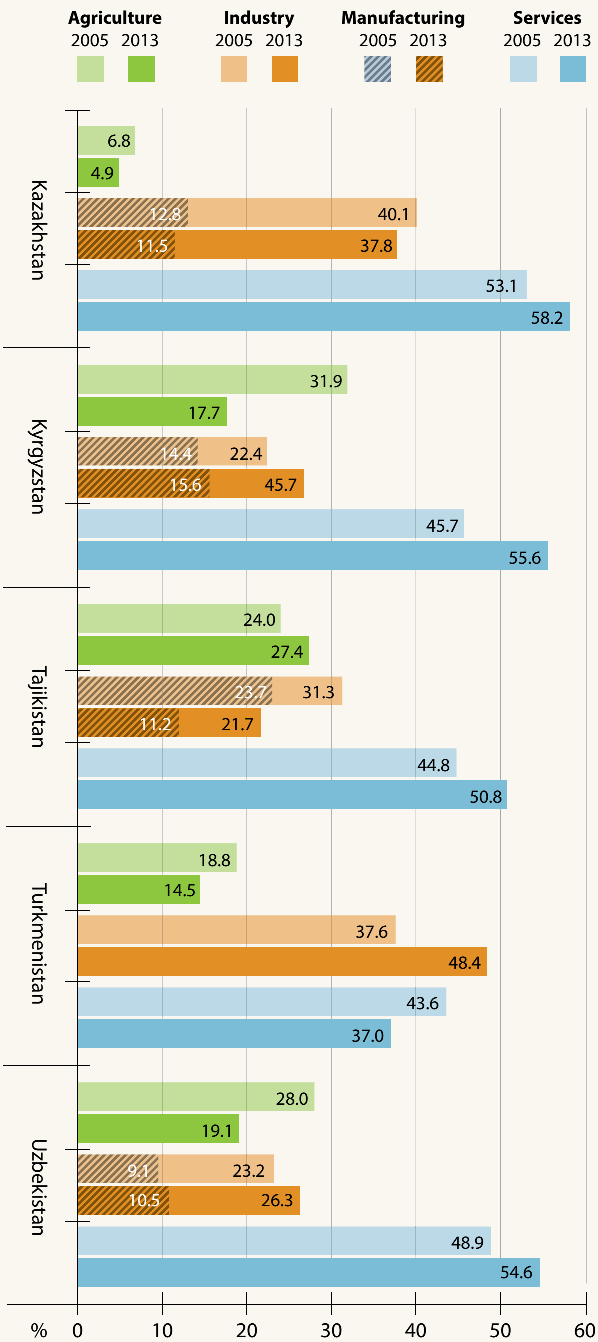
3. CAREC was founded in 1997. It partnered with six multilateral institutions in 2003 to help mainstream regional co-operation in transport, trade and energy, including infrastructure development: the Asian Development Bank (providing the secretariat since 2001); European Bank for Reconstruction and 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.

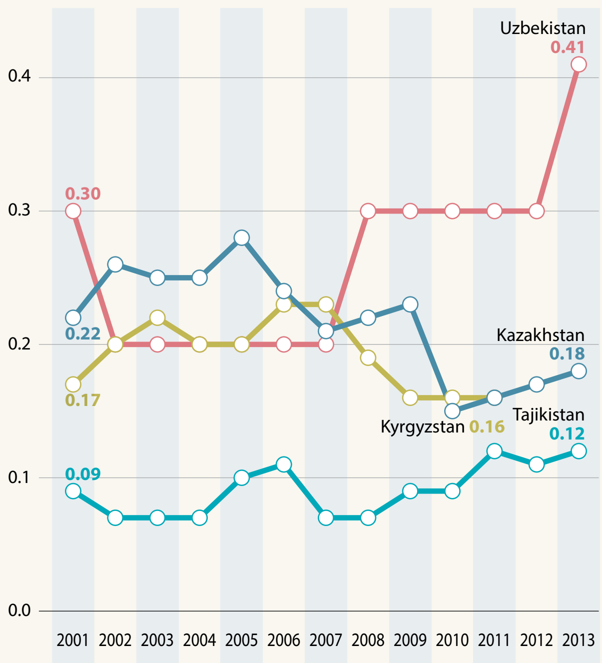
In 2013, the Earth Institute made an effort to measure the extent of happiness in 156 countries. Kazakhs (57th), Turkmens (59th) and Uzbeks (60th) were found to be happier than most, unlike the Kyrgyz (89th) and, above all, Tajiks (125th).

