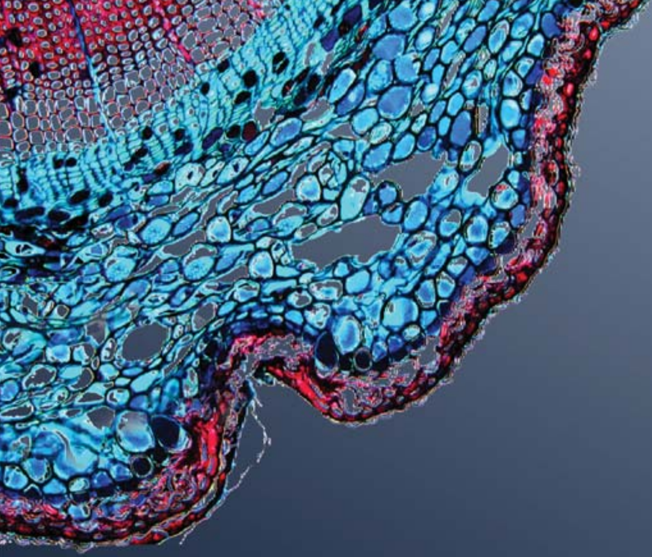
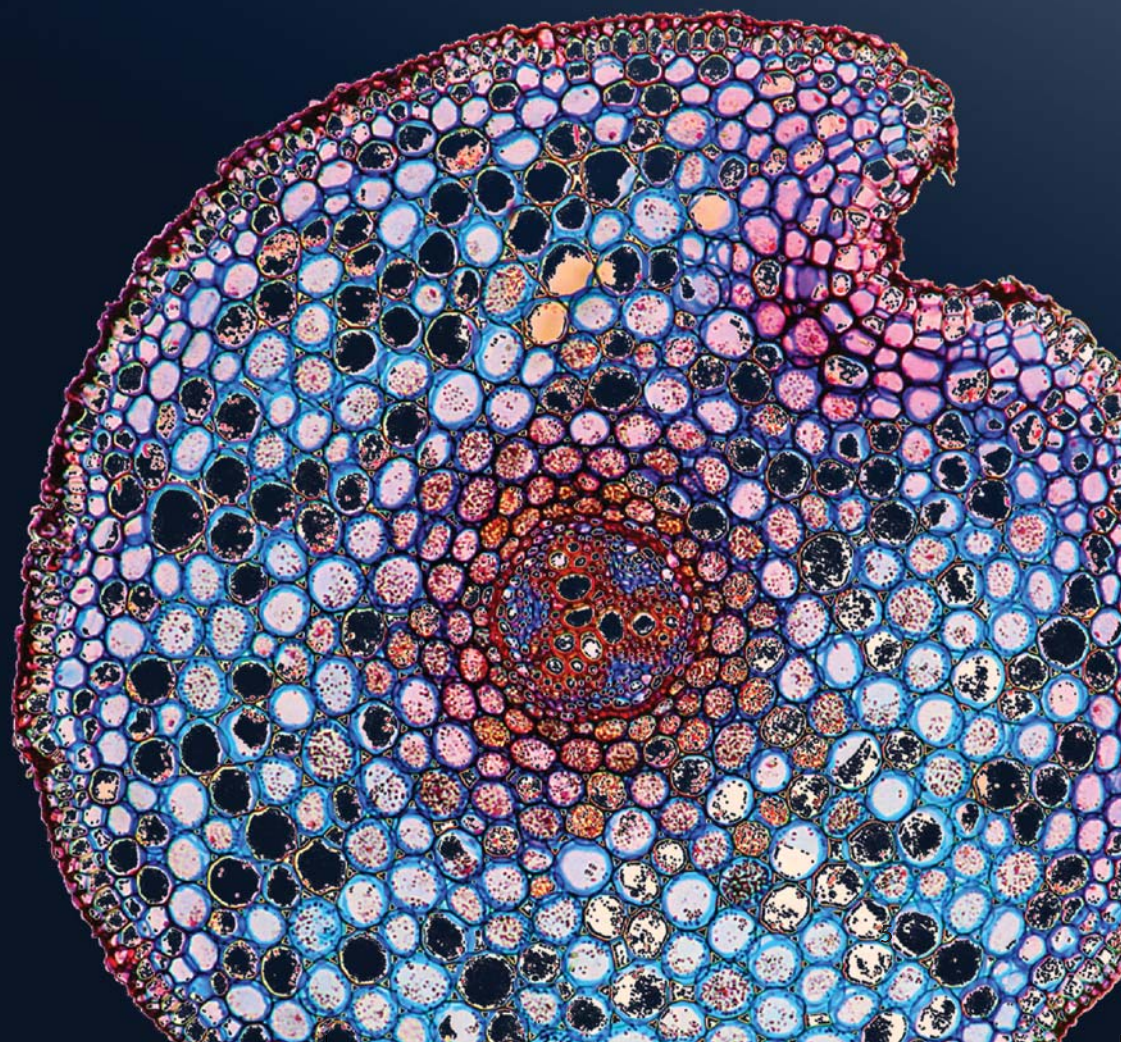


UNESCO SCIENCE REPORT 2010

The Current Status of Science around the World



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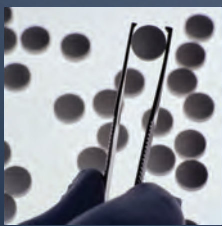

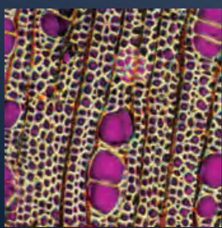

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Cover photos: top image: microscopic image of a corn grain tissue; bottom image: microscopic image of the cross section of the root of a buttercup (crowfoot) plant, *Ranunculus repens*. The propeller shaped pattern in the centre is the vascular tissue for transporting water and nutrients up and down the plant. The circles are the individual cells.
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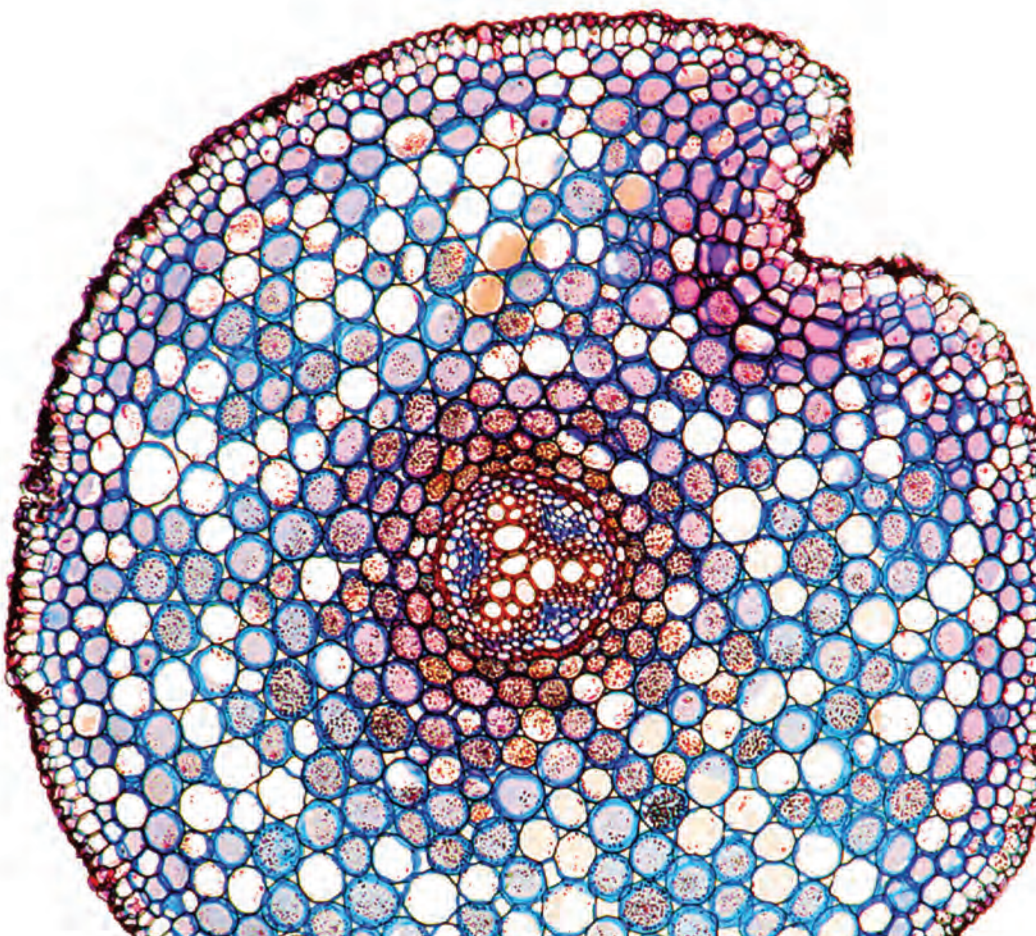
UNESCO SCIENCE REPORT 2010

The Current Status of Science around the World



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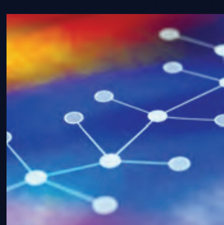
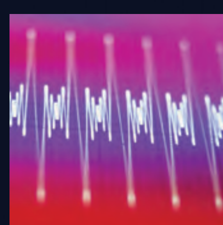
Director of Publication: Lidia Brito, Director
Editor: Susan Schneegans
Administrative Assistant: Sarah Colautti

Every five years, the *UNESCO Science Report* series updates the status of science worldwide. Each edition is heavily reliant on the expertise of the authors invited to write about the main trends and developments in scientific research, innovation and higher education in the country or region from which they hail. We would thus like to take this opportunity to thank each of the 35 authors for their commitment to making this an authoritative report.

The picture they have painted in the following pages is of a world that it is changing at a quickening pace. A greater number of chapters on individual countries have been included in the present report than in its predecessor to reflect the widening circle of countries emerging on the world scene. No doubt the *UNESCO Science Report 2015*, the next in the series, will have pursued its own mutation by 2015 to reflect the world it seeks to depict.

We would like to thank the following staff from the UNESCO Institute for Statistics for contributing a vast amount of data to the report: Simon Ellis, Ernesto Fernández Polcuch, Martin Schaaper, Rohan Pathirage, Zahia Salmi, Sirina Kerim-Dikeni and the Education Indicators team.



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FOREWORD

The *UNESCO Science Report 2010* holds a mirror to the evolving status of science in the five years since its predecessor was published in 2005. It shows in particular how, while the disparities between countries and regions remain huge, the proliferation of digital information and communication technologies is increasingly modifying the global picture. By making codified information accessible worldwide, it is having a dramatic effect on the creation, accumulation and dissemination of knowledge, while at the same time providing specialized platforms for networking by scientific communities operating at a global level.

The distribution of research and development (R&D) efforts between North and South has changed with the emergence of new players in the global economy. A bipolar world in which science and technology (S&T) were dominated by the Triad made up of the European Union, Japan and the USA is gradually giving way to a multipolar world, with an increasing number of public and private research hubs spreading across North and South. Early and more recent newcomers to the S&T arena, including the Republic of Korea, Brazil, China or India, are creating a more competitive global environment by developing their capacities in the industrial, scientific and technological spheres. One consequence is greater competition between countries to attract scientific personnel from abroad and to retain or recall their best researchers and graduates living abroad.

One encouraging finding of the report is that R&D funding has continued to expand globally as the result of greater recognition by governments worldwide of the crucial importance of science for socio-economic development. Those developing countries that have progressed fastest in recent years are the ones that have adopted policies to promote science, technology and innovation. Although Africa still lags behind other regions, signs of progress can be found in some countries on the continent, which today represents a growing contributor to the global R&D effort. The continent's mounting contribution to the global stock of knowledge comes as good news – all the more so since Africa is a priority for UNESCO. This progression shows that deliberate, well-targeted policies can make a difference when implemented with commitment and dedication even in difficult circumstances.

However, the report also points to persistent disparities between countries and, in particular, the marginal contribution that the least developed countries (LDCs) make to global science. This situation calls for all stakeholders, including UNESCO, to renew their support to LDCs for investing in science, transforming the policy environment and making the necessary institutional adjustments – in other words, for enabling S&T to realize its potential as a prime lever for development. This is a vast and complex task that can only be met through a major policy mobilization for science. Mobilizing policy for science remains critical to building the human and institutional capacities needed to overcome the knowledge gap and empower developing countries to build appropriate scientific research capabilities so as to address national and global challenges. We have a moral imperative to make science globally inclusive.

There are two possible scenarios for the way in which the geopolitics of science will shape the future. One is based on partnership and co-operation, and the other on efforts towards national supremacy. I am convinced that, more than ever, regional and international scientific co-operation is crucial to addressing the interrelated, complex and growing global challenges with which we are confronted. Increasingly, international diplomacy will take the form of science diplomacy in the years to come. In this respect, UNESCO must and will pursue its efforts to strengthen international partnerships and co-operation, in particular South–South co-operation. This science dimension of diplomacy was one of the original reasons for including science in UNESCO's mandate. It has fundamental significance for UNESCO nowadays, at a time when science has tremendous power to shape the future of humanity and when it no longer makes much sense to design science policy in purely national terms. This is most vividly evident in issues relating to global climate change and how societies will address it through green economies.

In line with my intention to place science at the centre of UNESCO's efforts to eradicate extreme poverty and foster social inclusion and sustainable development, I am confident that the *UNESCO Science Report 2010* will prove a useful tool in the necessary redefinition of the science policy agenda at national, regional and global levels and will provide valuable insights into the prospects for science and related policy challenges in the years ahead.

Irina Bokova
Director-General of UNESCO

Policies for science and technology must always be a mixture of realism and idealism.

Chris Freeman (1921–2010)
father of the 'national innovation system' concept

1 · The growing role of knowledge in the global economy

Hugo Hollanders and Luc Soete

THE GLOBAL PICTURE

The *UNESCO Science Report 2010* takes up from where its predecessor left off five years ago. The aim of this first chapter is to provide a global overview of developments over the past five years. We shall pay particular attention to 'new', 'less known', or 'unexpected' features revealed by the data and the chapters that follow.

We shall begin by briefly reviewing the state of the support system for science against the backdrop of the long, historically unique period of rapid global economic growth from 1996 to 2007. This 'growth spurt' has been driven by new digital technologies and by the emergence of a number of large countries on the world stage. It was brought to a sudden and somewhat brutal halt by the global economic recession triggered by the sub-prime mortgage crisis in the USA in the third quarter of 2008. What impact has this global economic recession had on investment in knowledge? Before we endeavour to answer this question, let us take a closer look at some of the broad trends that have characterized the past decade.

First and foremost, cheap and easy access to new digital technologies such as broadband, Internet and mobile phones have accelerated the diffusion of best-practice technologies, revolutionized the internal and external organization of research and facilitated the implantation abroad of companies' research and development (R&D) centres (David and Foray, 2002). However, it is not only the spread of digital information and communication technologies (ICTs) that has shifted the balance in favour of a more transparent and more level playing field[1]. The growing membership and further development of global institutional frameworks like the World Trade Organization (WTO) governing international knowledge flows in trade, investment and intellectual property rights have also sped up access to critical knowledge. China, for example, only became a member of WTO in December 2001. The playing field now includes a wide variety of capital- and organization-embedded forms of technology transfer which include foreign direct investment (FDI), licenses and other forms of formal and informal knowledge diffusion.

Secondly, countries have been catching up rapidly in terms of both economic growth and investment in knowledge, as expressed by investment in tertiary education and R&D. This can be observed in the burgeoning number of graduates in science and engineering. India, for example, has opted to establish 30 new universities to raise student enrollment from less than 15 million in 2007 to 21 million by 2012. Large emerging developing countries such as Brazil, China, India, Mexico and South Africa are also spending more on R&D than before. This trend can also be observed in the transition economies of the Russian Federation (Russia) and some other Eastern and Central European countries which are gradually climbing back to the levels of investment under the Soviet Union. In some cases, the rise in gross domestic expenditure on R&D (GERD) has been a corollary of strong economic growth rather than the reflection of greater R&D intensity. In Brazil and India, for example, the GERD/GDP ratio has remained stable, whereas in China it has climbed by 50% since 2002 to 1.54% (2008). Similarly, if the GERD/GDP ratio has declined in some African countries, this is not symptomatic of a weaker commitment to R&D. It simply reflects an acceleration in economic growth thanks to oil extraction (in Angola, Equatorial Guinea, Nigeria, etc) and other non-R&D-intensive sectors. If each country has different priorities, the urge to catch up rapidly is irrepressible and has, in turn, driven economic growth worldwide to the highest level in recorded history.

Thirdly, the impact of the global recession on a post-2008 world is not yet reflected in the R&D data but it is evident that the recession has, for the first time, challenged the old North–South technology-based trade and growth models (Krugman, 1970; Soete, 1981; Dosi *et al*., 1990). Increasingly, the global economic recession appears to be challenging Western scientific and technological (S&T) dominance. Whereas Europe and the USA are struggling to free themselves from the grips of the recession, firms from emerging economies like Brazil, China, India and South Africa are witnessing sustained domestic growth and moving upstream in the value chain. Whereas these emerging economies once served as a repository for the outsourcing of manufacturing activities, they have now moved on to autonomous process technology development, product development, design and applied research. China, India and a few other Asian countries, together with some Arab Gulf states, have combined a national targeted technology policy with the aggressive – and successful – pursuit of better academic research within a short space of time. To this end, they have made astute use of both monetary and non-monetary incentives, as well as

The Earth at night, showing human population centres

Photo: © Evirgen/ iStockphoto

1. This does not mean that each player has an equal chance of success but rather that a greater number are playing by the same set of rules.

institutional reforms. Although data are not easy to come by, it is well-known that many academic leaders in American, Australian and European universities have, in the past five years, been offered positions and large research budgets in fast-growing universities in East Asian countries.

In short, achieving knowledge-intensive growth is no longer the sole prerogative of the highly developed nations of the Organisation for Economic Co-operation and Development (OECD). Nor is it the sole prerogative of national policy-making. Value creation depends increasingly on a better use of knowledge, whatever the level of development, whatever its form and whatever its origin: new product and process technologies developed domestically, or the re-use and novel combination of knowledge developed elsewhere. This applies to manufacturing, agriculture and services in both the public and private sectors. Yet, at the same time, there is striking evidence of the persistence – expansion even – in the uneven distribution of research and innovation at the global level. Here, we are no longer comparing countries but regions within countries. Investment in R&D appears to remain concentrated in a relatively small number of locations within a given country[2]. In Brazil, for example, 40% of GERD is spent in the São Paulo region. The proportion is as high as 51% in South Africa's Gauteng Province.

PRE-RECESSION FACTS AND FIGURES

Economic trends: a unique growth spurt

Historically, global economic growth in the years bridging the Millennia has been unique. Over the period 1996–2007, real GDP per capita increased at an average annual rate of 1.88%[3]. At the broad continental level, the highest per-capita growth was witnessed by East Asia and the Pacific (5.85%), Europe and Central Asia (4.87%) and South Asia (4.61%). The figure was 2.42% for the Middle East and North Africa, 2.00% for North America, 1.80% for Latin American and the Caribbean and 1.64% for sub-Saharan Africa. The greatest divergence in growth rates occurred in sub-Saharan Africa: in 28 countries, GDP per capita grew by more than 5% but more than half of the 16 countries which witnessed negative per-capita growth rates were also in sub-Saharan Africa (Table 1).

2. For a more detailed analysis of specialization at the regional level within countries, see the *World Knowledge Report* (forthcoming) published by UNU-Merit.

3. Growth rates reported in this section reflect the average annual increase between 1996 and 2007 of per capita GDP in constant US$ 2 000 from World Bank data.

Table 1: Key indicators on world GDP, population and GERD, 2002 and 2007

	GDP (PPP$ billions) 2002	GDP (PPP$ billions) 2007
World	**46 272.6**	**66 293.7**
Developed countries	29 341.1	38 557.1
Developing countries	16 364.4	26 810.1
Least developed countries	567.1	926.4
Americas	**15 156.8**	**20 730.9**
North America	11 415.7	15 090.4
Latin America and the Caribbean	3 741.2	5 640.5
Europe	**14 403.4**	**19 194.9**
European Union	11 703.6	14 905.7
Commonwealth of Independent States in Europe	1 544.8	2 546.8
Central, Eastern and Other Europe	1 155.0	1 742.4
Africa	**1 674.0**	**2 552.6**
South Africa	323.8	467.8
Other sub-Saharan countries (excl. South Africa)	639.6	1 023.1
Arab States in Africa	710.6	1 061.7
Asia	**14 345.3**	**22 878.9**
Japan	3 417.2	4 297.5
China	3 663.5	7 103.4
Israel	154.6	192.4
India	1 756.4	3 099.8
Commonwealth of Independent States in Asia	204.7	396.4
Newly Industrialised Economies in Asia	2 769.9	4 063.1
Arab States in Asia	847.3	1 325.1
Other in Asia (excl. Japan, China, Israel, India)	1 531.5	2 401.1
Oceania	**693.1**	**936.4**
Other groupings		
Arab States all	1 557.9	2 386.8
Commonwealth of Independent States all	1 749.5	2 943.2
OECD	29 771.3	39 019.4
European Free Trade Association	424.5	580.5
Sub-Saharan Africa (incl. South Africa)	963.4	1 490.9
Selected countries		
Argentina	298.1	523.4
Brazil	1 322.5	1 842.9
Canada	937.8	1 270.1
Cuba	–	–
Egypt	273.7	404.1
France	1 711.2	2 071.8
Germany	2 275.4	2 846.9
Iran (Islamic Republic of)	503.7	778.8
Mexico	956.3	1 493.2
Republic of Korea	936.0	1 287.7
Russian Federation	1 278.9	2 095.3
Turkey	572.1	938.7
United Kingdom	1 713.7	2 134.0
United States of America	10 417.6	13 741.6

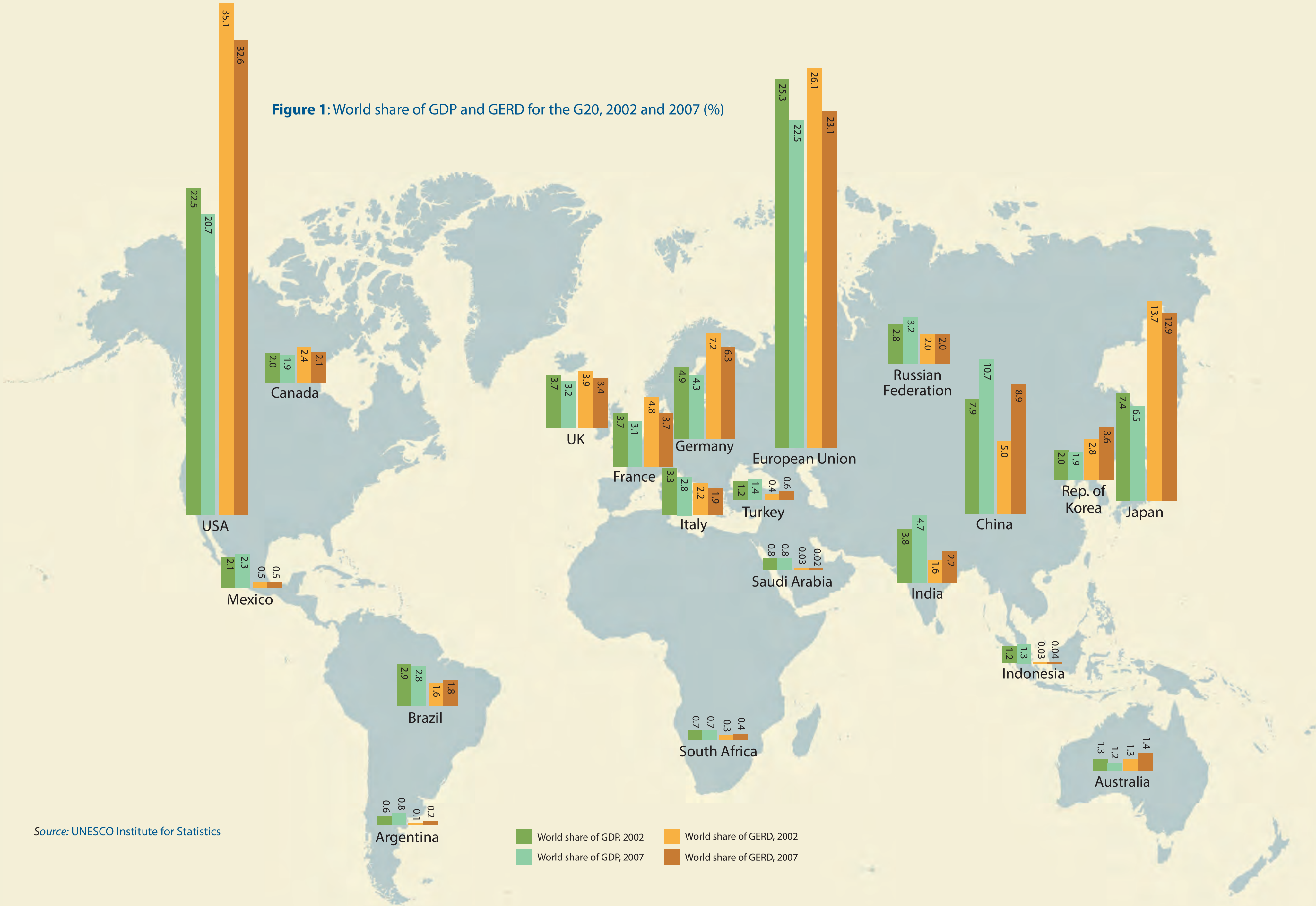
Note: Dollar amounts are in constant prices. The sum of GERD for some regions does not correspond to the total because of changes in the reference year. Furthermore, in numerous developing countries, data do not cover all sectors of the economy. Therefore, the data presented here for developing countries can be considered a lower bound of their real R&D effort. For the list of countries encompassed by the groupings in this chapter, see Annex I.

World GDP (%) 2002	World GDP (%) 2007	Population (millions) 2002	Population (millions) 2007	World population (%) 2002	World population (%) 2007	GERD (PPP$ billions) 2002	GERD (PPP$ billions) 2007	World GERD (%) 2002	World GERD (%) 2007	GERD as % of GDP 2002	GERD as % of GDP 2007	GERD per capita (PPP$) 2002	GERD per capita (PPP$) 2007
100.0	**100.0**	**6 274.3**	**6 670.8**	**100.0**	**100.0**	**790.3**	**1 145.7**	**100.0**	**100.0**	**1.7**	**1.7**	**126.0**	**171.7**
63.4	58.2	1 203.4	1 225.0	19.2	18.4	653.0	873.2	82.6	76.2	2.2	2.3	542.7	712.8
35.4	40.4	4 360.5	4 647.3	69.5	69.7	136.2	271.0	17.2	23.7	0.8	1.0	31.2	58.3
1.2	1.4	710.4	798.5	11.3	12.0	1.1	1.5	0.1	0.1	0.2	0.2	1.5	1.9
32.8	**31.3**	**861.2**	**911.4**	**13.7**	**13.7**	**319.9**	**433.9**	**40.5**	**37.9**	**2.1**	**2.1**	**371.4**	**476.1**
24.7	22.8	325.3	341.6	5.2	5.1	297.8	399.3	37.7	34.9	2.6	2.6	915.3	1 168.8
8.1	8.5	535.9	569.8	8.5	8.5	22.1	34.6	2.8	3.0	0.6	0.6	41.2	60.8
31.1	**29.0**	**796.5**	**804.8**	**12.7**	**12.1**	**238.5**	**314.0**	**30.2**	**27.4**	**1.7**	**1.6**	**299.4**	**390.2**
25.3	22.5	484.2	493.2	7.7	7.4	206.2	264.9	26.1	23.1	1.8	1.8	425.8	537.0
3.3	3.8	207.3	201.6	3.3	3.0	18.3	27.4	2.3	2.4	1.2	1.1	88.5	136.1
2.5	2.6	105.0	109.9	1.7	1.6	13.9	21.7	1.8	1.9	1.2	1.2	132.6	197.2
3.6	**3.9**	**858.9**	**964.7**	**13.7**	**14.5**	**6.9**	**10.2**	**0.9**	**0.9**	**0.4**	**0.4**	**8.0**	**10.6**
0.7	0.7	46.2	49.2	0.7	0.7	2.3^{-1}	4.4	0.3^{e}	0.4	0.7^{-1}	0.9	49.5^{-1}	88.6
1.4	1.5	623.5	709.2	9.9	10.6	1.8	2.6	0.2	0.2	0.3	0.3	2.9	3.7
1.5	1.6	189.3	206.3	3.0	3.1	2.5	3.3	0.3	0.3	0.4	0.3	13.4	15.9
31.0	**34.5**	**3 725.6**	**3 955.5**	**59.4**	**59.3**	**213.9**	**369.3**	**27.1**	**32.2**	**1.5**	**1.6**	**57.4**	**93.4**
7.4	6.5	127.1	127.4	2.0	1.9	108.2	147.9	13.7	12.9	3.2	3.4	851.0	1 161.3
7.9	10.7	1 286.0	1 329.1	20.5	19.9	39.2	102.4	5.0	8.9	1.1	1.4	30.5	77.1
0.3	0.3	6.3	6.9	0.1	0.1	7.1	9.2	0.9	0.8	4.6	4.8	1 121.4	1 321.3
3.8	4.7	1 078.1	1 164.7	17.2	17.5	12.9	24.8	1.6	2.2	0.7	0.8	12.0	21.3
0.4	0.6	72.3	75.4	1.2	1.1	0.5	0.8	0.1	0.1	0.2	0.2	7.0	10.2
6.0	6.1	373.7	399.3	6.0	6.0	40.1	72.3	5.1	6.3	1.4	1.8	107.3	181.1
1.8	2.0	107.0	122.9	1.7	1.8	1.1	1.4	0.1	0.1	0.1	0.1	10.0	11.8
3.3	3.6	675.0	729.7	10.8	10.9	4.8	10.4	0.6	0.9	0.3	0.4	7.1	14.3
1.5	**1.4**	**32.1**	**34.5**	**0.5**	**0.5**	**11.2**	**18.3**	**1.4**	**1.6**	**1.6**	**1.9**	**349.9**	**529.7**
3.4	3.6	296.3	329.2	4.7	4.9	3.6	4.7	0.5	0.4	0.2	0.2	12.2	14.3
3.8	4.4	279.6	277.0	4.5	4.2	18.9	28.2	2.4	2.5	1.1	1.0	67.4	101.9
64.3	58.9	1 149.6	1 189.0	18.3	17.8	661.3	894.7	83.7	78.1	2.2	2.3	575.2	752.5
0.9	0.9	12.1	12.6	0.2	0.2	9.8	13.6	1.2	1.2	2.3	2.3	804.5	1 082.8
2.1	2.2	669.7	758.4	10.7	11.4	4.3	7.0	0.5	0.6	0.4	0.5	6.4	9.2
0.6	0.8	37.7	39.5	0.6	0.6	1.2	2.7	0.1	0.2	0.4	0.5	30.8	67.3
2.9	2.8	179.1	190.1	2.9	2.9	13.0	20.2	1.6	1.8	1.0	1.1	72.7	106.4
2.0	1.9	31.3	32.9	0.5	0.5	19.1	24.1	2.4	2.1	2.0	1.9	611.4	732.3
–	–	11.1	11.2	0.2	0.2	–	–	–	–	0.5	0.4	–	–
0.6	0.6	72.9	80.1	1.2	1.2	0.5^{-2}	0.9	0.1^{e}	0.1	0.2^{-2}	0.2	6.8^{-2}	11.4
3.7	3.1	59.8	61.7	1.0	0.9	38.2	42.3	4.8	3.7	2.2	2.0	637.7	685.5
4.9	4.3	82.2	82.3	1.3	1.2	56.7	72.2	7.2	6.3	2.5	2.5	689.0	877.3
1.1	1.2	68.5	72.4	1.1	1.1	2.8	4.7^{-1}	0.3	0.5^{e}	0.5	0.7^{-1}	40.3	65.6^{-1}
2.1	2.3	102.0	107.5	1.6	1.6	4.2	5.6	0.5	0.5	0.4	0.4	40.9	52.1
2.0	1.9	46.9	48.0	0.7	0.7	22.5	41.3	2.8	3.6	2.4	3.2	479.4	861.9
2.8	3.2	145.3	141.9	2.3	2.1	15.9	23.5	2.0	2.0	1.2	1.1	109.7	165.4
1.2	1.4	68.4	73.0	1.1	1.1	3.0	6.8	0.4	0.6	0.5	0.7	44.0	92.9
3.7	3.2	59.4	60.9	0.9	0.9	30.6	38.7	3.9	3.4	1.8	1.8	515.8	636.1
22.5	20.7	294.0	308.7	4.7	4.6	277.1	373.1	35.1	32.6	2.7	2.7	942.4	1 208.7

-n = data refer to *n* years before reference year
e = UNESCO Institute for Statistics estimation based on extrapolations and interpolations

Source: for GERD: UNESCO Institute for Statistics estimations, June 2010; For GDP and PPP conversion factor:
World Bank, World Development Indicators, May 2010, and UNESCO Institute for Statistics estimations; for population:
United Nations Department of Economic and Social Affairs (2009) *World Population Prospects*: *the 2008 Revision*, and
UNESCO Institute for Statistics estimations

Figure 1: World share of GDP and GERD for the G20, 2002 and 2007 (%)



Source: UNESCO Institute for Statistics

The growing role of knowledge in the global economy

Figure 1 presents the 20 largest economic powers in the world. This list includes the Triad[4] and the newly industrializing countries of Mexico and the Republic of Korea, some of the most populated countries in the world such as China, India, Brazil, Russia and Indonesia, and a second layer of emerging economies that include Turkey, Saudi Arabia, Argentina and South Africa. With their newfound economic weight, these countries are challenging many of the rules, regulations and standards that governed the G7 and the Triad with respect to international trade and investment[5]. As we shall now see, they are also challenging the traditional dominance of the Triad when it comes to investment in R&D.

Trends in GERD: a shift in global influence

The world devoted 1.7% of GDP to R&D in 2007, a share that has remained stable since 2002. In monetary terms, however, this translates into US$ 1 146 billion[6], an increase of 45% over 2002 (Table 1). This is slightly higher than the rise in GDP over the same period (43%).

Moreover, behind this increase lies a shift in global influence. Driven largely by China, India and the Republic of Korea, Asia's world share has risen from 27% to 32%, to the detriment of the Triad. Most of the drop in the European Union (EU) can be attributed to its three biggest members: France, Germany and the United Kingdom (UK). Meanwhile, the shares of Africa and the Arab States are low but stable and Oceania has progressed slightly.

We can see from Figure 1 that China's share of world GERD is approaching its world share of GDP, unlike Brazil or India which still contribute much more to global GDP than to global GERD. Of note is that the situation is reversed for the Triad, even though the disparity is very small for the EU. The Republic of Korea is an interesting case in point, in that it follows the pattern of the Triad. Korea's world share of GERD is even double its world share of GDP. One of Korea's top priorities is to raise its GERD/GDP ratio to as much as 5% by 2012.

4. Composed of the European Union, Japan and USA

5. The great majority of the standards governing, for instance, trade in manufactured goods, agriculture and services are based on USA–EU norms.

6. All US$ in the present chapter are purchasing power parity dollars.

Figure 2 correlates the density of both R&D and researchers for a number of key countries and regions. From this figure, we can see that Russia still has a much greater number of researchers than financial resources in its R&D system. Three large newcomers can be seen emerging in the bottom left-hand side of the picture, namely China, Brazil and India, together with Iran and Turkey. Even Africa, as a continent, today represents a sizeable contributor to the global R&D effort. The R&D intensity of these economies or their human capital might still be low but their contribution to the stock of world knowledge is actually rising rapidly. By contrast, the group of least developed countries – the smallest circle in the figure – still plays a marginal role.

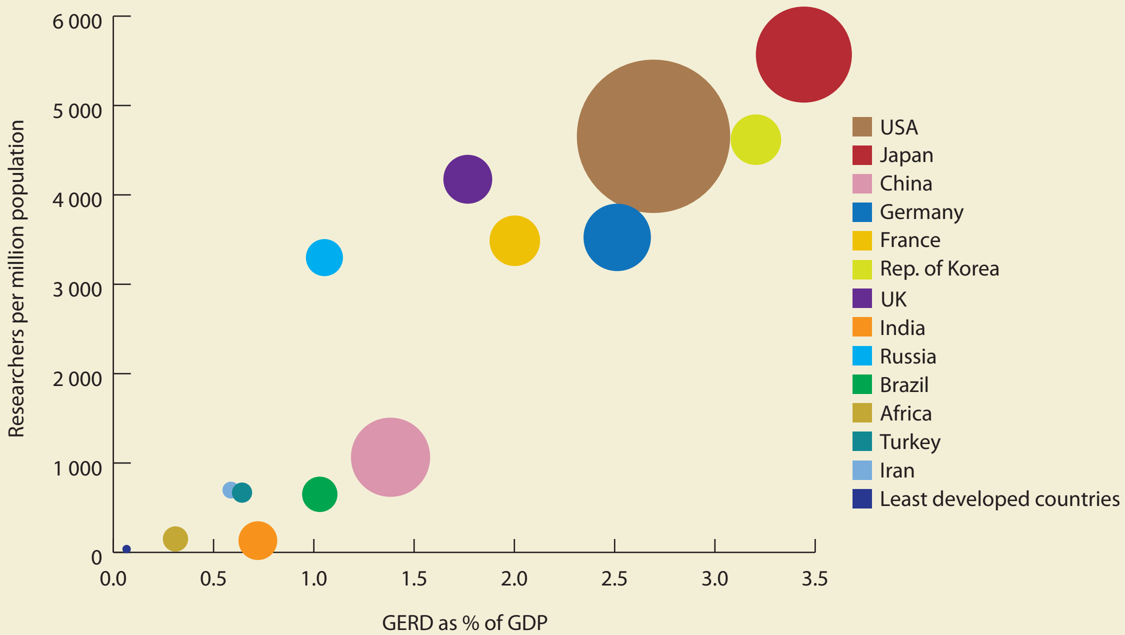
Catching up in business R&D

It is the trends in business investment in R&D (BERD) which best illustrate the rapid geographical changes taking place worldwide in privately funded R&D centres. Increasingly, multinational companies are decentralizing their research activities to parts of both the developed and developing worlds within a strategy to internalize R&D at the global level (Zanatta and Queiroz, 2007). For multinationals, this strategy reduces labour costs and gives companies easier access to markets, local human capital and knowledge, as well as to the host country's natural resources.

The favoured destinations are the so-called Asian 'tigers', the 'old' newly industrialized countries in Asia, and, secondly, Brazil, India and China. However, this is no longer a one-way traffic: firms from emerging economies are now also buying up large firms in developed countries and thereby acquiring the firms' knowledge capital overnight, as the chapter on India neatly illustrates. As a consequence, the global distribution of R&D effort between North and South is shifting rapidly. In 1990, more than 95% of R&D was being carried out in the developed world and just seven OECD economies accounted for more than 92% of world R&D (Coe *et al.,* 1997). By 2002, developed countries accounted for less than 83% of the total and by 2007 for 76%. Furthermore, as the chapters on South Asia and sub-Saharan Africa underscore, a number of countries not generally considered to be R&D-intensive are developing particular sectors like light engineering as a strategy for import substitution, among them Bangladesh and Cameroon.

From 2002 to 2007, the share of BERD in GDP rose sharply in Japan, China and Singapore, with a particularly steep curve in the Republic of Korea. The ratio remained more or

Figure 2: Global investment in R&D in absolute and relative terms, 2007
For selected countries and regions



Note: The size of the circle reflects the size of GERD for the country or grouping.

Source: UNU–MERIT based on data from the UNESCO Institute for Statistics and World Bank

less constant in Brazil, the USA and the EU and even declined in Russia. As a result, by 2007, the Republic of Korea was challenging Japan for the title of technological leader, Singapore had nearly caught up to the USA and China was rubbing shoulders with the EU. Notwithstanding this, the BERD/GDP ratio still remains much lower in India and Brazil than in the Triad.

Trends in human capital: China soon to count the most researchers

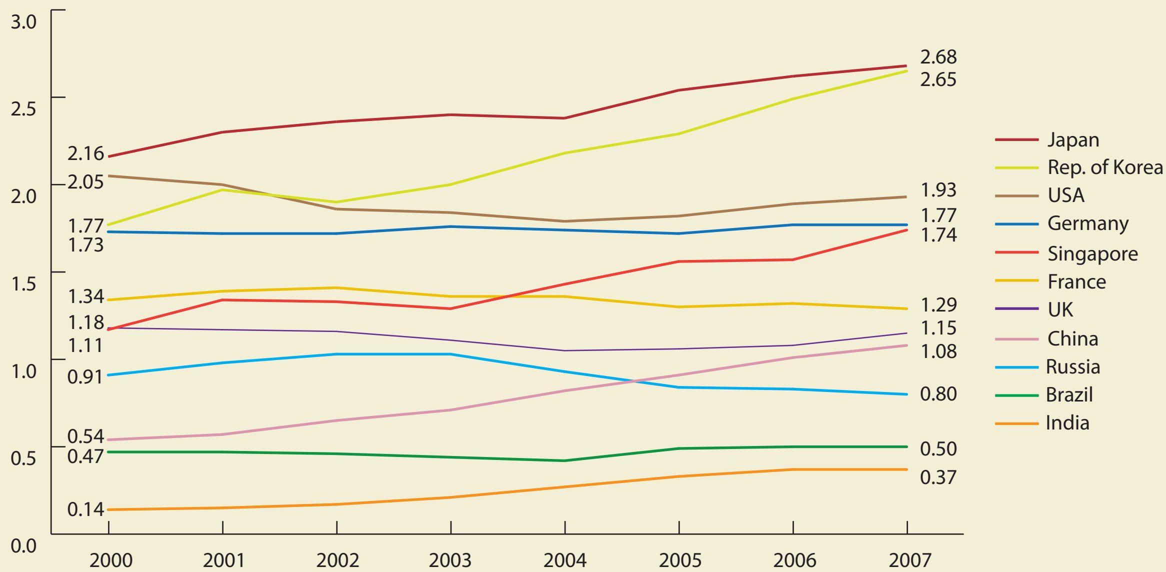
Here, we focus on another core area of R&D input: trends with regard to researchers. As Table 2 highlights, China is on the verge of overtaking both the USA and the EU in terms of sheer numbers of researchers. These three giants each represent about 20% of the world's stock of researchers. If we add Japan's share (10%) and that of Russia (7%), this highlights the extreme concentration of researchers: the 'Big Five' account for about 35% of the world population but three-quarters of all researchers. By contrast, a populous country like India still represents only 2.2% of the world total and the entire continents of Latin America and Africa just 3.5% and 2.2% respectively.

Although the share of researchers in the developing world has grown from 30% in 2002 to 38% in 2007, two-thirds of this growth can be attributed to China alone. Countries are training many more scientists and engineers than before but graduates are having trouble finding qualified positions or attractive working conditions at home. As a result, migration of highly qualified researchers from South to North has become the characteristic feature of the past decade. A 2008 report by the UK Parliamentary Office cited OECD data indicating that, of the 59 million migrants living in OECD countries, 20 million were highly skilled.

Brain drain preoccupies developing countries

Despite voluminous literature on migration, it is almost impossible to draw a systematic, quantitative picture of long-term migration of the highly skilled worldwide. Moreover, not everyone perceives the phenomenon in the same way. Some refer to brain drain, others prefer the term brain strain or brain circulation. Whatever the preferred terminology, several chapters in the present report – among them those on India, South Asia, Turkey and sub-Saharan Africa – highlight the serious issue that brain drain

Figure 3: BERD/GDP ratio for slected countries, 2000–2007 (%)



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

has become and the barriers that this flow of knowledge out of countries creates for domestic R&D. For instance, a national survey by the Sri Lankan National Science Foundation found that the number of economically active scientists in Sri Lanka had dropped from 13 286 to 7 907 between 1996 and 2006. Meanwhile, FDI flowing into India is creating internal brain drain, as domestic firms cannot compete with the attractive compensation packages offered to personnel by foreign firms based in India.

South–South and South–North migration data are not systematically covered by international statistical institutes but can be approximated by combining OECD data on migration of the highly skilled with UNESCO data on bilateral flows of international students (Dunnewijk, 2008). These data reveal that South to North and North to North are dominant directions for migration but that, overall, a much more varied array of destinations is emerging: South Africa, Russia, Ukraine, Malaysia and Jordan have also become attractive destinations for the highly skilled. The diaspora that has settled in South Africa originated from Zimbabwe, Botswana, Namibia and Lesotho; in Russia, from Kazakhstan, Ukraine and Belarus; in Ukraine, from Brunei Darussalam; in the former Czechoslovakia from Iran; in Malaysia from China and India; in Romania from Moldova; in Jordan from the Palestinian Autonomous Territories; in Tajikistan from Uzbekistan; and in Bulgaria from Greece.

A second factor is that the diaspora acts as a useful departure point for the design of policies for more effective technology transfer and knowledge spillovers. This phenomenon motivates countries to elaborate policies to lure highly skilled expatriates back home. This was the case in the Republic of Korea in the past and can be seen in China and elsewhere today. The aim is to encourage the diaspora to use the skills acquired abroad to bring about structural change at home. Moreover, the diaspora may be invited to participate 'from a distance', if the prospect of a permanent return home is unlikely. In Nigeria, Parliament approved the establishment of the Nigerians in the Diaspora Commission in 2010, the aim of which is to identify Nigerian specialists living abroad and encourage them to participate in Nigerian policy and project formulation.

Trends in publications: a new Triad dominates

The number of scientific publications recorded in Thomson Reuters' Science Citation Index (SCI) is the most commonly used indicator for scientific output. It is particularly valuable, in that it allows both for international comparisons at the aggregate level and for

Table 2: Key indicators on world researchers, 2002 and 2007

	Researchers (thousands)		World share of researchers (%)		Researchers per million inhabitants		GERD per researcher (PPP$ thousands)	
	2002	2007	2002	2007	2002	2007	2002	2007
World	**5 810.7**	**7 209.7**	**100.0**	**100.0**	**926.1**	**1 080.8**	**136.0**	**158.9**
Developed countries	4 047.5	4 478.3	69.7	62.1	3 363.5	3 655.8	161.3	195.0
Developing countries	1 734.4	2 696.7	29.8	37.4	397.8	580.3	78.5	100.5
Least developed countries	28.7	34.7	0.5	0.5	40.5	43.4	37.6	43.8
Americas	**1 628.4**	**1 831.9**	**28.0**	**25.4**	**1 890.9**	**2 010.1**	**196.4**	**236.9**
North America	1 458.5	1 579.8	25.1	21.9	4 483.2	4 624.4	204.2	252.8
Latin America and the Caribbean	169.9	252.1	2.9	3.5	317.1	442.5	130.0	137.4
Europe	**1 870.7**	**2 123.6**	**32.2**	**29.5**	**2 348.5**	**2 638.7**	**127.5**	**147.9**
European Union	1 197.9	1 448.3	20.6	20.1	2 473.9	2 936.4	172.1	182.9
Commonwealth of Independent States in Europe	579.6	551.5	10.0	7.6	2 796.1	2 735.3	31.7	49.8
Central, Eastern and Other Europe	93.2	123.8	1.6	1.7	887.2	1 125.9	149.4	175.1
Africa	**129.0**	**158.5**	**2.2**	**2.2**	**150.2**	**164.3**	**53.1**	**64.6**
South Africa	14.2[-1]	19.3	0.2[e]	0.3	311.4[-1]	392.9	158.9[-1]	225.6
Other sub-Saharan countries (excl. South Africa)	30.8	40.8	0.5	0.6	49.4	57.5	59.5	63.8
Arab States in Africa	84.1	98.4	1.4	1.4	444.1	477.1	30.2	33.3
Asia	**2 064.6**	**2 950.6**	**35.5**	**40.9**	**554.2**	**745.9**	**103.6**	**125.2**
Japan	646.5	710.0	11.1	9.8	5 087.0	5 573.0	167.3	208.4
China	810.5	1 423.4	13.9	19.7	630.3	1 070.9	48.4	72.0
Israel	–	–	–	–	–	–	–	–
India	115.9[-2]	154.8[-2]	2.3[e]	2.2[e]	111.2[-2]	136.9[-2]	102.6[-2]	126.7[-2]
Commonwealth of Independent States in Asia	41.4	39.7	0.7	0.6	572.5	525.8	12.3	19.4
Newly Industrialized Economies in Asia	295.8	434.3	5.1	6.0	791.4	1 087.4	135.6	166.6
Arab States in Asia	21.1	24.4	0.4	0.3	197.1	198.7	50.5	59.3
Other in Asia (excl. Japan, China, India, Israel)	93.2	127.1	1.6	1.8	138.1	174.2	51.6	81.8
Oceania	**118.0**	**145.1**	**2.0**	**2.0**	**3 677.6**	**4 208.7**	**95.1**	**125.9**
Other groupings								
Arab States all	105.2	122.8	1.8	1.7	354.9	373.2	34.3	38.4
Commonwealth of Independent States all	621.0	591.2	10.7	8.2	2 221.1	2 133.8	30.4	47.7
OECD	3 588.1	4 152.9	61.7	57.6	3 121.2	3 492.8	184.3	215.5
European Free Trade Association	48.3	52.9	0.8	0.7	3 976.6	4 209.1	202.3	257.3
Sub-Saharan Africa (incl. South Africa)	45.0	60.1	0.8	0.8	67.1	79.2	96.0	115.8
Selected countries								
Argentina	26.1	38.7	0.4	0.5	692.3	979.5	44.4	68.7
Brazil	71.8	124.9	1.2	1.7	400.9	656.9	181.4	162.1
Canada	116.0	139.0[-1]	2.0	1.9[e]	3 705.3	4 260.4[-1]	165.0	170.7[-1]
Cuba	–	–	–	–	–	–	–	–
Egypt	–	49.4	–	0.7	–	616.6	–	18.5
France	186.4	215.8	3.2	3.0	3 115.7	3 496.0	204.7	196.1
Germany	265.8	290.9	4.6	4.0	3 232.5	3 532.2	213.1	248.4
Iran (Islamic Republic of)	–	50.5[-1]	–	0.7[e]	–	706.1[-1]	–	93.0[-1]
Mexico	31.1	37.9	0.5	0.5	305.1	352.9	134.0	147.6
Republic of Korea	141.9	221.9	2.4	3.1	3 022.8	4 627.2	158.6	186.3
Russian Federation	491.9	469.1	8.5	6.5	3 384.8	3 304.7	32.4	50.1
Turkey	24.0	49.7	0.4	0.7	350.8	680.3	125.4	136.5
United Kingdom	198.2	254.6	3.4	3.5	3 336.5	4 180.7	154.6	152.2
United States of America	1 342.5	1 425.6[-1]	23.1	20.0[e]	4 566.0	4 663.3[-1]	206.4	243.9[-1]

-*n* = data refer to *n* years before reference year   e = UNESCO Institute for Statistics estimation based on extrapolations and interpolations

Note: Researchers are full-time equivalents. The sum of researchers and the world share do not correspond to the total for some regions because of changes in the reference year or the unavailability of data for some countries.

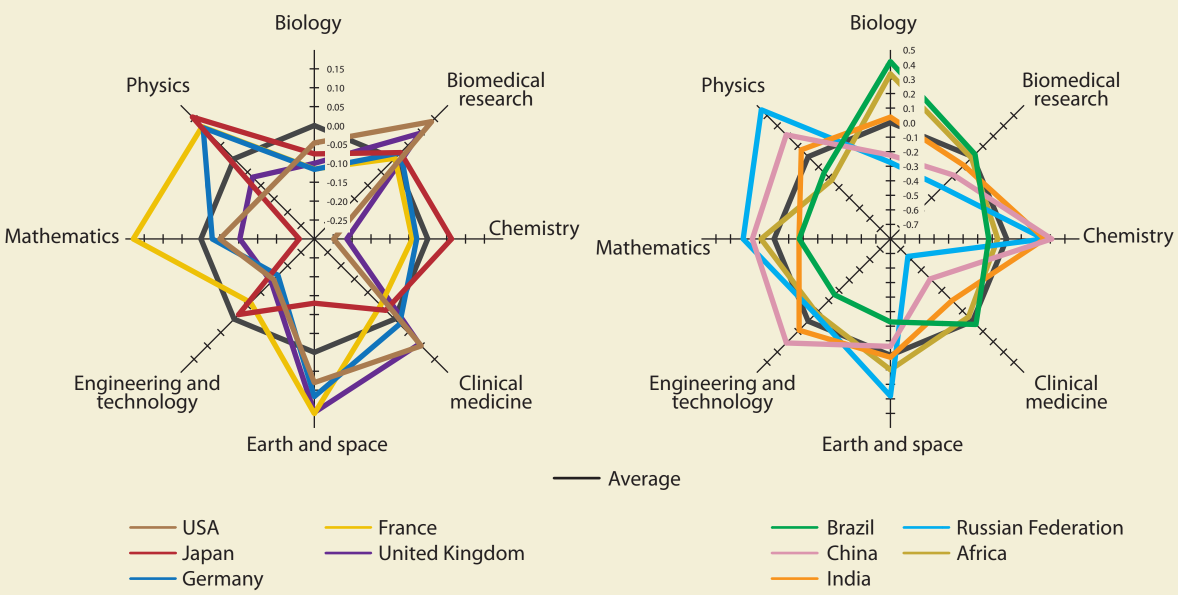
Source: for researchers: UNESCO Institute for Statistics estimations, June 2010; for PPP conversion factor: World Bank, World Development Indicators, May 2010, and UNESCO Institute for Statistics estimations; for population: United Nations Department of Economic and Social Affairs (2009) *World Population Prospects*: *the 2008 Revision*, and UNESCO Institute for Statistics estimations more detailed assessments of particular scientific fields. We begin with the aggregate analysis of scientific publications. As Table 3 highlights, the USA is still the country which leads the world when it comes to scientific output in absolute terms. However, its world share (28%) has fallen more than any other country over the past six years. The leading region for this indicator, the EU, has also seen its share dip by four percentage points to less than 37%. By contrast, China's share has more than doubled in just six years and now represents more than 10% of the world total, second only to the USA, even if the citation rate for Chinese articles remains much lower than for the Triad. Next come Japan and Germany. They are now on a par at just under 8%, Japan's world share having fallen farther than Germany's.

As for the BRIC[7] countries, their share of world publications has shown impressive growth, with the exception of Russia, which saw its share decline from 3.5% in 2002 to 2.7% in 2008. At the continental level, Latin America's share leapt from 3.8% to 4.9% but this was mostly thanks to Brazil. Growth in the Arab world remained sluggish. Africa's share of publications in the SCI made a bound of 25% between 2002 and 2008 from a very low starting point to attain 2.0% of the world total. Here, the rise was most noticeable in South Africa and the Maghreb but every African country saw the number of its articles recorded in the SCI progress. At the global level, scientific publishing is today dominated by a new triad: the USA, Europe and Asia. Given the size of Asia's population, one would expect it to become the dominant scientific continent in the coming years.

In terms of the relative specialization of countries in specific scientific disciplines, Figure 4 points to wide disparities. The first spider's web focuses on the traditionally dominant scientific countries. The black octagon represents the average, so the lines outside this octagon indicate a better-than-average performance in a given field. Of note is France's specialization in mathematics, recently confirmed by the award of the Abel Prize – the mathematical equivalent of the Nobel Prize – to two French mathematicians in 2010.

7. Brazil, Russian Federation, India and China

Figure 4: Scientific specialization of the Triad, BRIC countries and Africa, 2008



Source: UNU-MERIT based on data from Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

Table 3: World shares of scientific publications, 2002 and 2008

	Total publications 2002	Total publications 2008	Change (%) 2002–2008	World share of publications (%) 2002	World share of publications (%) 2008	Biology 2002	Biology 2008	Biomedical research 2002	Biomedical research 2008
World	**733 305**	**986 099**	**34.5**	**100.0**	**100.0**	**58 478**	**84 102**	**99 805**	**123 316**
Developed countries	617 879	742 256	20.1	84.3	75.3	49 315	62 744	89 927	100 424
Developing countries	153 367	315 742	105.9	20.9	32.0	13 158	29 394	14 493	32 091
Least developed countries	2 069	3 766	82.0	0.3	0.4	477	839	226	471
Americas	**274 209**	**348 180**	**27.0**	**37.4**	**35.3**	**23 868**	**33 785**	**47 500**	**54 671**
North America	250 993	306 676	22.2	34.2	31.1	20 234	24 976	44 700	49 590
Latin America and the Caribbean	27 650	48 791	76.5	3.8	4.9	4 321	10 232	3 426	6 216
Europe	**333 317**	**419 454**	**25.8**	**45.5**	**42.5**	**24 133**	**33 809**	**43 037**	**50 464**
European Union	290 184	359 991	24.1	39.6	36.5	21 522	29 516	39 261	45 815
Commonwealth of Independent States in Europe	30 118	32 710	8.6	4.1	3.3	1 153	1 447	2 052	2 054
Central, Eastern and Other Europe	29 195	48 526	66.2	4.0	4.9	2 274	4 348	3 524	5 014
Africa	**11 776**	**19 650**	**66.9**	**1.6**	**2.0**	**2 255**	**3 366**	**1 122**	**2 397**
South Africa	3 538	5 248	48.3	0.5	0.5	828	1 163	481	690
Other sub-Saharan countries (excl. South Africa)	3 399	6 256	84.1	0.5	0.6	1 072	1 575	381	1 110
Arab States in Africa	4 988	8 607	72.6	0.7	0.9	406	746	281	655
Asia	**177 743**	**303 147**	**70.6**	**24.2**	**30.7**	**10 796**	**20 062**	**19 022**	**31 895**
Japan	73 429	74 618	1.6	10.0	7.6	4 682	5 479	9 723	9 771
China	38 206	104 968	174.7	5.2	10.6	1 716	5 672	2 682	9 098
Israel	9 136	10 069	10.2	1.2	1.0	643	662	1 264	1 411
India	18 911	36 261	91.7	2.6	3.7	1 579	3 339	1 901	3 821
Commonwealth of Independent States in Asia	1 413	1 761	24.6	0.2	0.2	41	57	66	88
Newly Industrialized Economies in Asia	33 765	62 855	86.2	4.6	6.4	1 730	3 364	3 240	6 795
Arab States in Asia	3 348	5 366	60.3	0.5	0.5	200	355	239	447
Other in Asia (excl. Japan, China, Israel, India)	16 579	40 358	143.4	2.3	4.1	1 301	3 203	1 313	3 651
Oceania	**23 246**	**33 060**	**42.2**	**3.2**	**3.4**	**4 014**	**5 034**	**3 120**	**4 353**
Other groupings									
Arab States all	8 186	13 574	65.8	1.1	1.4	600	1 078	510	1 063
Commonwealth of Independent States all	31 294	34 217	9.3	4.3	3.5	1 189	1 497	2 110	2 128
OECD	616 214	753 619	22.3	84.0	76.4	49 509	64 020	90 365	102 634
European Free Trade Association	18 223	25 380	39.3	2.5	2.6	1 523	2 262	2 760	3 349
Sub-Saharan Africa (incl. South Africa)	6 819	11 142	63.4	0.9	1.1	1 860	2 636	844	1 751
Selected countries									
Argentina	4 719	6 197	31.3	0.6	0.6	826	1 287	664	883
Brazil	12 573	26 482	110.6	1.7	2.7	1 572	5 526	1 583	3 467
Canada	30 310	43 539	43.6	4.1	4.4	3 351	4 571	4 779	6 018
Cuba	583	775	32.9	0.1	0.1	129	156	65	81
Egypt	2 569	3 963	54.3	0.4	0.4	192	259	146	295
France	47 219	57 133	21.0	6.4	5.8	2 975	3 865	6 563	7 169
Germany	65 500	76 368	16.6	8.9	7.7	3 838	5 155	8 742	10 006
Iran (Islamic Republic of)	2 102	10 894	418.3	0.3	1.1	150	772	129	681
Mexico	5 239	8 262	57.7	0.7	0.8	874	1 669	558	911
Republic of Korea	17 072	32 781	92.0	2.3	3.3	617	1 755	1 893	3 824
Russian Federation	25 493	27 083	6.2	3.5	2.7	1 050	1 317	1 851	1 835
Turkey	8 608	17 787	106.6	1.2	1.8	546	1 435	532	1 155
United Kingdom	61 073	71 302	16.7	8.3	7.2	4 515	4 975	9 586	10 789
United States of America	226 894	272 879	20.3	30.9	27.7	17 349	21 234	41 135	45 125

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 (Scientific) Inc. Web of Science, (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

Publications by field of science											
Chemistry		Clinical medicine		Earth and space		Engineering & technology		Mathematics		Physics	
2002	2008	2002	2008	2002	2008	2002	2008	2002	2008	2002	2008
88 310	**114 206**	**229 092**	**307 043**	**41 691**	**60 979**	**96 194**	**139 257**	**23 142**	**37 397**	**96 593**	**119 799**
66 585	72 185	203 298	251 857	36 644	50 320	73 868	91 320	19 251	27 961	78 991	85 445
26 002	49 155	32 772	70 921	8 497	17 330	28 019	59 180	5 829	12 938	24 597	44 733
76 132 928			1 635	138	318	103 177		27	52	94	142
22 342	**25 803**	**95 140**	**126 471**	**18 611**	**24 883**	**29 465**	**37 841**	**8 355**	**12 114**	**28 928**	**32 612**
19 378	21 690	89 495	114 674	17 123	22 533	27 183	33 763	7 573	10 765	25 307	28 685
3 181	4 401	6 751	14 030	2 122	3 228	2 646	4 535	925	1 570	4 278	4 579
40 404	**44 644**	**104 060**	**135 042**	**21 202**	**30 763**	**39 625**	**53 069**	**11 834**	**18 064**	**49 022**	**53 599**
33 183	36 221	93 939	119 230	18 091	26 095	33 845	44 182	10 190	15 239	40 153	43 693
6 117	6 357	1 771	2 115	2 647	3 205	4 108	4 772	1 474	2 066	10 796	10 694
2 874	4 239	11 172	18 623	2 054	3 924	3 091	6 284	671	1 541	3 535	4 553
1 535	**2 012**	**3 075**	**5 640**	**918**	**1 486**	**1 306**	**2 358**	**494**	**893**	**1 071**	**1 498**
307 410 841			1 453	434	520	294 467		127	227	226	318
117	183	1 323	2 417	245	477	122	226	44	114	95	154
1 116	1 438	953	1 931	260	527	892	1 688	325	563	755	1 059
30 017	**50 501**	**40 557**	**65 957**	**7 456**	**15 001**	**32 946**	**58 754**	**5 544**	**11 614**	**31 405**	**49 363**
9 908	9 809	21 426	21 729	2 505	3 552	10 633	10 194	1 300	1 661	13 252	12 423
9 499	23 032	3 863	13 595	2 036	5 746	8 734	22 800	1 850	5 384	7 826	19 641
694	706	3 134	3 357	372	506	1 011	1 143	524	754	1 494	1 530
4 552	7 163	3 367	7 514	1 160	2 306	2 980	6 108	506	974	2 866	5 036
279	322	95	124	145	168 130		166	125 204		532	632
4 590	7 334	6 748	14 468	1 218	2 540	9 075	16 140	1 102	1 905	6 062	10 309
323	463	1 302	1 934	143	303	721	1 090	154	326	266	448
2 449	5 314	4 134	9 991	765	1 983	3 685	9 219	561	1 603	2 371	5 394
1 552	**2 038**	**7 528**	**11 598**	**2 126**	**3 323**	**2 497**	**3 403**	**716**	**985**	**1 693**	**2 326**
1 405	1 840	2 227	3 758	399	808	1 580	2 711	469	855	996	1 461
6 358	6 645	1 856	2 230	2 761	3 333	4 224	4 910	1 589	2 266	11 207	11 208
63 801	71 003	208 163	262 587	35 655	49 492	74 606	94 262	18 435	26 842	75 680	82 779
1 618	2 021	6 328	9 072	1 501	2 600	1 548	2 507	387	656	2 558	2 913
420	582	2 135	3 746	658	962	415	675	170	335	317	455
536	669	1 078	1 316	407	631	362	487	118	229	728	695
1 656	2 390	3 243	8 799	657	1 028	1 259	2 209	398	708	2 205	2 355
2 306	3 022	9 761	14 683	2 620	3 877	3 763	5 971	1 102	1 763	2 628	3 634
71	96	151	214	18	33 57		90	14 26		78	79
672 861 478			992	111	205	510 714		121	167	339	470
5 401	6 090	13 069	16 034	3 457	4 899	5 260	7 123	2 399	3 113	8 095	8 840
7 399	8 344	20 781	24 708	4 256	5 978	7 059	7 746	1 903	2 725	11 522	11 706
645	2 198	369	2 626	57	433	390	2 484	97	554	265	1 146
474	716	994	1 749	484	739	610	996	219	322	1 026	1 160
2 545	4 006	3 017	7 610	539	1 160	4 526	8 004	497	895	3 438	5 527
5 240	5 308	1 599	1 914	2 468	2 981	3 144	3 329	1 251	1 584	8 890	8 815
844	1 639	4 243	7 978	450	1 025	1 223	2 910	162	559	608	1 086
5 469	5 352	22 007	26 754	4 678	6 079	6 715	7 612	1 383	2 197	6 720	7 544
17 334	18 984	81 871	103 835	15 206	19 819	23 939	28 572	6 724	9 356	23 336	25 954

France also specializes in Earth and space sciences, like Germany. As for Japan, it has several strengths: physics, chemistry, engineering and technology. Interestingly, both the USA and UK specialize in biomedical research, clinical medicine and Earth and space.

The second spider's web focuses on the BRIC countries and Africa. Here, too, we observe some striking differences between countries in their scientific specialization. Russia shows a strong specialization in physics, mathematics and Earth and space sciences. Typically, China specializes heavily in physics, chemistry, mathematics and engineering and technology. By contrast, Africa and Brazil are strong in biology and India excels in chemistry.

These differences in scientific specialization are mirrored in the different country profiles that follow this first chapter. Countries appear to choose areas for scientific knowledge creation based on their own needs (clinical medicine), geographical opportunities (Earth and space sciences and biology) but also based on cultural affinities (mathematics, physics) and expertise born of industrial growth (chemistry).

Trends in scientific output: inequality in private knowledge creation

The fourth indicator on which we focus in this first chapter reflects the success of countries and regions in privately appropriating knowledge through, for example, the number of patents filed with the Triad patent offices, namely: the US Patents and Trademark Office (USPTO), European Patent Office and Japanese Patent Office. Patents filed with these three patent offices are generally considered to be of a high quality. As a technological indicator, patents are a good reflection of the strong cumulative and tacit character of knowledge, embedded as they are in a formally recognized, long-lasting intellectual property right. It is this characteristic which makes it costly to transfer knowledge from one setting to another.

The overall dominance of the USA is striking. This highlights the US technology market's role as the world's leading private market for technology licenses. Japan, Germany and the Republic of Korea are the other countries with the most patent-holders. India's share amounts to barely 0.2% of all Triadic patents, a share comparable to that of Brazil (0.1%) and Russia (0.2%). Table 4 illustrates the extreme concentration of patent applications in North America, Asia and Europe; the rest of the world barely accounts for 2% of the total stock of patents. Most of Africa, Asia and Latin America play no role at all.

India's patents tend to be in chemistry-related fields. Interestingly, the chapter on India considers that the introduction of the Indian Patent Act in 2005 to bring India into compliance with the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) has not had a negative effect on the country's pharmaceutical industry. In support of this argument, the author cites the strong growth in R&D investment since 2000, which was continuing unabated in 2008. However, he also observes that most of these patents are being granted to foreign companies located in India, based on R&D projects carried out in India, in a growing trend.

Of all the indicators used in the *UNESCO Science Report*, it is the patent indicator which points most strikingly to the inequality of knowledge creation at the global level.

The following trend helps to explain the huge volume of patents among OECD economies. In high-income countries, the lifespan of high-tech products is shortening, obliging companies to come up with new products more quickly than before. This can be seen in the rate at which new computers, software, video games and mobile phones, for instance, are appearing on the market.
High-tech firms are themselves largely responsible for this phenomenon, as they have deliberately set out to create new consumer needs by bringing out more sophisticated versions of their products every six months or so. This strategy is also a way of keeping ahead of the competition, wherever it may be. As a consequence, patents that used to be economically valid for several years now have a shorter lifespan. Developing new products and registering new patents every six months or so is an extremely labour- and investment-intensive exercise which obliges companies to innovate at a frenetic rate. With the global recession, companies are finding it harder to maintain this pace.

Knowledge appropriation versus knowledge diffusion

We now take a look at the opposite variable to patents, the number of Internet users. This variable should enable us to gauge whether easier access to information and knowledge has provided opportunities for a more rapid diffusion of S&T. The data on Internet usage in Table 5 paint

Table 4: USPTO and Triadic patent families by inventor's region, 2002 and 2007

	USPTO patents				Triadic patents*			
	Total		World share (%)		Total		World share (%)	
	2002	2007	2002	2007	2002	2006	2002	2006
World	**167 399**	**156 667**	**100.0**	**100.0**	**56 654**	**47 574**	**100.0**	**100.0**
Developed countries	155 712	141 183	93.0	90.1	55 456	45 923	97.9	96.5
Developing countries	12 846	17 344	7.7	11.1	1 579	2 125	2.8	4.5
Least developed countries	13	13	0.0	0.0	4	1	0.0	0.0
Americas	**92 579**	**85 155**	**55.3**	**54.4**	**25 847**	**20 562**	**45.6**	**43.2**
North America	92 245	84 913	55.1	54.2	25 768	20 496	45.5	43.1
Latin America and the Caribbean	450	355	0.3	0.2	115	101	0.2	0.2
Europe	**31 046**	**25 387**	**18.5**	**16.2**	**17 148**	**13 249**	**30.3**	**27.8**
European Union	29 178	23 850	17.4	15.2	16 185	12 540	28.6	26.4
Commonwealth of Independent States in Europe	350	332	0.2	0.2	151	97	0.3	0.2
Central, Eastern and Other Europe	2 120	1 708	1.3	1.1	1 203	958	2.1	2.0
Africa	**151**	**134**	**0.1**	**0.1**	**47**	**48**	**0.1**	**0.1**
South Africa	124	92	0.1	0.1	38	37	0.1	0.1
Other sub-Saharan countries (excl. South Africa)	15	16	0.0	0.0	3	3	0.0	0.0
Arab States in Africa	12	26	0.0	0.0	6	9	0.0	0.0
Asia	**47 512**	**50 313**	**28.4**	**32.1**	**15 463**	**15 197**	**27.3**	**31.9**
Japan	35 360	33 572	21.1	21.4	14 085	13 264	24.9	27.9
China	5 935	7 362	3.5	4.7	160	259	0.3	0.5
Israel	1 151	1 248	0.7	0.8	476	411	0.8	0.9
India	323	741	0.2	0.5	58	96	0.1	0.2
Commonwealth of Independent States in Asia	6	9	0.0	0.0	3	1	0.0	0.0
Newly Industrialized Economies in Asia	4 740	7 465	2.8	4.8	689	1 173	1.2	2.5
Arab States in Asia	46	58	0.0	0.0	15	18	0.0	0.0
Other in Asia (excl. Japan, China, Israel, India)	80	48	0.0	0.0	19	18	0.0	0.0
Oceania	**1 139**	**1 516**	**0.7**	**1.0**	**549**	**834**	**1.0**	**1.8**
Other groupings								
Arab States all	56	84	0.0	0.1	20	27	0.0	0.1
Commonwealth of Independent States all	356	340	0.2	0.2	154	98	0.3	0.2
OECD	159 320	147 240	95.2	94.0	55 863	46 855	98.6	98.5
European Free Trade Association	2 064	1 640	1.2	1.0	1 180	935	2.1	2.0
Sub-Saharan Africa (incl. South Africa)	139	108	0.1	0.1	41	39	0.1	0.1
Selected countries								
Argentina	59	56	0.0	0.0	12	17	0.0	0.0
Brazil	134	124	0.1	0.1	46	46	0.1	0.1
Canada	3 895	3 806	2.3	2.4	962	830	1.7	1.7
Cuba	9	3	0.0	0.0	5	0	0.0	0.0
Egypt	8	22	0.0	0.0	3	4	0.0	0.0
France	4 507	3 631	2.7	2.3	2 833	2 208	5.0	4.6
Germany	12 258	9 713	7.3	6.2	6 515	4 947	11.5	10.4
Iran (Islamic Republic of)	11	7	0.0	0.0	1	3	0.0	0.0
Mexico	134	81	0.1	0.1	26	16	0.0	0.0
Republic of Korea	3 868	6 424	2.3	4.1	523	1 037	0.9	2.2
Russian Federation	346	286	0.2	0.2	149	84	0.3	0.2
Turkey	21	32	0.0	0.0	9	10	0.0	0.0
United Kingdom	4 506	4 007	2.7	2.6	2 441	2 033	4.3	4.3
United States of America	88 999	81 811	53.2	52.2	25 034	19 883	44.2	41.8

*Data for 2006 are incomplete and should be interpreted with caution.

Note: The sum of the numbers, and percentages, for the various regions exceeds the total number, or 100%, 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) and OECD, compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, February 2009 a very different picture to that for patents. We find that the BRIC countries and numerous developing countries are catching up quickly to the USA, Japan and major European countries for this indicator. This shows the crucial importance of the emergence of digital communications like Internet on the world distribution of S&T and, more broadly, knowledge generation. The rapid diffusion of Internet in the South is one of the most promising new trends of this Millennium, as it is likely to bring about a greater convergence in access to S&T over time.

A systemic perspective on the congruence of S&T indicators

The concept of a national innovation system was coined by the late Christopher Freeman in the late 1980s to describe the much broader congruence in Japanese society between all sorts of institutional networks in both 'private and public sectors whose activities and interactions initiate, import, modify and diffuse new technologies' (Freeman, 1987). The set of indicators described above shed light on some features of each country's national system of innovation. One should bear in mind, however, that science, technology and innovation (STI) indicators that were relevant in the past may be less relevant today and even misleading (Freeman and Soete, 2009). Developing countries should not simply rely on adopting STI indicators developed by, and for, OECD countries but rather develop their own STI indicators (Tijssen and Hollanders, 2006). Africa is currently implementing a project to develop, adopt and use common indicators to survey the continent's progress in S&T via the periodic publication of an *African Innovation Outlook* (*see page* 299).

Figure 5 illustrates visually the different biases in countries' national innovation systems by matching four indicators. At first sight, the US system appears to be the most balanced: the US circles appear each time in the middle of the figure. However, its position with respect to human capital is weak and out of line with the trend in other highly developed countries: only 24.5% of the US population holds a tertiary degree, whereas in France, Germany or Japan, for instance,the proportion is close to, or greater than, 30%. One would expect the USA to perform better on the tertiary education axis, given its performance for the indicators on the other axes. It is true that the USA has some of the best universities in the world but rankings like that of Shanghai Jiao Tong University focus on research performance rather than the quality of education. In sum, the USA is reliant on a vast inflow of foreign researchers and other highly skilled people to drive the economy.

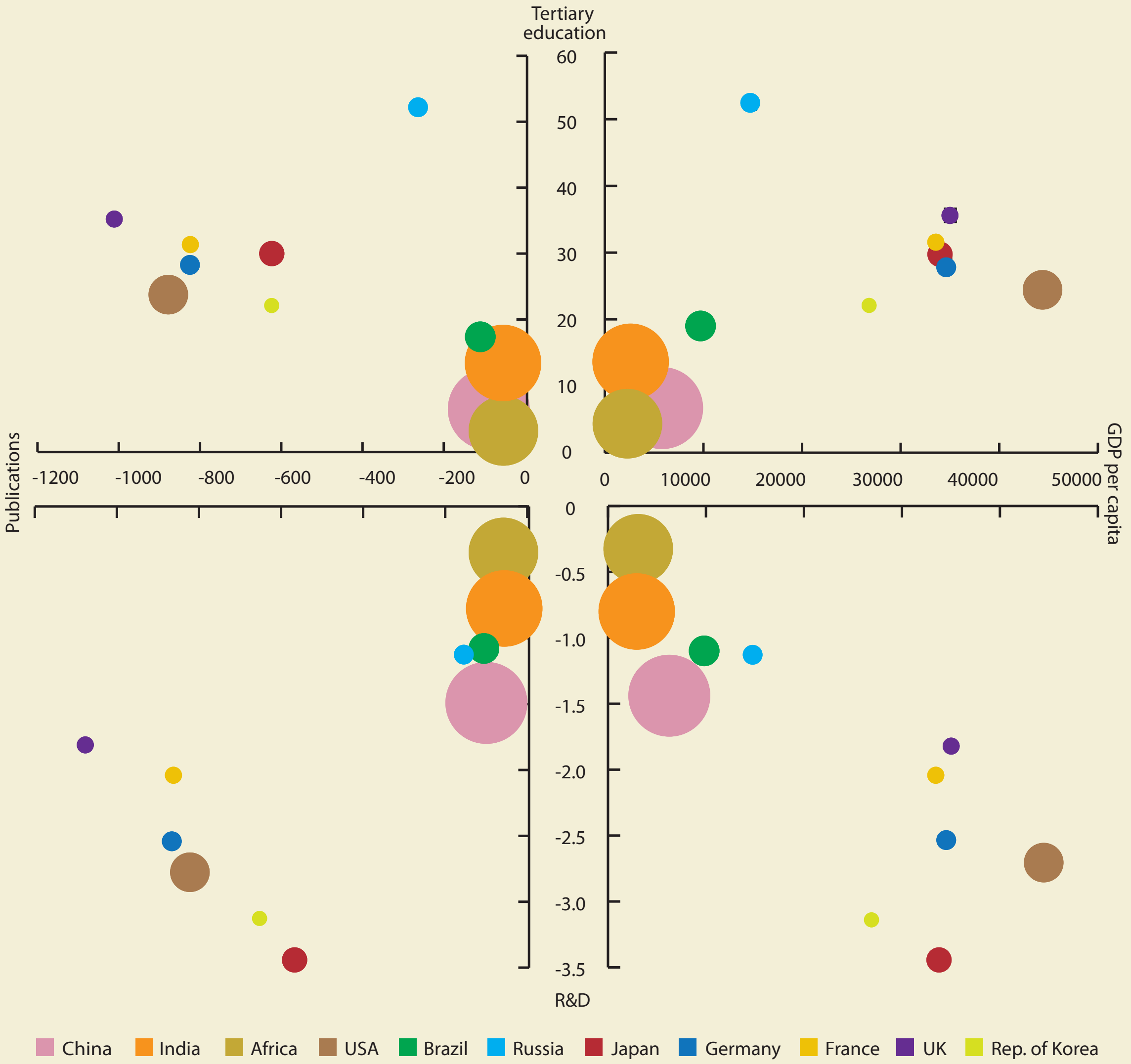
Table 5: Internet users per 100 population, 2002 and 2008

	2002	2008
World	**10.77**	**23.69**
Developed countries	37.99	62.09
Developing countries	5.03	17.41
Less-developed countries	0.26	2.06
Americas	**27.68**	**45.50**
North America	59.06	74.14
Latin America and the Caribbean	8.63	28.34
Europe	**24.95**	**52.59**
European Union	35.29	64.58
Commonwealth of Independent States in Europe	3.83	29.77
Central, Eastern and Other Europe	18.28	40.40
Africa	**1.20**	**8.14**
South Africa	6.71	8.43
Other Sub-Saharan countries (excl. South Africa)	0.52	5.68
Arab States in Africa	2.11	16.61
Asia	**5.79**	**16.41**
Japan	46.59	71.42
China	4.60	22.28
Israel	17.76	49.64
India	1.54	4.38
Commonwealth of Independent States in Asia	1.72	12.30
Newly Industrialized Economies in Asia	15.05	23.47
Arab States in Asia	4.05	15.93
Other in Asia (excl. Japan, China, Israel, India)	2.19	11.51
Oceania	**43.62**	**54.04**
Other groupings		
Arab States all	2.81	16.35
Commonwealth of Independent States all	3.28	24.97
OECD	42.25	64.03
European Free Trade Association	66.08	78.17
Sub-Saharan Africa (incl. South Africa)	0.94	5.86
Selected countries		
Argentina	10.88	28.11
Brazil	9.15	37.52
Canada	61.59	75.53
Cuba	3.77	12.94
Egypt	2.72	16.65
France	30.18	70.68
Germany	48.82	77.91
Iran (Islamic Republic of)	4.63	31.37
Mexico	10.50	21.43
Republic of Korea	59.80	81.00
Russian Federation	4.13	32.11
Turkey	11.38	34.37
United Kingdom	56.48	78.39
United States of America	58.79	74.00

Source: International Telecommunications Union, World telecommunications / ICT indicators database, June 2010, and UNESCO Institute for Statistics estimations; United Nations Department of Economic and Social Affairs (2009) *World Population Prospects: the 2008 Revision*, and UNESCO Institute for Statistics estimations

Japan provides a contrast. It clearly lags behind other highly developed countries in terms of scientific publications and GDP per capita. Its innovation system appears weak when it comes to translating the country's big investment in human research capital and R&D into sufficient scientific and economic value. The UK suffers from exactly the opposite problem: its performance in terms of scientific publications and economic wealth creation is by far superior to its investment in human research capital and R&D. Russia, on the other hand, shines when it comes to investment in human capital but fails on all other counts. China is still typically in a catching-up phase: its heavy investment in R&D has as yet not paid off but, of course, its economic structure remains dominated by non-technology-intensive activities.

Figure 5. The systemic matching between key S&T indicators
Selected countries and regions



Note: The size of the circles reflects the population size for each country or region studied.

Source: UNU–MERIT based on data from the UNESCO Institute for Statistics and World Bank

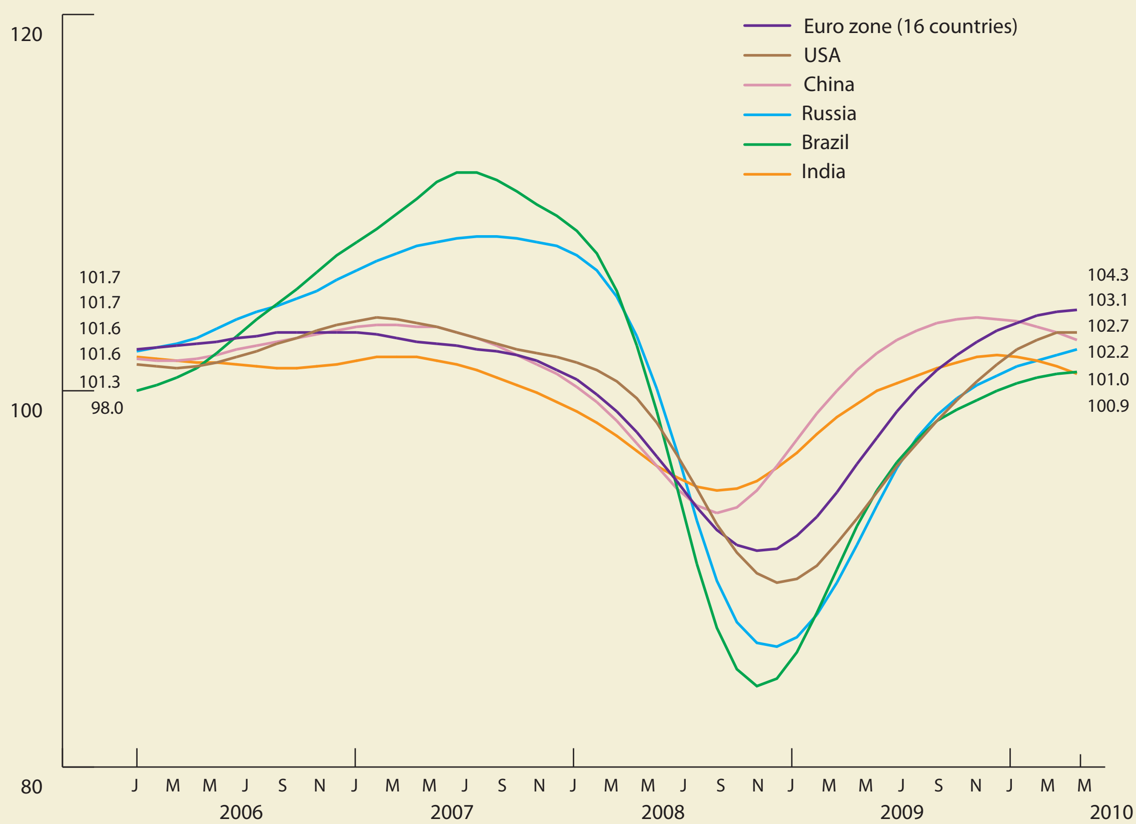
The national biases in Figure 5 also point to some of the implications for countries of the international migration of researchers and more broadly human capital. It is not surprising that there will be a lot of emigration from a country like Russia and a lot of immigration towards the USA, given the current biases in their national innovation systems.

IS THE GLOBAL ECONOMIC RECESSION BAD FOR KNOWLEDGE CREATION?

The global recession is likely to have had a severe impact on investment in knowledge across the globe. Many of the knowledge indicators described for 2007 and earlier may have been affected in the process and, hence, could not reliably predict the situation in 2009 or 2010. R&D budgets, especially, tend to be vulnerable to cutbacks in times of crisis. Patents and publications will in turn be affected by the drop in R&D expenditure but this will probably occur in the longer run and affect scientific output less directly, owing to pipeline effects that smother sharp fluctuations. As for trends in education of the labour force, this sector tends to be less affected by short-term distortions.

There are a couple of short-term indicators which might shed some light on the impact of the recession thus far. Here, we use the OECD´s composite leading indicator (CLI), which is available on short notice. This indicator uses monthly (de-trended) data on industrial production as a proxy for economic activity. It is a leading indicator because industrial production recovers early in an economic cycle. A turning point in the CLI signals that a turning point in the business cycle can be expected within 6–9 months. China showed a turning point as early as November 2008 and, consequently, an upturn in the business cycle in May–August 2009, as expected.

Figure 6. Industrial production in the BRIC countries, USA and Euro zone, 2006–2010



Source: OECD, Composite Leading Indicators (Amplitude adjusted series): http://stats.oecd.org/Index.aspx?DatasetCode=MEI_CLI

We can also interpret from the information in Figure 6 that Brazil was 10% above its long-term level for industrial production in 2007 before falling brutally to about 85% of this value in the first month of 2009. Industrial production in India and the Euro zone only stumbled, falling from around 103% to 90%. Recovery is expected to be strong enough to raise the level of industrial production above its long-term trend level. However, the data for the most recent months (June 2010) reveal that the rate of recovery is slowing down, raising concerns about a possible double dip.

In short, we can say that, between October 2008 and March 2009, the first signs of recovery appeared. Asia in general and China in particular were the first to recover. It is unlikely that R&D expenditure in China has been affected by the global economic recession because industrial production fell only 7% below its long-term trend value for a relatively short period. Moreover, circumstantial evidence on firms provided by the EU's R&D investment scoreboard in 2009 shows that China's R&D effort in 2008 actually increased, at least in telecommunications. There is no reason to assume that 2009 and 2010 will be much different, since China's economy grew by more than 7% even in 2007 and 2008.

For Brazil and India, on the other hand, it is likely that their total R&D effort will come under pressure in 2008 and 2009, due to the relatively low level of industrial production over a prolonged period of time. In fact, between July 2008 and March 2010, industrial production remained below its long-term trend level. On a brighter note, these countries have been catching up to the developed countries in terms of GERD for several years now. One might therefore expect more of a lull in these countries' rising R&D intensity than a significant drop.

As for the world's largest R&D-intensive firms, circumstantial evidence for 2009 reveals that the majority of the big R&D spenders in the USA cut their R&D expenditure by 5–25% that year, while a minority increased spending by 6–19%. Overall though, the USA and EU are most likely to keep their total R&D intensity at around 2007 levels. This means that both GDP and R&D expenditure will decline by equal shares, thereby keeping R&D intensity more or less constant over the year 2009–2010 (Battelle, 2009).

A CLOSER LOOK AT INDIVIDUAL COUNTRIES AND REGIONS

The choice of countries and regions in the *UNESCO Science Report 2010* nicely reflects the heterogeneity of S&T around the world, from the highly developed OECD nations to the four large emerging BRIC countries and the large number of developing countries which are playing a growing role in the global research effort. Here, we summarize the most insightful conclusions emerging from the regional and country studies in Chapters 2 to 21.

In the **United States of America** (Chapter 2), R&D has prospered over the past five years and continues to be an absolute government priority. A good example is the funding for the National Science Foundation, which doubled at the request of the Bush administration in 2007 and is set to double again under the Obama administration. Although the recession born of the sub-prime crisis hit the economy hard in 2009 and 2010, universities and research centres have continued to receive generous funding from both public funds and private endowments and industrial funds.

Whereas the Obama administration included a significant one-off investment in STI that also benefited R&D in the second stimulus package towards the end of 2009, there is now a clear risk that any increase in federal funding will be offset by reductions in funding by both state governments and private funds. Notwithstanding this, one important commitment by the Obama administration is to increase GERD from 2.7% to 3% of GDP. The administration is emphasizing energy R&D, especially clean energy.

Unlike public research, industrial R&D appears to have been hit relatively hard by the recession with a large number of researchers being laid off. Among the biggest R&D spenders have been the pharmaceutical industries, badly affected by the recession. In fact, the chapter notes that the pharmaceutical industry was already showing signs of stress before the recession, as the huge investment made in R&D does not appear to have resulted in many 'blockbuster' drugs recently.

The US university system still leads the world when it comes to research: in 2006, 44% of all S&T articles published in journals indexed in the SCI included at least one US-based author. Furthermore, of the top 25 institutions ranked by the Shanghai Jiao Tong University's Institute of Higher Education in 2008, 19 were based in the USA.

Canada (Chapter 3) has been less affected by the global economic recession than either the USA or Europe, thanks to its strong banking system and a real-estate market that avoided many of its neighbour's excesses. Furthermore, low inflation coupled with income from Canada's abundant natural resources have cushioned the impact of the global recession on the country's economy.

In March 2010, the federal government committed to investing in a range of new measures to foster research over the period 2010–2011. These include postdoctoral fellowships, as well as more general research funding for grant councils and regional innovation clusters. A considerable share of this funding goes towards research on particle and nuclear physics, as well as next-generation satellite technology. With the USA next door, Canada cannot afford to be complacent.

Steady investment in R&D appears to be paying off: between 2002 and 2008, the number of Canadian scientific publications in the SCI grew by nearly 14 000. However, if Canada can boast of a dynamic academic sector and generous public spending on STI and R&D, many businesses have not yet assimilated a 'knowledge creation' culture. Canada's productivity problem is first and foremost a business innovation problem. The result of the poor R&D performance in business is that academic research often appears to be a surrogate for industrial R&D.

The federal government has set out to foster public–private partnerships recently via two successful initiatives: an agreement between the federal government and the Association of Canadian Universities and Colleges to double the volume of research and triple the number of research results which are commercialized; and the Network of Centres of Excellence, which now total 17 across the country.

Chapter 4 on **Latin America** notes a persistent and glaring income gap between rich and poor across the continent. STI policies could play an important role in reducing inequality. However, it is proving difficult to establish ties between STI policies on the one hand and social policies on the other. The structural conditions prior to the global recession were particularly favourable to reform, in that they combined political stability with the longest period of strong economic growth (2002–2008) that the region had seen since 1980, thanks to a booming global commodities market.

Several Latin American countries have implemented an array of policies to foster innovation, in particular Argentina, Brazil and Chile. However, despite there being about 30 types of STI policy instruments in use across the region, national innovation systems remain weak. This is the case even among such keen proponents of STI policies as Brazil and Chile. The major stumbling block is the lack of linkages between the different actors of the national innovation system. For instance, good research coming out of the local academic sector does not tend to be picked up and used by the local productive sector. More generally, R&D investment remains low and bureaucracies inefficient. Training and building a critical mass of highly skilled personnel has become another burning issue.

The economic recession has generated an employment crisis that may well exacerbate poverty in the region and thus further increase the tension between STI policy and specialization, on the one hand, and poverty alleviation and social policies on the other.

Brazil (Chapter 5) experienced a booming economy in the years leading up to the global recession. Such a healthy economy should be conducive to business investment. However, patent numbers remain low and R&D activities sluggish in the business sector, leaving most of the funding effort to the public sector (55%). In addition, the majority of researchers are academics (63%) and the Brazilian economy is increasingly suffering from a shortage of PhD graduates. Researchers also remain unevenly spread across the country with national output being dominated by a handful of top universities.

The federal government is conscious of the problem. In 2007, it adopted a *Plan of Action in Science, Technology and Innovation for Brazilian Development* (2007–2010) which sets out to raise R&D expenditure from 1.07% of GDP in 2007 to 1.5% of GDP in 2010. Another target is to augment the number of scholarships and fellowships available to university students and researchers from 102 000 in 2007 to 170 000 by 2011. One key objective is to nurture an innovation-friendly environment in firms by strengthening industrial, technological and export policies, and increasing both the number of active researchers in the private sector and the number of business incubators and technoparks.

Cuba (Chapter 6) is a particularly interesting case study. Cuba's human development is among the highest in the region, on a par with Mexico. In terms of overall spending on S&T, however, it has slipped below the regional mean, the consequence of a slightly lesser effort on Cuba's part and, above all, a greater commitment to S&T across Latin America. Business funding in Cuba has halved in recent years to just 18% of GERD.