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

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 (Figures 4 and 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

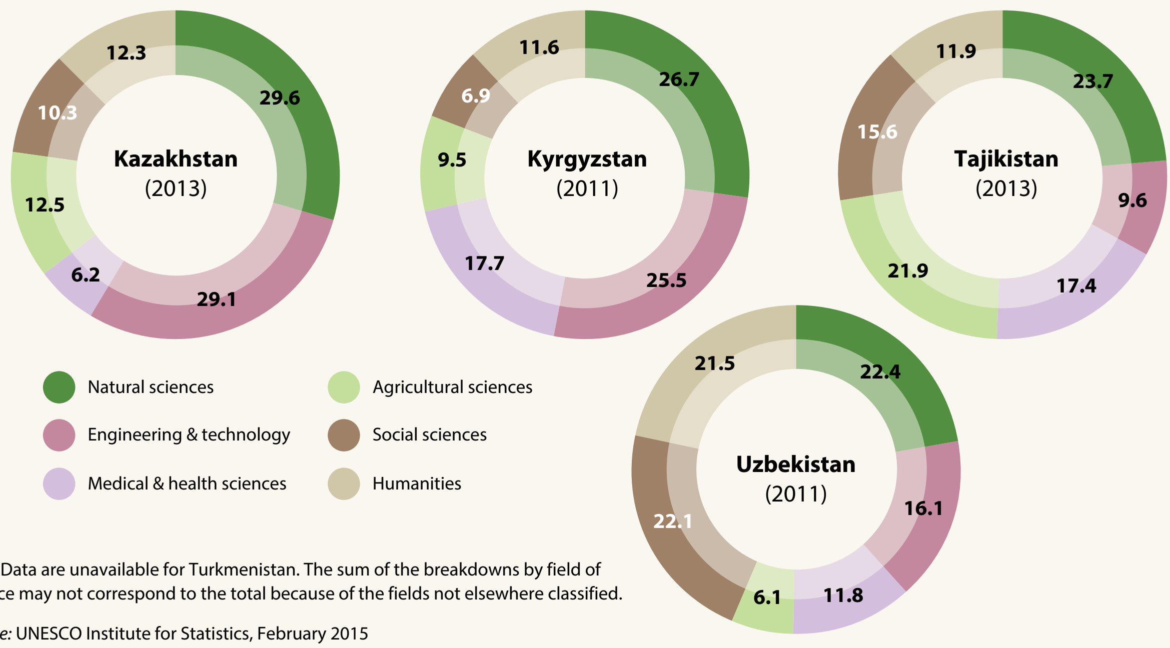
Note: Data are unavailable for Turkmenistan. The sum of the breakdowns by field of science may not correspond to the total because of the fields not elsewhere classified.

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.