Cuban enrollment in higher education is impressive, on the other hand, with first-year student rolls having doubled between 2004–2005 and 2007–2008, thanks largely to a surge in medical students. What is more, in 2008, 53.5% of S&T professionals were women. Many STI professionals work in public research institutes across the country, although the low number of researchers among R&D personnel (7%) is troubling.

The research strategy in Cuba is centred around a number of National Research Programmes in Science and Technology. A recent programme focusing on ICT managed to increase Internet access from 2% of the population in 2006 to nearly 12% a year later. Although Cuba is known for the development and production of pharmaceuticals, other priorities are emerging. These include energy R&D and disaster monitoring and mitigation, in light of the threat of stronger hurricanes, droughts, coral bleaching and flooding in future as a consequence of climate change. Cuba has begun modernizing its research infrastructure, notably its meteorological services.

The countries of the **Caribbean Common Market** (Chapter 7) have suffered acutely from the peak in international food and commodity prices in recent years. Jamaica, for instance, spent more on petroleum imports in 2007 than the total value of its exports. This situation has been exacerbated by the global recession, which has hit the crucial tourist industry hard.

Two of the region's largest countries, Jamaica and Trinidad and Tobago, have now put together long-term development plans (*Vision 2030* and *Vision 2020*, respectively) that emphasize the importance of STI for development. Expenditure on R&D remains dismally low, however, and private R&D moribund. Only the higher education sector is booming: two new universities have been established since 2004 on the island of Trinidad and the introduction of free tertiary education in Trinidad and Tobago in 2006 caused student enrollment rates to rise overnight. However, the leap in the student population has not been matched by a proportionate increase in academic staff numbers, putting research under strain. The region has great expectations for the Caribbean Science Foundation launched in September 2010 to revitalize R&D.

As Chapter 8 on the **European Union (EU)** highlights, the EU is increasingly a heterogeneous group of countries. Although the new member states are catching up in economic terms, there remains a yawning gap between the richest and poorest member states. When it comes to innovation, however, this heterogeneity knows no borders. Regions within a country that perform particularly well in innovation are dotted across the EU rather than being confined to the older (and richer) member states.

Although the EU is the undisputed world leader for publications recorded in the SCI, it is struggling to increase expenditure on R&D and develop innovation. This is visible in its inability to meet both the Lisbon and Barcelona targets of raising GERD to 3% of GDP by 2010. Another issue member states are struggling with across the EU concerns the institutional reforms of the university system. The dual challenge here is to improve the quality of research and revitalize the EU's poorly funded institutions of higher education.

On a more positive note, what sets the EU apart from many other regions is its willingness to acknowledge that it can only improve its performance in STI and R&D by pooling the capabilities of member states. This attitude has spawned a number of multilateral European agencies and programmes. These vary from large research organizations like the European Organization for Nuclear Research (CERN) where individual countries collaborate on the EU's Framework Programmes for Research and Technological Development to the Joint Technology Initiative and EUREKA, designed to stimulate research in industry. A number of new EU organizations have been set up, or are in the process of being set up, including the European Science Foundation and European Institute of Innovation and Technology, as well as funding agencies like the European Research Council.

Until the global economic recession hit in late 2008, all countries in **Southeast Europe** (Chapter 9) were growing at an average rate of around 3% a year. However, the region is particularly heterogeneous in terms of its socio-economic development, with a ten-fold difference between the richest (such as Greece and Slovenia) and poorest (Moldova) countries. Whereas the most advanced countries are implementing EU-focused strategies with an emphasis on innovation, the stragglers are still at the stage of attempting to design or implement a basic S&T policy and establish an R&D system. Two of the smaller countries are, of course, still in their infancy: Montenegro only gained independence in 2006 and Kosovo in 2008.

Today, demand for R&D and skilled personnel remains low in all but Slovenia, despite a growing number of tertiary graduates. Two reasons for the lack of demand for R&D are the small size of firms and their lack of capacity. For the non-EU members in the region, European integration represents the only viable project for ensuring social and political coherence. Without strong STI policies, the region is in danger of falling further behind the rest of Europe.

Turkey (Chapter 10) has been emphasizing STI policies in recent years. Between 2003 and 2007, GERD more than doubled and business expenditure on R&D grew by 60%. Domestic patent filings and grants also rose more than four-fold from 2002 to 2007. It is the private sector that has been driving economic growth since 2003.

A number of policy measures have been put in place to support STI. These include the *Vision 2023* Project in 2002–2004, the launch of the Turkish Research Area in 2004 and a major five-year implementation plan for the *National Science and Technology Strategy* (2005–2010). The *Ninth Development Plan* (2007–2013) has likewise focused on STI as a building block for Turkey.

However, challenges remain. The *Vision 2023* Project was a technology foresight exercise but it has unfortunately not spawned any policy initiatives to build capacity in priority technology areas. Moreover, the density of researchers remains poor and enrollment in tertiary education is lower than for countries with a similar income. Turkey also has an underdeveloped venture capital market and an insufficient number of high-growth firms. The government has introduced a number of measures to stimulate private-sector R&D, foster university–industry collaboration and develop international co-operation in R&D. These measures include tax incentives for technoparks, of which there were 18 in 2008.

The **Russian Federation** (Chapter 11) had been experiencing an economic boom in the years before the severe economic downturn towards the end of 2008. This was largely due to high oil prices, an initial weak currency and strong domestic demand. Both consumption and investment were high. The country reacted to the crisis by adopting an extensive recovery package but it is feared that this package may increase the government's tendency to intervene directly in the economy rather than furthering the kind of institutional reform needed to bring about modernization, especially as regards STI policy.

Without such institutional reforms, the national innovation system will continue to suffer from poor linkages between the different actors. Currently, there is a lack of co-ordination across departments, a high level of administrative complexity and poor linkages between science, academia and industry. These factors all act as barriers to co-operation and innovation. A notable feature is the imbalance between the country's STI performance and the growing mass of financial resources dedicated to R&D but jealously guarded within public research institutions where they are out of reach for industry and universities. As a result, universities play a minor role in new knowledge creation: they contribute just 6.7% of GERD, a stable figure for the past two decades, and only one in three universities performs R&D, compared to half in 1995. Private universities hardly perform any research at all. The higher education system has undergone widespread reform in recent years with the introduction of bachelor's and masters programmes which now cohabit with the Soviet degree system. By 2009, more than half of university staff held the equivalent of a PhD.

STI policies need to allow for greater academic mobility and co-operation; they also need to lay the groundwork for a radical modernization of the professional training of scientists and engineers. The latter point is all the more urgent in light of the country's ageing research population: 40% are above the official retirement age. Boosting support for university research has become one of the most important strategic orientations of STI and education policies in Russia. Since 2006, the National Priority Project for Education and a follow-up programme have provided 84 universities considered to be centres of excellence with an additional US$ 30 million each approximately to promote human resource development, high-quality R&D and educational projects, as well as permit the acquisition of research equipment.

No country in **Central Asia** (Chapter 12) devotes more than 0.25% of GDP to R&D. This is even the case for Kazakhstan and Uzbekistan, the countries with the most developed science systems. Other concerns are the ageing 'Soviet-generation' research population and an inadequate legal framework which is partly responsible for the low level of innovation by scientific organizations and private enterprises.

STI policy initiatives in the region include the Intellectual Nation 2020 programme unveiled in Kazakhstan in 2009. It plans to develop a network of schools in natural and exact sciences for gifted pupils and to raise GERD to 2.5% of GDP by 2020. Kazakhstan can already count on several technoparks. Tajikistan has also adopted a plan for S&T covering 2007–2015. As for Turkmenistan, it has also witnessed a revival of science since 2007, after research was virtually shut down for many years under the previous presidency. In Uzbekistan, a key measure has been the establishment of a Committee for the Co-ordination of the Development of Science and Technology in 2006. After identifying seven priority areas for R&D, the committee invited universities and scientific organizations to submit research proposals within a competitive bidding process. By the end of 2011, some 1098 projects will have been implemented within 25 broad research programmes in basic and applied research and experimental development.

Chapter 13 on the **Arab States** analyses the reasons for the lack of a national S&T strategy or policy in most Arab states, although all have sectoral policies for agriculture, water, energy and so on. Even where S&T strategies exist, innovation tends to be absent from these, primarily due to weak linkages between public and private R&D. However, Bahrain, Morocco, Qatar, Saudi Arabia, Tunisia, the United Arab Emirates, followed more recently by Jordan and Egypt, are tackling this issue by setting up science parks.

S&T policies and strategies are also beginning to emerge. Saudi Arabia adopted a national plan for S&T back in 2003 and, in 2006, Qatar implemented a five-year plan to increase GERD to 2.8% (from 0.33%). The planned submission of an S&T strategy for the entire Arab region to the Arab summit in 2011 for adoption is another promising sign. The future plan is expected to address the important issue of facilitating the mobility of scientists within the region and to enhance collaborative research with the sizeable community of expatriate Arab scientists. It is also expected to propose both national and pan-Arab initiatives in about 14 priority areas, including water, food, agriculture and energy. The plan may also recommend the launch of an online Arab S&T observatory, as a key to implementing measures at the country level will lie in first identifying some of the national challenges that Arab countries face.

Also promising is the number of funds for STI set up in the region in recent years. These include the 2008 EU–Egypt Innovation Fund and two national funds: the Mohammed bin Rashid Al Maktoum Foundation in the United Arab Emirates (2007) and the Middle East Science Fund in Jordan (2009).

Chapter 14 on **sub-Saharan Africa** highlights the move by a growing number of African countries to enhance their S&T capacity as part of poverty alleviation strategies. In 2008 alone, 14 countries requested UNESCO's assistance with science policy reviews. Although GDP per capita rose in the majority of African countries between 2002 and 2008, it remains low by world standards, a factor which has an impact on investment in STI. Moreover, GERD still attracts less public funding than the military, health or education sectors. South Africa is the only country which comes close to the 1% mark for R&D intensity (0.93% in 2007).

South Africa also dominates scientific publications, representing a 46.4% of the sub-continent's share, far ahead of the two next most prolific countries, Nigeria (11.4%) and Kenya (6.6%). Of note is that the number of articles recorded in the SCI has progressed for all sub-Saharan countries, even if only 17 could count more than 100 articles in this database in 2008.

A major challenge is the low literacy rate and poor quality of education, even if both literacy and enrollment rates have climbed in the past decade. To address these issues, the African Union issued a *Plan of Action for the Second Decade of Education for Africa* in 2006. Another major challenge is brain drain: at least one-third of all African researchers were living and working abroad in 2009. A growing number of countries are tackling the root cause of this problem by raising the salaries of academics and providing other incentives. Cameroon, for instance, used the writing-off of part of its debt to create a permanent fund in early 2009 which tripled the salaries of academics overnight. The number of academics appears to have already swelled by about one-third and the volume of scientific articles produced by state universities has likewise risen.

Five years after the adoption of *Africa's Science and Technology Consolidated Plan of Action* (CPA) covering the period 2008–2013, progress has been made in biosciences and water research and the first set of pan-African R&D statistics is due to be delivered in 2010. Concern has been voiced in some quarters, however, at the rate of progress. The CPA is intended to act as a framework for channelling greater funds into S&T across the continent but, five years on, the proposed mechanism for channelling this funding, the African Science and Innovation Facility, has not yet materialized.

South Asia (Chapter 15) has enjoyed reasonably good growth rates in the past few years and not suffered unduly from the global recession, with the notable exception of Pakistan which has seen its growth rates drop from 6.8% in 2007 to 2.7% in 2009. Pakistan is the country that spends the most on R&D (0.67% of GDP in 2007), IT and higher education of the countries under study, which do not include India and Iran. However, most R&D funding in Pakistan is consumed by the military sector (60%).

The region suffers from a lack of investment in STI. Moreover, there is a lack of linkages between public and private actors and no university–industry collaboration to speak of. It is noted in the chapter that, overall, Pakistan, Bangladesh and Sri Lanka seem better at producing basic knowledge than commercializing it. It will be interesting to follow the fortunes of the Sri Lanka Institute of Nanotechnology, which was set up in 2008 within a joint venture between the National Science Foundation and domestic corporate giants that include Brindix, Dialog and Hayleys. The new institute professes to take 'an industry-focused approach'.

In addition to the lack of innovation, South Asia suffers from low levels of literacy and education. Governments face the dual challenges of widening access while simultaneously making the education system relevant to the national economy. They are aware of the task at hand: Afghanistan, Bangladesh, Pakistan and Sri Lanka are all at various stages of higher education reform. Fortunately, they can count on several high-quality academic institutions in the region.

Iran (Chapter 16) is heavily reliant on its oil industry, which currently accounts for four-fifths of GDP. This situation weighs heavily on the country's STI policies, since these are not a priority for generating future prosperity. With research being funded mostly (73%) out of the public purse and with an interventionist government pursuing its own priorities, R&D tends to be focused on nuclear technology, nanotechnology, satellite launching and stem cell research. Policy research bears little relevance to national issues and remains cut off from socio-economic realities.

The most recent document outlining Iran's strategy for S&T is enshrined in the *Fourth Development Plan* (2005–2009). It focuses mainly on improving the university system at a time of strong demand for higher education: 81 000 students graduated in 2009, compared to 10 000 nine years earlier.

India (Chapter 17) is one of the world's fastest-growing economies, alongside China. Having been relatively spared by the global recession, it is pursuing a path of rapid growth. The past few years have seen a rise in private investment in R&D, with the majority of new companies belonging to knowledge-intensive sectors. A growing number of foreign companies are also establishing R&D centres on Indian soil. Most of these foreign centres focus on ICTs. In fact, India has become the world's leading exporter of IT services. Aerospace exports are also growing by 74% a year. Meanwhile, major Indian companies like Tata have been investing in high-tech companies abroad, in pursuit of technology.

In 2003, the government committed to raising overall research expenditure from 0.8% to 2% of GDP by 2007. Although GERD had only attained 0.88% of GDP in 2008, this target sent a clear signal that public policy was focusing on R&D. Moreover, the *Eleventh Five-Year Plan* to 2012 not only emphasizes innovation but also foresees a massive outlay on STI via a budgetary increase of 220%.

There is a general trend in India towards recognizing the 'I' in STI in both the policy and business sectors. Moreover, the adoption of the Indian Patent Act in 2005 to bring India into compliance with the TRIPS agreement has not caused the domestic pharmaceutical industry to slump, contrary to predictions. The pharmaceutical industry is flourishing, even if the domination of foreign firms in patents continues to cast a shadow. Another challenge is the steady flow of highly skilled people out of India and out of domestic firms unable to compete with the advantages offered by their India-based foreign rivals. The biggest challenge of all, however, will be for India to improve both the quantity and quality of Indian S&T personnel. The central government's decision to create 30 universities across the country, including 14 world-class innovation universities, augurs well for the future.

China (Chapter 18) has made great strides in economic development in the past decade with consistently impressive growth rates. In August 2010, China even overtook Japan to become the second-largest national economy in the world. Its R&D intensity has also been multiplied by a factor of six. Today, only the USA publishes more scientific articles, although the impact factor of Chinese articles in the SCI remains much lower than for the Triad, China figuring just behind the Republic of Korea and on a par with India for citations of scientific papers.

The government has issued a number of key policies in the past four years to maintain a high growth rate and become an innovation-driven nation by 2020, the ambitious target of the *Outline of the Medium- and Long-term Plan* for *National Science and Technology Development* adopted in 2005. The main mechanisms incite enterprises to invest more in innovation and Chinese researchers to return home from abroad. The government also plans to recruit 2000 foreign experts over the next 5–10 years to work in national laboratories, leading enterprises and research institutes, as well as in a number of universities. Another target is to raise the GERD/GDP ratio from 1.5% to 2.5% by 2020.

In parallel, the *Eleventh Five-Year Plan* to 2010 is developing STI infrastructure at a gruelling pace, with 12 new megafacilities and 300 national key laboratories planned, among other institutions. Another focus is the environment. As part of the strategy to reduce energy consumption and emissions of major pollutants, the government plans to ensure that non-fossil energy sources represent 15% of energy consumption by 2020.

Today, the main barriers to innovation are the rapidly growing innovation risk that enterprises face, the lack of support for systemic innovation and exploration, and weak market demand for innovation.

Japan (Chapter 19) was hit hard by the global recession in 2008. After stagnating at around 2% between 2002 and 2007, growth in GDP dropped below zero, plunging major companies into distress and resulting in bankruptcies and a surge in unemployment rates.

Japanese manufacturers have traditionally excelled in steadily improving production processes and accumulating production know-how within their organizations to achieve the ultimate goal of high-quality products at competitive prices. However, this Japanese model is losing its effectiveness in many industrial fields, as China, the Republic of Korea and other nations with lower labour costs emerge as tough competitors. Under such circumstances, Japanese manufacturers have come to believe that they must constantly innovate to survive in the global market.

One consequence of this new mindset has been the rapid expansion in university–industry collaboration in recent years, resulting in numerous university start-ups. In parallel, both R&D expenditure and the number of researchers seem to be rising in the private sector. In fact, Japan retains a dominant STI position in key industries such as automobiles, electronic components, digital cameras and machine tools.

In 2004, all Japanese universities were semi-privatized and turned into 'national university corporations', with both faculty and staff losing their status as public servants. The chapter argues that many academic policies imported chiefly from the USA, such as competitive R&D funding, centres of excellence and a shift towards more frequent temporary academic positions, may have undermined the unique features of the existing university system by helping the top universities but damaging R&D capacities at other universities and destroying old domestic research networks.

Chapter 20 focuses on what is probably the world's most committed country to STI: the **Republic of Korea**. It had been enjoying high growth rates for a decade before GDP shrank by 5.6% in 2008. Nevertheless, by 2009, the economy was already expanding again, thanks to a government-led stimulus package. Part of that package included greater R&D funding to stimulate national STI. As a result, public spending on R&D actually grew in 2008–2009.

The Republic of Korea considers STI to be at the heart of economic progress and crucial to achieving a number of national goals. One of the top priorities is to increase GERD to an impressive 5% by 2012, up from an already high 3.4% in 2008. Strong investment is coupled with strong policies. For instance, Initiatives for Establishing a National Technology Innovation System was implemented in 2004 with 30 priority tasks. In 2008, the new government implemented a follow-on strategy called the *Science and Technology Basic Plan (2008–2013)* which has set itself as many as 50 priority tasks. These two plans now constitute the basic framework for STI policy. In addition, a low carbon, green growth policy was declared a key national agenda in 2008.

The final chapter on **Southeast Asia and Oceania** (Chapter 21) covers a vast geographical area stretching from Australia and New Zealand to Singapore, Thailand, Indonesia and the 22 Pacific Island countries and territories. The global economic recession has largely spared this part of the world.

In Cambodia, Thailand and Fiji, science is given a low priority so the global recession has had little impact. Countries more attached to STI, such as Singapore, Australia and New Zealand, reacted to the recession by sharpening their STI policies and aligning them more on national priorities. One R&D priority common to just about all countries in the region is sustainable development and the role that STI can play in combating climate change.

Singapore stands out as the region's most rapidly growing investor in science. Between 2000 and 2007, its R&D intensity climbed from 1.9% to 2.5%. According to the World Bank, only Viet Nam and Singapore improved their ranking in the Knowledge Index between 1995 and 2008. Growth has been largely driven by Singapore-based scientists, many of whom have come from abroad to work in its well-funded laboratories. Between 2000 and 2007, the number of FTE researchers rose by 50% to an impressive 6 088 per million population. A key national strategy has been to cluster research institutes in ICTs and biomedical research into two national knowledge hubs. This strategy has paid off, as Singapore is an emerging hub for biomedical and engineering technologies.

However, Singapore is not the only country in the region to have shifted its focus from S&T policies to STI policies. Moreover, there is a growing emphasis in the region on cross-sector R&D, such as through collaborative-project funding schemes. The face of collaborative research is changing. The rapid rise of China and India has had a knock-on effect on S&T capacity in Southeast Asia and Oceania. For example, the commodities boom led largely by India and China in recent years fed mining-related R&D in Australia, resulting in greater business R&D.

It is no coincidence that academics based in China and India figure among the top three countries of origin for co-authors in several countries in the region. Researchers are also spending more time abroad as part of their training and ongoing collaborative projects. There is clearly a higher level of international engagement and co-operation in the region than before.

CONCLUSION

Key messages

What conclusions can be drawn from the analysis above? ***First and foremost***, the disparity in development levels from one country and region to another remains striking. In 2007, per-capita income in the USA was estimated to be 30 times higher on average than in sub-Saharan Africa. Differences in economic growth rates have been compounded over the years, leading to 'divergence, big time' over the past 150 years in income levels between rich and poor countries. In the late 19th century, for instance, Nigeria was considered to be no more than a decade behind the United Kingdom in terms of technological development. The origin of this divergence in economic growth can be found in the disparate levels of investment in knowledge over long periods of time. Even today, the USA still invests more in R&D than the rest of the G8 countries combined. Four-fifths of the world's top universities also happen to be on American soil.

The past decade has challenged this picture, largely thanks to the proliferation of digital ICTs, which have made codified knowledge accessible worldwide. For sure, some early newcomers, like the Republic of Korea, had been steadily catching up to, and even leap-frogging over, countries since the 20th century by developing first their industrial capacity then S&T. But others, such as China, Brazil or India, have initiated a new, three-way process of catching up simultaneously in the industrial, scientific and technological spheres.

As a result, the past five years on which the present *UNESCO Science Report* focuses have really begun to challenge the traditional leadership of the USA. The global economic recession has compounded the situation, even if it is too early for this to be fully encapsulated in the data. The USA has been harder hit than Brazil, China or India, thereby enabling these three countries to progress faster than they would have done otherwise. Furthermore, as highlighted in the chapters on China and India, we seem to be on the verge of a structural break in the pattern of knowledge contribution to growth at the level of the global economy. This is also reflected in the arrival on the world scene of large, multinational firms from emerging countries which are moving into a wide variety of sectors that range from mature industries such as steel-making, automobile manufacturing and consumer goods to high-tech industries like pharmaceuticals and aircraft manufacturing. Companies in these emerging economies are increasingly opting for cross-border mergers and acquisitions to secure technological knowledge overnight.

Thirdly, the increase in the stock of 'world knowledge', as epitomized by new digital technologies and discoveries in life sciences or nanotechnologies, is creating fantastic opportunities for emerging nations to attain higher levels of social welfare and productivity. It is in this sense that the old notion of a technological gap can today be considered a blessing for those economies possessing sufficient absorptive capacity and efficiency to enable them to exploit their 'advantage of relative backwardness'. Countries lagging behind can grow faster than the early leaders of technology by building on the backlog of unexploited technology and benefiting from lower risks. They are already managing to leapfrog over the expensive investment in infrastructure that mobilized the finances of developed countries in the 20th century, thanks to the development of wireless telecommunications and wireless education (via satellites, etc), wireless energy (windmills, solar panels, etc) and wireless health (telemedicine, portable medical scanners, etc).

Other factors are also creating unique advantages in terms of knowledge growth. This is particularly well illustrated by the rapidly expanding pool of highly skilled labour in China and India, among others, the large numbers of redundant workers in farming and petty trade, the relative gain in the replacement of obsolete equipment with state-of-the-art technologies and the spillover effects of investment in new technology. The recognition of the importance of knowledge acquisition is a common thread running through all chapters. In Bangladesh, for instance, light engineering is producing import-substitution products that are creating employment and alleviating poverty. Endogenous technologies include ferries, power plants, machinery and spare parts. But Bangladesh is also developing the high-tech sector of pharmaceuticals. It is now 97% self-sufficient in pharmaceuticals and even exports them to Europe.

Fourthly, there is growing recognition that it is the systemic 'congruence' between the various knowledge components of the innovation system that counts when it comes to devising a successful growth strategy, as we have seen in Figure 5. In many mainly middle- and high-income countries, there is a distinct shift occurring from S&T policy to STI policy. This is having the effect of steering countries away from the linear approach starting with basic research and ending up with innovation towards more complex, systemic notions of innovation. University–industry collaboration, centres of excellence and competitive research funding are all becoming popular among countries looking to increase their STI capacity. However, as the chapter on Japan illustrates, such shifts are not easy to implement. At a time when Japan's global influence in R&D is slipping somewhat, the author of this chapter argues that the 'imported' policies cited above may have damaged the existing academic system in Japan, favouring the best institutions to the detriment of others which have been allowed to fall behind. It is true that, now and then, 'imported' policies will indeed conflict with 'home-grown' policies. To complicate matters further, even countries which have integrated this systemic congruence in their STI policies still tend to underestimate it in their overall development policies.

Fifthly, there is a growing emphasis in STI policy on sustainability and green technologies. This trend can be found in practically every single chapter of the *UNESCO Science Report*, even in parts of the world not generally characterized by a large STI effort, such as in the Arab region and sub-Saharan Africa. This holds not only for clean energy and climate research but also for the repercussions on S&T fields upstream. Space science and technology, for example, are a rapidly growing field for many developing and emerging countries. Driven by concerns about climate change and environmental degradation, developing countries are attempting to monitor their territory more closely, often via North–South or South–South collaboration, as in the case of Brazil and China for the design of Earth observation satellites, or via projects like Kopernicus–Africa involving the African Union and European Union. At the same time, space science and technology are of course being harnessed to provide ICT infrastructure for use in wireless applications in health, education and other fields. Climate change-related research has emerged as an R&D priority when it was almost totally absent from the *UNESCO Science Report 2005*. As a general broad policy comment, one can today reasonably argue that laggard regions or nations always do well to improve their absorptive capacity and remove any 'barriers' preventing the flow of positive technological spillovers from technologically leading economies, be they from the North or South.

Last but not least, national STI policies clearly face a radically new global landscape today, one in which the territorial policy focus is coming under severe pressure. On the one hand, the steep drop in the marginal cost of reproduction and diffusion of information has led to a world in which geographical borders are less and less relevant for research and innovation. Knowledge accumulation and knowledge diffusion are able to take place at a faster pace, involving a growing number of new entrants and providing a threat to established institutions and positions. This globalizing trend affects research and innovation in a variety of ways. On the other hand, contrary to a possibly somewhat simplistic reasoning, globalization does not lead to a flat world, one in which gaps in research and innovation capabilities across countries and regions are constantly narrowed. Quite to the contrary, if there is clear evidence of a concentration of knowledge production and innovation emerging *across* a wider variety of countries than before within Asia, Africa and Latin America, this knowledge is growing at a highly differentiated pace *within* countries.

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Thomas Ratchford and William Blanpied on the Obama administration's plans for stimulating the economy

2 · United States of America

J. Thomas Ratchford and William A. Blanpied

INTRODUCTION

Research and development (R&D) in the United States of America (USA) have prospered over the five years since the *UNESCO Science Report 2005* was published. The political environment has remained conducive to a large federal role in defence and basic research, while the universities have continued to strive for excellence in research and teaching, beneficiaries of generous federal subventions and project support. Operating in a friendly policy environment, companies have invested unprecedented amounts in research. The threatening cloud on the horizon for R&D is the global economic recession.

The economic downturn first became visible in the USA in the last quarter of 2008, after the collapse of the country's credit system in what has become known as the sub-prime mortgage crisis. The crisis first hit the world's headlines after the federal government refused to bail out Lehman Brothers. The firm filed for Chapter 11 bankruptcy protection on 15 September 2008. American International Group, the world's largest insurer, was bailed out the next day at an eventual cost of between US$134 billion and US$180 billion. In the following weeks, several leading lending institutions also folded, including Bear Stearns. Others would be saved *in extremis* by federal intervention.

By the end of 2008, millions of mortgaged American homes had been seized by creditors. Between June 2008 and June 2009, 2 million jobs were lost. Unemployment rose from nearly 4% to about 10% of the working population, a deterioration not seen in over 25 years. By early 2009, two of the three leading car manufacturers were having to be bailed out by the federal government. Both General Motors and Chrysler were later reorganized following bankruptcy. As of May 2009, GDP had contracted by slightly more than 3% on an annual basis, with a low of 6.4% for the first quarter.

At the time of writing in October 2009, GDP had expanded for the first time in a year in the third quarter at an annual rate of 3.5%, according to the Department of Commerce. Economists were fearful, however, that the recovery might not last, as government programmes to stimulate consumer spending were due to expire and both public debt and unemployment kept rising steadily.

In the same issue in which its Breakthrough of the Year was announced on 19 December 2008 (Box 1), the American journal *Science* featured a one-page article entitled Breakdown of the year: financial meltdown. The credit crisis will undoubtedly have negative repercussions for investment in R&D in the USA, as in other countries, and may delay the commercialization of promising technologies. Although the *Science* article did not point the finger at the economists whose risk models were partially responsible for the financial crisis, nor at the handful of PhD physicists who were employed on high salaries by Wall Street firms to conduct such analyses, they were clearly culpable to some extent for the financial meltdown.

S&T IN THE OBAMA ADMINISTRATION

On 20 January 2009, Barack H. Obama was sworn in as the USA's 44th President after George W. Bush's eight years in office. The global economic recession President Obama inherited has provided a unique backdrop for his administration and its stance on science and technology (S&T).

In response to the deepening crisis, the incoming Obama administration proposed a second economic stimulus package which was approved by Congress – the US parliament – in February 2009. This package included significant one-time funding for federal S&T organizations through 2010. The Administration's detailed budget request for fiscal year 2010, submitted to Congress during the first week of May 2009, also included significant requests for these organizations.

The president articulated his vision of the future in an address to the National Academy of Sciences on 29 April 2009. He pledged an increase in gross domestic expenditure on R&D (GERD) from 2.7% to 3% of GDP, requiring a rise in both government and industrial expenditure. This, he emphasized, would contribute to the development of less expensive solar cells, learning software that could provide superior computer tutorials and, above all, alternative, clean energy sources. 'Energy,' he asserted, 'is this generation's great project.' He suggested that the USA should commit itself to reducing carbon pollution by 50% by 2050 against the 1990 base year. To this end, he reiterated his intention to create an Advanced Research Project Agency for Energy (ARPA-E) within the Department of Energy. This agency would be analogous to the Department of Defense's Advanced Research Project Agency (DARPA) in conducting high-risk, high-reward research.

Space shuttle *Endeavour* lifting off from NASA's Kennedy Space Center on 15 July 2009 for a rendezvous with the team at the International Space Station

Photo: NASA

If there is a common thread running through President Obama's S&T policies, funding and people, it is a commitment to a green future: reducing greenhouse gasses and using clean energy. This commitment is reflected in stronger standards for vehicle efficiency (CAFÉ standards) and proposals for a 'cap and trade' regime to reduce greenhouse gas emissions.

There is also a renewed emphasis on federal involvement in industrial technology development and a tilt towards fewer controls on some controversial research, such as that utilizing stem cells. It remains to be seen how these trends will endure beyond the current economic recession.

The fundamental policies that have undergirded the support for R&D in the USA for more than a half a century are expected to remain in place. These include generous federal support for basic research and a policy environment favourable to private-sector funding of R&D.

Overall, the Obama administration and the Democratic majority in Congress – the President himself being a Democrat – are expected to be more amenable to federal R&D expenditure than the Republican party, especially when it comes to federal programmes that strengthen industrial R&D. President Obama appears to be engaged on science issues and is known as a 'science guy'. His policy changes include new guidelines on embryonic stem cell research. These new guidelines allow federal funding for research only on new stem cell lines created from surplus embryos at fertility clinics. They include rigorous eligibility standards and lines created in the laboratory to study particular diseases are not allowed. The *New York Times*, in an editorial of 22 April 2009, complained that the new guidelines were 'disappointing'. The guidelines under President Bush, themselves a political compromise, permitted federal funding of research on 21 cell lines. The Obama guidelines also appear to be a political compromise but lean further towards the free scientific enquiry end of the spectrum. In July 2009, the Obama Administration further modified its rules regarding stem cell research in response to criticisms reported in the April *New York Times* editorial.

Of greater structural policy importance is an Obama memorandum insulating scientific decisions by federal government officials from political influence. Freedom of scientific enquiry is a cornerstone of any effective science policy regime and, in the modern world of federally funded research, the government role is central. Life for dissenters, even in science, has always been tough. The real test of this policy will be whether federal funding of scientific opinions not 'politically correct' will flourish.

Funding

President Obama views investment in science, technology and innovation (STI) as important components of the nation's economy, as emphasized in both his stimulus package and his 7 May budget request for R&D in his proposed budget for fiscal year 2010.

In a speech to the National Academy of Sciences on 29 April 2009, the president promised to meet two important benchmarks:

- *firstly*, that the nation would carry GERD to 3% of GDP by the time he left office, compared with the unofficial estimate of 2.7% for 2008. This ratio has never reached or exceeded 3%; it peaked at 2.9%, in 1962;
- *secondly*, that the research and experimentation tax credit would be made permanent. This is a tax credit for R&D investment by industrial firms which has been renewed by Congress periodically.

The president's promise has been greeted favourably by industry. Both pledges require substantial investment by industry and a concomitant favourable industrial research policy environment.

People

Material to the effects of these budget increases are the S&T leaders in the new administration. They have the responsibility to implement these increases wisely and to advise on how best to deploy S&T in the service of the nation.

The Obama administration has a strong S&T team. The fact that important appointments were made early on sent a positive signal. President Obama's choice for Science Advisor and Assistant to the President for Science and Technology was John Holdren, former head of the Harvard Kennedy School's Science, Technology, Public Policy Program at the Belfer Center for Science and International Affairs. Holdren is a strong supporter of controls on greenhouse gases. He has also, in the past, expressed support for clean coal and advanced nuclear technologies. Holdren has identified five major challenges for the nation: applying S&T to (1) the economy, (2) public health, (3) energy, (4) environment, and (5) national and homeland security.

Other stars in the Obama science galaxy include Energy Secretary Steven Chu, who is Lawrence Berkeley National Laboratory Director and a Nobel Laureate in physics. Jane Lubchenco, a marine scientist from Oregon State University, heads the National Oceanographic and Atmospheric Administration (NOAA). Lisa Jackson, a chemical engineer, is the Chair of the Environmental Protection Agency. These organizations have rarely, if ever, been headed by scientists in the past. Francis Collins, former head of the Human Genome Project, has been nominated Director of the National Institutes of Health (NIH). Regina Benjamin, an Alabama family physician who served for almost two decades as one of the few doctors in a shrimping village

Box 1: Breakthroughs of the year

Scientists working at American institutions – many of them foreign-born or working in collaboration with scientists from other countries – have continued to obtain important results across a broad spectrum of scientific fields since the *UNESCO Science Report 2005* was published. These breakthroughs include both discoveries with potential for commercial application and those that serve primarily to deepen human understanding of the physical and living Universe.

Each December, *Science*, the respected journal of the American Association for the Advancement of Science (AAAS), publishes an article on what it entitles the Breakthrough of the Year. Here are the 'winners' in recent years from the USA and elsewhere:

(2004) Martian exploration

Science selected two robots launched by the National Aeronautics and Space Administration (NASA) as its breakthrough of the year. *Opportunity* and *Spirit*, which roamed over different portions of Mars, both discovered evidence that water may once have existed on the planet. If water did once exist on Mars, as was confirmed in 2008 by other Martian rover robots, then some form of life may once have existed, or may still exist, on the planet.

(2005) The Poincaré Conjecture

In 1904, the French mathematician Henri Poincaré advanced a conjecture in the branch of mathematics known as topology – that is, the study of the surfaces of multidimensional objects. (The surface of a three-dimensional object has two dimensions; that of an N-dimensional object, N-1 dimensions.) Poincaré proved that differences in surfaces of any N-dimensional object differ only in the number of their holes. He then conjectured that a three-dimensional space that is the surface of a four-dimensional object cannot 'hide any interesting topology' from what he referred to as the 'fundamental group'. Mathematicians had proved 'analogous statements for spaces of every dimension higher than three' by the early 1980s but proof of Poincaré's original conjecture for three-dimensional spaces was not forthcoming until 2002 when the Russian mathematician, Grigori Perelman, who had collaborated earlier with the American mathematician Richard Hamilton, built on Hamilton's work to publish the first of three papers demonstrating how any type of three-dimensional surface can evolve into another without encountering any roadblocks, known to typologists as 'singularities'. In 2006, topologists reached the consensus that Perelman had, in fact, proved the Poincaré conjecture.

(2006) Evolution in action

Science focused on a pair of results which deepened our understanding of Darwinian evolution, as well as the relationship between humans and other primates. The first of these breakthroughs occurred 'in September [when] an international team published the genome of […] the chimpanzee'. These results indicated that humans and chimps differ by only about 1% in the nucleotide bases of their respective genomes, or by approximately 4% of their DNA. The second set of results concerned the emergence of new species, which form 'when existing populations of species begin to adapt in different ways and eventually stop interbreeding'. Two separate teams of researchers found evidence for the ways in which this speciation occurs in European blackcaps, a type of warbler found in Germany and Austria, as well as in European corn borers living throughout Western Europe.

(2007) Human genetic variation and disease

In 2001, the sequencing of the human genome was completed and its results were made available to

continued

Box 1: *Continued*

researchers throughout the world. Geneticists then turned their attention to how minute differences in the genomes of individuals differentiate them from one another. In 2005, the UK's Wellcome Trust recruited 200 researchers from several countries to analyse the DNA of 17 000 people. Significant results for 2007 focused on type 2 (adult-onset) diabetes genes, including the discovery of four new diabetes-associated gene variants. 'New gene associations now exist for heart disease, breast cancer, restless leg syndrome, atrial fibrillation, glaucoma, amyotropic lateral sclerosis, multiple sclerosis, rheumatoid arthritis, colorectal cancer, ankylosing spondylitis and autoimmune diseases.'

(2008) Seeing exoplanets

Prior to 2008, astronomers had succeeded in using indirect methods to identify over 300 exoplanets, that is, planets orbiting stars other than our Sun. The most common of these indirect methods measures the slight wobbling of a star, indicating variation of the gravitational attraction between the star and a massive, orbiting object. During 2008, at least four groups reported direct, telescopic observations of the light from the mother star by orbiting exoplanets. Since the light emitted from the star itself is significantly brighter than the light reflected from a daughter planet, sophisticated techniques are required to pinpoint the latter. Exoplanets identified thus far – including those reported prior to 2008 – are typically considerably more massive than the planet Jupiter, itself one million times more massive than Earth. Significant technological advances will be required if exoplanets with masses comparable to Earth are to be detected.

Other frontier discoveries

In recent years, 'runner-up' discoveries have included:

- (2004) the discovery by Australian researchers of a new, tiny species of hominid in Indonesia known as the Hobbit;
- (2005) the discovery by astrophysicists of the first known binary system of pulsars. Runners-up for 2005 also included the landing of the first human-made object on a moon of another planet, Titan, a satellite of Saturn;
- (2006) the identification by plant molecular biologists of the identity of florigen, a signal that initiates the seasonal development of flowers;
- (2006) Sequencing of more than one million base pairs of Neanderthal DNA, completed by researchers in Europe and the USA, concluding that Neanderthals diverged from our own ancestors approximately 450 000 years ago and suggesting that Neanderthals and modern humans may have interbred;
- (2007) the demonstration by glaciologists that the great ice sheets covering Greenland and Antarctica are shrinking at a considerably greater rate than had previously been expected;
- (2008) the discovery that, when different classes of crystals of substances known as transition oxides are placed in layers, the results could herald the birth of new types of micro-devices to rival those which now dominate the electronics industry, silicon-based devices;
- (2008) a systematic survey of many genes in cancer cells detected genetic mistakes which led to the breakdown of normal cell division. In 2008, reports on the genetic flaws leading to pancreatic cancer and glioblastoma, two of the most deadly forms of cancer, were announced;
- (2008) a new catalyst, a mixture of cobalt and phosphorus, uses electricity to separate water molecules into their constituent hydrogen and oxygen atoms. If developed on an industrial scale, this catalyst could serve as the basis for storing energy derived from wind, solar and other sources for later use. Researchers have known for some time that platinum provides a catalyst for the separation of water into its constituents. However, since platinum is rare and expensive, the newly identified cobalt–phosphorus catalyst could provide the means for making significantly more effective use of renewable energy sources.

Source: authors

along the Gulf of Mexico coast, has been nominated Surgeon General, a position often called 'the nation's physician'. Geneticists Harold Varmus, a Nobel Laureate and former Director of NIH, and Eric Lander of the Massachusetts Institute of Technology have been named Co-Chairs of the President's Council of Advisors on Science and Technology.

R&D INPUT

R&D expenditure

GERD in the USA has continued to rise since the turn of the century, reaching an estimated US $368.1 billion in 2007. Private industry contributed approximately 67% of the total and the federal government 27% (Figure 1).

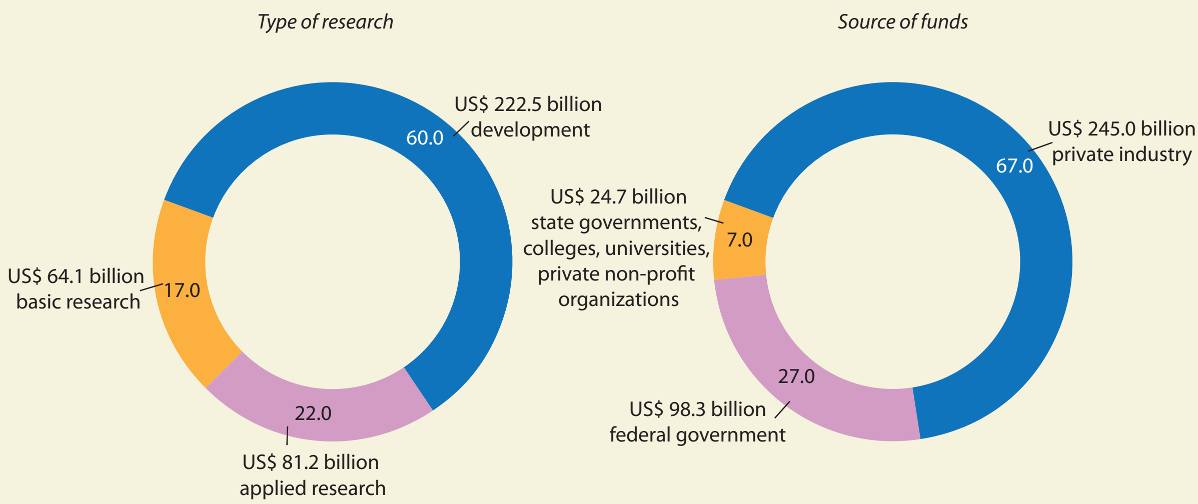
These numbers are derived from data provided by the National Science Foundation (NSF). This body is required by law to gather, analyse and disseminate a large variety of data related to S&T, including GERD. Whereas data on federal government expenditure are readily accessible to the NSF, those related to industry and other funding sources are obtained via surveys, which require more time to gather and analyse. For this reason, GERD data appearing in subsequent sections of the present chapter which were obtained from other sources are sometimes given for 2008 or, in rare cases, 2009. Additionally, the R&D Budget Program of the American Association for the Advancement of Science (AAAS) provides estimates of federal expenditure for both 2008 and 2009. These data, however, relate to the president's requested budget submitted to Congress in February or March each year, rather than to actual congressional appropriations which are not finalized until late the same year or, in some cases, early the following year.

Figure 2 shows trends in GERD by funding source between 1990 and 2007, expressed in both current and 2000 constant (that is, inflation-adjusted) US dollars.

The USA consistently invests more money in R&D than the rest of the G8 countries combined. Its share of G7 expenditure on R&D has fluctuated between 48% and 53% over the past 25 years and has exceeded 50% since 1997.[1] In 2006, the USA's share of the G7 total was 53%.

1. Russian data only go back to 1990, which is why comparisons dating back to the 1980s speak of the G7 rather than the G8.

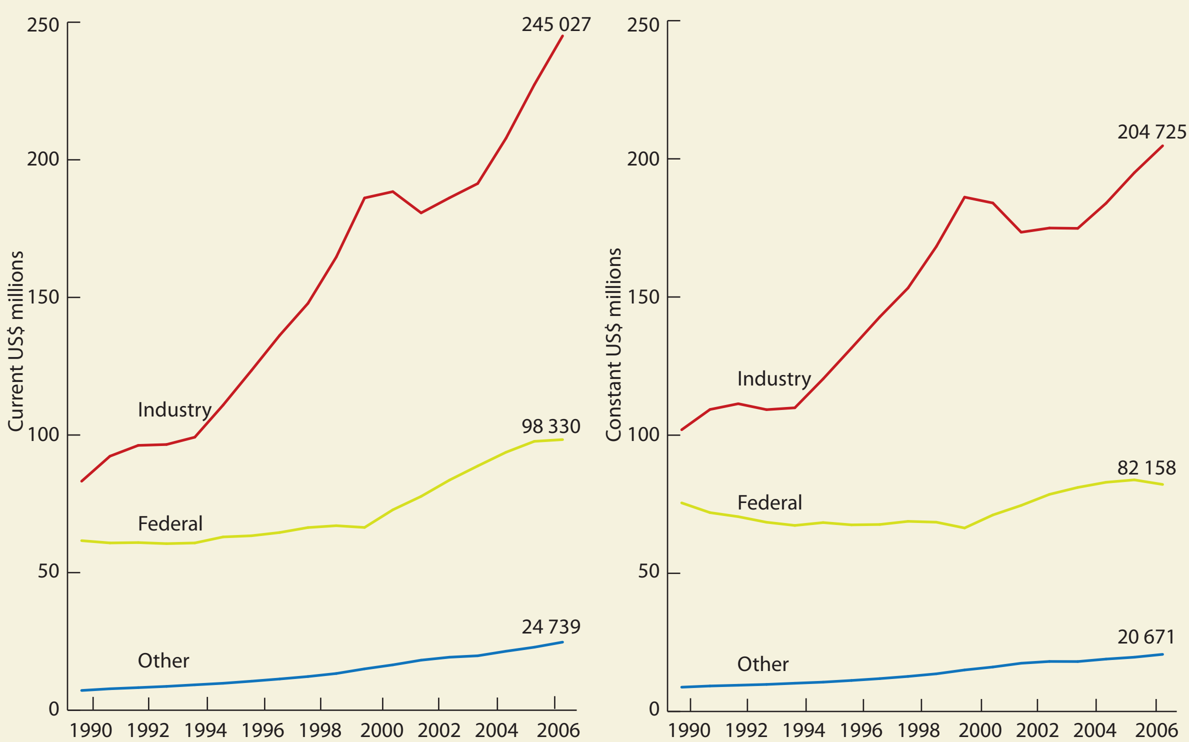
Figure 1: GERD in the USA by type of research and source of funds, 2007 (%)



Note: percentages may not add up to 100% because of rounding

Source: National Science Foundation

Figure 2: GERD in the USA by source of funds, 1990–2007
In millions of current and constant 2000 dollars



Note: Data for 2007 are preliminary.

Source: National Science Foundation

In 2007, the ratio of GERD to GDP in the USA was 2.67%, down from its most recent high of 2.81% in 2003. The NSF's unofficial estimate for 2008 is 2.70%. With a GERD/GDP ratio of 3.67% in 2007, Japan is the only G8 country with a higher ratio. However, several smaller countries have also boasted higher GERD/GDP ratios than the USA in recent years: Israel 4.71% (2005), Sweden 3.64% (2007), Finland 3.47% (2007), Republic of Korea 3.37% (2008), Switzerland 2.93% (2004), and Iceland 2.86% (2003).

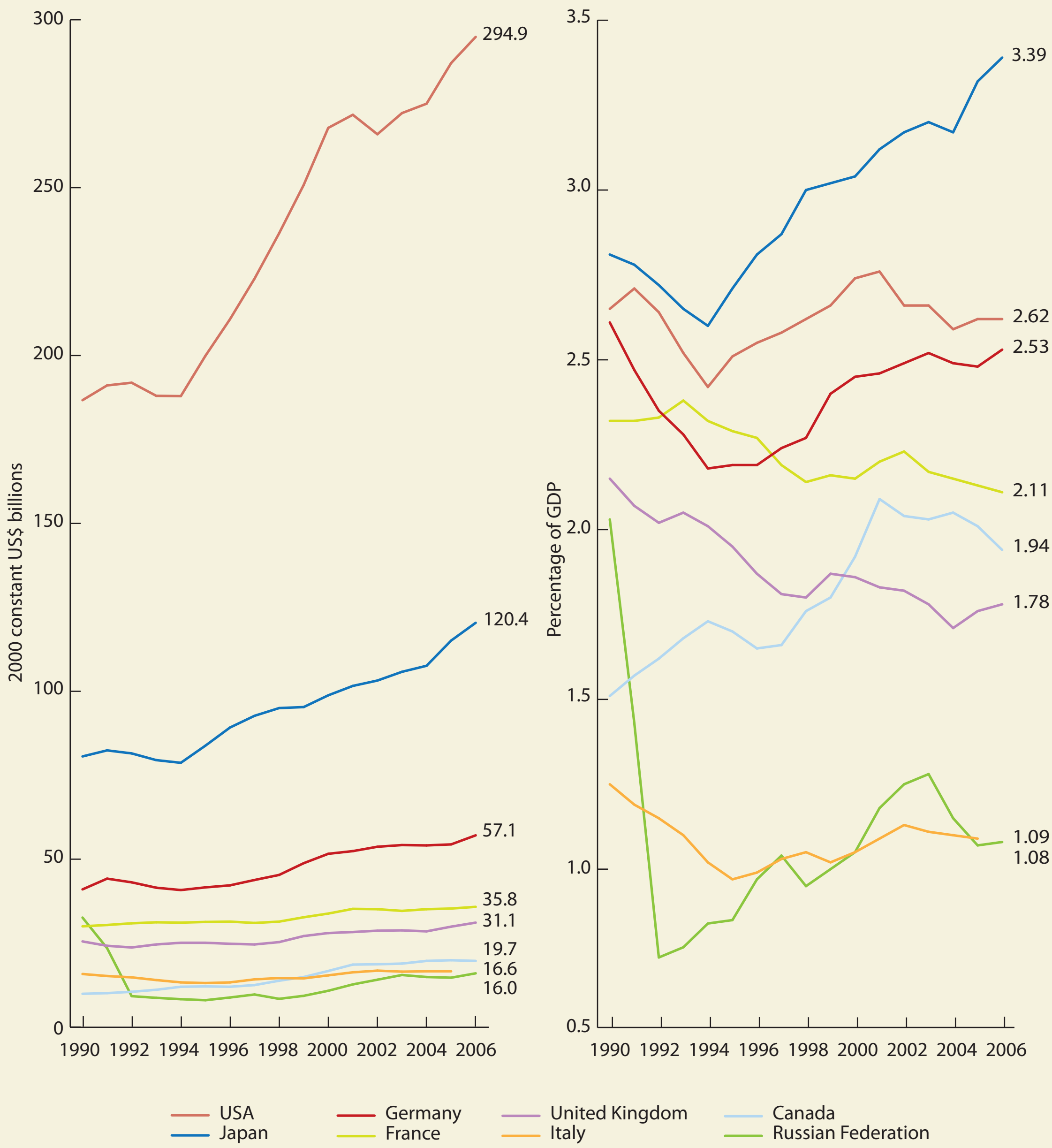
Figure 3 shows the trend in GERD for the USA and the other G8 countries since 1990. Usually, but not always, high GERD/GDP ratios for smaller countries signal the presence of large multinational companies with associated large R&D budgets. Such is also the case in the USA. In 2004, R&D expenditure for multinational corporations headquartered in the USA amounted to approximately US$152.4 billion. Microsoft, for example, invested US$7.8 billion in R&D, the highest of any multinational corporation. Others headquartered in the USA with significant expenditure were Pfizer (US$7.7 billion), Ford (US$7.4 billion), General Motors (US$6.5 billion), IBM (US$5.7 billion), Johnson and Johnson (US$5.2 billion) and Intel ($4.8 billion).

R&D AND THE FEDERAL GOVERNMENT

Federal funding

In fiscal year 2008, covering the period to 30 September 2008, the federal government obligated an estimated US$112.8 billion for GERD. Table 1 shows the estimated breakdown of federal expenditure on R&D in 2008 by

Figure 3: Trends in GERD in the G8 countries, 1990–2006
In constant 2000 US$billions and as a percentage of GDP



Note: based on data provided to the OECD by NSF and other US statistical agencies. OECD statistical guidelines for tallying national R&D expenditure differ slightly from those used by the USA. Data on Japanese R&D in 1996 and later years may not be consistent with data in earlier years because of changes in methodologyConversions of foreign currencies to US dollars are calculated by the OECD based on each country's GDP implicit price deflator and purchasing power parity exchange rates.

Source: OECD (2008), *Main Science and Technology Indicators*, Volume 2008/1

Table 1: Federal R&D in the USA by major socio-economic objective, 2007–2009
Budget authority in millions of dollars

	2007 Actual	2008 Estimate	2009 Budget	2008–2009 Dollar change	2008–2009 Percentage change	Share of total 2009 (%)
Defence*	82 658	81 500	84 513	3 013	3.7	57.4
Non-defence	59 276	60 941	62 848	1 907	3.1	42.6
Space	10 988	11 676	12 334	657	5.6	8.4
Health	30 396	30 663	30 813	150	0.5	20.9
Energy	1 922	2 460	2 474	14	0.6	1.7
General Science	8 712	8 744	10 225	1 481	16.9	6.9
Environment	2 096	2 153	2 060	-93	-4.3	1.4
Agriculture	1 950	1 972	1 637	-335	-17.0	1.1
Transportation	1 380	1 359	1 366	7	0.5	0.9
Commerce	516	557	576	19	3.3	0.4
International	246	255	255	0	0.0	0.2
Justice 369		355	356	1	0.3	0.2
All other	700	746	752	6	0.8	0.5
Total R&D	**141 933**	**142 441**	**147 361**	**4 920**	**3.5**	**100.0**

* Includes Department of Defense, defence R&D in the Department of Energy and defence-related R&D in the Department of Homeland Security
Note: Classifications generally follow the government's budget function categories, with the exception of health. All figures are rounded to the nearest million. Changes are calculated from unrounded figures.

Source: AAAS estimates based on data from OMB and agency budget justifications

major socio-economic objective. Of the total, a little over half was devoted to national defence and one-fifth to health. The USA is unique both among countries of the Organisation for Economic Co-operation and Development (OECD) and G7 countries in its heavy emphasis on defence and health.

Principal supporting agencies

Although more than 25 federal agencies report GERD obligations, only seven reported GERD obligations in excess of US$1 billion in 2007. The budget of these agencies accounted for over 96% of federal GERD, or approximately US$108 billion.[2]

The principal funding sources and performers of R&D in the Department of Health and Human Services are the National Institutes of Health. A significant change since the *UNESCO Science Report 2005* in terms of federal support for R&D is that seven rather than six federal agencies are now in the billion-dollar R&D club and account for over 96% of federal expenditure (Table 2). The Department of Homeland Security, created in response to the jihadist attacks on the USA of 11 September 2001, combined bureaux within several existing cabinet departments; it has now joined the ranks of those principal performers and supporters of federal expenditure on R&D.

The American Reinvestment and Recovery Act (2009)

On 9 February 2009, Congress enacted the American Recovery and Reinvestment Act, commonly known as the stimulus package, which President Barack Obama signed into law a week later, on 17 February. The rationale and general outline of the Act had been proposed by Obama on 6 January, two weeks prior to his inauguration. The approximately US$800 billion stimulus package contains substantial funding for S&T, in excess of US$30 billion. These investments are made in the context of the Obama administration's emphasis on clean energy, education, basic research, health care, broadband communications, medical discoveries and infrastructure such as roads and schools. Specific R&D increases found in the stimulus package include:

2. The US$108 billion total exceeds the US$98.3 billion total federal R&D appropriations for fiscal year 2007, since several agencies are permitted to carry over unexpended funds from one fiscal year to the next, including the Department of Defense.

Table 2: Basic research budget for the primary US federal agencies, 2003 and 2008

	Basic research budget in 2003 (US$ billions)	Basic research in 2008 (US$ billions)
National Institutes of Health	14.1	16.5
National Science Foundation	3.4	4.0
Department of Energy	2.6	3.5
National Aeronautics and Space Administration (NASA)	2.4	2.3
Department of Defense	1.4	1.8
Department of Agriculture	0.9	0.9
Department of Homeland Security	–	0.3
Total for the agencies listed here	**24.8**	**29.4**
Total for all federal agencies	**–**	**30.3**

Source: AAAS; Ratchford and Blanpied (2005) United States of America. In: *UNESCO Science Report 2005*

- **National Science Foundation:** US$3 billion, including US$2.5 billion for research and related activities, US$400 million to build major research facilities and US$100 million for improving instruction in science, mathematics and engineering.
- **National Institutes of Health (NIH):** US$10 billion, including US$1.3 billion for the National Center for Research Resources (US$1 billion of which is for competitive awards, construction and renovation of extramural research facilities); US$8.2 billion for the Office of the Director (US$7.4 billion for institutes, centres and a Common Fund); and US$500 million for repair and improvement of NIH buildings and facilities.
- **Department of Energy:** US$18.4 billion, US$16.8 billion of which is for energy efficiency, renewable energy sources and batteries and the remainder for science programmes.
- Department of Energy's new **Advanced Research Project Agency:** US$400 million is provided for high-risk, high-payoff research into energy sources and energy efficiency.
- **National Aeronautics and Space Administration (NASA):** US$1 billion, including US$400 million for science, US$150 million for aeronautics and US$400 million for exploration.
- **National Institute of Standards and Technology (NIST):** US$600 million total including US$220 million for research, competitive grants, fellowships and equipment; US$360 million is to address maintenance and construction of NIST facilities.
- **US Geological Survey:** US$140 million compared with a total 2009 budget of US$1.04 billion for surveys, investigations and research.
- **Department of Defense:** US$300 million for research, testing and evaluation, in addition to the energy initiative of the Advanced Research Project Agency noted above.

President Obama's budget request for 2010

On 7 May 2009, President Obama submitted his detailed budget request to Congress for fiscal year 2010 beginning on 1 October 2009. This included an appeal for R&D of US$147.4 billion, an increase of US$555 million over the previous fiscal year appropriated by Congress and an amount over and above that provided in the February stimulus package. Of this amount, US$29.4 billion was earmarked for basic research (Table 2), US$29.7 billion for applied research and the balance for technological development.

In fiscal year 2007, Congress had accepted the Bush administration's request to double the budgets of the National Science Foundation (NSF), the Office of Science of the Department of Energy and the National Institute of Standards and Technology. The Obama administration's fiscal year 2010 request is on track to double the budget of these three organizations by fiscal year 2016.

The role of 'mission agencies'

With a single exception, all of the federal government's cabinet departments and independent agencies that perform and/or support R&D do so in pursuit of their congressionally mandated missions. The exception, the NSF, was mandated by Congress at the time of its creation in 1950 to 'advance the progress of science' by supporting science and engineering research in universities, colleges and other non-profit institutions, as well as mathematics, science and engineering education at all levels. The NSF has since enjoyed functional autonomy.

Of the federal government's US$94.2 billion in R&D expenditure for 2007, US$24.4 billion was devoted to activities in laboratories and other facilities managed directly by a federal department or agency. Among the latter, the 27 research facilities of the National Institutes of Health (NIH), most of them located in Bethesda in the State of Maryland, immediately north of Washington, DC, provide the principal example. In 2007, just under 10% of NIH's US$28.4 billion budget was allocated to research in these 27 facilities. The remainder was allocated to awards for university faculty, most often in medical schools, in the form of research grants based on competitive, peer-reviewed proposals. Many of these research projects involve large, expensive epidemiological studies.

Federally Funded R&D Centers

An additional US$13.2 billion from the 2007 federal budget for R&D was allocated to the 37 Federally Funded Research and Development Centers (FFRDCs), often called national laboratories. Specific to the USA, these centres are managed by universities, companies and non-profit institutions on behalf of the federal government and with its full support. Of these 37 centres, 16 are university-managed, 5 are industry-managed and 16 are managed by non-profit organizations.

Sixteen of the FFRDCs are funded by the Department of Energy (DoE) and managed on its behalf. These 16 organizations performed R&D funded to the tune of almost US$9 billion during fiscal year 2006, three-quarters of the R&D performed by all the FFRDCs combined. Approximately 60% of DoE's R&D budget is allocated to supporting these facilities. DoE-supported FFRDCs include the Los Alamos, Livermore and Sandia National Laboratories, which were originally established for the purpose of developing nuclear weapons, beginning with Los Alamos in 1943. Although the first two had been managed from the outset by the University of California, DoE announced in 2003 its intention to open up their management to bids from other potential contractors. Both are now managed by consortia which include both the University of California and a number of industrial organizations. Four of the FFRDCs reported expenditure on R&D of more than US$1 billion in fiscal year 2006: Los Alamos National Laboratory, Sandia National Laboratory, the Jet Propulsion Laboratory (managed by the California Institute of Technology on behalf of NASA) and the Livermore National Laboratory.

DoE-supported national laboratories also include several whose purpose is to house and maintain large-scale research facilities on behalf of university users groups, including the Ernest Orlando Lawrence Berkeley Laboratory managed by the University of California and the Fermi National Accelerator Laboratory managed by a consortium of universities known as Associated Universities Inc.

In addition to those supported by DoE, nine FFRDCs are supported by the Department of Defense (DoD), an additional five by the National Science Foundation which, by law, cannot operate its own research facilities, and one each by NASA, the NIH, the Department of Homeland Security, the Nuclear Regulatory Commission, the National Security Agency and the Internal Revenue Service.

S&T IN INDUSTRY

The effect of the recession on industrial R&D

The year 2008 began with an optimistic outlook for industrial R&D funding. The annual Industrial Research Institute (IRI) survey of projections of member companies – which perform the majority of industrial R&D in the USA – indicated robust growth for total company R&D. Companies planned to increase hiring of new graduates to conduct R&D. The ratio of R&D to sales was projected to rise, indicating an increase in technological intensity.

The economic climate deteriorated dramatically throughout 2008 and well into 2009. Although industrial R&D rose to its highest level in 2007 and 2008, reliable projections in mid-2010 showed a levelling out in 2009 and even a modest reduction in 2010. Pfizer Inc. announced in January 2009 that it was laying off as many as 800 researchers, 5–8% of its 10 000 research employees. Pfizer has the biggest R&D budget of any drug-maker (US$7.5 billion). The large pharmaceutical companies have had a lot of trouble designing effective strategies for R&D, due to the 'lumpy' or irregular pay-off resulting from the 'blockbuster' drug model that requires a huge financial investment in development and testing. Some industry experts call for 'big pharmas' to buy more of the new drugs for their pipelines rather than develop these in house.

On 29 April 2009, the IRI hailed the Obama administration's R&D spending plans as 'the largest commitment to scientific research and innovation in US history, more than what was spent at the height of the space race in 1964'. However, painful changes are likely in industry. As IRI President Edward Bernstein noted, 'Now more than ever, R&D groups are under pressure to restructure their organizational and technological capabilities in key areas.'

The business-oriented *Wall Street Journal* took a generally optimistic view of R&D in industry in a front-page article dated 6 April 2009. The *Journal* provides a contrasting view of multinationals Apple and Motorola, pointing out that Apple boosted R&D spending by 42% between 1999 and 2002, resulting in the iPod and iTunes lines. Motorola, on the other hand, slashed R&D spending by 13% in 2002, causing R&D expenditure to trail revenue. Motorola's market share and stock price have since plummeted. The *Journal* states, ' R&D spenders say they've learned from past downturns that they must invest through tough times if they hope to compete when the economy improves.'

The bottom line appears to be a likelihood of substantial reductions in industrial R&D during the economic recession, probably lagging behind the economic indicators by a year or so, both on the way down and on the way up. The carrot of future products and sales may well limit the depth of the R&D recession but turmoil is likely. This will cause many companies to rethink their overall R&D and innovation strategies, probably strengthening the open innovation option growing so popular.

Formal research strategies and budgets for 2009 may show small increases but early indications are that 2009 and probably 2010 will likely show contractions in funding of industrial R&D. In some companies, there have already been large lay-offs of research staff, resulting from economic pressure and a realization that money alone will not fill the product pipeline.

An impending downturn in funding for industrial R&D

The impending downturn in funding of industrial R&D will come as something of a 'culture shock', as industrial R&D has prospered in recent decades in the USA. In 2007, the last year for which NSF estimates are available, industry funded 67% of national R&D and performed 72%. A year earlier, the figures were 65% and 71% respectively. With hindsight, this appears to be a fluctuation rather than a trend: in 2007, the ratio of industrial GERD to GDP was 1.88%, compared with 1.85% in 2001; comparable ratios for federal expenditure were 0.64% and 0.69%, respectively.

The overall growth in GERD has far outpaced that for GDP in real terms for over 50 years, with industrial R&D growing much faster than federal R&D. For example, in 1953, the non-federal (mostly industry) GERD/GDP ratio (0.63%) was only one-third that of 2007 (1.95%). The comparable federal numbers are 0.73% and 0.71%, a slight decrease over this long period. Industrial R&D has contributed most of the real growth in US R&D. This trend demonstrates the increasing importance of industrial technology in a growing US economy. Companies have been putting their money where their mouths are.

A market advantage dependent on 'spending enough'

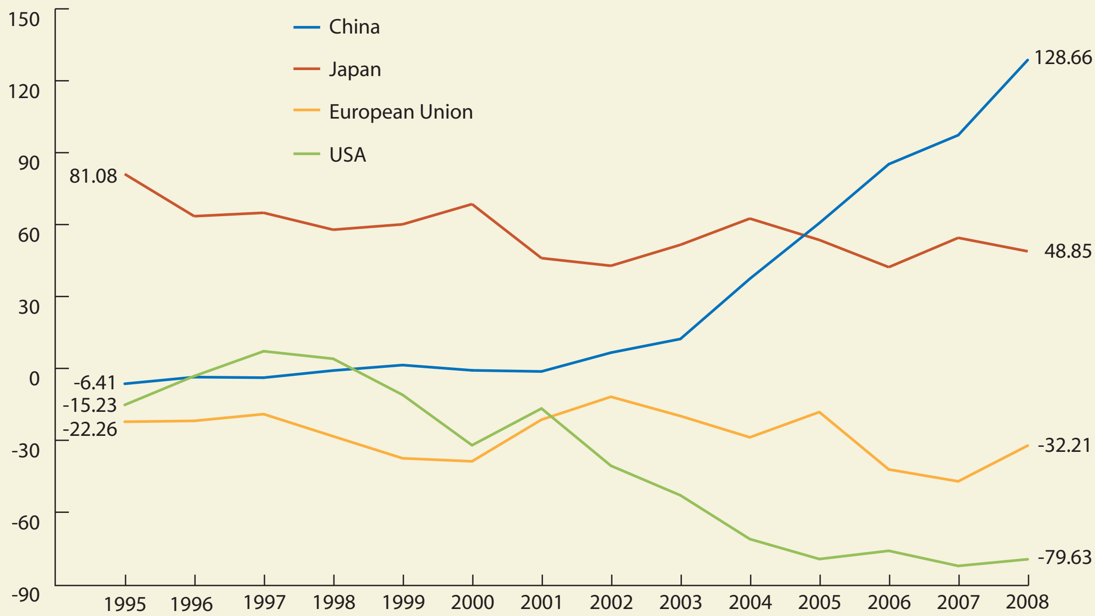
Technological intensity varies between industries, companies and countries. It is relatively easy, in principle, to measure input to the innovation chain, the ultimate reason companies invest in R&D. Measuring output is much more difficult, since management, government policy environments and pure luck play such important roles. It is probable that market advantage depends on a company spending 'enough' on R&D, according to the norms of its industry group; beyond that, managerial and strategic considerations – not to mention luck – appear to control the outcome.

Measures of technological intensity include the ratio of R&D to net sales, GERD/GDP ratio, high-tech manufacturing exports, patents and R&D per employee. Each of these presents problems. For example, high-tech products can be manufactured and assembled by multinational companies in countries with little scientific infrastructure. Nothing more than a moderately educated labour force, incentives and good management are necessary.

Figure 4 shows the US trade balance for high-tech goods. The swing from a surplus for the USA to a large deficit over the period from the mid-1990s to the present occurred in spite of the USA's lead in technology during this period. Competitive considerations led to less expensive offshore manufacturing strategies, with China being the preferred host country, followed by India.

The GERD/GDP ratio tends to fluctuate in the USA between 2.5% and 3%, depending on the relative growth of R&D and GDP. Most large industrialized countries have similar ratios. The ratio for non-federal R&D has steadily increased since 1953, from about 0.7% to about 2%, a healthy indicator of the technological intensity of industry.

Figure 4: Trade balance for high-tech goods in the USA, 1995–2008
Other countries and regions are given for comparison



Notes: Here, the European Union excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta and Slovenia. China includes Hong Kong.

Source: National Science Board (2010) *Science and Engineering Indicators*

Table 3: Funding of industrial R&D in the USA by major industry, 2003, 2005 and 2007
US$ millions

	All R&D			**Federal R&D**		
	2003	**2005**	**2007**	**2003**	**2005**	**2007**
All industries	200 724	226 159	269 267	17 798	21 909	26 585
Manufacturing industries	120 858	158 190	187 477	13 133	15 635	18 170
Non-manufacturing industries	79 866	67 969	81 790	4665	6 274	8 415
Chemicals	23 001	42 995	46 329*	307	169	211*
Machinery	6 304	8 531	9 865	80	109	69
Computers and electronic products	39 001	48 296*	58 599	6 506	8 522*	8 838
Aerospace products and parts	13 205	15 005	18 436	5 356	4 076	5 040
Software x		16 926	*	x	33	*
Professional/S&T services, including R&D services	27 967	32 021	40 533	4 237	5 839	7 608

X = data for 2003 and 2004 have been suppressed by the source to prevent disclosure of confidential information.
* data are for 2006 because the data for 2005 or 2007 have been suppressed by the source to prevent disclosure of confidential information.
If no data at all are given, this means the data for 2006 have also been suppressed.

Source: National Science Board (2010) *Science and Engineering Indicators*

One commonly used measure is the R&D/net sales ratio. This ratio in the USA currently hovers around 3.7% for those companies doing R&D (Table 3). There is a huge difference in this ratio from one industry to another, with the R&D/net sales ratio for software and Internet being 10 times that of chemicals and energy. Within particular industries, large companies tend to have higher ratios than small ones.

Multinational companies

Multinational companies are among the largest investors in R&D (Table 4). Of the 19 that spend more that US$4 billion on R&D annually, seven are headquartered in the USA (namely, Microsoft, Pfizer, Ford, General Motors, IBM, Johnson and Johnson, and Intel, whose total R&D expenditure in 2004 totalled US$45.1 billion), four in Japan, three in Germany, two in Switzerland and one each in Finland, the Republic of Korea and the UK. The R&D/net sales ratio for larger multinational companies tends to be higher than that for smaller (though still large) companies, replicating the distribution pattern for US companies.

US multinationals comprise US parent companies and their foreign affiliates. Like most multinationals, US multinationals conduct research in many of the countries in which they do business. The reasons for this often relate to designing products and services for local markets or adapting them to local markets. Over the past decade, about 85% of the combined global R&D expenditure by US multinationals has been spent at home. Foreign affiliates' R&D expenditure grew at a faster rate than US parents and the share of foreign affiliates' R&D expenditure within US multinationals rose one-third. Perhaps more important are changes in the geographical distribution of this expenditure (Figure 5).

Company R&D			Company R&D/ sales ratio (%)		
2003	2005	2007	2003	2005	2007
182 926	204 250	242 682	3.2	3.3	3.5
107 725	142 555	169 307	3.1	3.6	3.7
75 201	61 695	73 375	3.3	2.0	0.9
22 693	42 826	55 319	5.6	6.9	7.9
6224	8 422	9 796	4.2	3.6	3.7
32 495	42 463	49 760	9.3	9.0	8.4
7 849	10 928	13 397	3.5	4.8	5.1
15 095	16 893	19 634	23.4	21.9	19.6
23 730	26 181	32 924	10.2	10.0	9.5

Trends in technology trade

The balance of trade in technology is one measure that has been receiving substantial attention in recent years. 'Trade in technology' means trade in intellectual property measured by the payment of royalties and licensing fees. Figure 6 shows the continuing strength of the USA by this measure. The USA maintains an impressive trade surplus in intellectual property. Not all of this trade in intellectual property is 'technology' in the usual sense of understanding by scientists and engineers, and the majority of the trade takes place between affiliated companies. It does, however, provide a stable and somewhat intellectually defendable marker for national technological strength over time.

The services sector has grown faster than manufacturing for at least two decades and is driving economic activity around the world. The World Bank estimates that services accounted for 56% of the global economy in 1980 as opposed to 68% in 2003. Knowledge-intensive services are both high-tech-oriented and market-oriented. They more than doubled from 1986 to 2005, from US$4.5 trillion to US$11.5 trillion in constant dollars, growing at an inflation-adjusted rate of 4.8%, compared with 2.7% for other services during this period.

Service-sector R&D has also grown rapidly. Although this growth is impressive, the manufacturing sector is still more technologically intensive than the services sector.

An R&D crisis in 'big pharma'

The large pharmaceutical companies, almost all of which are multinational, have been among the biggest spenders on R&D. In response to these large infusions of research funding, they have in the past produced a steady stream of 'blockbuster' drugs. By keeping a stream of new pharmaceuticals in the pipeline, they have assured investors of greater profits, in spite of the very large investments required in clinical trials and other costs incurred in bringing new products to market.

In recent years, this business plan appears to have ceased working effectively. The money has continued to pour into

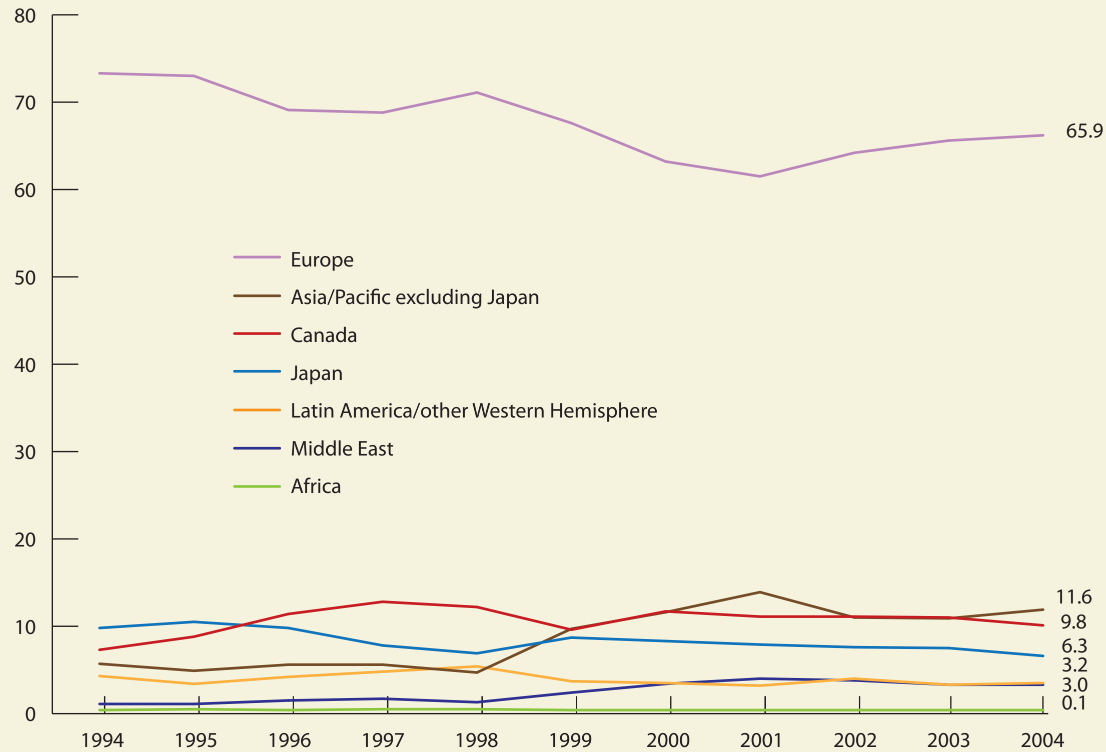
Table 4: Top R&D spending corporations, 2003 and 2004

	R&D rank		R&D expense ($ millions)			Sales ($ millions)		R&D intensity (%)	
Company (country)	**2004**	**2003**	**2004**	**2003**	**Change (%)**	**2004**	**2003**	**2004**	**2003**
Ford Motor (USA)	1	2	7 400	7 500	–1.3	171 652	164 196	4.3	4.6
DaimlerChrysler (Germany)	2	4	7 187	7 076	1.6	180 448	173 307	4.0	4.1
Toyota Motor (Japan)	3	6	7 052	6 372	10.7	173 254	161 517	4.1	3.9
Pfizer (USA)	4	3	6 613	7 131	–7.3	52 516	45 188	12.6	15.8
General Motors (USA)	5	7	6 500	5 700	14.0	190 812	182 005	3.4	3.1
Siemens (Germany)	6	5	6 431	6 436	–0.1	95 480	94 293	6.7	6.8
Microsoft (USA)	7	1	6 184	7 779	–20.5	39 788	36 835	15.5	21.1
Matsushita Electric Industrial (Japan)	8	8	5 748	5 409	6.3	81 377	69 854	7.1	7.7
GlaxoSmithKline (UK)	9	9	5 251	5 162	1.7	37 655	39 656	13.9	13.0
Johnson & Johnson (USA)	10	13	5 203	4 684	11.1	47 348	41 862	11.0	11.2
International Business Machines (USA)	11	10	5 167	5 068	2.0	96 293	89 131	5.4	5.7
Volkswagen (Germany)	12	14	4 823	4 479	7.7	113 004	110 705	4.3	4.0
Intel (USA)	13	15	4 778	4 360	9.6	34 209	30 141	14.0	14.5
Nokia (Finland)	14	12	4 742	4 776	–0.7	37 176	37 415	12.8	12.8
Sony (Japan)	15	11	4 688	4 805	–2.4	66 864	70 009	7.0	6.9
Samsung Electronics (Rep. of Korea)	16	25	4 529	3 337	35.7	77 494	61 284	5.8	5.4
Honda Motor (Japan)	17	16	4 368	4 193	4.2	80 784	76 231	5.4	5.5
Novartis (Switzerland)	18	20	4 207	3 756	12.0	28 247	24 864	14.9	15.1
Roche Holding (Switzerland)	19	17	4 192	3 925	6.8	25 742	25 698	16.3	15.3
Merck (USA)	20	29	3 885	3 178	22.2	23 430	22 486	16.6	14.1
AstraZeneca (UK)	21	23	3 803	3 451	10.2	21 426	18 849	17.7	18.3
Nissan Motor (Japan)	22	28	3 718	3 309	12.4	80 094	69 382	4.6	4.8
Robert Bosch (Germany)	23	24	3 681	3 366	9.4	50 818	46 182	7.2	7.3
Hitachi (Japan)	24	22	3 630	3 472	4.5	84 304	80 619	4.3	4.3
Hewlett-Packard (USA)	25	21	3 506	3 652	–4.0	79 905	73 061	4.4	5.0

UK = United Kingdom

Source: Institute of Electronics and Electronics Engineers (IEEE), IEEE Spectrum Top 100 R&D Spenders, Standard & Poor's data (2005), http://www.spectrum.ieee.org/dec05/2395, accessed 24 April 2007;. National Science Board (2008) *Science and Engineering Indicators 2008*

Figure 5: Regional shares of R&D performed abroad by foreign affiliates of US multinationals, 1994–2004 (%)



Note: Data for majority-owned affiliates. Preliminary estimates for 2004.

Source: Bureau of Economic Analysis, Survey of US Direct Investment Abroad (annual series). See appendix table 4-45; National Science Board (2008) *Science and Engineering Indicators 2008*

R&D but the new blockbusters have not come out the other end. This came to a head in early 2009 when the drug-maker Pfizer laid off 800 researchers. This admission that results had not kept up with the billions of R&D dollars being invested sent shivers through the industry and the wider biomedical research community.

The case of the rising pharmaceutical industry in India provides an interesting contrast (*see page* 368). Biocon, a leading Indian pharmaceutical company headquartered in Bangalore, has yet to produce a product with its label for sale anywhere in the world – even in India – although it may soon market a drug for treating diabetes which can be administered orally. Rather, the company has developed critical enzymes that it sells or licenses to large pharmaceutical concerns. Biocon also arranges, in India, for clinical trials of new drugs and has received approval to do so from the US Food and Drug Administration.

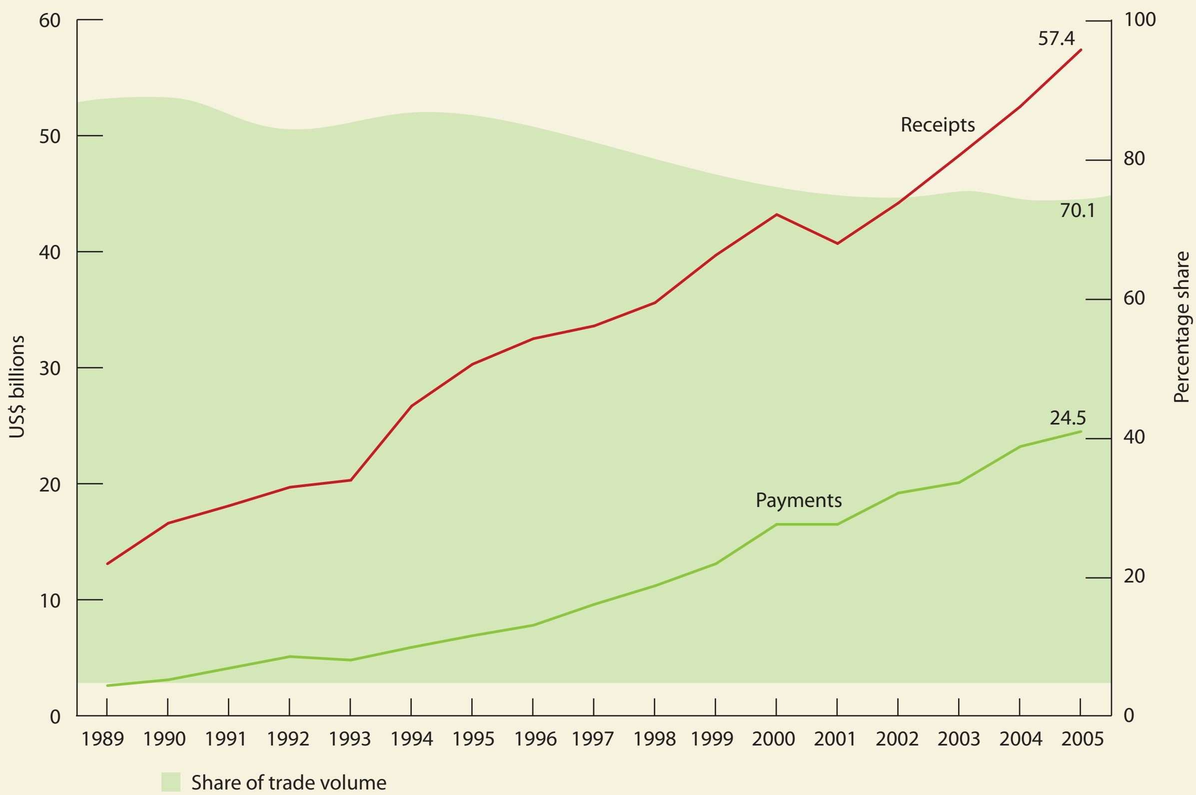
OTHER FUNDERS AND PERFORMERS

Uncertain times for state funding of university research

The approximately US$ 18.0 billion (4.9%) of total US GERD not generated in 2006 by either industry or the federal government was accounted for mainly by colleges and universities from their own funds (US$ 9.9 billion) and non-profit organizations other than colleges and universities (US$ 8.1 billion).

By far the largest fraction of the research funds expended by colleges and universities from their own funds in 2006 came from either directed grants from state governments or from general funds allocated from those same sources. State government budgets suffered considerably because of the economic downturn starting in December 2007. Unlike the federal government, many states cannot run

Figure 6: US trade receipts and payments for intellectual property, 1989–2005



Source: Bureau of Economic Analysis, Survey of Current Business 86(10):50–54 (2006). See appendix table 6-22; National Science Board (2008) *Science and Engineering Indicators 2008*

deficits, as they are obliged to balance their budgets from year to year. One result has been that state support for education at all levels has been subject to often severe budget cuts. In the case of state universities, these cuts involve their research as well as their instructional budgets. State governments provide negligible support to private universities.

States differ considerably in terms of the amount of R&D performed within their borders by universities, industry and federal government facilities, including FFRDCs. Virtually all of these activities are funded by industry or by the federal government. In 2005, 59% of total US R&D was performed in 10 of the country's 50 states. California alone accounted for approximately one-fifth of all US R&D that year. Federal R&D accounted for 85% of R&D in New Mexico, the state in which the two largest FFRDCs in terms of performance are located: the Los Alamos National Laboratory and the Sandia National Laboratory.

Non-profit bodies leaning towards basic and applied research

In 2006, non-profit institutions other than universities and colleges invested approximately US$8.1 billion in R&D, with virtually the entire amount being devoted to basic and applied research rather than development. Between 1986 and 2005, R&D funding from the academic and non-profit sectors grew at an annual rate of almost 6%, greater than that of either the industrial or federal sectors, although it declined slightly between 2005 and 2006.

Non-profit organizations in the USA both fund and perform research, although typically each such body emphasizes one or the other of these functions. Non-profit organizations depend heavily upon endowments, which contracted considerably with the economic downturn that became apparent during 2008. This has obliged non-profit organizations to reduce the level of their activities for the duration of the crisis.

Two examples of non-profit organizations are the Carnegie Institution and the Howard Hughes Medical Institute. We shall not dwell on the former, as it has already been profiled in the *UNESCO Science Report 2005*. We could say a few words about the Howard Hughes Medical Institute, though. It was founded in 1953 by the aviator and industrialist of the same name. The institute is headquartered in Chevy Chase in the State of Maryland and has an endowment of US$18.7 billion. It typically commits almost US$700 million per year to biomedical research through a competitive grants programme. Currently, its 300 investigators are located in 64 universities, research institutes, medical schools and affiliated hospitals. The institute also distributes more than US$80 million annually for science education.

TRENDS IN THE UNIVERSITY SYSTEM

Since the end of the Second World War, US universities have moved from the periphery of the nation's research system to a position at its vital centre. Although, in 2006, they performed only about 14% of national R&D in dollar terms, they performed 57% of the country's basic research. This function has become increasingly important as industry has largely abandoned in-house basic research in favour of more focused, short-term applied R&D offering a more rapid return on investment (Box 2 and Figure 7).

Between 1995 and 2002, the number of patents granted to universities increased substantially, as did the royalty income derived from licensing those patents. Patents peaked at just under 3 300 in 2002 before declining to about 2 700 in 2005. However, the median net royalties from university-held patents grew from approximately US$600 000 in 2002 to over US$900 000 in 2005. Even though these amounts are small compared to the total US$47.8 billion in R&D performed by universities in 2006, these data indicate that an increasing fraction of university research is potentially available for exploitation by industry. At the same time, universities are at least equally important as the source of new generations of scientists and engineers. Some critics contend that they may be neglecting their teaching function in favour of research, particularly in disciplines that have a reasonable potential for commercial development.

When university–industry research partnerships emerged during the late 1970s, considerable concern was expressed that universities could become 'job shops' for industry. These concerns have not materialized, although a few lesser universities may have followed this course. Disputes between universities and industrial partners over the shares of income derived from their research collaborations are rare, primarily because contracts detailing these and other essential matters are negotiated in advance.

One area where concern does seem to be growing in the USA, especially among journal publishers, is the risk of a conflict of interest between scientific researchers and private industry affecting the results of some research (Box 3).

The essential role of research universities

The bulk of academic research and advanced teaching at graduate level are carried out by a relatively small number of US universities. According to the Carnegie Foundation for the Advancement of Teaching, there are currently approximately 3 400 degree-granting institutions in the USA serving approximately 14.5 million students. Among these, 127 are classified as research universities by the foundation, defined as being institutions that offer a full range of baccalaureate and graduate programmes and obtain more than US$15.5 million annually in federal grants. Ranked in order of their R&D performance, the top 100 US universities account for 80% of all such expenditure and the top 200 for 96%.

The impact of the economic recession on universities

In 2006, the total budget for university R&D amounted to US$47.8 billion. The federal government financed two-thirds of this and industry a little less than one-fifth. The great majority of university R&D was devoted to basic research (Figure 8).

The economic recession has had an impact on all US institutions of higher education, research universities included. Private universities depend on income from their endowments to support both their research and instructional activities. The value of these endowments, and therefore the income from them, have decreased markedly since 2007. For example, the income on endowments of Harvard and Yale have decreased by approximately 25%, or approximately US$50 million, obliging these universities to cut back on their research and teaching programmes.

Typically, the research of new faculty members is supported for up to two years by their universities until they succeed in

Box 2: Basic research: a cornerstone of US science policy for 65 years

Support for basic research has been a cornerstone of US science policy ever since 1945, when Vannevar Bush presented his influential report, entitled *Science – the Endless Frontier*, to President Harry Truman. In his report, Bush argued that the federal government not only had the authority but also the obligation to support research – particularly basic research – in universities and other non-profit organizations.

The importance of federal investment in basic research has long ceased to be a politically contentious issue. Federal investment in basic research has been supported by both the Republican and Democratic presidential administrations for decades. Both political parties in Congress have upheld this position, the only issues in dispute being the level of support and its distribution among agencies, programmes and disciplines. Some disagreements among the two parties have also arisen over the appropriateness of federal support for some pre-competitive R&D in industry. This disagreement concerns R&D that lies on the boundary between research and commercial development, resulting in what are sometimes called 'generic or enabling technologies', such as combustion and corrosion. There are also serious disagreements about a proposal to build a space base on the Moon or to undertake an inhabited mission to Mars.

Prior to the Second World War, the federal government provided almost no support for basic research in universities and performed little or no basic research in its own laboratories. Research in private universities was supported from their endowments and by private companies and philanthropic organizations. Research in state universities was also supported, in part, by the governments of their respective states. Thanks in large measure to the arguments presented in *Science – the Endless Frontier*, this situation began to change so that, by 1953, the first year in which consistent data were gathered, the federal government became – and has remained ever since – the principal supporter of basic research (Figure 7).

Source: authors

Figure 7: Basic research in the USA by performing sector and source of funds, 2007 (%)

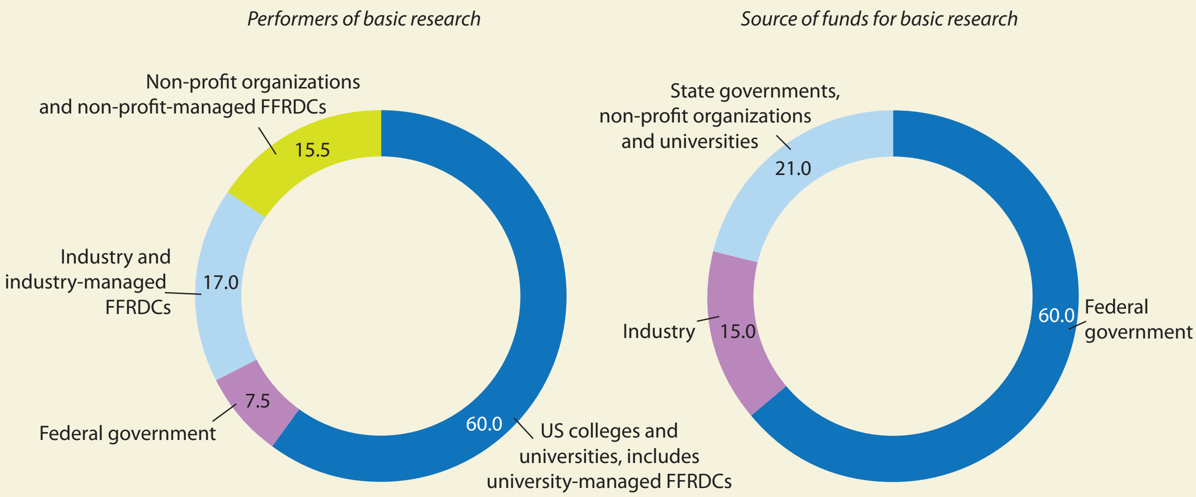
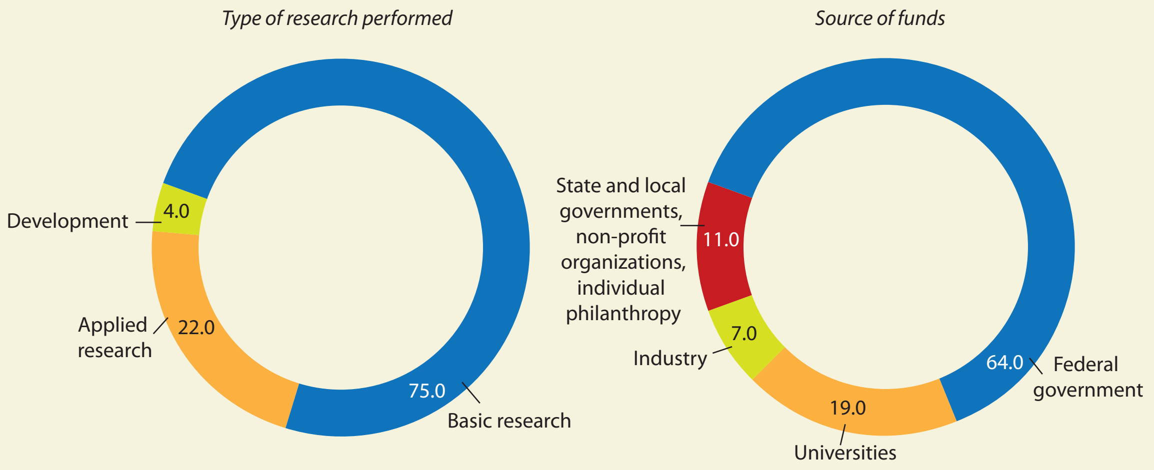


Figure 8: University R&D in the USA by type of research and source of funds, 2006 (%)



Note: percentages may not add up to 100% because of rounding

Source: National Science Foundation

winning external research grants. But universities can no longer afford to be quite so generous. Innovative instructional programmes are also being scaled back, as are funds for undergraduate scholarships. In the case of state universities, significant budget reductions have been the order of the day for their institutions of higher learning, with the effects of such cutbacks being comparable to the reduced endowment income of private universities, as state governments struggle to balance their budgets – unlike the federal government, state governments must balance their budgets annually.