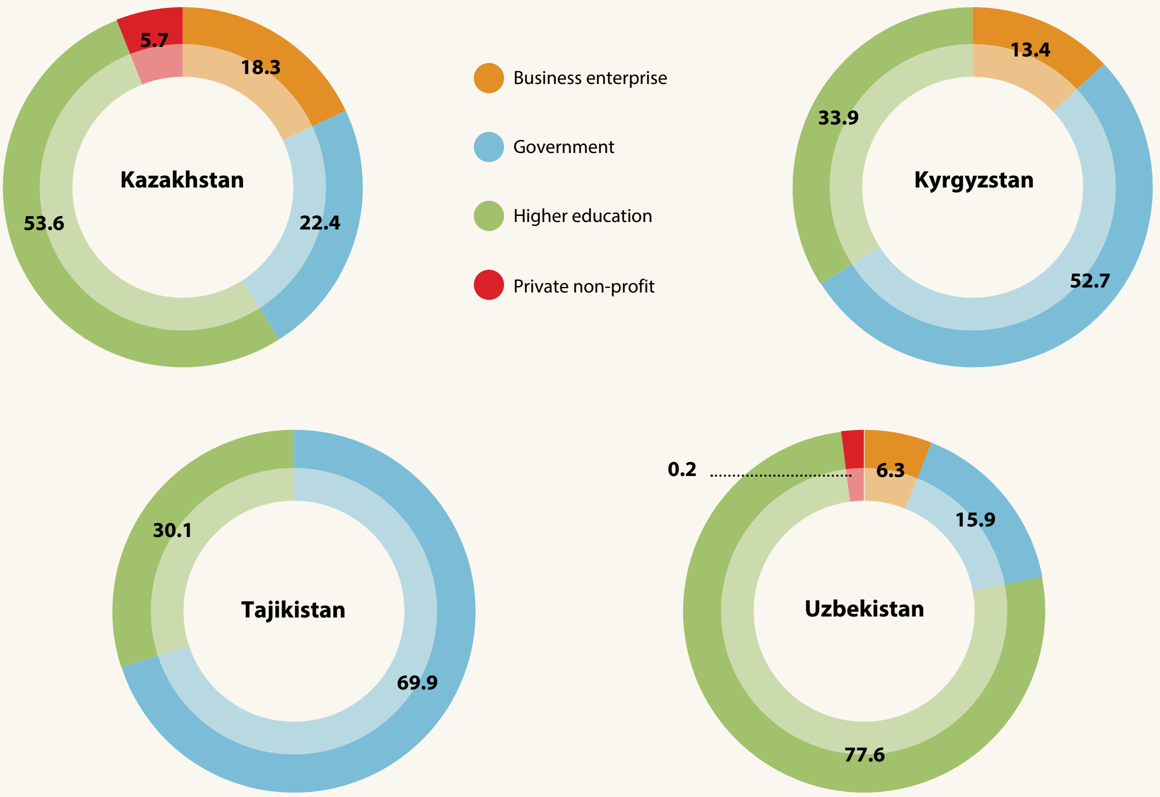
Figure 14.4: Central Asian researchers by field of science, 2013 (%)



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.

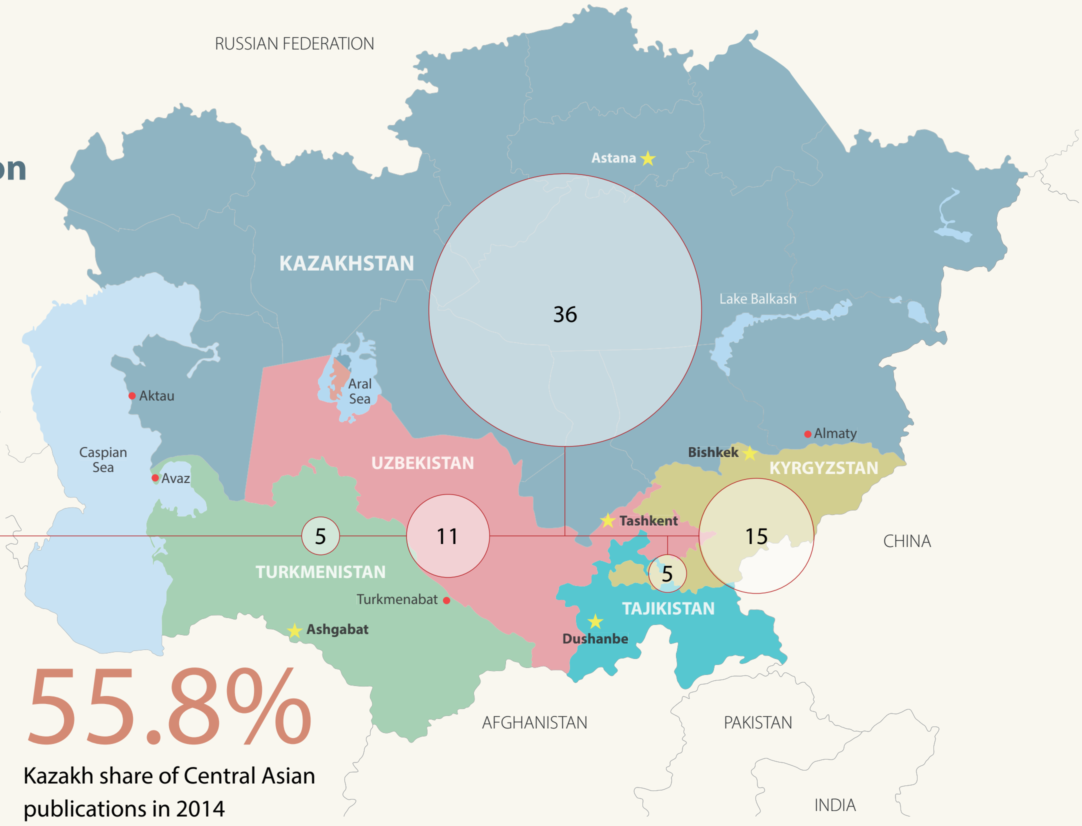
The number of patents registered at the US Patent and Trademark Office is minimal. Kazakh inventors were granted just five patents by this office between 2008 and 2013 and Uzbek inventors three. No patents at all were recorded for the other three Central Asian republics.

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

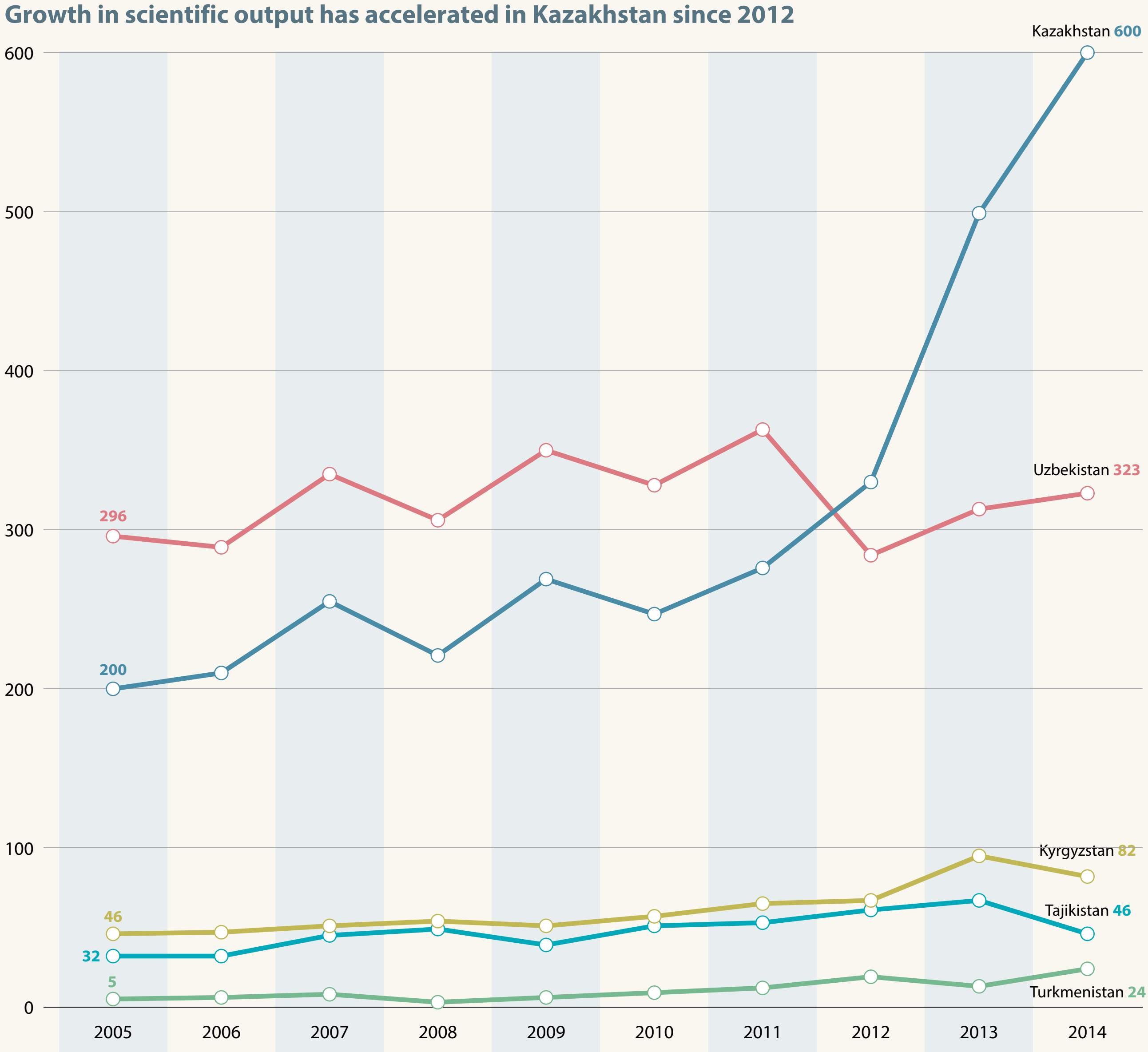
Publications per million inhabitants, 2014