Although state universities, like private universities, support the large majority of their research on federal grants and, to a lesser extent, on grants from non-profit organizations, they also depend heavily upon state government appropriations. State governments themselves are suffering from a sheer drop in revenue receipts from unemployed and underemployed residents who are now paying less income tax than previously.

Some of these austerity measures may be offset by additional federal funding from the very large federal economic stimulus programme.

Growing competition for research universities

By several yardsticks, US research universities qualify as the world's best in science and engineering, taken collectively. For example, in 2006, approximately 44% of the approximately 890 000 S&T articles published in journals around the world listed by Thomson Reuters, source of the Science Citation Index (SCI), involved at least one US author. Of the latter, 74% were from academia.

US research universities remain the destination of choice for many foreign graduate students. Since 2003, the Shanghai Jiao Tong University's Institute of Higher Education has ranked the world's top 500 universities in terms of the quality of their teaching and research. American universities have consistently dominated the upper tier of these annual rankings since they were first published. Of the top 25 institutions ranked in 2008, 19 were American. The others were the Universities of Cambridge (4th), Oxford (10th), Tokyo (19th) and Kyoto (23rd), as well as the Swiss Federal Institute and Toronto University, which tied for 24th place.

That a Chinese organization should have decided to carry out exhaustive periodic surveys to rank the world's leading universities may itself suggest that Chinese universities intend to become internationally competitive. One possible indicator of this intention is that Tsinghua University in Beijing seems to have reached its goal of offering 50% of all its graduate courses in English by 2008. Not only does this reflect the university's desire to guarantee that its doctoral recipients are proficient in English; it also signals Tsinghua's intention of attracting significant numbers of foreign students.

Box 3: Growing concern about conflict of interest in scientific journals

Academic institutions in many countries have responded to declining public funding in recent years by developing research collaborations with private industry. This has helped to boost the revenue of universities and given a more commercial flavour to academic research conducted within these public–private partnerships.

The publishers of some scientific and medical journals in the USA are becoming increasingly concerned, however, that 'the conduct of science can be influenced by biases introduced by conflicts of interest between scientific investigators and private industry' (Goozner *et al.*, 2009).

'One consequence of these proliferating industry–academic collaborations,' observes the Associate Editor-in-Chief of the US journal *Addiction*, Thomas Babor of the University of Connecticut Health Center, 'has been the creation of real as well as apparent conflicts of interest, particularly in the case of "dangerous consumption industries," such as alcohol, tobacco and gambling' (Babor, 2009).

'Conflicts of interest have also been prominent in cases where financial interests have compromised patient care,' he says, such 'as when the negative side effects of experimental drugs become known only after they have been rushed to market without appropriate scientific evaluation, or when the outcomes of positive trials are published selectively, as with the selective serotonin re-uptake inhibitor antidepressants in the USA,' described by Kirsch *et al.* (2008).

Even in cases where the author of a research paper discloses the identity of his or her sponsor in the journal, this can be misleading. In one instance, a scientist writing about her research in relation to addiction to gambling duly identified her sponsor as being a research centre within a respected US university. It turned out that the centre was funded by a private foundation which was itself funded by … casinos in the country's gambling capital, the city of Las Vegas!

Goozner *et al.* (2009) propose model guidelines for scientific and medical journals to adopt to ensure the disclosure of conflict of interest by authors writing in their journals. They write that 'organizations are paying greater attention to conflict of interest disclosure' in the context of redefining the rules of engagement between academic investigators and private industry. 'The need for common standards in defining conflicts of interest has never been greater,' they add.

According to Babor, the common standard 'should apply to the complex and growing financial arrangements that have developed in recent years between vested interests and independent scientists.' It should also apply to situations where a particular author has strong non-financial interests that the reader of his or her scholarly work should want to know about in order to judge the meaning and value of a particular publication. Finally, the policy should be consistent across journals in a field of study in order to prevent some authors and their sponsors from gaming the system.'

Source: Babor (2009); Goozner *et al.* (2009)

Despite their high quality, US research universities face growing international competition. In 2002, the USA produced 30.9% of the world's articles in science and engineering, authorship being dominated by academia. This compared with a neat 10.0% for Japan and 84.0% for all OECD countries. Comparable percentages for 2008 were 27.7%, 7.6% and 76.4%. China exhibited the most striking increase in its share of the world's natural science and engineering articles, rising from 5.2% in 2002 to 10.6% in 2008 (*see page* 10).

A growing fragmentation of research universities

One problem facing US research universities is a consequence of their phenomenal success. As research has advanced, it has become increasingly specialized. Consequently, many university departments whose faculties conducted research in a number of sub-specialties have fragmented into independent departments, each devoted to one of these sub-specialties. This is perceived by many as being problematic, since it dilutes the fundamental role of research universities as institutions for the discovery and transmission of fundamental knowledge. Moreover, many universities that were once primarily institutions within a core college of arts and sciences plus a few professional schools, such as law and medicine, now include less 'academic' schools devoted to what are considered more 'practical' curricula such as finance and marketing. While in itself, this may not be a problem, it has led to further fragmentation of research universities.

A resistant glass ceiling

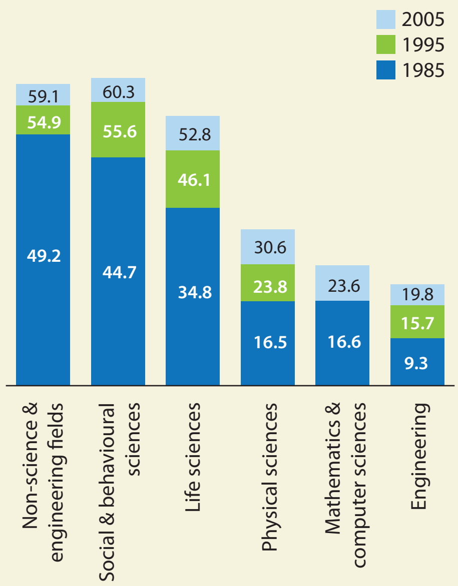
For the past three decades, the National Science Foundation (NSF) and other federal agencies have mounted major programmes in concert with professional science and engineering societies to convince more women and ethnic minorities to seek careers in science and engineering.

However, there is indisputable evidence that many of these talented female and ethnic minority PhDs continue to encounter the proverbial 'glass ceiling' as they attempt to advance in the conservative, slow-to-change academic hierarchy (Figures 9 and 10).

A vulnerable university environment

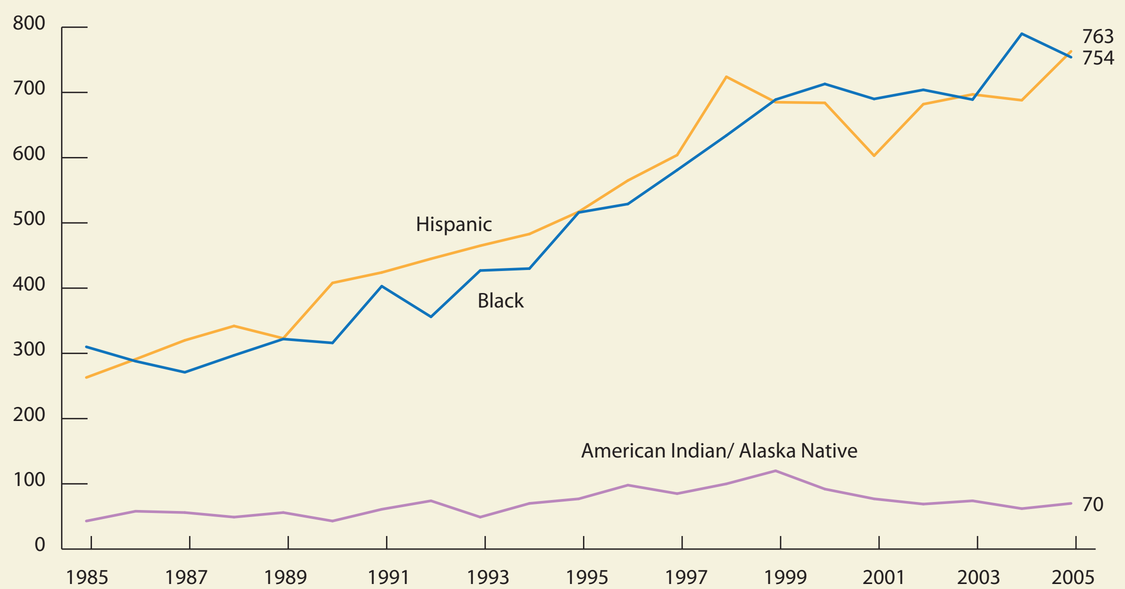
A problem unique to research universities supported by state governments, as opposed to private universities, is the dependence of their budgets on the changing whims of state governors and legislatures. Although leading state universities derive the bulk of their research budgets from federal grants, funding from state governments remains the bedrock of their research and teaching programmes. While one state governor and state legislature may recognize the importance of the research and educational offerings of their university, their successors –faced with budget deficits – may

Figure 9: Share of doctorates awarded to female US citizens, 1985, 1995 and 2005 (%)



Source: National Science Board (2008) *Science and Engineering Indicators*

Figure 10: Doctorates awarded to US citizens in science and engineering, by ethnic minority, 1985–2005



Source: National Science Board (2008) *Science and Engineering Indicators*. National Science Foundation, Division of Science Resources Statistics, Survey of Earned Doctorates, WebCASPAR database: http://webcaspar.nsf.gov. See appendix table 2-32.

decide that sharp reductions in university budgets can do little harm in the short run. They fail to understand that reconstituting a diminished educational institution takes many years to accomplish. This problem has become increasingly apparent during the current economic recession.

Although many, if not most, individual faculty are economic and political liberals – at least with the money of others! –research universities in the USA are fundamentally conservative institutions. When they do change, they most often do so slowly and deliberately. The evolution of American colleges into research universities proceeded slowly following the American Civil War (1861–1865). Only during the past 60 years have those universities flourished and become the core of the country's S&T system. Clearly, US research universities cannot afford to rest on their laurels or assume that the public understands and appreciates the essential role they play in the furtherance of society's fundamental goals. The quality of the research and teaching provided by East Asian universities has been rapidly improving in the past few years. Chinese universities in particular aspire to compete with universities throughout the world and above all those in the USA – and could do so with considerable success.

HUMAN RESOURCES in S&T

Characteristics of the labour force

Estimates of the size of the US science and engineering (S&E) labour force vary depending on which criteria are used to define who is a scientist or engineer: education, occupation, field of degree, field of employment and so on. In 2006, 17.0 million individuals had at least one degree in a field of science or engineering, a figure that climbed to 21.4 million if one added related fields such as health or technology.

In 2004, approximately 15 530 individuals reported they had received a science or engineering degree at the bachelor's or higher level during the previous year. Among these, approximately 5 120 (33%) were employed directly as engineers or in scientific occupations, whereas the remainder (approximately 10 400 graduates) were employed in positions not directly related to science or engineering. Among the latter, two-thirds said that their positions were at least somewhat related to their degrees, including many in management, marketing and sales.

In 2003, 59% of all degree-holders in a scientific field or engineering were employed in the for-profit sector and 13% by government, with the non-profit sector, four-year colleges and universities, other educational institutions and self-employment accounting for the balance. Among those with doctorates in a scentific field or engineering, 44% were working in four-year colleges and universities, 33% in the for-profit sector and 9% in government.

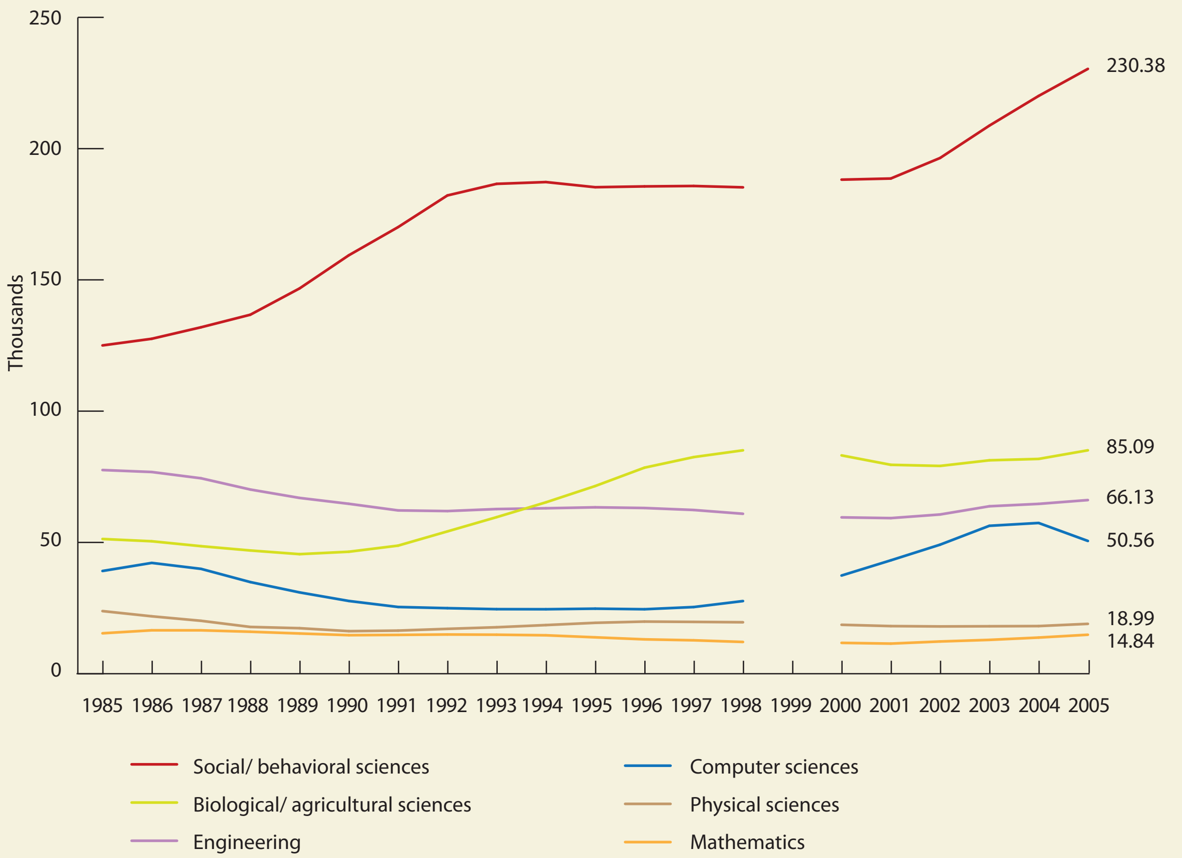
No sign of a supply crisis in higher education

Figure 11 illustrates the trends in bachelor's degrees awarded by US colleges and universities in selected science and engineering fields over a 20-year period. Figure 12 shows comparable trends for doctoral degrees awarded during the same period.

Although concerns have been voiced for well over a decade now that too few US undergraduate students are choosing to specialize in S&T fields, a major 'supply crisis' has yet to materialize. One possible legitimate ground for these concerns used to be that the university-age cohort in the US population was steadily declining. However, that trend has recently reversed. Enrollment in US institutions of higher education rose from 12.7 million in 1986 to 16.9 million in 2004. The number of individuals aged 20–24 years in the US population is expected to keep rising through 2050. However, the demographic composition of this population is expected to change, with the rise in enrollment projected to come mainly from minority groups, particularly Asians and Hispanics. The dual challenge will be to ensure that the percentage of students who elect to specialize in S&T fields remains at least constant and that the education they receive fulfils the employment requirements for at least the first half of the 21st century.

Among the 16.9 million students attending US colleges and universities in 2004, approximately 583 000 (3.5%) were enrolled in science and engineering programmes, defined as involving traditional disciplinary or interdisciplinary studies. The number of bachelor's and master's degrees awarded by US colleges and universities in science and engineering fields reached new heights in 2005 of approximately 466 000 and 120 000 respectively. All but computer science experienced increases; however, in the latter field, the number of bachelor's degrees had already increased sharply from 1998 to 2004 before

Figure 11: Bachelor's degrees earned in selected S&T fields, 1985–2005



Note: Physical sciences include Earth, atmospheric and ocean sciences. Data are not available for 1999.

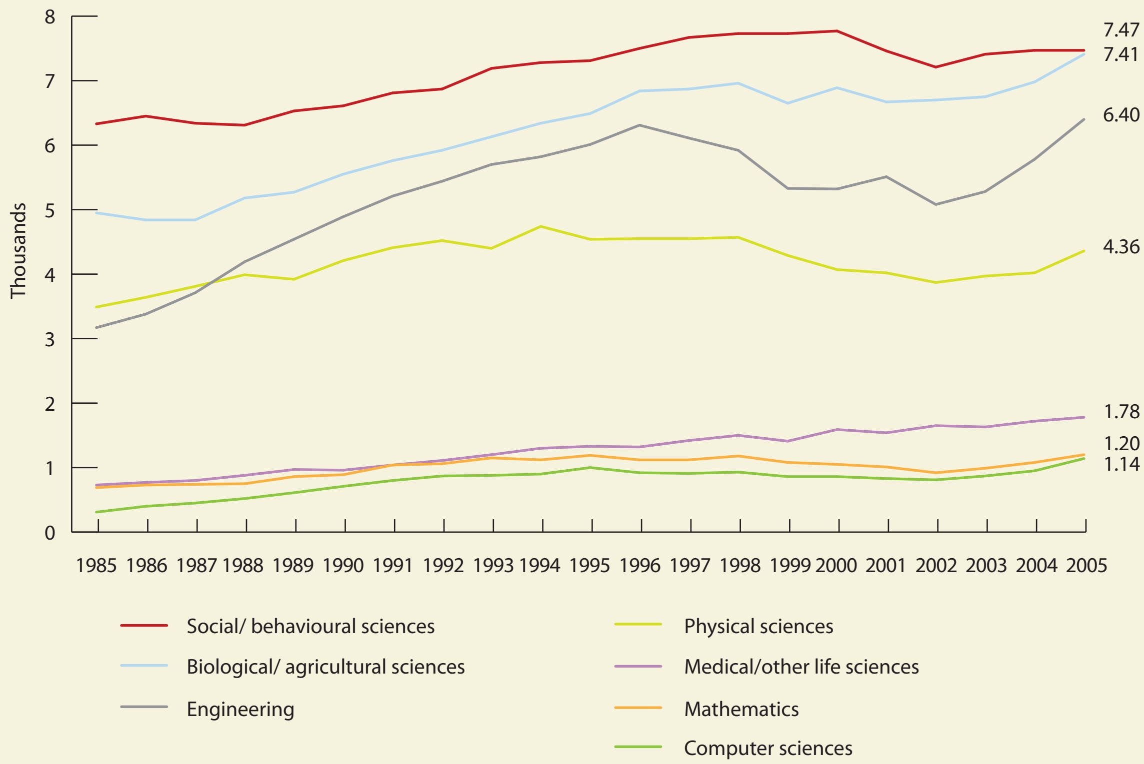
Source: National Center for Education Statistics, Integrated Postsecondary Education Data System, Completions Survey; National Science Foundation, Division of Science Resources Statistics, WebCASPAR database: http://webcaspar.nsf.gov. See appendix table 2–27; National Science Board (2008) *Science and Engineering Indicators 2008*

declining in 2005. The number of doctoral degrees awarded by US institutions of higher education also reached a new peak of almost 30 000 in 2005, the strongest growth being in engineering and in the biological and agricultural sciences. Virtually all of the growth in doctorates reflected higher numbers of temporary visa holders. These students earned 10 800 (36%) of the doctorates awarded in science and engineering in the USA in 2005, compared with 5 000 (21%) in 1985.

Foreign students most numerous in PhD programmes

Foreign students on temporary visas earn a larger proportion of their degrees at the doctoral level than at any other level. In 2005, students in this category earned 50% or more of all doctoral degrees awarded in the USA in mathematics, computer sciences, physics and engineering. Proportions were considerably lower in other scientific fields: just 26% in the biological sciences, for example, and 22% in medical sciences and other life sciences. Between 1985 and 2005, all but two of the top 10 countries sending doctoral candidates in science and engineering to the USA were in Asia, with Canada and Mexico being the two exceptions. During this 20-year period, students from China, Chinese Taipei, India and the Republic of Korea earned more than half of all doctorates in S&T fields awarded in the USA to students from foreign countries. In 2005, 3500 of these doctorates went to Chinese nationals, followed by 1 250 Indians and an approximately equal number of Koreans.

Figure 12: Doctoral degrees earned in the USA in selected S&T fields, 1985–2005



Notes: Physical sciences include Earth, atmospheric and ocean sciences.

Source: National Science Foundation, Division of Science Resources Statistics, Survey of Earned Doctorates, WebCASPAR database: http://webcaspar.nsf.gov. See appendix table 2-31; National Science Board (2008) *Science and Engineering Indicators 2008*

Between 1985 and 2004, the number of doctoral degrees awarded by Chinese universities rose from close to zero to approximately 14 000, compared to the slightly more than 20 000 awarded in the USA. This means that China has now become the world's second-largest producer of PhDs in science and engineering, followed by Germany, the UK, Japan and the Republic of Korea. This trend reflects the growing quality of graduate education in China's universities. Enrollment in engineering has grown less rapidly than in other fields, however, reflecting burgeoning opportunities in business, education and law. In 1994, 46% of bachelor's degrees were in engineering. By 2004, that proportion had dropped to 37%.

Foreign enrollment in US graduate schools continues to be substantial, particularly as concerns Asian students. In 2005, foreign students who had passed their university entrance exam for the bachelor's degree outside the USA accounted for 60% of all students enrolled in PhD programmes in engineering at American universities, 38% of those enrolled in natural sciences and 21% of those enrolled in the behavioural and social sciences. France and the UK continue to compete with the USA for foreign students and, in recent years, Australia and Japan have joined the fray, with relative success in attracting students from Asia.

Of the approximately 3.4 million immigrant scientists and engineers now working in the USA, approximately 30% originally came to study. In 2005, somewhat more than 70% had plans to stay once they completed their degree and 50% had firm offers of employment. Between 2002 and 2005, more than 90% of Chinese recipients of a US doctorate in science or engineering reported plans to stay in the USA and 60% that they had accepted firm offers for employment or postdoctoral research positions. The figures for Indian recipients of a US doctorate were similar: 88% and 63%.

CHANGING TOOLS IN R&D MANAGEMENT

Deciding on the amount and distribution of R&D funds, be it in government or industry, is the easy part of management. Measuring output is much harder but even that is not as hard as ensuring an adequate output. To be successful in managing R&D, you need the right tools and the ability to apply these deftly.

If you are in government, you are going to use very different R&D management tools from those used in industrial R&D. Whereas the former seeks a maximum social return, the latter is looking for a maximum (mainly short-term) economic return on investment for stockholders or other owners. Accountability is thus not the same in government and industry. This is made more complex by the difficulty in measuring return on anything other than very short-term development efforts.

New government tools

The US government has recognized the difficulty in measuring the effectiveness of government investment in basic research and both mathematics and science education. Some years ago, in the midst of efforts to hold federal agencies more accountable for their expenditure, the Government Performance and Results Act of 1993 (GPRA) was enacted. Applying this to basic research programmes, such as those supported by the NSF, proved extremely challenging. The result was the development of a measurement metric quite different from the usual GPRA approach and the establishment in 2002 of an NSF Advisory Committee for GPRA Performance Assessment. This committee provides advice and recommendations to the NSF director regarding NSF's performance under the GPRA.

The GPRA as applied to the NSF focuses on demonstrating significant achievement for four long-term qualitative and strategic goals. These are: discovery; learning; research infrastructure; and stewardship. Admittedly, it is very difficult to quantify progress towards these broad goals.

The committee's report of 31 July 2008 commends NSF for meeting its goals and for implementing some of the committee's recommendations from the previous year. In this review, the committee randomly selected 'highlights' NSF submitted from its programme which were evaluated against stated criteria. The bottom line is that, over time, this evaluative process has been effective in assessing and improving the quality of the NSF research portfolio.

New tools for industrial R&D

Industrial R&D marches to a very different drummer. As noted above, the time-frame is much more immediate. This is true for several reasons. For one thing, the discount rate means that results recognized in the medium to long term are worth less than short-term results. Another is that intellectual property is more difficult to define and protect as one moves further into the future. One characteristic common to both industrial and government-supported research is the need for excellent human resources. Good people are indeed necessary but not a sufficient condition for success in R&D.

Industrial R&D managers use a variety of tools to maximize the return on R&D investment. These tools include recruiting and retaining excellent staff who are team players, recognizing the importance of intellectual property and being amenable to rapid changes in order to meet customer needs and adapt to new technology platforms and organizational realignments.

Obtaining knowledge required for the development of new products and processes is a key objective of companies. The classic 'make or buy' options are now more complex.

Knowledge feeds the innovation process. Although the best knowledge (technology in many cases) may be available, it may not be enough in itself to spur innovation. Innovation requires vision, acceptance of new ideas, risk-taking and an understanding of markets. It often involves teams of scientists, engineers and marketers and the ability to support networks within the organization or company that utilizes a common language understood by scientists and sales personnel alike.

How have things changed? Charles Larson, president-emeritus of the Industrial Research Institute, recently compared effectiveness of industrial R&D now and 10 years ago. He concluded that things had not changed as much as expected. Researchers are more business-oriented today but are not taking more risks.

Technology intelligence, although important, is less so than projected a decade ago. Information technology has had less of an impact than expected. Teams are the norm. Management remains a challenge and the innovation system is not yet integrated adequately in many, if not most, companies.

'Spend wisely' for R&D effectiveness

A raft of studies over several decades have indicated that greater R&D spending results in better sales and profit margins. The market has translated this indication into higher stock prices for the benefit of the company's stockholders. In his 1987 Nobel Prize Lecture, economist Robert Solow alluded to the 'growth accounting' work of the late Edward Denison. Solow stated that 'gross output per hour of work in the US economy doubled between 1909 and 1949; and some seven-eighths of that increase could be attributed to "technical change in the broadest sense"… [I]n the thirty years since then … [t]he main refinement has been to unpack "technical progress in the broadest sense" into a number of constituents of which various human-capital variables and "technological change in the narrow sense" are the most important. … 34 % of recorded growth is credited to "the growth of knowledge" or "technological progress in the narrow sense"'.

Over the last generation, companies have changed their approach to R&D. Time horizons have been shortened. Intellectual property is vigorously protected. Knowledge needed for innovation is obtained in the cheapest way possible.

Some analyses in recent years have found little or no correlation between R&D spending, on the one hand, and the growth in sales, earnings or shareholder returns for the company on the other. These results imply that just putting more money into R&D does not ensure an economic advantage. These same studies show that companies which 'under-spend' by investing substantially less in R&D than their competitors do poorly. The answer to this conundrum appears to be 'spend wisely'. This means using all R&D management tools available in the toolbox and using them cleverly. This is a tall order. Companies, at least before the current recession, tended to ignore these correlations and were tempted merely to accelerate their spending on R&D in an effort to become more competitive.

INTERNATIONAL SCIENTIFIC CO-OPERATION – AND COMPETITION

On a global scale, we are seeing both growing co-operation and competition in R&D. This holds true for industry but also for academia and government research installations. The importance of international co-operation for science throughout the world was emphasized at the Fourth World Science Forum in Budapest, Hungary, on 10 November 2009, also World Science Day.

International co-authorship

International co-operation has long been regarded as an essential aspect of non-proprietary research, particularly when it comes to basic research. The rise of the Internet has galvanized co-operation in cross-border academic research, especially that between individual investigators and their institutions. In 2005, approximately 27% of SCI papers published by scientists and engineers working in US institutions had at least one co-author from a non-US institution, compared with approximately 17% in 1995. This varied among scientific disciplines. For example, in astronomy, 58% of all US papers had foreign co-authors in 2005, compared with 42% in 1995; the share of co-authored papers in physics was 38% in 2005, up from 28% in 1995, whereas 33% of those in the geosciences were co-authored in 2005, up from 28% in 1995.

Trends in co-operation in small science and megascience

The past decade has seen an atrophy of formal, government-to-government research co-operation protocols and an increase in projects between individuals. Today, the role of governments in small science is to provide a policy framework that encourages such co-operation, including the provision of financial support. The Internet has served as an enabler of this dispersed co-operation. Without the speed and ease of communication and the virtually unlimited data available on the web, co-operation in small science would be a much more modest affair. This burgeoning collaboration is reflected in the scientific literature.

Megascience projects predominantly concern basic research involving very expensive central facilities or large, distributed research programmes spread over many geographical locations. Megascience projects are often too costly for any one country to fund and execute.

They need greater involvement by governments and the institutions of organized science. The USA took the lead in establishing the OECD Megascience Forum in 1992, now the OECD Global Science Forum.

Like Japan, the USA also supports the European-led Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland, where collisions between protons and anti-protons at higher energies than ever achieved before will permit the recreation of conditions prevailing in the early Universe. After the LHC came through its first operational tests with flying colours in September 2008, it was anticipated that experiments could begin by mid-2009. However, an unfortunate malfunction of one of its critical elements threatened to delay this promising *début*. The LHC was repaired, however, and restarted in November 2009.

The USA is also a participant in the International Thermonuclear Experimental Reactor (ITER) now under construction in the south of France (*see page* 158). ITER is the largest, most ambitious international collaborative scientific project ever conceived and implemented. Unfortunately, due to inaction by Congress, the USA was unable to meet its commitment to the project in 2008. Whereas many other countries make multi-year commitments to co-operative projects, US commitments are often held hostage to the country's annual budget process. This shortcoming in the US policy framework is long-standing and may be insoluble.

Research alliances, outsourcing and offshoring

Industrial R&D continues its drive for greater efficiency. This means quicker results that are closer-coupled to business strategy. Hundreds of new alliances in technology or research are formed each year by companies in areas such as information technology (IT), biotechnology, advanced materials and automotive technology. Not surprisingly, the majority of such alliances involve companies headquartered in the USA, Western Europe and Japan. It is not uncommon for companies to co-operate closely in developing technology in one line of business or in one geographical market, while competing fiercely with another. The common goal is to develop technology-intensive products at minimum cost while preserving a market advantage wherever possible.

Alliances, partnerships and outsourcing have become more common with other companies, offshore R&D centres, federal laboratories and universities. These partnerships are not limited to peers; they increasingly involve customers, to ensure the products developed are what customers want. Accessing, co-ordinating and moving this knowledge results in investments in IT.

Perhaps the strongest trend in R&D management relates to 'open innovation'. 'Open innovation' has come to encompass all sorts of outsourcing and co-operative activities with government laboratories, universities and other companies. Progress is being made thanks to smarter R&D strategies but the target continues to be elusive in the face of relentless global competition.

Open innovation means that companies have evolved from a stance of 'making' the technology they use to 'buying' large portions of it. Shorter product cycles dictated by changing markets demand that innovations adhere to shorter timelines. The results of these changes have dramatically impacted the ways companies obtain technology. These changes include more outsourcing of R&D, licensing technology from other companies and universities, greater use of consortia and alliances for pre-competitive and other research, outsourcing fundamental research to universities and contracts with federal laboratories. These trends reflect attempts to invest innovation resources in a smarter way.

In part because S&T is correctly perceived to be a significant prerequisite for socio-economic development, competition among companies headquartered in different countries has become intense. Many US-based companies have moved critical components of their operations to other countries where trained human resources can be obtained more cheaply. This has created considerable controversy in the USA because of the implications for employment.

However, companies also recognize that, in order to succeed, they need to become integral to what Auerswald and Branscomb (2008) have referred to as the 'globally networked enterprise' in an article published in *Technology in Society.* To this end, companies in several industries, most prominently IT and pharmaceuticals, have established R&D centres in several countries. The most prominent of these – located primarily in China and India – do more than simply conduct R&D to adapt companies' products to local markets. Rather, their R&D aims to develop new products that can be marketed worldwide.

Comparing S&T quality and quantity internationally

Earlier sections of the present chapter referred to international comparisons of the quantity and quality of R&D and R&D institutions. Here, we shall summarize some of these rankings:

- The USA has invested more in GERD than all the other G7 countries combined for more than a decade. In 2006, its share of all such G7 expenditure was 53% of the total.

- For several years, the US GERD/GDP ratio among the G7 countries has been second only to Japan's. In 2007, the respective ratios for Japan, the USA, Germany, France and the UK were 3.4%, 2.7% 2.5%, 2.0% and 1.8%.

- The European Union is the favoured destination for R&D shares by foreign affiliates of multinational corporations, accounting for 66% in 2006, well ahead of Canada (10%) and Japan (6%).

- The US trade volume in intellectual property is by far the world's largest, accounting for 70% of the world total in 2006.

- The number of triadic patent applications[3] filed by inventors in the USA in 2003 acounted for approximately 37% of all 54 000 triadic patents filed in that year, up from 35% in 2000. In 2003, inventors in the European Union filed 28% of such applications, down from 30% in 2000. Asian (primarily Chinese, Indian, South Korean and Taiwanese) inventors filed 28% of all triadic patent applications in 2003, approximately the same percentage as in 2000.

- In 2005, the percentage of SCI publications with at least one author from an American institution exceeded that of the European Union. The USA accounted for 27% of the total, compared with 26% for the European Union. The share of publications with at at least one Asian author increased from 16% in 1995 to 19% in 2005.

- According to the annual surveys conducted by Shanghai Jiao Tong University, in 2008, 19 of the top-ranked 25 universities were American (*see page* 47).

- In 2004, the USA ranked fourth in terms of its expenditure on basic research as a fraction of GDP: 0.48%. The USA was preceded by Switzerland (0.84%), Israel (0.76%) and France (0.52%). Denmark (0.46%) and the Republic of Korea (0.44%) ranked fifth and sixth respectively. The highest ranking G7 country in addition to the USA and France was Japan, which ranked eleventh at 0.36%.

SCIENCE, TECHNOLOGY AND THE PUBLIC

A strong interest in science among the general public

Periodic surveys commissioned by the National Science Foundation for almost 30 years indicate strong and consistent public support for scientific research. For example, 70% of the approximately 2 000 respondents to surveys in 2001 and 2006 agreed that the benefits of scientific research outweighed harmful results; approximately 80% of those surveyed during both years agreed that the government should fund basic research. In 2006, approximately 60% of those surveyed said that they had visited an informal science institution, such as a museum or a zoo, during the past year, a proportion that has remained roughly constant since 1979. According to data published in *Science and Engineering Indicators 2008*, public interest in S&T elsewhere in the world, including Europe and Japan (but excluding China), is lower than in the USA.

Although the US public is largely supportive of scientific research, it generally has relatively poor factual knowledge about science. In the surveys conducted in 2001 and 2006, the mean of the correct answers to 12 factual questions was approximately 6.5. Factual knowledge is positively related to the level of formal schooling, income and the number of courses taken in science and mathematics in tertiary education. People who score well on survey questions that test for information typically learned at school also appear to know more about nanotechnology and the Earth's polar regions, topics that have not been central to the content of science education in the USA.

Surveys indicate that a reasonable fraction of respondents do pay attention to, and form definitive attitudes towards, specific science-related issues. For example, between 2005 and 2007, the percentage of Americans expressing a 'great

3. Triadic applications refers to applications to the patent offices of the USA, European Union and Japan.

deal' of worry about 'the quality of the environment' rose from 35% to 43%. While there is strong positive support for research in general, attitudes towards some specific applications are more problematic. In 2005, two-thirds of Americans said that they supported 'the use of products and processes that involve biotechnology'. Similarly, when surveys ask about medical technologies that are to be derived from stem cell research in the context of anticipated health benefits, public response is relatively positive. But technologies that involve cloning human embryos elicit strong negative responses.

Confidence in scientists

Despite the fact that only a small minority of the US public believes it is well-informed about S&T and despite misgivings about specific research applications, public confidence in the leadership of the scientific community, including in medicine, was second only to its confidence in the military in 2006 and considerably greater than its confidence in other institutions, such as organized labour, major companies and the executive and legislative branches of the US government. The only institution whose leadership approached the level of public confidence enjoyed by science and medicine was the US Supreme Court.

CONCLUSION

A cloudy future

The future of R&D in the USA is cloudy, more so than in decades. This is in no small part due to the global economic recession now upon us. Industrial research and research supported by states and endowed funds are likely to take a substantial hit, at least in the short term. They are closely coupled to the economy and financial markets, both of which were in a downward spiral in 2009. State universities are especially vulnerable to cutbacks, which were already being felt in a majority of the states in 2009.

For the short term, it appears that R&D in the USA functions like some of the toxic assets so often mentioned as a root cause of the economic crisis: future valuations are murky. Any increase in federal funding over the short term, for reasons noted below, will probably be offset by decreases in funding by states, foundations and industry, all deeply wounded by the economic recession.

The 2009 Global R&D Funding Forecast from *Battelle and R&D Magazine* was issued in December 2008. The economic recession was well-recognized by that time, although it rapidly worsened in 2009. This forecast, which uses a variety of data sources, acknowledges the uncertain economic climate, including slower sales and lower earnings. In spite of this dark cloud, the forecast is for about 2% growth in US GERD (PPP) in 2009. Given the deflationary pressures worldwide, this would probably translate into 2% or more real growth. We shall see if this is the real outcome.

As time goes by, the popularity of new and tested management tools in both the public and private sectors will increase. In industry 'open innovation' strategies appear to be growing more widespread. 'Better management' appears to have broad support both in industry and in government. This is likely to be enhanced by the government's deepening role in innovation, including its more direct funding of 'generic or enabling technologies'.

Whether these changes and the economic downturn generally will substantially shift the balance between public sector and private sector support of R&D remains to be seen. Federal support of R&D may actually increase in the short term as part of funding for an economic stimulus package. Certainly, in the short term, the balance seems likely to shift towards the public sector in general and the federal government in particular. The longer the economic recession lasts, the more likely this will be the case.

The Obama administration's plans for stimulating the economy include billions of dollars for S&T. This American Recovery and Reinvestment initiative includes both short-term economic stimuli to jump-start the economy and a longer-term component that aims to lay the groundwork for transforming the economy in the 21st century. Within an overall programme that approaches one trillion dollars, *Transforming our Economy with Science and Technology* aims to 'put scientists to work looking for the next great discovery, creating jobs in cutting-edge technologies and making smart investments that will help businesses in every community succeed in a global economy'.

The extent to which Congress – and the nation as a whole – will accept President Obama's vision of the future, particularly during the most severe economic recession in 70 years, remains to be seen. The future is both unfathomable and incredibly challenging.

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Dr Ratchford has published extensively on both science for policy and policy for science, with emphasis in recent years on Asia, especially China and India. He has co-authored all the chapters on the USA in the *UNESCO Science Report* since the series began in 1993.

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Dr Blanpied received his PhD in Physics from Princeton University in 1959. He is a fellow of the American Physical Society and the American Association for the Advancement of Science. He is the author or co-author of four books, as well as numerous articles in peer reviewed, professional journals.

In April 2003, he was designated as an International Affiliated Fellow of the National Institute for Science and Technology Policy. In the fourth quarter of the same year, he served as a guest lecturer in the School of Policy and Management at Tsinghua University in Beijing.

While Canada is a relatively solid performer in science, technology and innovation, it needs to aim for a bigger role on the world stage.

Paul Dufour

3 · Canada

Paul Dufour

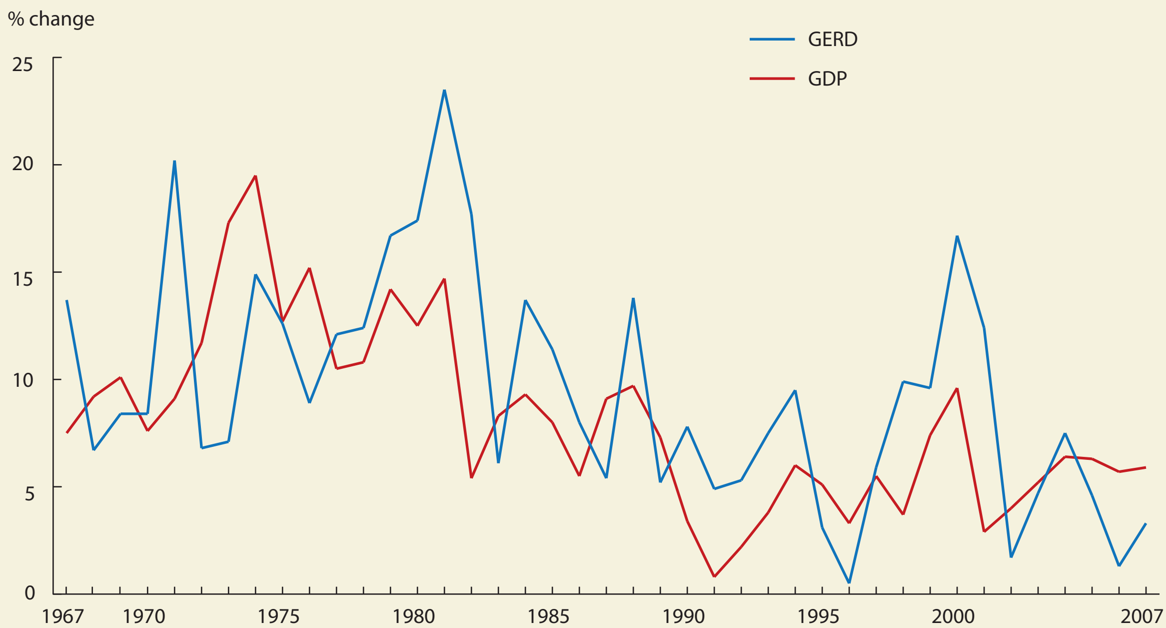
INTRODUCTION

The present chapter describes the evolution over the past decade of the science and innovation systems of Canada, a northern nation that has traditionally relied on its natural resources and geography for socio-economic progress. We shall examine what Canada has done to mobilize the international currency of knowledge and skills for competitive advantage while managing its more conventional assets in a sustainable and responsible manner. We shall also point to some longstanding structural characteristics of the economy that have contributed to the continued poor performance of industrial research and development (R&D) and innovation. By default, the public research sector – and institutions of higher education in particular – has largely come to be seen by policy-makers as a surrogate for innovation.

Canada is unquestionably a major player in global science, with considerable assets. We shall describe some of the more recent experiments that have made Canada one of the world's premier science and research players. We shall also underscore the current challenges Canada faces in overcoming the principle weaknesses in its approach to innovation. This comes at a time when the world is faced with a severe economic recession. Canada has not been spared but has perhaps been affected to a lesser extent than other countries. Thanks to its comparative strengths – a banking system among the strongest in the world and a real estate market that has avoided the excesses seen in other countries – a more rapid recovery is predicted. Furthermore, core inflation is at its lowest point in over 50 years and commodity income from the country's considerable natural resources has helped to mitigate the negative impact on the economy. As in other countries, unemployment has risen – it stood at 7.9% nationally as of June 2010. In recent years, real GDP has grown (Figure 1), from CAN$ 1.091 trillion in 2004 to CAN$ 1.226 trillion in 2008, with GDP per capita currently at approximately CAN$ 46 000 per annum. A two-year stimulus package of CAN$ 62 billion to 2010/2011 is in place, representing about 4.2% of GDP, with a deficit projected by the federal government at around CAN$ 50.2 billion in 2009/2010.[1]

1. In July 2009, the Bank of Canada declared that Canada was on the path to recovery from recession.

Figure 1: Annual growth in GERD and GDP in Canada, 1967–2007 (%)



Source: Statistics Canada

The Canadian Coast Guard vessel Louis S. St Laurent

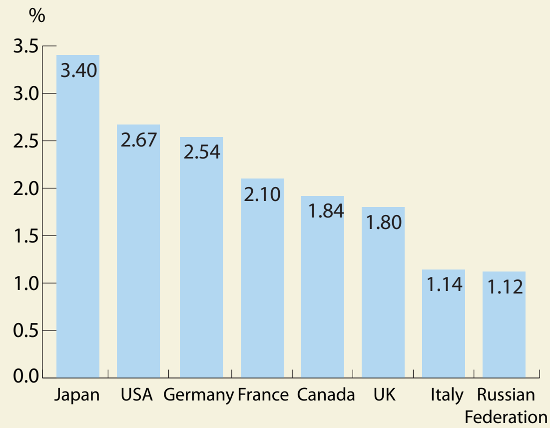
Photo: Natural Resources Canada

Canada is a G8 economy (Figure 2) with a population of 34 million in a North American integrated economy. An officially French and English bilingual nation, it has an ageing but highly educated and multi-ethnic population. Canada covers a huge land mass – second only to the Russian Federation in size – and is exposed to extreme climates, straddling as it does the Arctic Circle. Its vast territory is well connected by sophisticated information and communication technology (ICT) networks. Also of note is that Canada has no constitutionally defined division of labour in relation to science and technology (S&T), being a federated state which practices power-sharing among the central government, the ten provinces and three territories that make up its political landscape.

Canada has a number of structural and cultural characteristics that mark its approach to science and innovation. In recent years, basic questions have emerged as a result of the federal *Science and Technology Strategy* released by the minority Conservative Party government in May 2007 (Government of Canada, 2007). The strategy's four principles are: promoting world-class excellence, focusing on priorities, fostering partnerships and enhancing accountability. For example, are priority areas sufficiently focused on future investments? If Canada wants to compete, how should it do so and on what basis? How does one assess impact? And what roles do skills, education, talent and ingenuity play in all of this? As the central government possesses no Ministry of Education and no full-time, dedicated Cabinet-level Minister for Science,[2] these are indeed critical questions of national importance, particularly in the context of the current economic recession, major industrial restructuring and significant new investments in S&T and innovation by the US administration (*see page* 36). As a result, a national debate has resurfaced on the potential loss of Canada's brain power to its neighbour to the south and on Canada's future global competitiveness. Furthermore, a recent report by the government's Science, Technology and Innovation Council (STIC) has noted that, while Canada is a relatively solid performer in STI, it needs to aim for a bigger role on the world stage. As the report puts it, 'while we have been good, we now need to be great' (STIC, 2009).

2. In September 2008, the Conservative government appointed a Minister of State for Science and Technology reporting to the Minister of Industry, the first such position since 1990. With this latest appointment, Canada has had 23 elected politicians with some titled responsibility for S&T since 1971.

Figure 2: GERD/GDP ratio for the G8 countries, 2008



Note: Data for Japan and Germany are for 2007. Data for Canada, France, Italy and the UK are preliminary.