34.5% Kazakh share of Central Asian publications in 2005

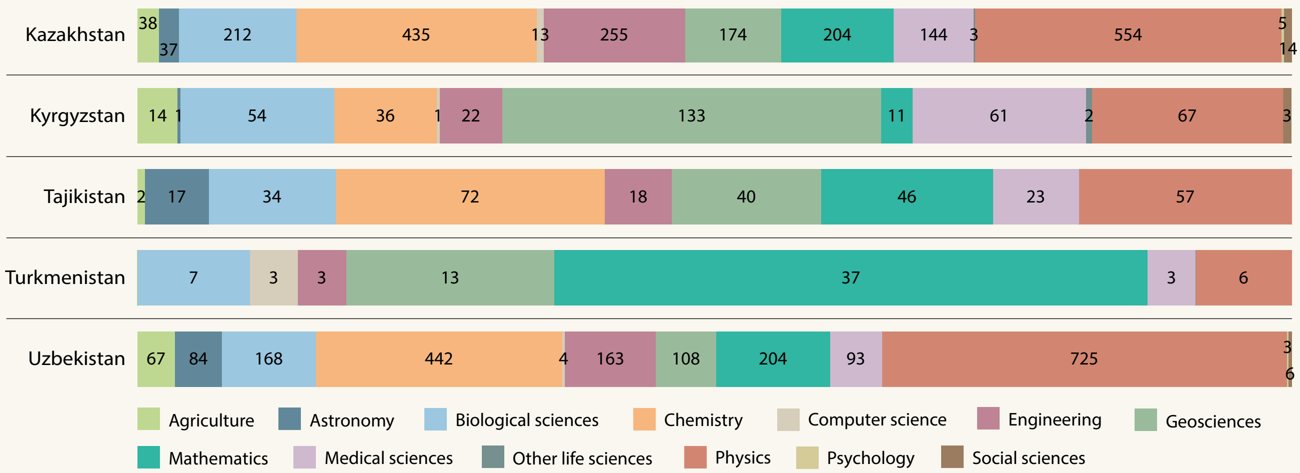
55.8% Kazakh share of Central Asian publications in 2014

Growth in scientific output has accelerated in Kazakhstan since 2012



The most prolific countries – Kazakhstan and Uzbekistan – specialize in physics and chemistry

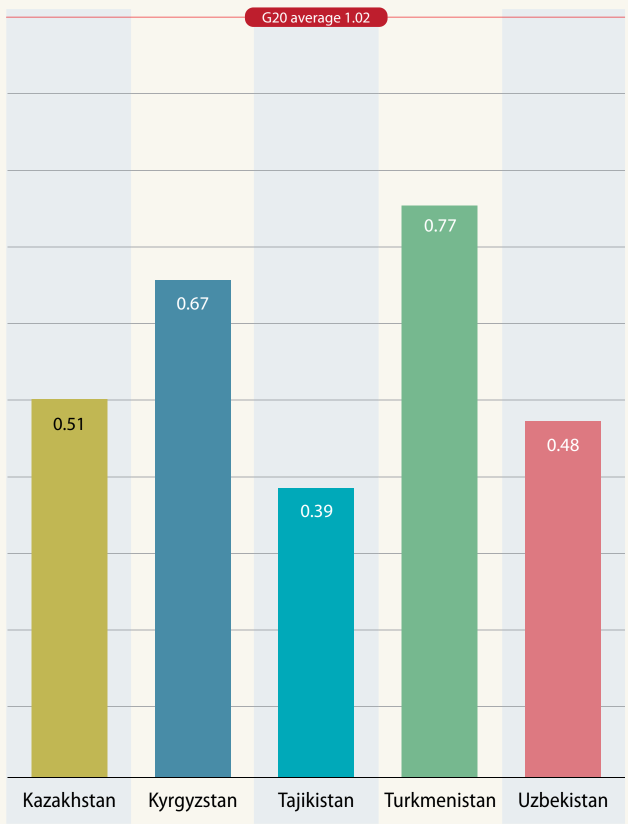
Cumulative totals by field, 2008–2014



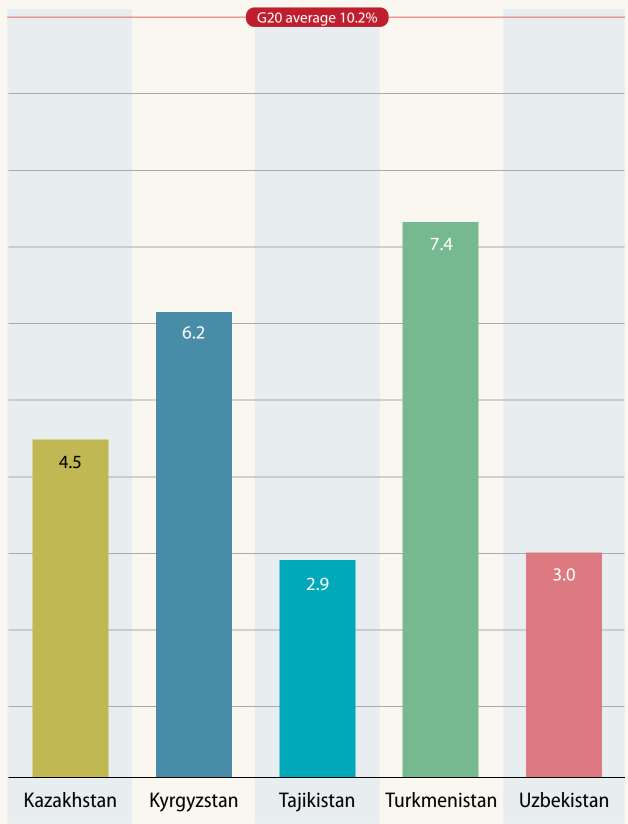
Note: Totals exclude unclassified articles.

The average citation rate is low

Average citation rate for publications, 2008–2012



Share of publications among 10% most cited, 2008–2012 (%)



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**

<table>
<tr><th colspan="2">KAZAKHSTAN 2030 STRATEGY
Targets to 2020</th><th>KAZAKHSTAN 2050 STRATEGY
Targets to 2050</th></tr>
<tr><td>State Programme for Educational Development, 2011–2020</td><td>State Programme for Accelerated Industrial and Innovative Development, 2011–2014</td><td></td></tr>
<tr><td>
■ 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].
</td><td>
■ 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.
</td><td>
■ 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.
</td></tr>
</table>

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 interference 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.;