Source: UNESCO Institute for Statistics database; Statistics Canada

TRENDS IN INNOVATION

The end of a long investment cycle?

Several observers have noted that a country like Canada, situated immediately to the north of the world's largest knowledge superpower, cannot afford to remain complacent about its own approach to innovation. Over the dozen years since 1997, federal and provincial governments have invested a combined amount of well over CAN$ 20 billion in R&D (Table 1), much of it in the academic and medical research sectors but increasingly in specific targeted areas where Canada and its regions have a competitive advantage. These areas, notionally defined by the current federal S&T strategy, include natural resources and energy, environmental science and technologies, health and related life sciences and ICTs. Canada is also a global player in such disciplinary fields as astronomy and space science, clinical medicine and genomics, Earth sciences and mathematics (CCA, 2006). Between 2002 and 2008, the number of Canadian publications inventoried in the Science Citation Index rose from 30 305 to 43 539, an increase spread evenly across all major fields of science (Figure 3).

In terms of overall refereed journal publications, Canada ranks sixth in the world (Figure 4). Some 60% of Canadian scientific papers are co-authored with the country's largest scientific partners, the United Kingdom and USA (Science-Metrix, 2008) [Table 2].

Table 1: Trends in GERD in Canada, 1999–2008

	GERD in CAN $ millions	GDP in CAN $ millions	GERD/GDP ratio
1999	17 638	982 441	1.80
2000	20 556	1 076 577	1.91
2001	23 133	1 108 048	2.09
2002	23 536	1 152 905	2.04
2003	24 691	1 213 175	2.04
2004	26 783	1 290 906	2.07
2005	28 126	1 373 845	2.05
2006	28 599	1 449 215	1.97
2007	29 170	1 532 944	1.90
2008	29 487	1 600 081	1.84

Note: Data for 2007 and 2008 are preliminary.

Source: Statistics Canada

In part, this large-scale, long-term investment cycle in R&D since 1997 has come about through continuous budget surpluses over the decade leading up to the recession in 2008. As a result, Canada has been at the forefront of the G8 in terms of gross domestic expenditure on research and development (GERD) per capita in the higher education sector and is second only to Sweden among countries of the Organisation for Economic Co-operation and Development (OECD) in this category. R&D in the higher education sector now constitutes roughly 35% of the country's total R&D performance (Figure 5).

However, other data cloud this rosy picture. Business R&D expenditure in Canada as a percentage of GDP declined by 20% from 2001 to 2007. Canadian industry's spending on R&D was just over 1% of GDP in 2006, well below the OECD average of 1.56% and the US average of 1.84%. Business R&D represents only about 54% of R&D performed in the country and is concentrated in a handful of companies, with only 19 firms spending more than CAN$ 100 million per year on R&D (Figure 6). The top ten companies have carried out one-third of all R&D over the past two decades (OECD, 2008). Even more troubling, one firm, Nortel, responsible for a large portion of this one-third of business R&D, has been severely weakened by its inability to recover from the high-tech market crash in 2000–2001 and, more recently, from the global recession. In January 2009, facing flagging market demand, Nortel filed for bankruptcy protection, leading to most of its key assets being gradually sold off. Business R&D spending in the manufacturing sector especially appears to be in slow decline, although R&D in the services sector has maintained some staying power.

There are other worrying signs. The labour market demand for science and engineering graduate students appears to be weakening. Since 1984, relative labour productivity in Canada's business sector has fallen from more than 90% of the US level to about 76% in 2007. Canada ranked 15th out of 18 countries in a recent assessment of growth in labour productivity. When compared to the USA, Canada has shown much slower growth in labour productivity since 2000 in three major sectors: manufacturing; information and culture; and finance, insurance and real estate. The average investment per worker in ICTs in Canada was only about 60% of the US level in 2007. In short, some have concluded that Canadian business – with a few notable exceptions – tends to be seen as a technology follower, not a leader.

Government investment choices

Historically, government investment in S&T has been largely a non-partisan issue. All political parties support it but to varying degrees and with a different emphasis from one period to another. For example, once it had absorbed a serious budgetary deficit, Canada's previous Liberal Party administration (1993–2005) decided from 1997 onwards to invest in knowledge on a large scale relative to other discretionary expenditure, reasoning that fostering a sound knowledge economy would greatly benefit Canadians.

Table 2: Trends in scientific publications in international collaboration for G8 countries, 2002 and 2008

	2002	2008	Percentage change
Canada	12 144	20 030	+65
France	19 782	28 046	+42
Germany	26 930	36 668	+37
Italy	12 553	19 027	+52
Japan	14 213	18 162	+28
Russian Federation	8 884	8 778	-1
United Kingdom	23 898	35 663	+49
USA	57 161	83 854	+47

Source: Knowledge Assessment Methodology database; Thomson Reuters Inc. Science Citation Database Expanded, compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

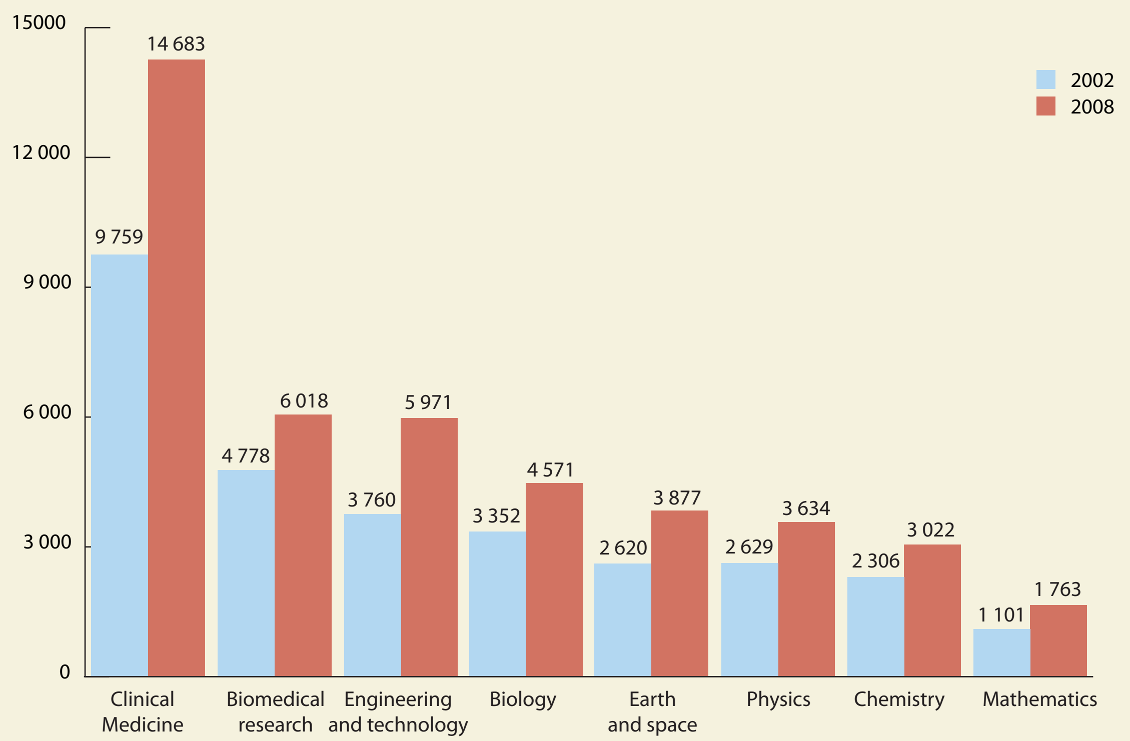
To some extent, this investment has paid off but it has also raised expectations of continued funding on a similar scale. The current government has also supported new R&D investment under its federal *Science and Technology Strategy* released in May 2007. However, it has been criticized in the media as well as in some research circles for an overemphasis on investment in scientific infrastructure at the expense of more significant renewed programme funding for the three main grants councils – the Natural Sciences and Engineering Research Council (NSERC); the Canadian Institutes of Health Research; and the Social Sciences and Humanities Research Council – and other research funding institutions like Genome Canada. In the face of the ambitious research funding and aggressive science and education policy agenda announced by the Obama administration, some fear a loss of talent and research expertise to a re-energized US research system.

Over the past decade, a number of new science and innovation programmes and institutional projects have been successfully introduced into the research system. These include the 2000 Canada Research Chairs, the Networks of Centres of Excellence, the Canada Foundation for Innovation, Genome Canada and numerous scholarship programmes. These have been accompanied by funding increases for the three major grants councils for university research and by provisions for indirect research costs. In all, an estimated CAN$ 16 billion in new federal research funding has pushed Canada to the forefront of the international S&T arena but has also resulted in calls for greater accountability and for the socio-economic impact of S&T projects to be demonstrated.

A persistently poor R&D culture in much of the business sector

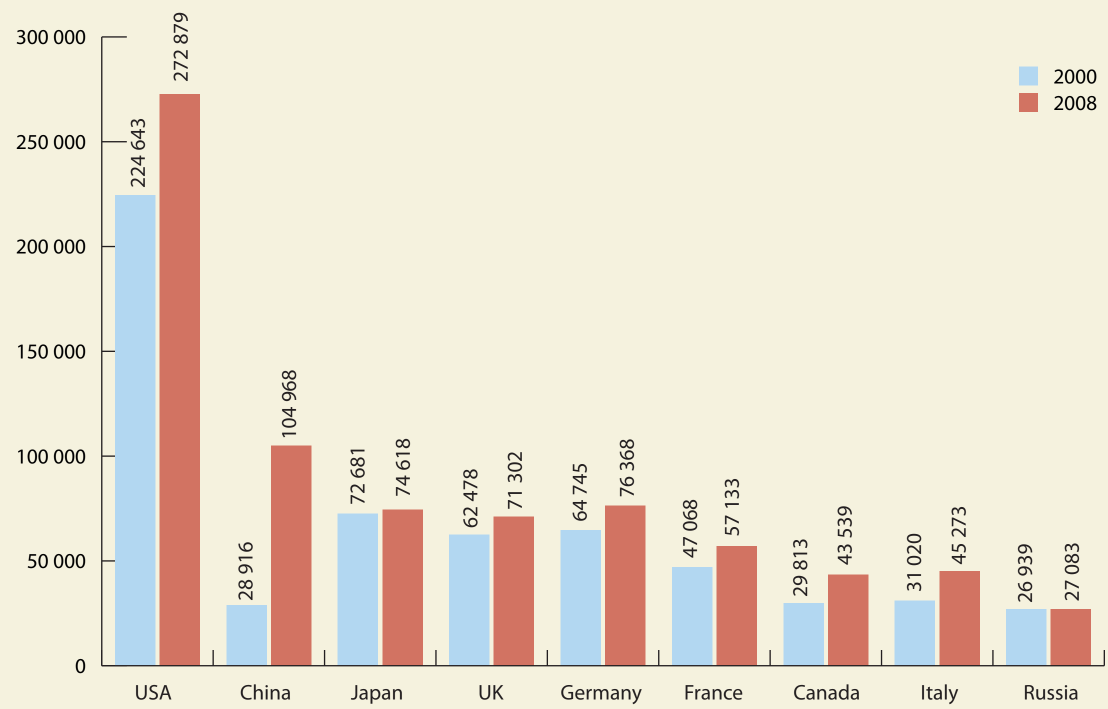
Focusing on supply issues is a constant reminder that demand for knowledge must also be well grounded. In Canada, this continues to be problematic. The debate over Canada's weak business R&D is perennial, going back

Figure 3: Publications in Canada by major field of science, 2002 and 2008



Source: data from Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

Figure 4: Scientific publications in the G8 countries and China, 2000 and 2008



Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

to the early 1960s (Dufour and de la Mothe, 1992). Whereas, in most leading developed economies, the private sector plays an active role in driving and championing the need for an enhanced innovative capability, in Canada, business leadership is largely lacking. In part, this is because many Canadian-based firms are weak performers of R&D. This is to some extent a function of their status as branches or plants of foreign-based multinationals but it can also be attributed to the fact that Canada has been a global commodity producer, an area where R&D has not been considered a major business input.[3]

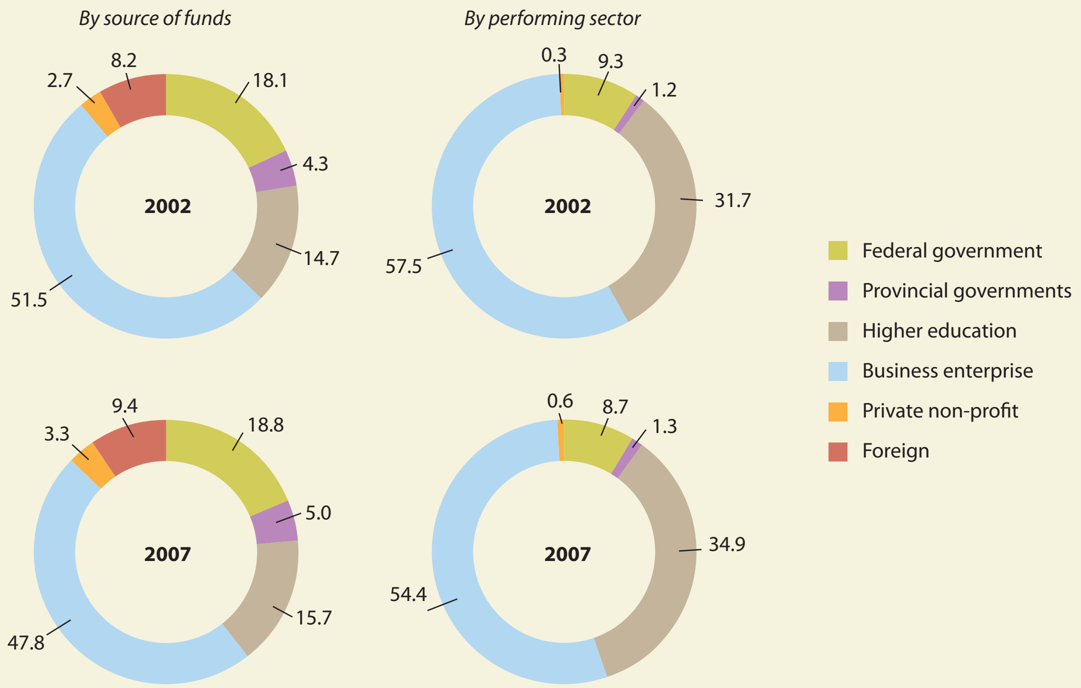
A 2009 study by the Council of Canadian Academies has argued that there is no single cause for weak innovation in Canada. Rather, a sound understanding and analysis of the factors that influence business decision-makers, sector by sector, is also required (CCA, 2009*a*). It has made the point rather convincingly that Canada's productivity problem is actually a business innovation problem and that business strategies do not emphasize innovation as a key competitive tool. Canada's place in 'upstream' North American industries and a small domestic market that is geographically fragmented provide less incentive for a business to innovate in order to survive. Others also argue that there is insufficient advocacy from the various private sector associations to invest in innovation and devote greater attention to the importance of innovation and research for competitiveness.

Jump-starting the innovation process

Arguably then, the higher education research sector has come to be seen as a surrogate for industrial R&D in Canada, along with some key public technology institutions. There have been numerous attempts by successive governments at both the federal and provincial levels to shape new public sector levers to stimulate the commercialization of knowledge through public–private partnerships. One good example of this is the agreement negotiated by the federal government with the Association of Canadian Universities and Colleges (AUCC)

3. It should be noted, however, that multinational firms operating in Canada appear to invest more in R&D than their Canadian-owned counterparts.

Figure 5: GERD in Canada by performing sector and source of funds, 2002 and 2007 (%)



Source: Statistics Canada

in 2002; it stipulated that Canadian universities were to double the amount of research they performed and triple their commercialization performance, in addition to intensifying the training of graduate researchers and contributing to the socio-economic development of their communities. As a result of this entente, the AUCC has produced various accountability measures and benchmarks to monitor and update these commitments. For example, according to its data, the income received by Canadian universities from the commercialization of research results almost doubled between 2002 and 2006, while spin-offs from universities grew from 718 in 1999 to 1068 in 2006 (AUCC, 2008).

Another novel case can be found with the Networks of Centres of Excellence (NCE) programme mentioned earlier. A competitive-based initiative, the programme was launched in 1989 with the objective of not only developing a network of excellence around the country to address specific research challenges but also of working in concert with industry to generate practical applications from basic research programmes. There are now 20 NCEs, all chosen via a competitive process covering a gamut of strategic research areas across the country. They include three devoted explicitly to major social issues. By all accounts, the programme has met with considerable success. For example, according to a recent progress report on the federal S&T Strategy (Government of Canada, 2009) in 2006–2007, the NCEs have:

- partnered with close to 2 000 companies, government departments and agencies, hospitals, universities and other organizations in Canada and around the world;
- employed more than 6 000 researchers and highly qualified personnel;
- supported their scientists in filing 110 patents and publishing 4 309 papers in refereed journals;
- obtained or launched negotiations on 20 licenses and generated four spin-off companies.

Building on this model, the federal government has experimented with hybrid, more commercially driven designs to engage industry actively. In 2007, the Business-Led Networks of Centres of Excellence programme was announced to fund large-scale collaborative networks. These are expected to increase private-sector investment in research in Canada, support the training of skilled researchers and shorten the time-lines between research and commercialization. Up to five centres are to be supported for four years through this new programme. Centres of Excellence in Commercialization and Research have also been created to the tune of CAN$ 350 million over five years. These advance research and commercialization of technologies, products and services in four priority areas identified by the 2007 federal *Science and Technology Strategy*. The first batch of these centres was simply announced by the federal government in 2007 but, since then, centres have undergone a selection process combining international peer review with advice from the private sector.

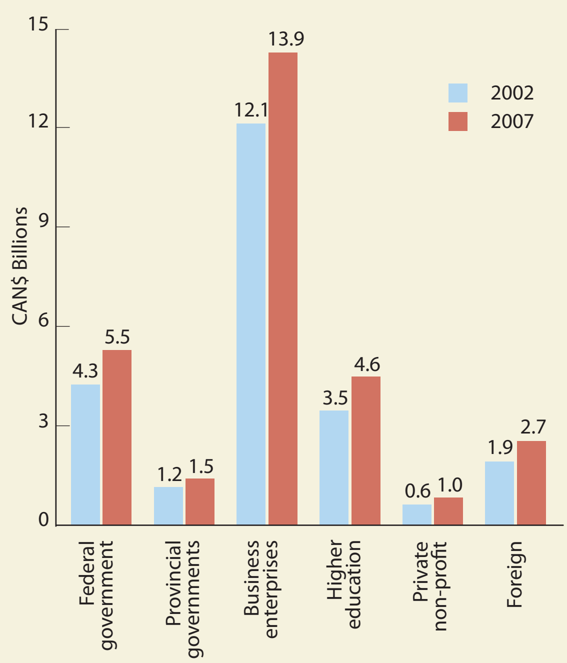
There have been other efforts to jumpstart the innovation process in Canada. These range from some of the most generous R&D tax credits in the world to new forms of venture capital support and even targeted research funds for automotive innovation, aerospace, forestry and defence – important employment sectors of the Canadian economy. In addition, given Canada's tremendous scope in energy assets, investments have been made in energy research and technology, including the establishment of Sustainable Development Technology Canada in 2001, a foundation that supports groundbreaking technologies from the private sector in climate change, clean water and next-generation renewable fuels. Along with a Clean Energy Fund announced in 2009, more than CAN$ 3.5 billion has been invested in energy research and technology, with more likely to come.

The National Research Council of Canada, the premier technology motor of the public sector (with laboratories across the country), has also increased its financial support – to CAN$ 200 million for two years – for the well-established Industrial Research Assistance Program designed to help solve the innovation challenges of small and medium-sized companies. As of October 2009, this new funding had reached over 1 200 firms and created over 4 500 jobs on top of the 455 new graduates hired by small firms. In parallel, federal government laboratories in various areas that include natural resources, national defence, the environment, and agri-food and agriculture have developed initiatives to commercialize their technologies.

The three grants councils have also been responsive. For example, the Natural Sciences and Engineering Research Council has funded three strategic networks to focus on challenges in manufacturing, forestry and fisheries. Some of the provinces have also invested significantly in research and innovation. The province of Ontario has created a Ministry of Research and Innovation to focus the provincial government's commitment to making innovation the driving force of Ontario's economy. Alberta has announced a major initiative on clean energy and supports a four-part technology commercialization action plan. As for Quebec, it has introduced an ambitious CAN$ 1.16 billion science and research strategy that includes funding for participation in key international S&T ventures.

Despite all of these efforts to improve the demand for knowledge, including some new funds to foster industrial R&D internships for students wishing to work in the private sector, the overall weakness in private sector performance persists.

Figure 6: GERD in Canada by source of funds, 2002 and 2007



Source: Statistics Canada

PERSONNEL ISSUES

The need for a strong national agenda in higher education and research

In many respects, Canada has two Achilles Heels. The first, as we have seen, is the lacunae of aggressive private-sector commitment to innovation. The second is 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. While education remains almost exclusively a provincial matter, responsibility for S&T and research are undefined constitutionally. As a result, different levels of government intercede with different instruments for varying outcomes. This makes for a complex web of actors and recipients, often with unco-ordinated leadership. A landmark study in 1984 by the defunct Science Council of Canada on science education involving all jurisdictions made this point clearly (Science Council of Canada, 1984). Other studies have since pointed out the need for a pan-Canadian vision for education, research and skills. Furthermore, despite the occasional federal/provincial/ territorial S&T ministerial meetings, Canada's one and only attempt at a truely *national* S&T strategy, adopted by all levels of government in 1987, has long since lapsed.

Data show that enrollment in Canadian universities in the 2006/2007 academic year rose only 0.9%, the smallest rate since 2000. Of some concern is a persistent disaffection among students for the natural sciences and mathematics: in recent years, enrollment has fallen in several areas, including mathematics and computer and information sciences (Figure 7).

However, it is worth noting that Canadian secondary school pupils perform well in science, according to the OECD's Programme for International Student Assessment. In 2006, they ranked third – after pupils in Finland and Hong Kong in China.

Taking full advantage of a highly educated foreign-born population

Nearly half (47%) of Canada's population of working age holds a tertiary degree. Canada's large foreign-born population is also highly educated. The country has the highest ratio in the world of foreign-born PhDs to native PhDs and is second only to the USA for highly skilled foreign-born workers. Taking full advantage of the immigrant population for enhanced socio-economic development is a challenge.

Evidence shows that Canada succeeds in attracting highly skilled immigrants on a permanent basis but fares less well when it comes to attracting and retaining foreign students at advanced levels of education. In fact, one of the earlier policy experiments was structured precisely to address this question of retention: the CAN$ 2 billion Canada Research Chairs (CRC) Programme was designed in 2000 to attract top talent to Canada's universities and keep them there. Two thousand CRCs have been allocated on a competitive basis to 70 participating universities across the country. The chairs are allocated according to a two-tier principle: CAN$ 200 000 per chair for established 'stars' for seven years, tenure that is renewable, and CAN$ 100 000 per year for five years for junior or rising stars. One of the features of this ongoing programme is that universities have to provide a strategic research plan on how they would allocate the chairs and in what areas. This requirement has encouraged Canadian universities to become more focused in some of their research. The success of this model has been adapted elsewhere around the globe and, in 2007, the International Development Research Centre, Canada's premier research development agency, joined up with the CRC programme to create a new initiative for selected university chairs in the developing world. In 2009, under this programme, eight research teams were selected to receive up to CAN$ 1 million each over five years, each to address a key development challenge.

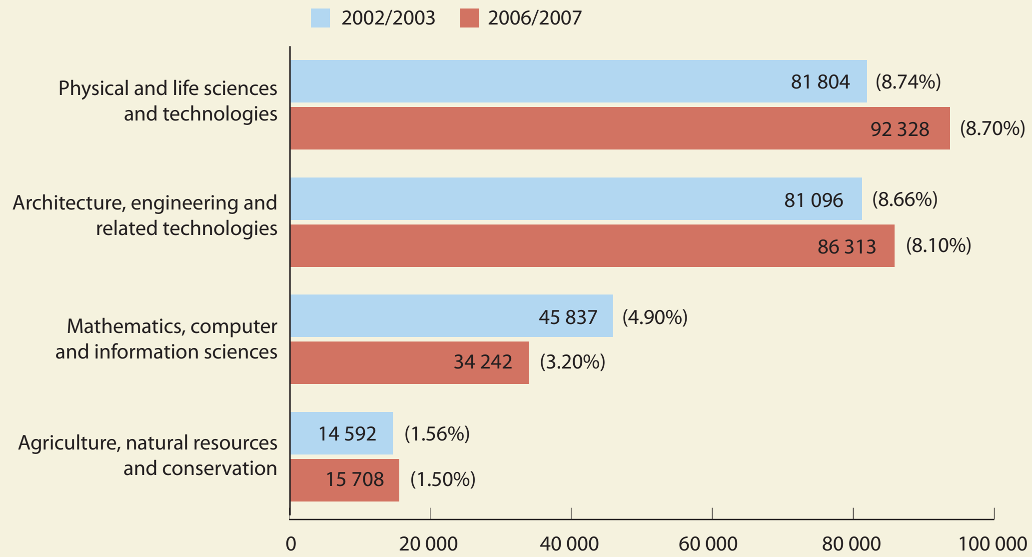
Other measures have been put in place under the 2007 federal *Science and Technology Strategy*. The Vanier Canada Graduate Scholarships Program supports 500 Canadian and international doctoral students each year with three-year scholarships valued at up to CAN$ 50,000 per annum. Launched in September 2008, these awards are expected to attract and support world-class doctoral students who demonstrate a high standard of scholarly achievement in graduate studies along with strong leadership skills.

Building on the CRC programme, a Canada Excellence Research Chairs Program was launched in 2009, with a budget of CAN$ 10 million over seven years to support 20 researchers and their teams in establishing research programmes at Canadian universities and research hospitals.

Provincial governments promoting an entrepreneurial culture

Provincial governments are active as well. Quebec has the highest provincial GERD/GDP ratio in Canada, at 2.7%. It is followed by Ontario at 2.3%. These two provinces, which contain most of Canada's manufacturing heartland,

Figure 7: Enrollment in scientific disciplines in Canada, 2002/2003 and 2006/2007
Number of students and percentage of total university enrollment



Note: 2005/2006 and 2006/2007 enrollments for the University of Regina are not available.

Source: Statistics Canada

dominate the provincial R&D landscape. Firms in Ontario account for 48% of total industrial spending in R&D, while those in Quebec account for 30% (Statistics Canada, 2009). For example, the Ontario government's CAN$ 3 billion Innovation Agenda (Government of Ontario, 2008) provides funding for the development and teaching of commercial skills across sectors and disciplines. It supports programmes to spark the interest of young people in innovation. As well as providing funding for theoretical physics and quantum computing, Ontario invested CAN$ 100 million in an initiative centred on genomics research in 2009, along with a CAN$ 250 million Emerging Technologies Fund to be co-invested with venture capital funds-for companies in clean technology, life sciences and digital media and ICTs.

Other provinces, such as Alberta, Quebec, British Columbia and Saskatchewan, are all actively engaged in promoting science and an entrepreneurial culture through science popularization, outreach and scholarships. Most provinces have embedded science and research functions in ministries responsible for small business, entrepreneurship or innovation. A few have S&T councils advising their government on emerging trends and new policy directions, among them British Columbia and Quebec. Alberta has adopted a new approach to innovation with the creation of Alberta Innovates, a set of four corporations that will address specific innovation challenges for the province.

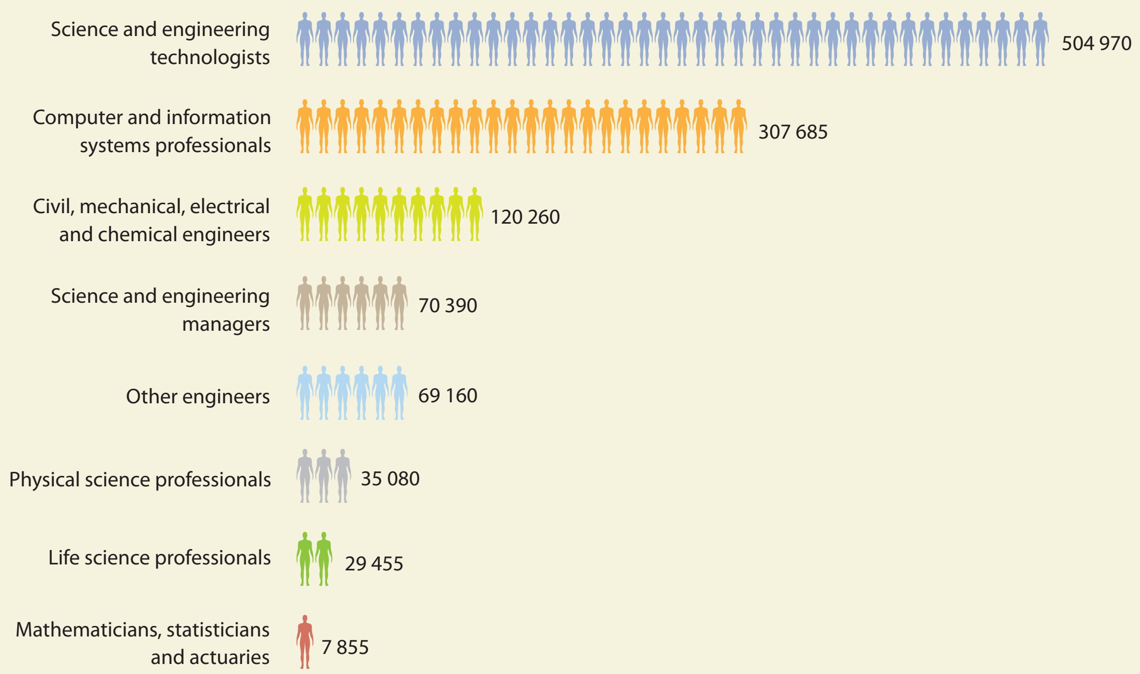
Several provinces have research and technology councils that develop technology commercialization and cluster strategies to enhance innovation specific to their region, often in conjunction with federally funded research bodies located in their province or territory. Some of the regional agencies for economic development supported by the federal government are active in this arena.
One example is the multimillion-dollar Atlantic Innovation Fund established in 2000, which supports research in the four Atlantic provinces: Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador.

INVESTMENT IN INFRASTRUCTURE

Laying the foundations for innovation

Funding is a good start but researchers also need a well-appointed home if they are to be successful. In 1997, the federal government initiated an experiment that it dubbed the Canada Foundation for Innovation (CFI).

Figure 8: S&T labour force in Canada, 2006



Source: Statistics Canada

Despite its name, the programme is actually designed to ensure the provision of state-of-the-art research capacity, equipment and facilities to universities, colleges and hospitals across Canada. Envisioned to last for five years, with an initial investment of CAN$ 800 million, its success has been such that its lifespan will carry it beyond 2010 – with a combined projected investment of almost CAN$ 10 billion over the past decade. CFI is structured to leverage 60% of its funding from other sources, including the provinces. Since its inception, CFI has supported, through open competition, 6 000 projects at 128 research institutions in 64 Canadian communities (Government of Canada, 2009). An analysis of CFI's impact over the past five years indicates that this new infrastructure has led to:

- the creation of more than 4 000 jobs in the public and private sectors;
- the training of almost 11 000 technical personnel;
- the generation of more than 9 000 research collaborations;
- the development of more than 1 500 international research collaborations;
- the registration of 1 750 intellectual property rights claims;
- the development of 760 new or improved products, processes or services; and
- the creation of almost 200 spin-off companies.

Another major investment in infrastructure has come through the CANARIE Advanced Research Network, a sophisticated, ultra-high-speed broadband network linking the country's universities, hospitals, federal laboratories and other facilities with top institutions around the globe. CANARIE received an additional CAN$ 120 million in the 2007 budget. In 2009, as part of a broader economic stimulus package, the federal government also invested CAN$ 2 billion for improvements to knowledge infrastructure in the country's colleges and universities.

Several organizations have also called for greater attention to be paid to entrepreneurship and producing business, management and financial talent at Canada's business schools. Virtually every study on competitiveness makes this point, arguing that innovation requires better-informed managerial talent, rather than solely investment in more scientists and engineers. When a 2009 study by the Council of Canadian Academies examined how the research produced by Canadian business and finance schools was faring, it found that, while overall output from this research tended to rank above the world average in most traditional disciplines, there was a lack of explicit relevance to potential end-users (CCA, 2009*b*).

SCIENCE GOVERNANCE

Science governance faces challenges of its own

Fixing and fuelling innovation systems also requires a sound regulatory environment, high technical standards and well-framed conditions to support the business environment. In a country with a long-standing social democratic tradition, informed advice and public engagement on the country's future directions is a *sine qua non* condition. Sound scientific advice and a strong science and innovation culture are central to these tenets. Canada has experimented with various institutional forms of scientific advice in the past but few have survived. The longest-standing of these was the Science Council of Canada, which was closed by the federal government in 1992 after 26 years of providing a public face and dialogue on Canadian science policy.

In 2008, after a four-year experiment, the Office of the National Science Advisor (which had been set up under the former Liberal Party prime minister) was disbanded. Borrowing from similar models in other countries, the office had been an attempt to address an obvious gap in the government's ability to mobilize effectively its advisory capacity internally on key public policy issues. Issues it actively supported over its short life-span include (Carty, 2008):

- the creation of the Canadian Academy of Science in 2005, now the Council of Canadian Academies, an independent organization with a 10-year grant endowment of CAN$ 30 million designed to assess the science underlying important public policy issues. The Council has produced several reports at the request of the government, following a landmark report in 2006 on the state of S&T in Canada (CCA, 2006) which formed the basis of the federal government's strategy for priority-setting.[4] Assessments published by the Council include the potential for gas hydrates in Canada, the impact of nanotechnologies on health and the environment, the sustainable management of groundwater, business innovation, the transmission of influenza and design options for a proposed new international Arctic research station. Other assessments on animal health and biodiversity are under way;
- advising on what became a CAN$ 156 million contribution to the International Polar Year (2007–2008), the largest ever global programme dedicated to polar research. Canada led 44 projects in this venture, which focused on the impact of climate change and adaptation measures, as well as the health and well-being of Northerners and Northern communities. This investment stimulated a major outreach programme in addition to mobilizing communities, researchers and the next generation of scholars in Arctic research. The government has also committed to establishing a world-class research station in the high Arctic; a feasibility study is currently being finalized on its potential location;
- in collaboration with the heads of the research councils and agencies, the development of a draft framework for the funding, evaluation and oversight of major Canadian investments in science and infrastructure. Since 2008, Canada has continued to support several such ventures, including NEPTUNE Canada, a CAN$300 million public–private sector collaboration on the Pacific Coast involving Canada and the USA that will use a cabled observatory to expand knowledge of the ocean and ocean floor. Other projects include the Canadian Light Source in Saskatchewan, the Sudbury Neutrino Observatory in Ontario and a major contribution to the Large Hadron Collider near Geneva in Switzerland (*see page* 158);
- with the co-operation of aid agencies and other departments and agencies, the drafting of an action plan to help mobilize R&D to meet the needs of the developing world, especially in the context of Canada's previous G8 commitments in health, agriculture and innovation for development in Africa. A multi-million dollar Development Innovation Fund was announced in 2007 to assist in funding breakthroughs in health and related areas for the benefit of developing countries. Canada's International Development Research Centre (IDRC) was one of the first organizations to support the establishment of

4. STIC has subsequently produced a set of sub-priorities for the design of Canada's research support programmes at the request of the Minister of Industry.

Africa's Science and Technology Consolidated Plan of Action by the New Partnership for Africa's Development (NEPAD), announced in South Africa in 2005 (*see page* 297);

- in conjunction with other international obligations, the National Science Advisor worked closely with the international trade department to help design the International Science and Technology Partnerships programme (ISTP) that is now providing CAN$ 20 million for enhanced R&D partnerships with Brazil, China, India and Israel. The ISTP has led to over 30 funded joint projects with China and India (ISTP, 2009). Moreover, a new experiment in trilateral co-operation involving Canada, China and Israel in agri-innovation shows considerable promise for other such partnerships in the future (ISTP, 2009). In addition, the National Science Advisor helped to shape the Canada–California Strategic Innovation Partnership (CCSIP), which has since resulted in the creation of a bilateral Cancer Stem Cell Consortium announced by the Minister of Health and the Governor of California in May 2008. In December 2008, a CAN$ 2 million joint call for proposals was launched under the CCSIP, resulting in over 100 expressions of interest from some 23 Canadian universities.

In 2007, the federal government phased out several other S&T advisory groups, including the Council of S&T Advisors and the National Biotechnology Advisory Council. These were replaced with a new Science, Technology and Innovation Council (STIC) made up of experts from across the country and senior officials from various science-based departments. An advisory body that reports to the Minister of Industry, the STIC constitutes an element of the federal Science and Technology Strategy of 2007.

The STIC provides S&T advice on issues referred to it by the government, such as the design of new S&T scholarships or how to enhance Canada's S&T role internationally. The council is mandated to produce a regular national report benchmarking Canada's performance in S&T against international standards of excellence, the first of which was published in May 2009 (STIC, 2009). Unlike similar bodies in other jurisdictions, the public is not privy to the work of STIC, with the exception of its national report. STIC provides advice to the government on a confidential basis.

CONCLUSION

Looking forward

The next phase of Canada's knowledge investment is unclear, in a rapidly changing S&T environment with diminishing expectations and new priorities, and amid pressing domestic and global demands. From 2001, when Canada's R&D effort reached a high of 2.09% of GDP, GERD declined to 1.84% of GDP in 2008 (Table 1). Federal R&D expenditure is expected to drop to 2.6% in 2008/2009 from 2.9% the previous year. In 2008, direct federal funding of R&D amounted to CAN$ 5.2 billion, or just under one-sixth of the country's total R&D funding. While the federal government's overall spending on S&T was about CAN$ 9.9 billion in 2008–2009, S&T accounted for about 4.1% of the total federal government budget, down from 4.6% over the previous two years.

Responding in part to critics of its tepid investment to date, the federal government announced in March 2010 a suite of new innovation and research measures spanning 2010 and 2011. These include a five-year postdoctoral fellowship programme of CAN$ 45 million; small increases over two years to the grants councils (totalling CAN$ 32 million per year); a one-time investment of CAN$ 75 million to Genome Canada; CAN$ 135 million to the NRC for its regional innovation clusters; and CAN$ 50 million over the same period to TRIUMF, Canada`s premier national facility for nuclear and particle physics. The 2010 Budget also invested CAN$ 397 million over five years to develop the next-generation remote-sensing radar satellite: RADARSAT. A programme for college and community innovation will also receive an additional CAN$ 15 million per year and CAN$ 49 million in annual funding for two years has been earmarked for the regional development agencies to enable them to continue supporting innovation across the country. The proposed Canadian High Arctic Research Station received new funding for a pre-construction design phase and the ISTPP programme with India, China, Brazil and Israel was extended for another two years with an additional CAN$ 8 million. Nonetheless, with a looming austerity programme to reduce Canada`s budget deficit by 2016, many predict tougher times ahead for research and other areas of discretionary spending. The onus will be on the research and innovation community to continue to make its case.

There is an animated and re-emerging public policy debate at the moment on limiting potential brain drain, as US spending on R&D and other incentives are ramped up proportionately more than Canada's own investment. The same can be said of investment by other competitors, such as China, France, Germany, India and the Republic of Korea. In a trend that is somewhat in line with other countries, government policies are increasingly focusing on the need to frame research for commercial results and direct areas of priority. Nonetheless, even the co-founder of Canada's largest high-tech company, Research in Motion – makers of the Blackberry – has warned of the perils of ignoring basic research (Lazaridis, 2009). Mike Lazaridis has invested over CAN$ 150 million of his personal fortune to create the world-class Perimeter Institute for Theoretical Physics (PI) and the Institute for Quantum Computing. These are both located at Waterloo, Ontario, one of the country's most dynamic knowledge clusters. Some of the funding for these two institutes has come from federal and provincial governments.[5]

Canada's structural weaknesses in competitiveness and innovation remain but projects to enhance technology and its commercialization are on the rise. These are still too few and far between, however. If Canada is to maintain its current level of prosperity, they will need to be expanded on, with all relevant sectors working together. Examples of such projects are:

- the Medical and Related Sciences (MaRS) Discovery District in Toronto;
- the biopharma and nanotechnology clusters in Quebec;
- the marine and oceans research complexes in Halifax and St John's;
- the nanotechnology, energy and water research institutes in Alberta; and
- the biotechnology and bio-products cluster in Saskatchewan.

The mission of Canada's over 200 federal laboratories, which serve the public good in areas that include health, the environment, agriculture and food safety, is changing as the R&D capacity of these laboratories slowly erodes. In recognition of this decline, these laboratories received a two-year injection of CAN$ 250 million from the federal government to help cover the cost of deferred maintenance. An expert panel appointed by the federal government in 2008 examined ways in which the federal laboratories might better adopt new business models, in collaboration with universities, and analysed various forms of privatization. Several new models for partnership in the fields of materials, geosciences and nanotechnologies are being put in place as a result. One good example is the National Institute for Nanotechnology, established in 2001 on the campus of the University of Alberta with the support of the NRC and federal and provincial governments.

Diversifying partners in scientific collaboration

Canada's global partnerships are also shifting to address the country's changing domestic needs. A recent study has demonstrated that, while the USA continues to be the country's largest S&T partner by far – in 2008, over 51% of Canadian scientific papers were co-authored with US researchers, streets ahead of the next biggest partner, the UK (8.1%) – the fastest growth in bilateral scientific collaboration is occurring with emerging Asian and Latin American economies, as well as with some Nordic countries. These countries include China, Finland, the Republic of Korea and Norway (Science-Metrix, 2009).

With respect to multilateral membership of various 'clubs', Canada continues to participate in such groups as the Asia–Pacific Economic Cooperation (APEC), the Organization of American States (OAS),[6] the United Nations, the Francophonie – bringing together French-speaking countries – and the North Atlantic Treaty Organization. Despite some significant earlier investment in development research, there are signs of a slowdown, as aid and capacity-building shift towards other geopolitical priorities, among them Afghanistan and the Americas. Canada's expertise in supporting S&T for development was put to the test with the G8 and G20 meetings in 2010, as it sought to strengthen partnerships with Africa and other developing regions in specific programmatic areas associated with global health via the launch of the Development Innovation Fund. Funding will be delivered by Grand Challenges Canada, a programme instigated by the federal government in 2008 and endowed with CAN$225 million over five years. The programme will *'support the best minds in the world as they search for breakthroughs in global health and other areas that have the potential to bring about enduring changes in the lives of the millions of people in poor countries.'* Grand Challenges Canada will be implemented in collaboration with the IDRC and the Canadian Institutes of Health Research.

5. The origins and development of the Perimeter Institute are related well in an interesting book by its former Executive Director (Burton, 2009).

6. See Annex I for the member countries of APEC and OAS.

Developing a science culture

In addition to the pursuit of priority-setting and the examination of its appropriate place in shaping future public policy and investment in innovation and R&D, other debates are emerging. These are centred on improving the science culture and outreach in the country, including by augmenting the participation of women and the Aboriginal population in the knowledge society (Dufour, 2009). Women account for 47% of the labour force and 57% of university graduates but only 20% of doctoral degrees awarded in science and engineering.

Some of the responsibility for Canada's deteriorating appreciation of the value of knowledge centres on its lack of a science culture in its widest form, both in the political realm and among certain segments of the population and research community. There is an antagonism here between what some have termed a 'politically clueless research community versus a scientifically illiterate political class'. A Science Media Centre has been proposed to improve science communication within the media. Efforts are also under way at various science centres and museums across the country to strengthen public understanding. Events include a National Science and Technology Week and a major physics festival organized by the Perimeter Institute. Some provinces, especially in Quebec, have long-standing traditions and tools in support of science outreach, given the promotion of science in the French language.

Overall, however, the science culture gap remains. The scientific communities must share some of the responsibility for this. Often poorly organized, with limited means of outreach and inadequate communication tools, the research lobbies are increasingly faced with having to make a better case for why the future of the country lies with more, rather than less, research and technology – innovation in its broadest sense.

The private sector is also struggling to be more effective in articulating its own needs and concerns over the lack of necessary resources and strategic vision. If it can succeed in forging stronger partnerships, while recognizing the value of adopting new business innovation models, the private sector can emerge as a stronger actor in the country's competitive future.

With continued public policy leadership and by building on its considerable physical and intellectual assets within a larger societal debate on knowledge for development, Canada's innovative path shows considerable promise as sets out to enhance its reputation as a Northern Minerva.[7]

7. Usually associated with the Roman goddess of wisdom, Minerva, this term was deployed to refer to the Royal Society of Canada at the turn of the last century.

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It is the academic sector which is the most dynamic actor in creating innovation systems in Latin America… As a result, local knowledge is underutilized by productive sectors that have little demand for it.

Mario Albornoz, Mariano Matos Macedo and Claudio Alfaraz

4 · Latin America

Mario Albornoz, Mariano Matos Macedo and Claudio Alfaraz

INTRODUCTION

The global economic recession has struck Latin American countries[1] with varying intensity: in 2009, growth slowed in some countries, like Brazil, and was negative in others, like Argentina. However, the impact of the recession seems to have had a less dramatic impact on the region than on other parts of the world. At the time of writing in early 2010, the worst appears to be over, with Latin American economies now on a path to recovery. Peru, Chile and Brazil should lead with growth rates of more than 3.5% in 2010. The Brazilian government announced in late 2009 that the country had relegated the recession to the past; effectively, Brazil's employment rate has risen steadily since the second half of 2009. Argentina's economy is also showing signs of recovery and should grow by 1.5% in 2010, albeit at a slower pace than before the recession. Mexico, on the other hand, has been deeply affected, due to the imbrication of its economy with North American markets. However, Mexico should bounce back in 2010, with growth forecast of around 3%. Venezuela will not be so fortunate, as its economy is expected to contract slightly again in 2010 (Casamérica, 2010).

In the meantime, the gap between rich and poor in Latin America remains one of the widest in the world. The region faces pressing social issues such as poverty and marginalization, which deprive many of education, health care and housing, among other basic rights. The impact of the current recession on employment will probably exacerbate social tensions and push some communities farther to the margins of society.

According to 2006 data from the United Nations Economic Commission for Latin America and the Caribbean – the last year for which data are available – more than one-third of Latin Americans, or 200 million people, live beneath the breadline and 13.4%, or 80 million, in extreme poverty. The stratum composed of 40% of Latin American homes in the lowest income bracket concentrates as little as 14% of aggregate income, on average (ECLAC, 2007).

Even though these figures have improved slightly since 2002 as a result of growth, the structural weaknesses of Latin American countries persist: economies oriented towards commodities, low levels of industrialization, a regressive income distribution rate and limited access to international funding as a result of difficulties in repaying foreign debt in earlier decades.

Paradoxically, the fact that Latin American countries are producers of commodities has been a comparative advantage in the past few years of growing international demand. Recent data show that international prices for commodities are going up again, which is very good news for Latin American economies. If this is confirmed as a long-term trend, the pace of economic growth will not be so negatively affected in coming years by price fluctuations.

One of the main symptoms of persistent poverty is growing urban segregation, with slums spreading in many of the region's major metropolises. In parallel, a report by the International Labour Organization (ILO, 2007) notes that, among Latin American youth aged 15–24 years, 30 million out of a labour force of 48 million are employed in the informal economy where working conditions are poor. A further 10 million are unemployed. Of the 22 million young people who neither study nor work and have never registered as unemployed, 79% live in urban areas. This shows that equity, an intrinsic dimension of development, has still not been attained in Latin American countries, despite being a long-standing goal.

Even an emerging economy like Brazil presents the urban–rural, rich–poor divide that is widespread in Latin America. The problem of uneven development, with scientific institutions being concentrated essentially in the capital and other major cities, is typical of the region and can be observed, for example, in São Paulo and Rio de Janeiro, Buenos Aires and Mexico City.

It is difficult to consider Latin America as a whole, since one of the most prominent characteristics of the region is its heterogeneity, both between and within countries. Just five countries concentrate 80% of regional GDP (Figure 1). This concentration highlights the need for very diverse development strategies, which will in turn have an impact on the type of science, technology and innovation (STI) policy adopted by each country.

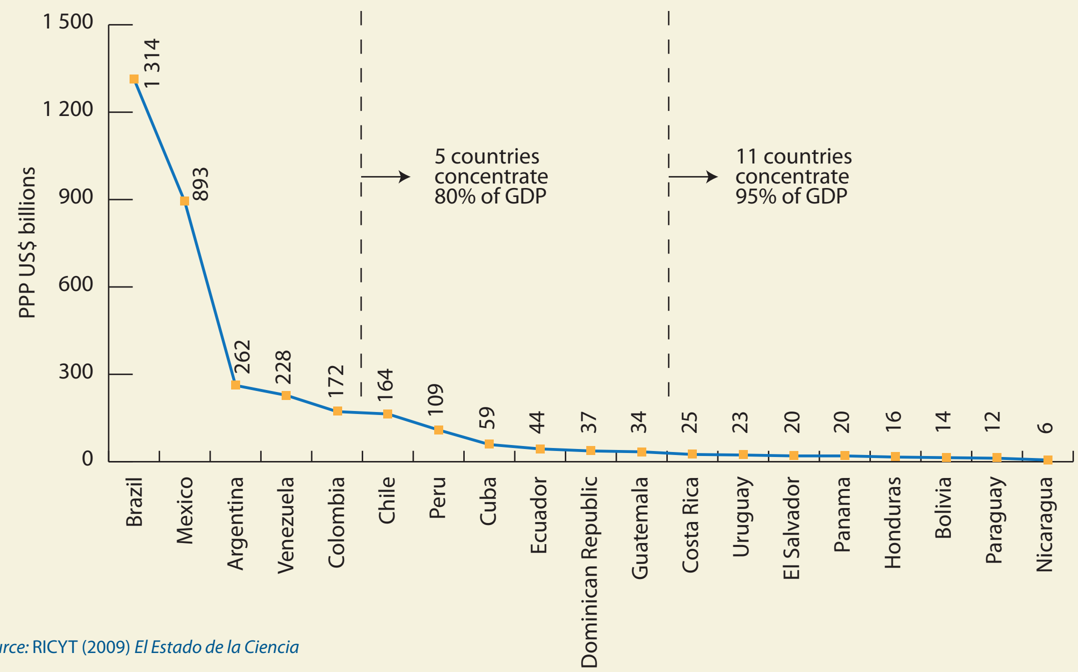
New development paths must be explored in Latin America if the region is to generate more wealth and improve wealth distribution. These new paths must value available resources, among which knowledge must take a central place. STI must play an increasingly important role in achieving growth and equality.

Professor Ana Belen Elgoyhen and a colleague at the Institute for Genetic Engineering and Molecular Biology in Argentina. Professor Belen Elgoyhen was the region's laureate for the L'OREAL-UNESCO award for Women in Science in 2008 for her contribution to understanding of the molecular basis of hearing.

Photo: Michelle Pelletier/L'Oréal

1. 'Latin America' refers in the current chapter to the countries in Figure 1. See also the individual chapters that follow on Brazil and Cuba.

Figure 1: Distribution of GDP in Latin America, 2007



Source: RICYT (2009) *El Estado de la Ciencia*

STI POLICIES TO PROMOTE INNOVATION AND SOCIAL EQUITY

Most of the region's existing institutions were inspired by what is now known as the 'linear model'. The aim of the linear model was primarily to ensure good-quality basic research. It was assumed that this would guarantee the availability of applied research and that the benefits of science would in turn overflow into society as a whole. The linear model met with some success in creating or consolidating the scientific community of each country but was of little efficacy when it came to transferring knowledge to the productive sector; this gave rise to the configuration of an academic sector relatively isolated from society. The outdated linear model is still alive and well in many countries of the region.

The Conference on Science, Technology and Innovation for Sustainable Development in Latin America and the Caribbean, organized by UNESCO in Havana, Cuba, in 2005, addressed the lack of correlation between the spheres of production and the use of knowledge, which in turn leads to a mismatch between the expectations of the scientific and business communities as to the use of knowledge. The conference also addressed the issue of existing tensions between democratization, on the one hand, and the satisfaction of social needs, on the other, and emphasized the effect of those tensions on science and technology (S&T) policies, in the sense that research and development (R&D) could make a remarkable contribution to social cohesion and the exercise of citizenship.

With Latin American countries now attempting to promote innovation within a development strategy that includes social equity, it has become necessary to revisit science policy models and instigate institutional modernization. Signs of change can be detected in the organization of R&D and STI policies in many Latin American countries. Since the mid-1990s, Argentina, Brazil, Chile, Colombia, Mexico and Venezuela, among others, have all been implementing institutional reforms to speed up procedures for resource allocation and make these procedures more transparent. In more recent years, other countries have followed the same path, among them Paraguay, Peru and Uruguay. Reforms have also focused on assessing R&D results, promoting innovation, strengthening the relationship between research centres and business, designing long-term policies, employing strategic intelligence tools, monitoring public opinion on S&T issues and disseminating knowledge. Among other reforms characteristic of the most advanced institutional systems is the adaptation of universities to the new social reality, with the development of linkages to enterprises and other social actors.

There has been a shift in policy from the linear model towards a more dynamic model, in which R&D is demand-driven and based on specific needs for knowledge and policy is supportive of innovation. One example is the creation of the Agency for the Promotion of Science and Technology in Argentina in 1996, which has been endowed with funds to finance R&D and innovation (Box 1). In Chile, multiple funds have been set up since 1981 to finance a wide range of projects ranging from centres of excellence to projects for innovation and the creation of networks linking public and private R&D institutes. In Brazil, sector-specific funds were created in 1999 to raise the level of R&D funding (*see page* 106). More recently, Uruguay established the National Agency for Research and Innovation (ANII) in 2005 to consolidate competitive funds. The same year, a loan from the InterAmerican Development Bank enabled Peru to set up a Science, Technology and Innovation Fund to finance R&D programmes and projects of private enterprises. The Fund's Board of Directors is made up of representatives of the scientific and academic communities, the government and private sector.

Currently, S&T policies in the region are based on specific legislation, much of which was drafted in the founding moments of countries' respective S&T systems. Nevertheless, a significant change came about at the turn of the century in many countries with the passing of legislation that restructured S&T institutions and, in many cases, incorporated innovation, thereby creating an STI system: Argentina's Congress passed a Science Law in 2001, a year before Mexico passed its own Science Law, followed by a second law establishing the statutes of the National Council for Science and Technology (CONACYT) in 2006. The National Council of Innovation for Competitiveness was created in Chile by President Lagos in 2005 and renewed in 2006 by President Bachelet to provide the presidency with a permanent advisory body. This set of institutional novelties reflects, on the one hand, the growing visibility of S&T policies within the framework of broader development policies and, on the other hand, the beginning of a new generation of policy instruments incorporating innovation.

As regards the composition of the institutional systems of S&T, the heterogeneity across the region is again apparent here. Although there are public organizations dedicated to R&D in every Latin American country, the circumstances in the various countries vary from those having large and complex systems – such as Brazil, Argentina, Mexico and Chile – to those with only a sprinkling of weak institutions of higher education and no S&T system worthy of the name. A study published in 2009 by the InterAmerican Development Bank and the Centre for Studies on Science, Development and Higher Education (Centro REDES) in 2009 identifies 30 different types of S&T policy instruments grouped in six main categories. The only countries having instruments for every category are Argentina, Brazil, Chile, Mexico and Uruguay. Colombia and Venezuela have very incipient S&T systems compared to those of the five leaders, according to Emiliozzi (2009) and Lemarchand (2009).

In recent years, many countries have implemented mechanisms and programmes to evaluate the performance of public STI policies. The evaluation of public policies, through different assessments, follow-up, monitoring and accountability mechanisms, has been one of the elements promoted by the state reforms introduced throughout the region since the 1990s.

On a political level, there has also been greater government interest in promoting a science culture and citizen participation. Latin America has been no stranger to the trend towards democratization of knowledge. Many surveys of the public perception of science have been conducted in recent years, as a result of the creation of a network within which academics and officials of national S&T organizations in Latin American countries have been working together to build a consensus on methodology (Box 2).

R&D INPUT

Trends in R&D expenditure

The Achilles Tendon of STI policies in Latin America remains the low level of investment in R&D, with the notable exception of Brazil, which contributes as much as 60% of the region's investment in R&D. There has, however, been an upturn in the region since 2004. After remaining stable at around US$ 10 billion from 1996 to 2004, gross domestic expenditure on R&D (GERD) jumped to US$ 23.1 billion in 2007, boosted by economic growth (Figure 3).

In 2006, GERD in Latin America and the Caribbean represented 0.68% of GDP, or 1.9% of global spending on R&D.

Box 1: Promoting innovation in Argentina

Founded in 1996, Agentina's National Agency for the Promotion of Science and Technology (*Agencia Nacional de Promoción Científica y Tecnológica, ANPCYT*) channels funding into R&D projects and infrastructure development. A decentralized body, it reports to the Ministry of Science, Technology and Productive Innovation (MINCYT) set up in 2007.

The agency manages the following funds:

- the Technological Fund of Argentina (*Fondo Tecnológico Argentino, FONTAR*), which finances technological modernization and innovation in the productive sector, including via technological services for institutions and small and medium-sized enterprises, technical assistance and training, entrepreneurial incubators and technology parks and poles;
- the Scientific and Technological Research Fund (*Fondo para la Investigación Científica y Tecnológica*, FONCYT), which provides public or private non-profit R&D institutions with subsidies;
- the Trust Fund for Promotion of the Software Industry (*Fondo Fiduciario de Promoción de la Industria del Software*, FONSOFT), which was created by law in 2004 and finances development of the software industry in small and medium-sized enterprises;
- the Sectoral Fund (*Fondo Argentino Sectorial*, FONARSEC), which provides subsidies for the upgrading of R&D capacities for transfer to the productive and social sectors.

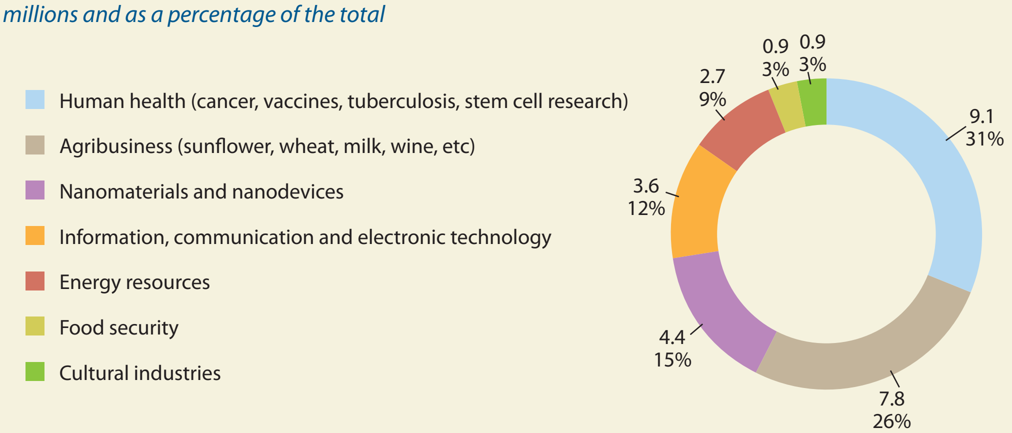
In 2008, the agency awarded a total of US$ 234.6 million for the execution of 2293 R&D projects. Of this, US$ 135 million went to FONCYT, US$ 94 million to FONTAR and US$ 5 million to FONSOFT. Some 22% (US$ 30 million) of the total amount allocated to FONCYT in 2008 was awarded within its Programme in Strategic Areas (Figure 2).

The Observatory of Venture Capital, a non-profit organization, was set up by the Science and Technology Ventures Institute (IECYT) in 2003 to group entrepreneurs and researchers. According to a 2008 survey by the observatory, the most attractive sectors for venture capital in Argentina are software and computer sciences (17%), the food industry (14%), Internet (13%), non-financial services (13%), media and entertainment (10%), biotechnology (10%), automation (7%) and health (7%). Start-up companies tend to attract the most funds (77%).

Although US$ 70 million in venture capital was available in 2008, the observatory found that less than 10% was actually invested. The survey also found that venture capital was mostly mobilized from national sources, even though European funds and funds from the InterAmerican Development Bank and other multilateral agencies were also available.

Source: ANPCYT (2009); Jacobsohn and López (2008)

Figure 2: Sectors benefiting from FONCYT's Programme in Strategic Areas, 2008
In US$ millions and as a percentage of the total



Source: ANPCYT (2009) *Bioscience and Biotechnology for the Promotion of Agriculture and Food Production*

Box 2: Public perception of science

Surveys of the public perception of science have been conducted nationwide in Latin American countries over the past two decades. In 2007, one of these surveys focused on six cities: Buenos Aires (Argentina), Bogotá (Colombia), Caracas (Venezuela), Panama City (Panama), São Paulo (Brazil) and Santiago (Chile). The questionnaire was developed around four topics: information and interest in science; citizenship and public policies on S&T; attitudes towards S&T; and social appropriation of S&T.

The survey found that only one in ten newspaper readers and television viewers were interested in topics related to S&T. The same held true for web searches for information on science, reading of science magazines or specialized books and visits to museums, science centres and exhibitions.

Likewise, in the part of the survey devoted to citizenship and public policies on S&T, most respondents were unable to name a single scientific institution in their country.

The results were more ambivalent when the question targeted public perception of a country's prominence in S&T: optimism was stronger in Bogotá and São Paulo, where half of respondents considered their respective countries to be 'very' or 'somewhat' prominent. The four remaining cities were more pessimistic, with Santiago (Chile) heading this category.

One set of questions analysed the value people attached to science as a career choice. Most respondents considered the profession of scientist to be rewarding, which is consistent with the high value generally attached to the profession in terms of social prestige. However, not all the cities considered the income of scientists to be adequate; whereas most respondents in São Paulo, Santiago and Caracas said that scientists in their countries were well paid, two-thirds of respondents in Buenos Aires felt that researchers received inadequate compensation.

In terms of the public perception of the risks and benefits of S&T, respondents in all but Caracas said that, in the next 20 years, 'many' or 'plenty of' risks derived from S&T activities would have to be addressed. However, this did not prevent 76% of respondents from pointing out that S&T could bring 'many' or 'plenty of' benefits. Likewise, most respondents said that they were aware of the political and economic implications of science, as well as of the need to consider criteria other than technical elements for the development of laws and regulations. Respondents also tended to be in favour of promoting citizen participation in decision-making related to S&T.

Most respondents were found to attach value to having S&T in their lives. This was reflected in their perception of S&T as being useful for understanding the world, for health care, for conservation of the environment and for decision-making in their capacity as consumers, among other aspects.

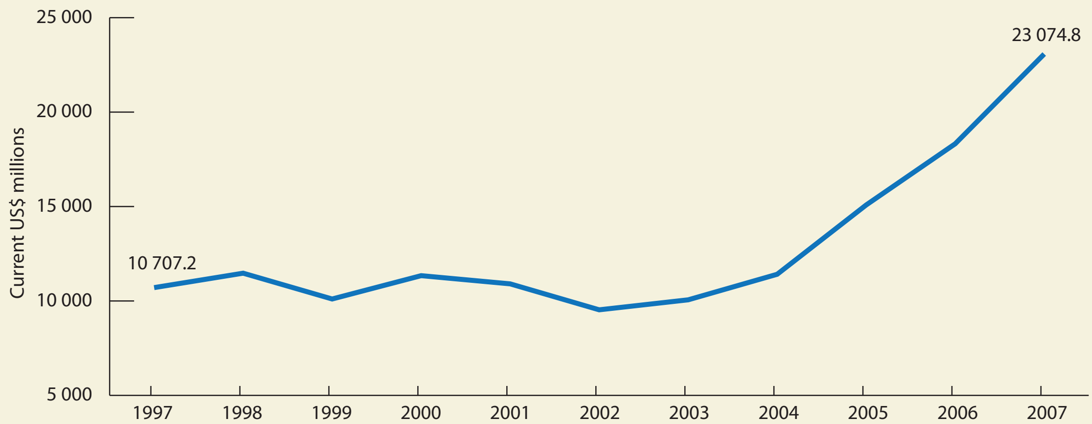
Source: authors

If we convert this figure to reflect purchasing power parity (PPP), the percentage climbs to 3.0% of the world total (*see page* 2). This suggests that Latin America's GERD/GDP ratio has remained stable since 2002, even if its global share expressed in US$ PPP is up slightly from 2.8%. Economic growth across the region has thus not translated into a stronger financial commitment to R&D. Mexico and Argentina even fall below the region's mean value, although, in the case of Argentina, this poor performance is due to the 2002 economic crash (Figure 4). Brazil, Mexico, Argentina and Chile alone account for nine-tenths of the region's investment in R&D (Figure 5).

In recent years, several countries have instituted reforms to decentralize and allocate resources via competitive mechanisms. Such is the case of Peru, which created the National Fund for Scientific and Technological Development and Innovation (FONDECYT) in 2006 to raise, manage, administer and channel domestic and foreign resources for the activities of the National Science, Technology and Innovation System (SINACYT). Furthermore, a series of initiatives have given public research institutions greater organizational and financial autonomy.

In Latin America, R&D is largely dependent on public funds. Nearly two-thirds of R&D is funded by the government. Moreover, nearly 40% of government funds are invested in university research, the remainder being channelled into public research institutes. This funding pattern runs counter to that of industrialized countries, where up to two-thirds of the resources allocated to R&D come from the business sector.

Figure 3: GERD in Latin America, 1997–2007

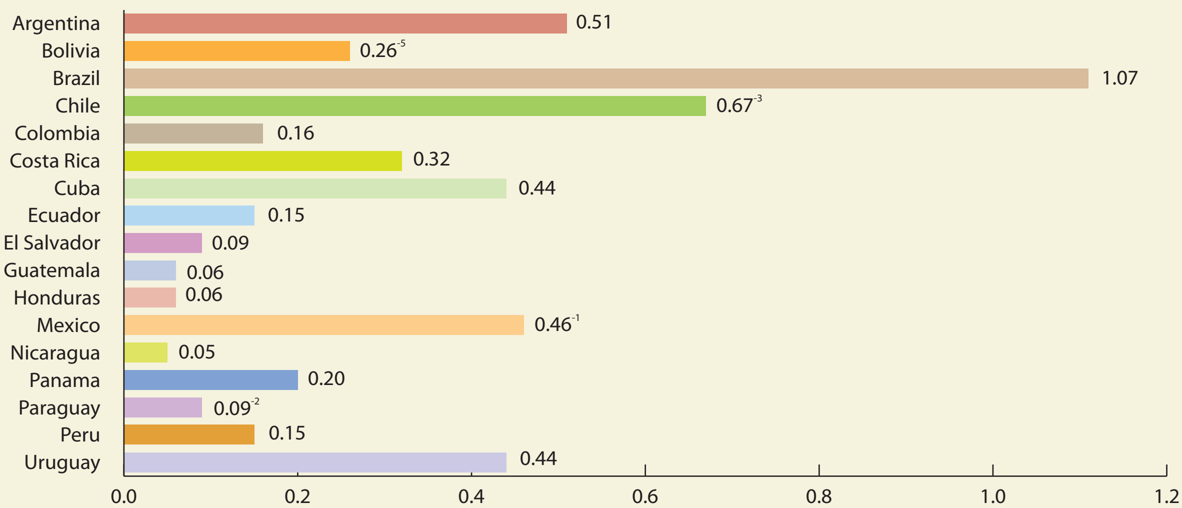


Note: does not include data for Venezuela and Dominican Republic

Source: RICYT (2009) *El Estado de la Ciencia*

Fostering private R&D investment and innovation is an issue of major concern to most countries, as it is a process that requires specific financial instruments to stimulate investment. In this context, those countries with greater relative development have incorporated more ambitious objectives in their STI policies for fostering business R&D. In Argentina, Brazil, Chile, Colombia and Mexico, policies set out to encourage innovation in small and medium-sized enterprises and to foster the development of high-tech industries and sector clusters. Additional measures to support infrastructure, modernization, technology dissemination and the training of skilled personnel are also in place. Some of these objectives are also reflected in the policies of the remaining countries.

Figure 4: GERD/GDP ratio in Latin America, 2007 (%)

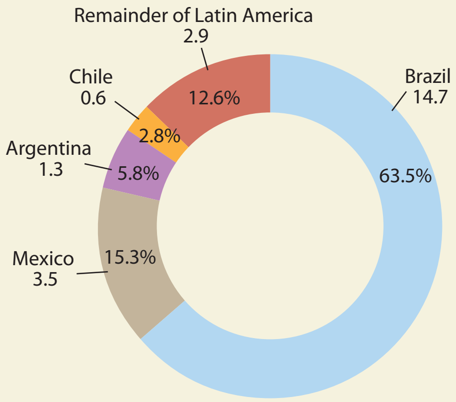


-*n* = data refer to *n* years before reference year

Source: RICYT (2009) *El Estado de la Ciencia*

Figure 5: Distribution of GERD among Latin American countries, 2007

In current US$ billions and as a percentage share



Note: The data are 2004 for Chile and 2006 for Mexico.

Source: RICYT (2009) *El Estado de la Ciencia*

Almost all countries in the region have developed instruments and provide direct public funding for business R&D and innovation. Argentina, Chile, Colombia, Mexico and Panama, for example, all use grant funds, basket funds and project-financing mechanisms. In addition, many countries have implemented tax mechanisms to stimulate R&D and innovation in this sector (*on Brazil, see page* 108). Most countries also employ other public instruments to fund innovation, such as venture capital, seed funds and measures for small and médium-sized enterprises or technology business incubators (Figure 6).

Trends in researchers

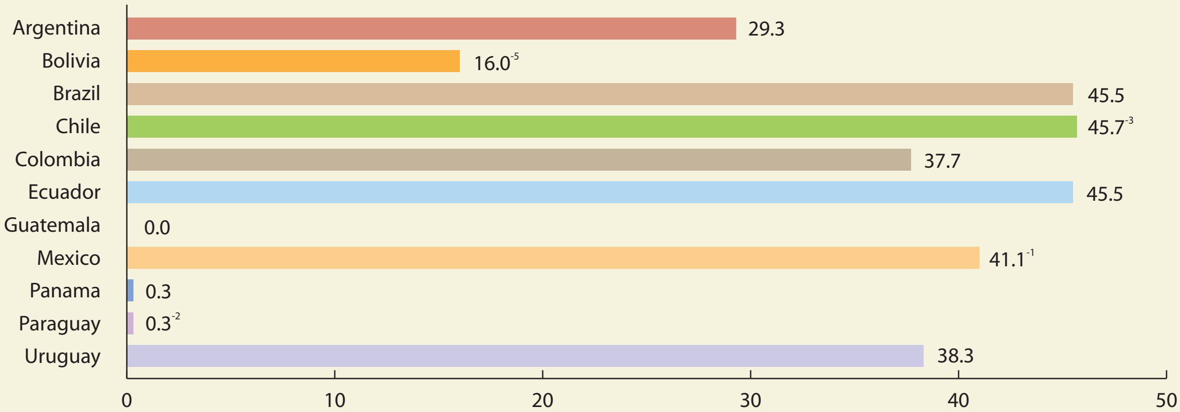
Disposing of an adequate number of scientists and engineers is a prerequisite for sustaining policies for development and social inclusion. For this indicator, the regional scenario is looking more promising than for investment: Latin American countries counted more than 252 000 full-time equivalent (FTE) researchers in 2007. Although they accounted for only 3.5% of the world total, placing Latin America and the Caribbean in a marginal position, this share is higher than that for GERD (*see page* 8).

The number of researchers and engineers in Latin American countries nearly doubled between 2000 and 2007 (Figure 7). Between 1996 and 2000, annual growth ranged between 3% and 4%. After a brief deceleration in 2001 when growth stood at around 2%, the positive trend regained momentum. This trend contrasts with the ups and downs in the curve for GERD (Figure 3).

This performance underscores the efforts made by many countries to implement training policies to consolidate their S&T base. For example, one of the main thrusts of Brazil's *Plan* for 2007–2010 is to train and retain human

Figure 6: Share of GERD funded by the business sector in Latin America, 2007

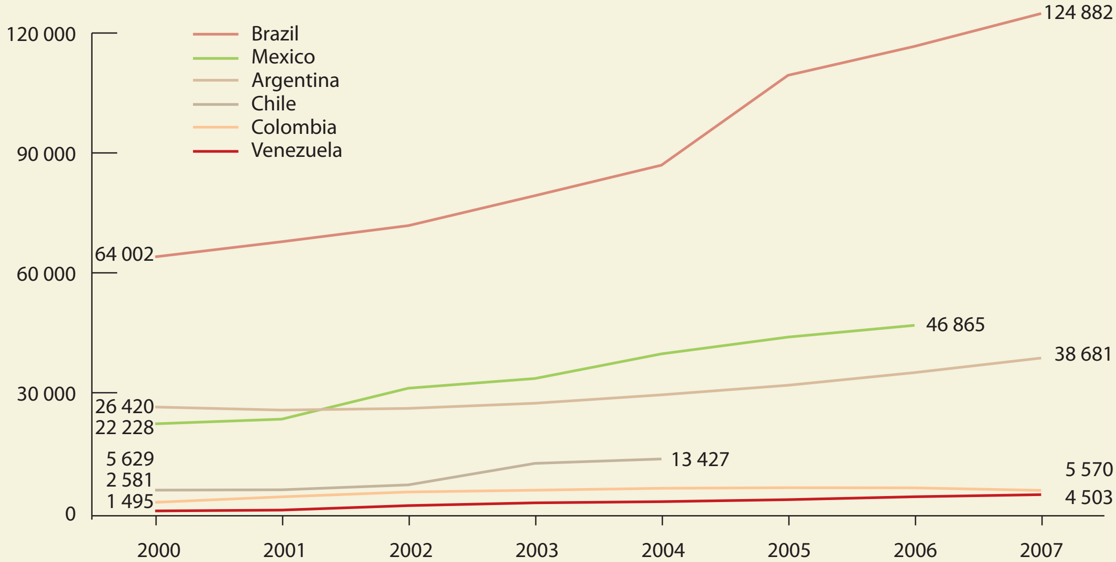
As a percentage of total GERD



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

Source: RICYT (2009) *El Estado de la Ciencia*

Figure 7: Researchers in Latin America, 2000–2007
Full-time equivalent, selected countries



Source: RICYT (2009) *El Estado de la Ciencia*

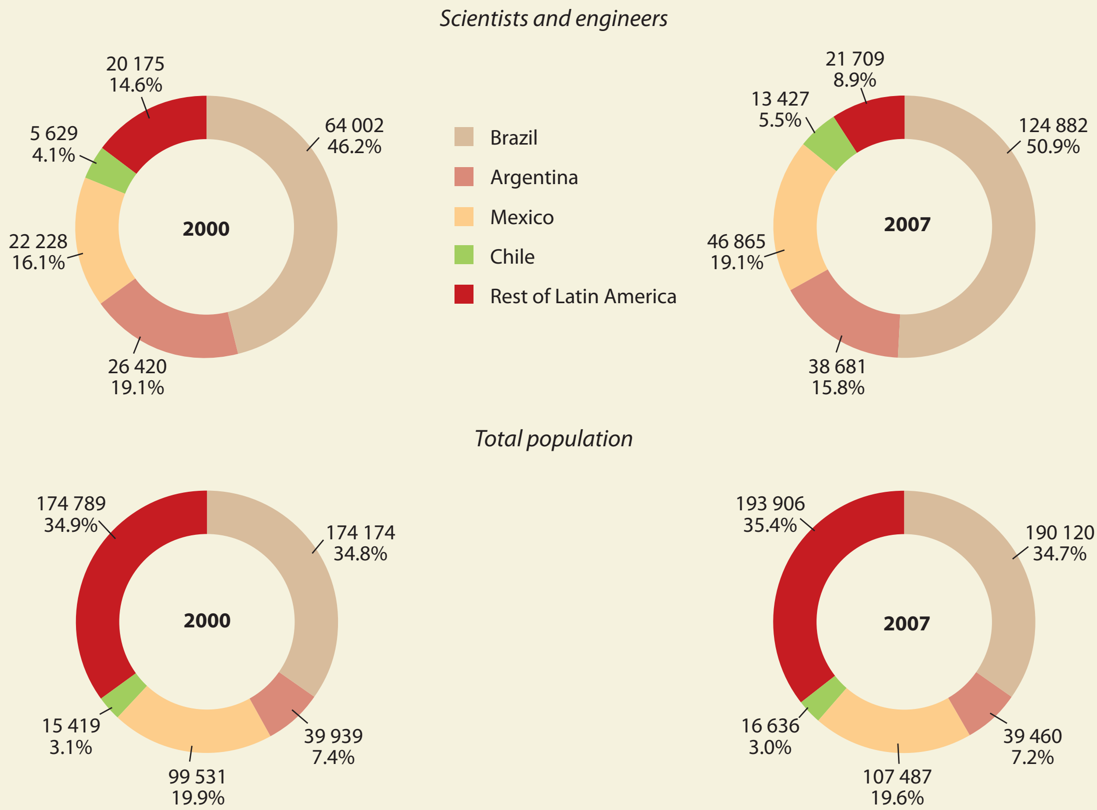
resources in priority areas (*see page* 118). Similarly, the goal of Argentina's *Medium-Term Strategic Plan* (2005–2015) is to attain the ratio of three scientists and engineers for every 1 000 Argentinians who are economically active. Argentina is moving towards this goal. Ever since 2005, Argentina's primary body for promoting S&T, the National Council for Scientific and Technological Research (CONICET), has taken in 1 500 PhD students annually, leading to a pool of nearly 7 000 active scholarship-holders in 2009. Chile and Venezuela have taken similar steps.

Nevertheless, the distribution of scientists and engineers among Latin American countries confirms the region's heterogeneity. If improving access to knowledge tools is one of the main strategies for societies wishing to embrace socially and environmentally sustainable development, there is an evident correlation between the distribution of S&T capabilities and the distribution of wealth. Figure 8 shows that four countries concentrate more than 90% of scientists and engineers in Latin America, even though some small countries like Cuba also have a high ratio (*see page* 124). The region's heterogeneity must be taken into account in any assessment of regional capacities. Moreover, strengthening the scientific capacity of the weakest countries should be an important goal of development policies and policies fostering regional cohesion.

Consolidating a country's S&T base means being able to count on a critical mass of scientists, engineers and other highly skilled professionals. This depends mainly on two factors, the existence of a university system with a high standard of excellence at the graduate and postgraduate levels, and a set of conditions preventing large-scale migration of the most highly qualified professionals.
As regards the first factor, very few doctoral candidates are trained each year in most Latin American countries (Figure 9). This is partly due to a university tradition of prioritizing excellence in undergraduate studies via much more comprehensive curricula than in English-speaking countries. If Brazil counts proportionally more doctoral candidates than Argentina, Chile or Mexico, this is because, since the 1960s, Brazil has implemented a sound, sustainable doctoral training policy (*see page* 111). Brazil also has the advantage of having a university system based on the Anglo-Saxon model, rather than on that of any other Latin American country.

Most countries offer budgetary and financial incentives, as well as scholarships, to strengthen higher education in S&T disciplines. In some countries, there are specific funding channels for improving the infrastructure of higher education centres in these areas of study. Examples are Argentina, Colombia and Peru. Furthermore, even if they differ, most countries have policies to facilitate education and the placement of scientists and engineers.

Figure 8: Distribution of scientists and engineers in Latin America, 2000 and 2007



Note: The most recent data are 2006 for Mexico and 2004 for Chile.

Source: RICYT (2009) *El Estado de la Ciencia*

Trends in migration

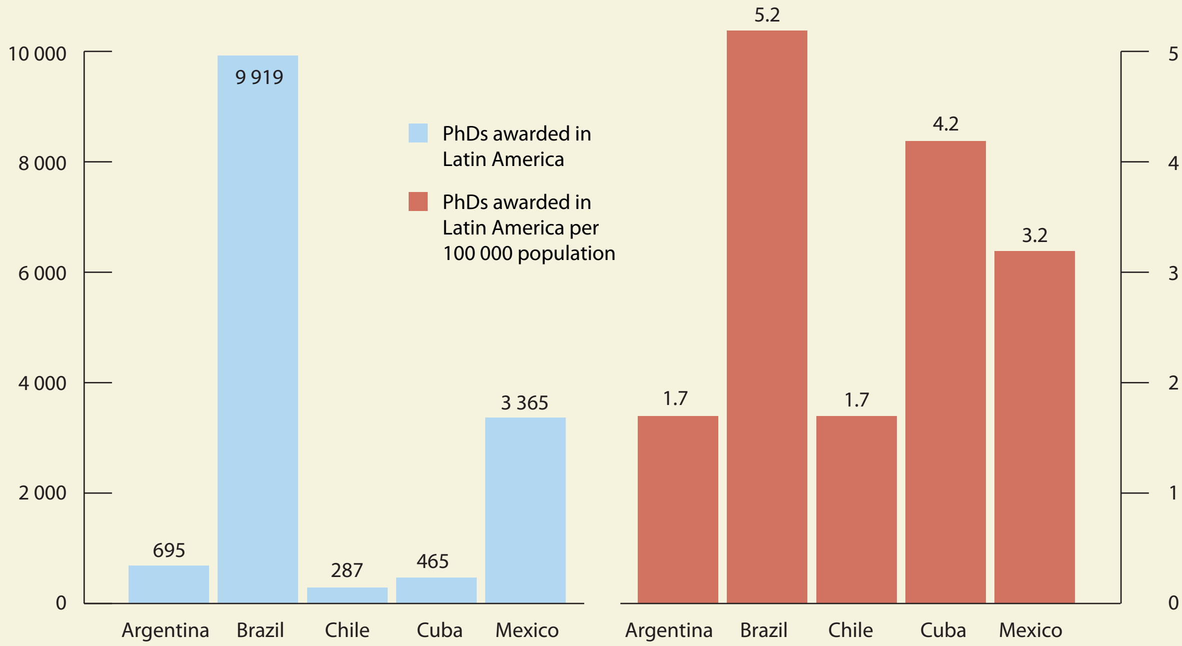
Three different aspects of brain drain in Latin America deserve consideration: the magnitude of the phenomenon, the loss of qualified personnel[2] and, lastly, the educational selectivity of migration streams or, in other words, the ratio of university-trained personnel to the total number of migrants from a country (Luchilo, 2007). Recent censuses on this theme carried out in the member states of the Organisation for Economic Co-operation and Development (OECD) show that approximately 1.5 million Latin American university graduates resided in OECD countries at the time (Luchilo, 2007). The magnitude of brain drain was low for Argentina (4.7%) and Brazil (3.3%), medium for Mexico (14.3%) and Colombia (11%), and high for Nicaragua (30.9%) and Cuba (28.9%).

Within the broader phenomenon of migration of highly qualified labour, it is particularly interesting to analyse the migration of scientists and engineers. Data from the US National Science Foundation (NSF) show that, by the late 1990s, foreigners represented 21.5% of active R&D personnel in the USA. Latin Americans made up 9% of this group, far behind the largest group, the Asians, with 60%. By the turn of the century, Spain had become another pole of attraction for highly qualified Latin American immigrants. The 2001 Spanish population census[3] shows the presence of approximately 9 000 Latin American PhD-holders residing in Spain. In 2001, most were Argentinian (1 247), followed by Colombian (907), Venezuelan (664), Ecuadorian (638) and Peruvian (576) PhD-holders.

2. Qualified personnel is defined as the ratio of university graduates to total graduates born in a given country.

3. The next Spanish population census will be conducted in 2011.

Figure 9: PhDs awarded in Latin America, 2007
Selected countries



Source: RICYT (2009) *El Estado de la Ciencia*

Two causes of brain drain are low wages in the country of origin and the underutilization of human resources, owing to the low absorption of professional and technical personnel. In addition to this, younger workers find it highly desirable to pursue graduate and postgraduate studies abroad. They generally feel that studying abroad will offer them better opportunities for their professional and economic future. The combination of a global educational offer, lower related costs and the multiplication of agreements between the universities of different countries only serve to nourish this phenomenon (Martínez Pizarro, 2005).

Gender issues

With 41% of all S&T-related jobs held by women, up 10 percentage points on a decade ago, Latin America is one of the regions with the highest female participation in science. This bright picture is counterbalanced, however, by the persistence of institutional practices and preconceptions symptomatic of a devaluation of women's work. This translates into the so-called 'glass ceiling', those invisible barriers that prevent women from attaining senior positions.

In this context, universities represent an institutional sector open to women, female participation being high in faculty and academic research positions. Although there are no aggregate data at the national level for all Latin American countries on personnel distribution by gender and institutional sector, some trends can be derived from observing countries with a high impact on regional science and those universities that enjoy great scientific prestige. In six countries of the region, women hold between 30% and 55% of all academic research positions in institutions of higher education. These participation levels are higher than in other regions, the European Union included.

In Argentina, for example, women hold 30% of all research positions in business enterprises, 46% in non-profit organizations and 55% in public universities. A similar distribution can be observed for scholarship-holders. This could translate into a build-up of the pool of women researchers in the near future. However, a not-so-optimistic interpretation points to the progressive exclusion of women as they try to advance in their scientific career.

If we compare women's participation in the economic and scientific spheres, it becomes apparent that science is more gender-inclusive in Latin America than elsewhere in the world: in half of the Latin American countries studied

(RICYT, 2009), women were better represented in the S&T sector than in the labour force in general. In some cases, there was even a gap of between 4 and 20 percentage points. The question of access to primary and secondary education is relevant in this respect, since a student needs to accumulate a certain number of years of formal education before being admitted to a university programme in science. In Latin America, a region with low- and middle-income countries but one of the world's highest levels of social inequality, school attendance by girls has progressed consistently to the point where, in some cases, girls and boys have equal access to primary and secondary education.

Gender equality has come to the university campuses of Colombia, Chile, Costa Rica, Cuba and El Salvador in recent years. Women even make up 60% of students in Uruguay, Mexico and Panama, and 55% in Argentina, Venezuela, Paraguay and Brazil. You have to look to Peru, Bolivia and a few others to find a slight gender imbalance in favour of men. Of note is that the ratio of women to total students is higher among graduates than among enrolled students, suggesting a higher graduation rate for women than men. Female enrollment has also increased gradually at the postgraduate level in almost all fields of study, on a par with the growing availability of courses in the region.

R&D OUTPUT

If scientific productivity in terms of research papers has experienced remarkable growth in the past decade, both quantitatively and qualitatively, the transfer of this knowledge to the productive sectors has made little progress. There is a lack of dynamism in the region when it comes to patenting, suggesting that Latin American countries (led by Brazil) are far more present in the 'science mainstream' but unable to translate this into innovation.

Trends in scientific papers

The number of papers by Latin American authors listed in Thomson Reuter's Science Citation Index (SCI) more than doubled between 1997 and 2007. Although this indicator is controversial for some disciplines, it nevertheless illustrates a substantial increase in the quality of science in Latin American countries.

The share of Latin American scientists in the SCI grew steadily between 1997 and 2007, from 2.3% to 3.4%. Sustained steady growth relies on the performance of the most dynamic Latin American countries, particularly Brazil, which went from accounting for 41% of Latin American papers in 1997 to 47% in 2007. All countries experienced growth, albeit to a lesser degree in most cases. One exception is Peru, where the number of scientific papers tripled between 1997 and 2007. Interestingly, Mexico, with output similar to that of Argentina, has surpassed the latter ever since Argentina's economic crisis in 2002 (Figure 10).

In other databases, a similar phenomenon can be observed and, in some cases, the progression is even steeper. In PASCAL, a multidisciplinary database created in France by the Institute for Scientific and Technical Information of the National Centre for Scientific Research, the Latin American share nearly doubled between 1997 and 2007 from 2.2% to 3.8%. In the database of the Commonwealth Agricultural Bureaux (CAB), the Latin American share was even greater but growth was smaller: from 5.4% in 1997 to 7.8% in 2007. In the Chemical Abstracts database (CA), the share was smaller but did increase from 1.5% to 2.0%. Databases in biology (BIOSIS), medicine (MEDLINE), engineering (COMPENDEX) and physics (INSPEC) followed the same general trend (Figure 11).

It is worth pointing out that Argentina, Chile and Venezuela share a common pattern of growing output in papers involving international collaboration, with the flipside being a falling number of non-collaborative papers. On the other hand, the ratio of published collaborative papers to non-collaborative papers for Brazil and Mexico, the countries with the greatest output in Latin America, has remained unchanged.

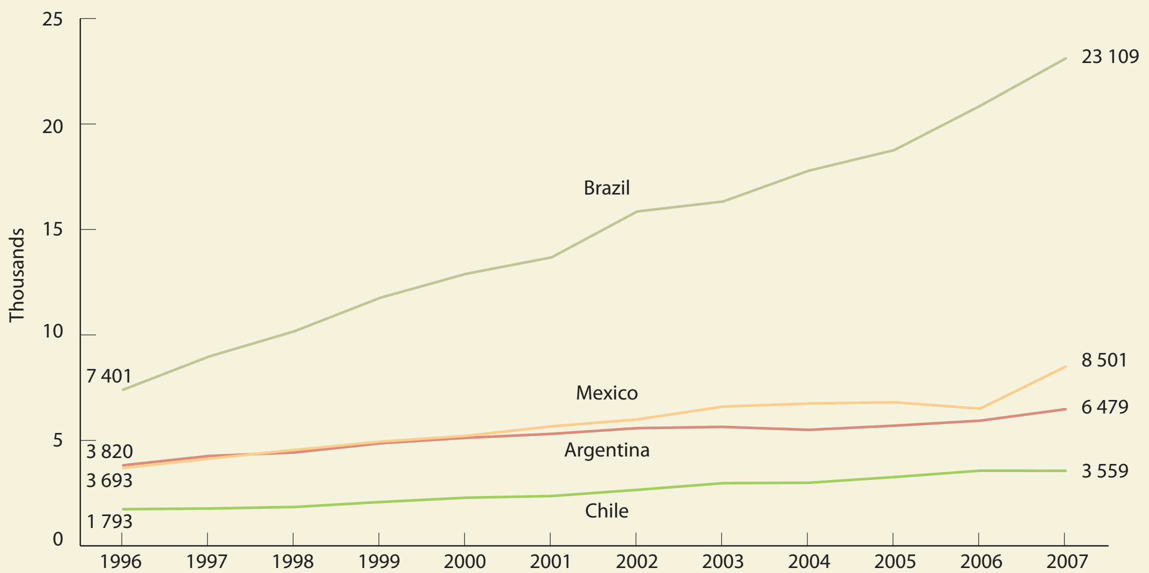
Trends in patents

The number of patents is one of the indicators used to measure the efficiency of R&D systems in exploiting knowledge in the economic sphere. This indicator is less relevant for Latin America than for more industrialized countries insofar as both the economic structure and legal frameworks discourage patenting in most Latin American countries. However, an analysis of patent data helps to understand the technological situation in the region and confirms the initial diagnosis that research in Latin America is conducted primarily in academic settings with extremely weak ties to industry.

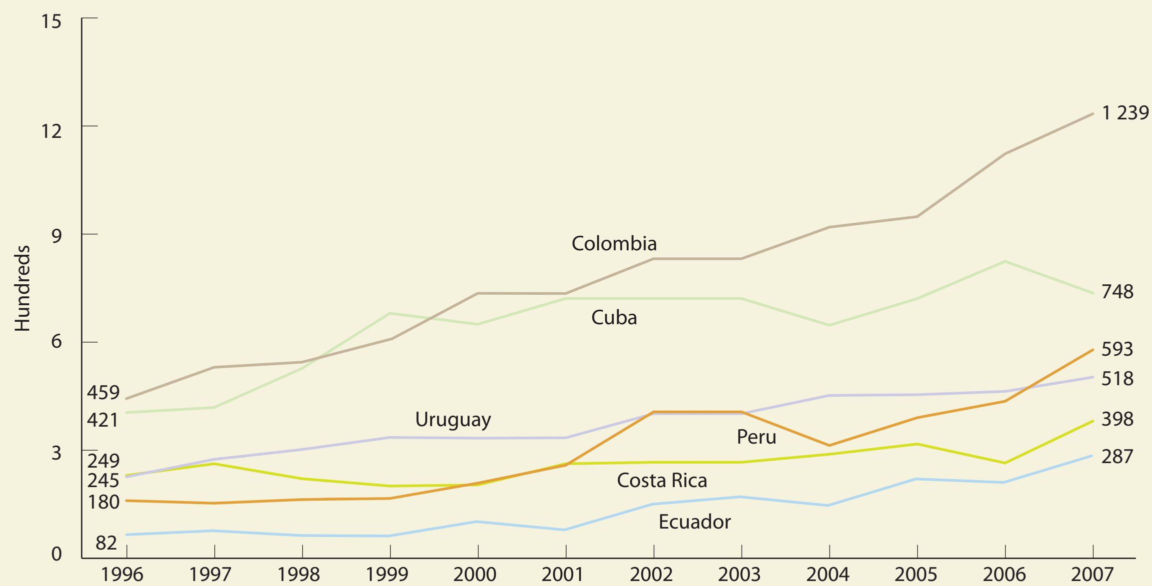
The number of resident patent applications in Latin America grew by more than one-third over the period 1997–2007. The number of non-resident patent

Figure 10: Scientific publications in Latin America, 1996–2007

Share of papers for top 4 Latin American countries

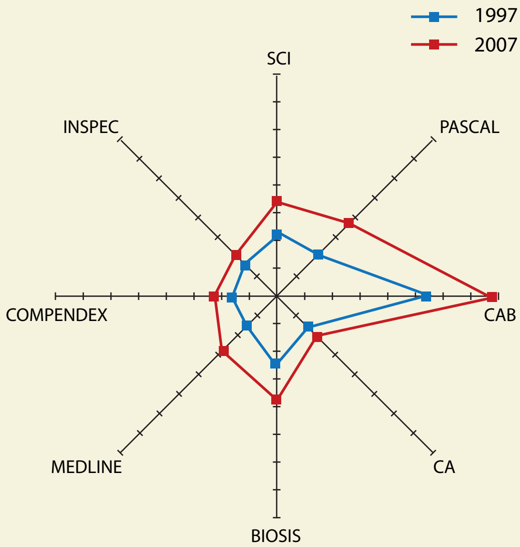


Share of papers for middle 6 Latin American countries



Source: RICYT

Figure 11: Latin America's presence in various bibliographic databases, 1997 and 2007

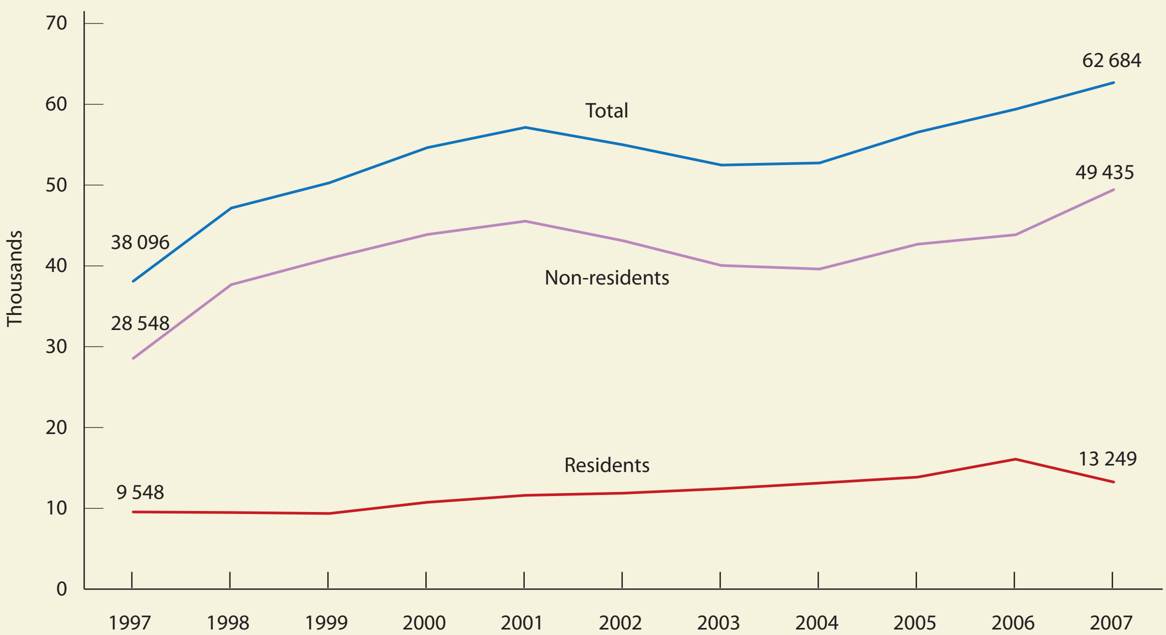


Source: RICYT (2009) *El Estado de la Ciencia*

applications grew even faster, by almost 60%. By 2007, non-resident patent applications were three or four times more common than those filed by residents: of 63 000 patents filed in 2007, just 21% were filed by residents (Figures 12 and 13). This distribution is in marked contrast to the figures for industrialized countries.

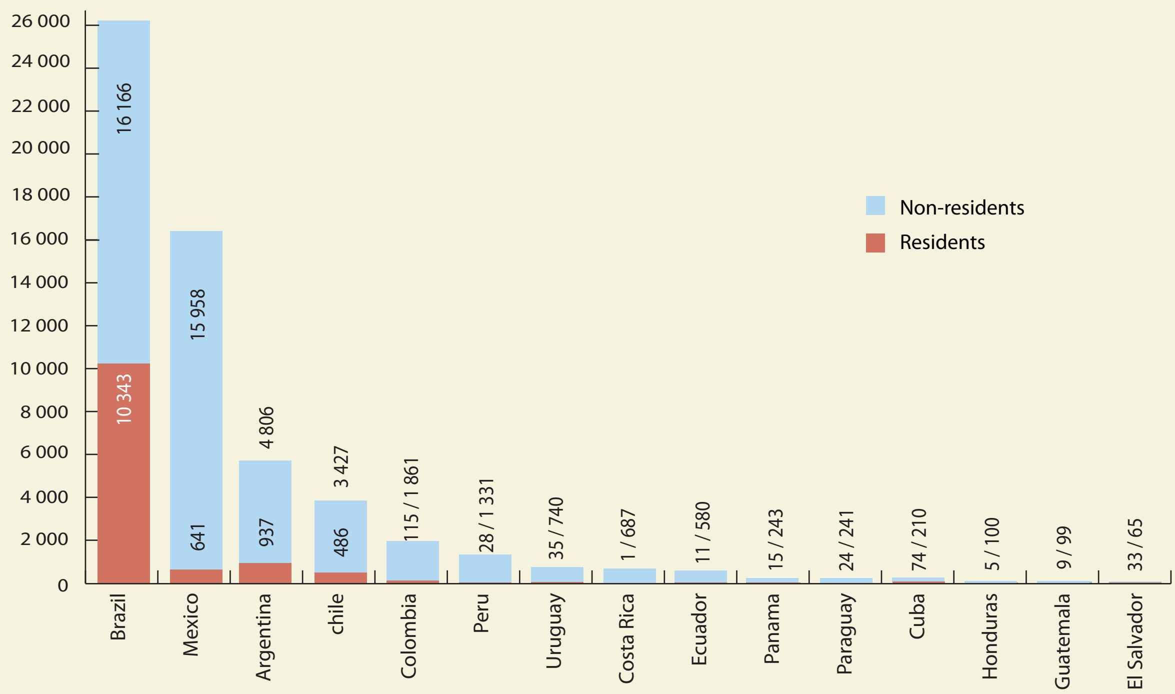
International patent databases provide a measure of protected inventions in the main markets around the world: the European Patent Office (EPO), the United States Patents and Trademark Office (USPTO) and the Patent Co-operation Treaty (PCT) database of the World Intellectual Property Organization (WIPO). The USPTO database is a very important indicator of technological development around the world. Over 180 000 patents are granted each year in the USA to holders from all countries. In the 2000–2007 period, the four Latin American countries with the greatest presence totalled 1 591 patents, 43% of which belonged to Brazil. The EPO database, which registers over 55 000 patents a year, included 222 patents from the most dynamic Latin American countries, 138 of

Figure 12: Evolution in patent applications in Latin America, 1997–2007



Source: RICYT

Figure 13: Patent applications in Latin America by residents and non-residents, 2007



Note: Data are 2006 for Brazil and 2005 for Ecuador and Paraguay.

Source: RICYT (2009) *El Estado de la Ciencia*

which were granted to Brazilian patent-holders. The last database is that of the PCT treaty, administered by WIPO. This database contains a total of 3 824 records from the top four Latin American countries, 62% of which are accounted for by Brazilian authors (Figure 14).

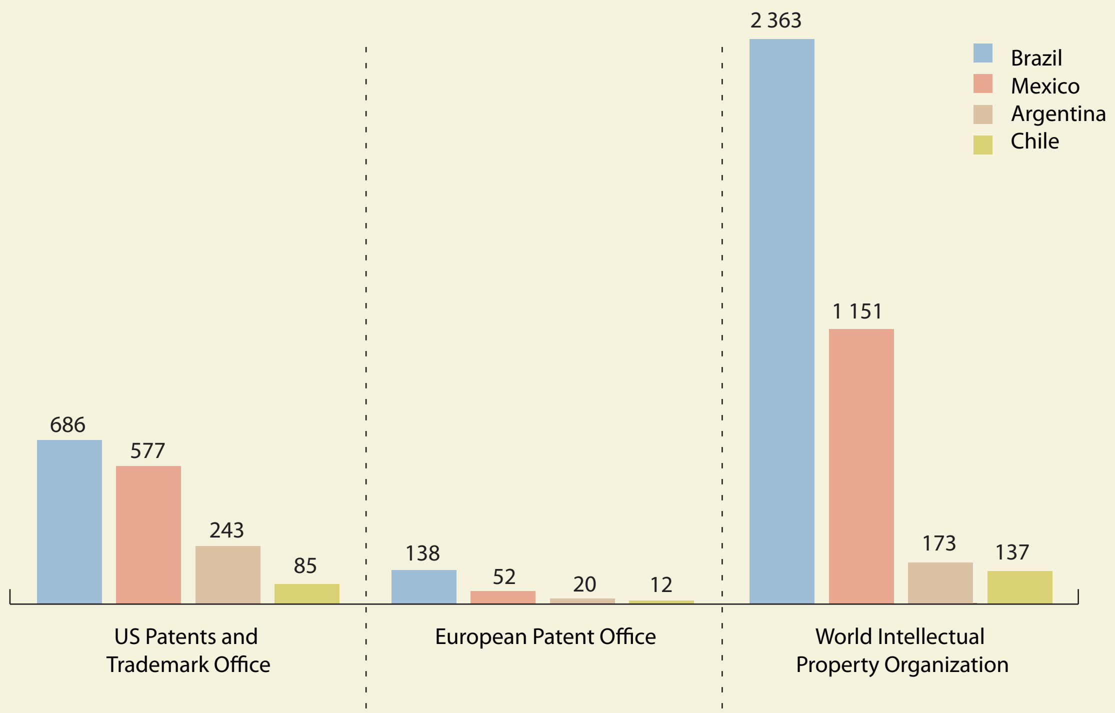
Various diagnostic studies and S&T policy documents elaborated by experts and governments in the region show that S&T systems in Latin America are characterized, with some exceptions and nuances, by a lack of strong links and poor co-ordination between the public R&D sector – encompassing universities mainly – and the business sector.

The policies implemented show that the question of stimulating co-operation between the public and private sectors has been a fairly recent concern. This concern has translated into the creation of instruments to promote public–private sector co-operation in R&D and innovation. There is a series of instruments available in those countries with greater relative development, in the form of support programmes for the development of R&D and innovation via public and private consortia.
In this area, Chile, for instance, has chosen innovative formats (Box 3). The creation of centres of excellence and sectoral clusters comprising both public and private institutions and the promotion of business incubators and technology parks are also part of this experiment to dynamize links between the private and public sectors. Most countries have put in place technology transfer and dissemination policies, as well as programmes for the development of technology infrastructure and access to new technologies. Technological development and extension centres have become widespread in the region.

NEW R&D PRIORITIES

R&D priority-setting in the region via related policies has undergone different stages. Initially, the criteria for resource allocation were exclusively oriented towards excellence, in keeping with the guidelines for basic research. During the years when emphasis was placed

Figure 14: Patents held by Latin Americans in international databases, 2000–2007



Source: Prepared by CAICYT (CONICET)

on applied research and technological development, priorities were established around productive sectors and public administration. Currently, in line with the new institutional orientations mentioned above, issues related to innovation and the generation of a competitive advantage have made their way onto the agenda. Countries with greater relative development have incorporated priorities in those S&T fields with the greatest potential, such as biotechnology, nano-technology and information technologies. In parallel, several countries have developed medium- and long-term strategic plans.

There is an array of different instruments in Mexico for promoting STI. These policy tools have three main thrusts: training of scientists and engineers, scientific research, and innovation and technological development. The first of these thrusts includes several postgraduate scholarships, as well as employment services and instruments for co-operation. The second thrust includes specific instruments for supporting basic and applied research as well as incentive measures for the repatriation of researchers residing abroad. Last but not least, the area related to innovation and technological development provides businesses with tax incentives, programmes offering researchers sabbatical stays in the industrial sector and mechanisms designed to foster innovation networks.

In Argentina, the *Medium-Term Strategic Plan* (2005–2015) has been designed to address challenges related to innovation and social development. The *Plan* establishes four strategic goals to guide the medium- and long-term development of STI. The first goal has a social dimension and relates to improving quality of life and social development. The second goal addresses the responsible exploitation of natural resources and environmental protection. The third goal relates to strengthening innovation in industry and agricultural production, particularly in the most advanced fields, those that nurture the development of a knowledge economy and society. The fourth goal sets out to strengthen Argentina's S&T capabilities and develop its support infrastructure.

Box 3: R&D technology business consortia in Chile

Consortia are instruments designed to strengthen the relationship between science and the users of scientific advances in the public and private sectors at national and international levels, with a view to creating new business opportunities and boosting competition. A technology consortium is an association of business entities and academic, scientific and technological institutions formed to undertake joint development of a research, development and innovation programme. This instrument seeks to make a significant impact through the adoption, transfer and commercialization of research results.

The consortia in Chile were created in 2006 to develop cutting-edge S&T research through public–private partnerships. The aim is to apply knowledge to industry, with a view to bringing together the different links in a given production chain. These mechanisms have been designed to enable productive companies, universities and other technological entities to form alliances to solve production challenges have a bearing on competitiveness and, in the process, develop new products, patent any breakthroughs and commercialize them.

These consortia receive support from three quarters: the Bicentennial Science and Technology Programme of the National Commission on Scientific and Technological Research (CONICYT), the INNOVA Chile programme of the Production Development Corporation (CORFO) and the Fundación FIA (Foundation for Agricultural Innovation) of the Ministry of Agriculture. The consortia receive considerable financial support of around US$ 34.5 million in public funds, in order to implement initiatives over a maximum period of five years.

Turning to the private sector, the idea here is to mobilize much larger sums of money from the participating companies and technological entities. Each initiative has to take the form of a business entity, the specialization of which will ensure excellence in research and the application of the results to the productive sector via the adoption, transfer, commercialization and dissemination of research findings, as well as training and inclusion of highly qualified personnel in areas of crucial importance for both Chilean industry and the regions. The first technology consortia are focusing on fruit-farming, the dairy and wine industries, forestry, health research, aeronautics and the development of by-products from waste generated by export industries.

Source: authors

Nanotechnology

Nanotechnology is witnessing rapid development worldwide, as reflected in the number of scientific publications and patents: around the world, the number of scientific articles on nanotechnology and nanosciences listed by the SCI doubled between 2000 and 2006 and the number of patents granted through the PCT increased by more than 30%. Latin America has followed the global trend: its publications on nanotechnology grew by 95% between 2000 and 2006. Several countries in the region are striving to seize the opportunities offered by this field.

As in other fields, Brazil is the most prominent country for nanotechnology: in 2006, it ranked 18th in the world for publications related to nanotechnology, with 827 articles indexed by the SCI. Mexico came second with 376 articles (26th) and Argentina third (37th) with 220. Trailing these countries, we find Chile (with 104 publications), Colombia (60) and Cuba (45). Taking into account that, in 2006, 49 433 articles on nanotechnology were indexed by the SCI, the total output of these six countries amounts to 3.3% of the total. This percentage share tallies with Latin America's average contribution to the large databases on exact and natural sciences. However, this number greatly exceeds the region's average contribution to the fields of physics, chemistry and technology.

Nanotechnology tends to give rise to collaboration. An analysis of the publications produced jointly by Latin American and non-Latin American authors shows strong co-operation between the USA and Brazil, through which other Latin American countries such as Colombia and Cuba are participating in the global network.

Mexico likewise has direct ties with the USA. Spain, meanwhile, serves as a rallying point to the global network for countries such as Argentina, Chile, Uruguay and Venezuela.

The region's weakness in terms of productivity becomes apparent when we examine the number of patents filed in the PCT database. This database lists 43 887 nano technology patents granted between 2003 and 2006, out of which only 100 (0.22% of the total) are held by Latin Americans. In this context, Brazil is, once again, the leading country insofar as it holds 45 of the 100 patents, followed by Mexico with 20, Argentina with 11 and Chile with 9. The remainder of the patents belong to Cuba, Honduras, Panama and Uruguay. Of note is that, in 2006, Brazil doubled the number of patents it had held in 2003.

The region's showing improves slightly when it comes to inventors: according to the PCT database, 277 patents (0.51% of the total) belonged to a Latin American inventor for the period 2003–2006. Once again, first place goes to Brazil, with 84 patents. Argentina ranks second, with 46 patents, followed by Mexico, with 41. Chile trails this group with 18 patents and Colombia with 13 – reflecting the fact that Colombian investors participated in developing patents even though the country does not own any. There were ten other Latin American countries where local investors owned patents.

Going against the global trend, the specialization of Latin Americans in the field of nanomedicine and nanobiology (BIO) is remarkable and has earned them third place in the world. This field represents 82% of the patents granted to Argentina, 69% of Brazilian patents and 45% of Mexican patents.

In conclusion, there are encouraging indicators for nanotechnology in Latin America, in spite of the fact that the region is going through an incipient stage of development in this field. Both the number of articles published in scientific journals and the volume of patents have grown in recent years. However, the region's percentage share for both articles and patents related to nanotechnology remains low. In this field, the productive structure would seem to be lagging behind the academic capacity. In this regard, Latin Americans conducting R&D on nanosciences and nanotechnology – two fields which are increasingly being integrated into international networks – represent a reservoir of capacity.

Biotechnology

The region's capabilities in biotechnology are, to a large extent, derived from its historical S&T development. There are various institutions and groups in Latin America with a long-standing tradition in agricultural research and biology, among other areas related to biotechnology research. Brazil, Argentina and Mexico stand out in this field. Among the leading groups in Brazil are those based at the University of São Paulo, the Fiocruz Foundation and the University of Campinas. In Argentina, the University of Buenos Aires, the Institute of Biology and Experimental Medicine (IBYME) and the National University of La Plata occupy a prominent place. The National Autonomous University of Mexico (UNAM) is also of international repute.

Latin America provides 3% of the 365 783 documents on biotechnology available in the SCI for the period 2000–2007. Within Latin America, MERCOSUR countries (*see page* 96) account for 65% of publications, or 2% of the world total. Brazil's leadership in this field is unrivalled: the country accounts for 76% of articles produced by MERCOSUR countries and 49% of articles for Latin America as a whole. Brazil's growth in recent years largely exceeds that of its regional peers. The trend has even accelerated: in 2000, Brazil increased its productivity by a factor of 2.5 over its immediate rival in biotechnology, Mexico; in 2007, Brazil's productivity grew by a factor of 3.3. If we contain the analysis to the MERCOSUR countries, the picture is similar: whereas, in 2000, Brazil produced twice as many articles as its immediate rival in the trade bloc, Argentina, in 2007 it produced four times as many. Even though Mexico and Argentina have shown very similar production rates and growth patterns over the same period, Mexico has experienced slightly higher growth than Argentina since 2002.

This bibliographical analysis reveals that Latin American countries tend to build relationships with the leading countries in this field. This is hardly surprising, considering the degree of concentration in biotechnology worldwide: the USA, Japan, Germany, UK and France produced slightly more than 70% of all papers on biotechnology published in 2000–2007. As a result, Latin American countries have tended to build stronger relationships with extra-regional countries – mainly the USA and, to a lesser extent, in Europe – than with each other. Brazil and Argentina have, for example, developed ties through joint publications with authors from countries beyond the region.

Box 4: Aeronautics in Brazil: the case of EMBRAER

The development of the aeronautic industry was promoted by the Brazilian government in the 1940s as an instrument for the country's technological development. The first step towards this goal was the founding in 1954 of the Institute for Research and Development (IPD), the current Aeronautic and Spatial Institute (IAE). In 1965, the IPD was entrusted with designing a plane equipped with a turboprop engine. The aircraft made its maiden flight three years later before being commercialized under the name of Bandeirante.

In 1969, the Ministry of Aeronautics created the *Empresa Brasileira de Aeronáutica S.A.* (Brazilian Aeronautic Enterprise, EMBRAER). EMBRAER's mission was to produce aircraft designed using Brazilian technology on a commercial scale. Bandeirante's first three series were delivered to the Brazilian Air Force in 1973. In the same year, the firm Transbrasil purchased the first Bandeirante for commercial use. The planes were first exported in 1975. EMBRAER would ultimately conquer 36 markets around the world.

On the orders of the Ministry of Aeronautics, EMBRAER developed its first combat aircraft, the Tucano, which made its maiden flight on 16 December 1980. The aircraft would go on to become the most successful project for military training ever built, with more than 650 units sold all over the world.

In July 1981, EMBRAER was invited to join the Italian AMX International Programme to construct a subsonic combat aircraft. Together with an Italian firm, EMBRAER worked on developing the AMX fighter, designed to replace the old military fleets of Italy and Brazil. The first Brazilian AMX made its maiden flight on 16 October 1985. This project allowed EMBRAER to access new technologies that would be crucial for future projects.

The development of a regional aircraft to replace the Bandeirante began in the late 1970s. The result was a twin-turboprop commercial airliner called the EMB-120 Brasilia with a capacity for 30-40 seats certified for commercial service in 1985. Unlike the Bandeirante, the Brasilia started out as an export product, entering into service for the American airline Atlantic Southeast Airlines. The EMB-120 Brasilia owed its success to the trust won by EMBRAER in the world aviation market thanks to the Bandeirante.

Officially, production of the Brasilia ended in 2002 with 350 units having been sold; however, the aircraft is still being produced on demand.

Today, EMBRAER produces commercial, military and business aircrafts. It has always been one of Brazil's top three exporters. Worldwide, EMBRAER is the third-biggest airline manufacturer after Boeing and Airbus for the number of staff and the amount of aircraft delivered annually. The company has its headquarters in São José dos Campos in São Paulo where its main factory and centre for design and engineering are also located.

On 31 May 2005, EMBRAER announced plans for two new aircraft, the Phenom 100 and 300, oriented towards the business aviation market. The new models are intended to complement the existing offer of the Legacy 600 in the segments of light and very light aircraft. In addition, the company announced in May 2006 the forthcoming commercialization of an executive version of its jet E-190 known as Lineage 1000. The first two aircraft were delivered in December 2008.

Source: authors

One-third (37%) of the papers written by Brazilians on biotechnology in the period under review were written in collaboration with scientists from other countries. Of the total, 83% is accounted for by five countries: almost half (47.6%) are publications in collaboration with the USA, while between 11.0% and 6.5% are produced in collaboration with France, the UK, Germany and Canada. Meanwhile, 48% of Argentina's total production in this field results from collaborative work with other countries: the USA accounts for 34%, whereas Spain, Brazil, France and Germany account for between 17% and 10% each.

As regards patents, the WIPO database lists, through the PCT, 73 231 patent filings on biotechnology within the period 2000–2007. Two hundred and thirty patents are held by Latin Americans from 11 countries. Of these countries, only three owned patents for each year during the said period: Brazil (82), Cuba (55), a protectionist country in terms of inventions which fosters patenting over publication, and Mexico (51). Argentina held 15 patents throughout this period, showing significant growth over the last two years.

Box 5: Argentina's technological showcase: the case of INVAP

INVAP is an enterprise that has excelled in the field of nuclear, space and industrial development over the past 30 years. It was founded in 1976 as a joint venture between the National Atomic Energy Commission and the government of the Province of Rio Negro. It is an exceptional case in the region, as it is a leading international supplier for the global nuclear and satellite technology market. Run like a private enterprise, INVAP has attained a high level of sophistication in technological development equivalent to that of enterprises from most developed countries.

INVAP is also a shining example of co-ordination between the public and private sectors. Emerging initially as a spin-off of the Argentine National Commission for Atomic Energy, the enterprise is a reflection of a policy for training highly qualified personnel which has been sustained over time by the Rio Negro government. At the same time, INVAP is the living proof that a national technology producer can find a place in the global market. Most notably in the field of nuclear energy, the firm has positioned itself as a supplier to various emerging economies, although sales to countries with greater relative development have also been recorded.

INVAP did not take long to become an exporter of nuclear technology. By the early 1980s, it had sold equipment and systems to Romania, India and Peru. The most noteworthy exports in the enterprise's history have been, however, those of research reactors. INVAP has built this type of equipment in Peru (1978), Algeria (1985), Egypt (1995) and Australia (2000). Construction of the reactor in Peru constituted a strategic decision that would ultimately make Argentina an exporting country for this type of technology. This initial step enabled the enterprise to accumulate extensive skills that have favoured its growing integration in foreign markets, driven by an aggressive export policy that has been sustained ever since.

In parallel, the enterprise has developed capacities in nuclear medicine. INVAP develops and manufactures equipment and accessories for radiotherapy and related areas, in addition to offering consultancies and other services for the development and operation of radiotherapy. The enterprise has exported equipment to Venezuela, Syria, India, Egypt, Brazil and Cuba.

In a more recent development, INVAP has ventured into the construction of space satellites. In co-operation with the National Space Activities Commission (*Comisión Nacional de Actividades Espaciales,* CONAE), the enterprise has to date designed and built three Scientific Applications Satellites that are still in operation. The space agencies of the USA, France, Italy, Denmark and Brazil have all used these satellites to install their own apparatus and services, and other countries have expressed interest in adding their own. Thanks to this work, INVAP has become the pivot for co-ordination between Argentinian space and nuclear networks.

Source: authors

In sum, the region is brimming with opportunities to develop biotechnology. Several groups are currently working in this field, in tandem with groups which are world leaders. Several successful examples, such as the cloning of calves in Brazil and Argentina at the turn of the century, illustrate the region's potential in this field.

Technological development

Despite the fact that many of the plans drawn up by S&T agencies have not translated into effective improvements in productivity, many Latin American countries have succeeded in developing major technologies. This has been achieved either as a result of stakeholder interest or strategic decisions sustained by successive governments over time in the form of state policies. The most outstanding examples of stakeholder interest relate to technological capacities acquired initially to serve the military but which were subsequently adapted by economic interests for peaceful applications. Both the Brazilian aeronautics industry and Argentine nuclear technology are worthy of mention (Boxes 4 and 5). In the field of ICTs, Costa Rica's policy has been exemplary (Box 6).

Box 6: ICTs in Costa Rica

With a population of just 4 million, Costa Rica has managed to position itself in recent years as a leading producer of information technology (IT) in the region. One milestone was the arrival of Intel in 1998. Other high-tech multinational companies like Hewlett-Packard and IBM soon followed suit. The arrival of these firms, along with the creation of similar domestic firms, has generated around 100 000 jobs.

The IT enterprises of Costa Rican origin are mainly based on software production. According to a 2005 survey, these enterprises devote as much as 12% of their budget to R&D. However, the same survey reveals a lack of linkages between firms and universities. Most R&D-allocated funds come from the enterprises themselves. Other funding sources – such as universities, international organizations and foundations – appear to be marginal.

Costa Rican IT development has been oriented towards exports. The country is currently the region's main high-tech exporter to the USA and its products also reach the markets of Mexico and other Central and South America countries. However, the Costa Rican IT industry does not owe its competitiveness to either exports or low labour costs but rather to its highly qualified workforce, the product of education policies sustained for decades. Almost all professionals in the sector hold a university degree, even if the proportion of professionals with a master's degree or PhD is relatively low. In addition, the country has deliberately avoided attracting cheap labour-intensive industries to its shores, thereby providing a safeguard against competitors offering lower costs.

In parallel, there is a transparent, predictable system in place for attracting foreign direct investment. This favours the establishment of international firms on Costa Rican soil. The country has also been able to project an image of stability and democracy. These factors are complemented by natural assets: the country enjoys a favourable geographical position, with ports on both the Atlantic and Pacific oceans, and a capital that is only a two-hour flight from Miami in the USA.

Source: authors

TRENDS IN SCIENTIFIC CO-OPERATION

The Mercado Común del Sur, or MERCOSUR, groups five countries: Argentina, Brazil, Paraguay, Uruguay and Venezuela. At the time of its founding in 1991, there were only four members. They were joined by Venezuela in 2007.

In 2005, the MERCOSUR adopted the Science, Technology and Innovation Framework Programme for 2006–2010, to promote the advancement of knowledge in strategic areas, including scientific knowledge of natural resources. This framework programme established four programmatic goals. The first relates to the 'strategic dimension of some research fields and includes STI activities to address adequately the challenges facing the region and its particularities. The issues to be considered in this area relate to advanced and alternative energy (hydrocarbons, hydraulic, nuclear and biomass energy), sustainable development (non-renewable natural resources, urban development, sanitation, etc.), ICTs, biotechnology, nanotechnology and new materials.

We can see from the foregoing that explicit R&D policies formulated by those Latin American countries with greater capacities in S&T have in common that they tend to be aligned on major world trends with economic goals, particularly investment in biotechnology and nanotechnology. They give little priority to social issues and emphasize some advanced fields, such as nanotechnology and biotechnology, in accordance with the economic relevance of both. However, it is worth questioning whether the magnitude of the effort being made will suffice to bring about major achievements. Some common activities, however, have been developed in biotechnology and information society technologies, with the financial support of the European Union.

Latin American countries have grasped the importance of internationalizing R&D. In many countries, programmes have been put in place to promote international co-operation in R&D as well as programmes for co-operation in specific areas, such as energy, biotechnology and ICTs.

Almost all Latin American countries are linked to one another through bilateral co-operation agreements which include horizontal co-operation mechanisms in S&T. One example is the Argentinian–Brazilian Biotechnology Centre (CABBIO), which dates from 1987. It co-ordinates a network of biotechnology research groups that implement binational projects. High-level training is also dispensed via the Argentinian–Brazilian Biotechnology School (EABBIO) run by CABBIO (UNESCO, 2010). The South American Programme for the Support of Co-operative Activities in Science and Technology (PROSUL) was created, at Brazil's initiative, in 2001. The idea behind it was for a common platform to be established for regional initiatives supported by the programme. In future, the platform will favour the development of projects of common interest that could be submitted to national and multilateral fora dedicated to the promotion of R&D. (*For details of other Brazilian initiatives, see page* 117.)

Another experience worth mentioning is the Andrés Bello Agreement,[4] the secretariat (SECAB) for which administers a forum for co-operation in STI. In the private sector, the impact of the Latin American Association of Technological Management (ALTEC) is noteworthy.[5]

International organizations have actively promoted co-operation in STI in Latin America, particularly UNESCO and the Organization of American States. Other international bodies have played a prominent role in their capacity as a factory of ideas for development strategies. These include the United Nations Industrial Development Organization (UNIDO), the United Nations Development Programme (UNDP), the Pan-American Health Organization (PAHO) and the United Nations Economic Commission for Latin America and the Caribbean (ECLAC). Last but not least, it is important to mention the pivotal role played by the InterAmerican Development Bank (IDB) in financing the development of R&D activities and infrastructure in the region. Over the past 20 years, the IDB has disbursed hundreds of billions of dollars in loans to several Latin American countries for the purpose of strengthening their S&T capacities. To a lesser extent, the World Bank has also contributed to the financing of S&T policy-making. It has also had an influence on the re-engineering or redesigning of institutions.

Latin America's co-operation with the European Union in the field of STI has developed along two avenues since the Interregional Framework Co-operation Agreement between the European Community and Mercosur was signed in 1999: participation in the European Union's six-year framework programmes for research and technological development, and co-operation specifically oriented towards specific issues defined by the European Commission. One example is BIOTECSUR, a biotechnology platform that is part of the Biotech MERCOSUR European Union project resulting from an agreement signed in November 2005 by the European Community and MERCOSUR (UNESCO, 2010). The homogeneity of the instruments implemented has gradually given rise to co-operation agreements involving several countries and, subsequently, to 'block to block' agreements like that entered into by the European Union and the MERCOSUR in 2010 for a political and trade association.

Currently, there is a slew of instruments available for Latin American co-operation in S&T, among which the Ibero-American Programme of Science and Technology for Development (CYTED) has occupied a prominent position since 1984. The purpose of CYTED is to promote a culture of co-operation as a strategic tool for improving and supplementing domestic capabilities, for internationalizing domestic innovation systems, contributing to institutional modernization and fostering the development of a Latin American scientific community.

The Organization of Ibero-American States,[6] with its Science, Technology and Society programme, has also played a key role in orienting Latin American S&T towards the goals of social cohesion and citizen empowerment. More recently, The Latin American Knowledge Pool created in 2005 within the framework of the Latin American summits of heads of state and government, offers an opportunity to achieve this convergence and meet the challenges outlined above. In this context, new instruments are being defined. One example is the *Centro de Altos Estudios Universitarios* (Centre for Advanced University Studies), which aspires to foster the creation of postgraduate networks among Ibero-American universities.

4. The member countries of the intergovernmental organization created in 1970 via this agreement are Bolivia, Colombia, Chile, Ecuador, Peru, Venezuela, Panama, Spain, Cuba, Paraguay, Mexico and the Dominican Republic.

5. SECAB was founded in 1978 and ALTEC in 1984.

6. See Annex I for the member countries of the Organization of Ibero-American States.

CONCLUSION

Latin American countries were inspired by the idea of using S&T as an instrument for development in the decades following the Second World War. They had made some remarkable achievements by the 1970s, only for these efforts to be frustrated in later decades by the rise of rigidly liberal policies. The desire to achieve development through S&T did, however, find a favourable terrain in the early years of the 21st century and these conditions prevailed until the current global economic recession. Between 2002 and 2008 when the recession hit, a prosperous cycle of the global economy had favoured a six-year expansion cycle in Latin America which was the region's longest and greatest since 1980. This has placed Latin America in a stronger position to weather the storm than in earlier times of economic turbulence.

'The current structural conditions are incomparably more favourable than those in previous decades', stated Viotti (2008) just before the onset of the global recession. Although he was referring to the Brazilian experience, the statement is valid for most Latin American countries. These conditions were:

- several years of stability, both in economic terms and in the democratic process;
- an expanding domestic market as a result of stability and recent social policies;
- energy demand that is under control in most Latin American countries. Such is the case of Bolivia with its large gas reserves, of Ecuador, with its new oil reserves, and of Brazil, thanks to both the recent discovery of oil fields and ethanol. Brazil has become a leader in technology related to the production and use of ethanol in combustion engines, a technology that also contributes to reducing greenhouse gas emissions;
- a region that appears to be well-placed to benefit from growing global demand for commodities, particularly food, and from the resulting increase in the price of commodities.

Several Latin American countries have seized this opportunity to implement an array of policies to foster innovation and lay the groundwork for a new generation of development policies. This is particularly true of Brazil, Chile, Argentina and Mexico, as well as smaller countries such as Colombia, Costa Rica and Panama.

However, big hurdles remain. The global economic recession has generated an employment crisis that threatens to exacerbate poverty in the region. There is a predominant tension in the labour world between the demand for better wages and the demand for maintaining jobs, with each impinging on the other. The social crisis remains acute in the region. The International Monetary Fund estimates that poverty will grow by 15% in 2009. In this context, countries urgently need to expand their policies for social development, inclusion and citizenship. Institutions responsable for S&T policy have a role to play in this regard.

Some authors consider that Brazil has progressed over the past decade towards a more adequate institutional structure for fostering innovation, having drawn on the experiences of others (Arruda *et al*., 2006). In their opinion, Brazil now possesses a broad set of instruments similar to those available in developed countries. They admit, however, that there is room for improvement as far as the country's legal framework is concerned, as gaps remain. It is true that Brazil has a panoply of new instruments inspired by international practices at its disposal, not to mention vast resources for supporting innovation and business R&D.

Most Latin American countries have gone down a similar path. As we have seen earlier, there are now about 30 different types of S&T policy instruments in the region. These instruments cover the full spectrum, ranging from support for basic research according to criteria for excellence to encouraging entrepreneurial innovation (Emiliozzi, 2009; Lemarchand, 2009). However, most of these sophisticated instruments will not suffice in and of themselves to inverse trends overnight. Despite all the advances in conceptual frameworks and the diversification of instruments, the constitution of national innovation systems remains incipient in every country of the region.

R&D and innovation policies were initially designed according to the science-push model, to later be dubbed the linear model. This model still predominates in Latin America, in spite of the aforementioned attempts by the most advanced countries in the region to instigate demand-pull and innovation policies. In the mid-1990s, Bell (1995) described this feature as the survival of conceptual frameworks dating from the 1960s to address the challenges of the 1990s. Today, this phenomenon persists even in those countries that tend to be the most advanced for the adoption of innovation policies, such as Brazil or Chile. Viotti (2008) admits that, even in his own country, Brazil, the old culture still prevails, despite the new set of policy instruments. Consequently, businesses are reduced to playing the role of users or consumers of the knowledge produced by R&D institutions, even if this knowledge was created with no regard for the actual needs of users.

It is the academic sector which is the most dynamic actor in creating innovation systems in Latin America. Even the design of promotional policies for fostering innovation in the productive sector is the work of academics. Little progress has been made towards fixing an agenda for new industrial and technological policies. As a result, most Latin American countries share the common feature that local knowledge is underutilized by productive sectors that have little demand for it, resulting in a lack of articulation between the innovation process and academic knowledge. Indeed, in many cases, both sectors remain in ignorance of one other and are even reluctant to engage in joint activities of potential mutual benefit. The region demonstrates a paradox in that countries possess an acceptable scientific sector in various disciplinary fields which produces valuable knowledge that is potentially applicable to the productive sector, yet their economies demand very little local knowledge and are scarcely innovative. This is poles apart from what happens in other regions. It is even contrary to the path followed by Asian countries, whose economies have benefited from appropriating knowledge produced elsewhere to compensate for the lack of a well-developed academic sector of their own.

In addition to the lack of linkages between actors of the innovation system, with the exception of a handful of sectoral clusters, the institutional structure is precarious in Latin America. In some cases, there are heavy, inefficient bureaucracies. In Brazil, for instance, duties related to public policy management for industrial development and S&T have been delegated to non-governmental organizations; these have a complex institutional structure and lack the political, technical and operational capacity to exercise such duties effectively.

In conclusion, some of the problem areas of S&T policy pinpointed in reports are the following:

- There are difficulties in integrating and implementing the existing policy instruments.
- There is inadequate co-ordination, not only as far as the instruments themselves are concerned but also on the part of the institutions responsable for implementing them.
- The allocation of resources is fragmented and thus incapable of fostering critical changes in the innovation process.
- Investment in R&D remains very low. Even in those fields which demand advanced knowledge and skills, such as biotechnology and nanotechnology, greater resources are needed to achieve a critical mass.
- In a region with persistent social problems where much of the population is deprived of basic social benefits, it is often difficult to establish ties between S&T policies, on the one hand, and social policies, on the other. For instance, health-related R&D is often separated from general research policies. Moreover, there are conceptual difficulties in linking R&D policies with social inclusion policies.
- The problem of training and retaining a critical mass of highly skilled personnel is a growing concern for governments in the region. In order to address this issue, some governments have implemented policies to modernize the university system, combined with measures to staunch brain drain and take advantage of the human scientific capital scattered around the world.

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Mario Albornoz was born in 1944. His field of expertise relates to science, technology and higher education policies. He is a professor of philosophy and senior researcher at the National Research Council of Argentina. For political reasons, he had to move to Spain between 1984 and 1996, where he worked for the Office of Studies at the Spanish National Research Council. In 1985, he accepted the responsibility of supervising the regional research centres belonging to the Argentine National Research Council for Science and Technology (CONICET) and, between 1986 and 1994, held the position of Secretary for Science and Technology at the University of Buenos Aires. He was Head of the Centre for Studies on Science, Development and Higher Education (Centro REDES) in Buenos Aires from the time of its creation in 2002 until 2007 and remains a member.

Currently, he is Director of the Master's Programme on Management of Science, Technology and Innovation, established jointly by the National University of General Sarmiento, the Institute for Economic and Social Studies (IDES) and Centro REDES. He also co-ordinates the Ibero-American Observatory of Science, Technology and Society belonging to the Organization of Ibero-American States. In tandem, he has co-ordinated the Ibero-American Network of Science and Technology Indicators (RICYT) since 1995.

Mariano de Matos Macedo was born in 1953 and holds a PhD in Economics from the Institute of Economics at the State University of Campinas in Brazil. Since 1980, he has been a professor at the Federal University of Parana State and researcher at the Institute of Social and Economic Development (IPARDES) in the same state. From 1991 to 1994, he was President of IPARDES.

Director of Social Policies at the Brazilian Institute of Applied Economic Research from 1996 to 1999, he then worked for the Federal Ministry of Planning and the Budget. From 2003 to 2008, he was President of the Technology Institute of Parana State. Together with Eduard Viotti, he is the author of *Indicators of Science and Technology in Brazil*, published by Unicamp Editora in 2003.

He is currently a member of the Permanent Commission on Indicators of Science and Technology, which has been created to advise the Ministry of Science and Technology on issues related to development and the improvement of indicators, as well as the methodology and mechanisms of collection, analysis and disclosure of national data on science and technology. He is also responsible for a review currently being undertaken by the Centre of Strategic Studies and Management under the Ministry of Science and Technology for an Analysis of the Process of Decentralization of Science and Technology in Brazil.

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Industrial R&D still suffers from a lack of government support, even though the situation has improved radically over the past eight years.

Carlos Henrique de Brito Cruz and Hernan Chaimovich

5 · Brazil

Carlos Henrique de Brito Cruz and Hernan Chaimovich

INTRODUCTION

Brazil is the largest and most populous country in Latin America, with an estimated 190 million inhabitants. It is also the ninth-largest country in the world in terms of purchasing power and an emerging economy on the world scene. If the global economic recession triggered by the sub-prime crisis in the USA in 2008 slowed down business spending on research and development (R&D) somewhat in 2009, there was no noticeable decrease in the government sector. The impact of the global economic recession seems to be already over in Brazil, with the economy expected to grow by 7% in 2010. Federal and state government fiscal revenues are up again, as is R&D expenditure.

Like other Latin American countries, Brazil enjoyed strong economic growth between 2002 and 2008, thanks largely to a favourable global commodities market. The election of a new president, Luiz Inácio Lula da Silva (known as Lula), slowed the momentum somewhat during the federal government's transition period in 2003 but, after 2004, the Brazilian economy embarked on what seems to be a sustainable path of economic growth, with rates averaging 4.7% per year. In parallel, both the business sector and the federal and state governments began increasing R&D expenditure. This did not reflect a change in priorities on the part of the federal government, however, as witnessed by the constant ratio between R&D expenditure and federal fiscal revenue between 2001 and 2008 (2.1%). Between 2002 and 2008, the intensity of gross domestic expenditure on R&D (GERD) increased by just 10%, from 0.98% to 1.09% of GDP. Over the same period, GDP grew by as much as 27%, from R$ 2.4 trillion to R$ 3.0 trillion[1]. In other words, Brazil's R&D intensity progressed more slowly than the economy as a whole. President Lula promised to raise the GERD/GDP ratio to 2.0% by the end of his first mandate in 2006 when he presided the first meeting of the Science and Technology Council in 2003 and in his message to Congress the same year. In 2007, when R&D expenditure stood at 1.07% of GDP, the federal government announced plans to raise the GERD/GDP ratio to 1.5% by 2010. This target features in the *Plan of Action in Science, Technology and Innovation for Brazilian Development,* adopted in 2007.

1. In constant Brazilian reais (R$) for 2008 in the present chapter.

Thanks to sustained economic growth in recent years, the US$ 23 billion[2] spent on R&D in 2008 compares well with investment levels in Spain (US$20 billion) and Italy (US$ 22 billion) in absolute value. We shall see later, however, that Brazil nevertheless lags behind both countries when it comes to translating R&D investment into results.

One important feature of GERD in Brazil is that the public sector shoulders most of the burden (55%), a phenomenon common to almost all developing countries. Approximately three-quarters of scientists continue to work in the academic sector. Brazilian scientists published 26 482 scientific articles in journals indexed in Thomson Reuter's Science Citation Index in 2008, making the country the 13th largest producer of science in the world. More than 90% of these articles were generated by public universities.

The business sector is also dynamic, however, and in recent years has developed some world-class industries. Brazil is self-sufficient in oil and can boast of having developed the world's most efficient systems for growing soybean and producing ethanol from sugarcane. It manufactures competitive commuter jet planes and the world's best flex-fuel cars. The business sector has also developed a national system of electronic voting that is capable of totalizing more than 100 million votes on election day. Despite these achievements, the Brazilian business sector registered only 103 patents at the United States Patents and Trademark Office (USPTO) in 2009. We shall see why in the following pages.

Although business leaders have long recognized the importance of creating knowledge to drive competitiveness, it is only in the past ten years that effective policies have been put in place to foster industrial and service-sector R&D. It was in 1999, after a long period during which the focus was almost exclusively on academic research, that Brazilian science and technology (S&T) policy started including business R&D as a progressively relevant target not only for the use of knowledge but also for its creation. This was followed by a series of milestones, beginning with the creation of the first sectoral funds in 1999 then the validation of the entire strategy in 2001 by the Second National Conference on Science, Technology and Innovation and culminating

2. All dollar amounts in the present chapter are in purchasing power parity dollars.

Image taken by the CBERS-2 satellite on 10 April 2005 showing Florianópolis, the capital of the State of Santa Catarina in southern Brazil. Visible is the continental part of the city, the island of Santa Catarina and a few small surrounding islands.

Photo: CBERS/INPE

in the Innovation Bill prepared for Parliament in 2002 and approved in 2004. In 2003, there was an important development with the announcement of the national Innovation, Technology and Trade Policy (PITCE). PITCE connected innovation policy to the objectives for exports and established priority areas for government action, namely: semiconductors and microelectronics; software; capital goods; pharmaceuticals and medication; biotechnology; nanotechnology; and biomass. Four years later, the federal government announced its *Plan of Action in Science, Technology and Innovation for Brazilian Development* to 2010.

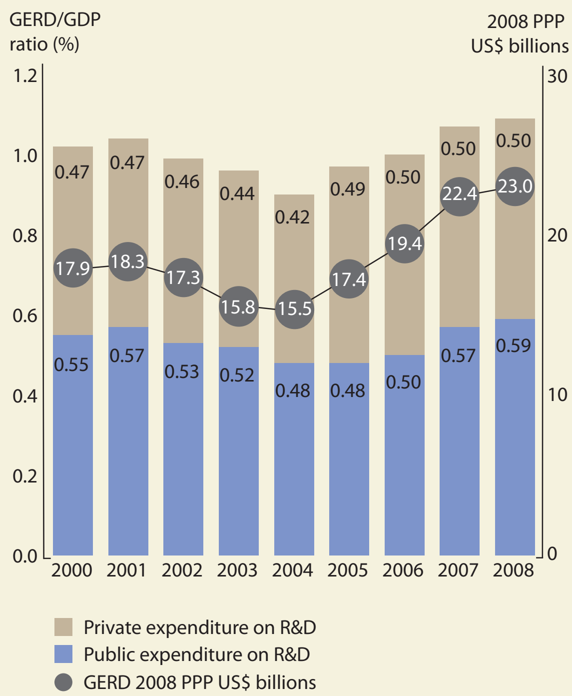
The booming economy has been conducive to business investment in R&D. However, despite a much more clement environment for R&D since 2004, some barriers remain in place. These include the difficult access to capital owing to high interest rates, poor logistics which hamper exports and an inadequate education system which penalizes not only social development but also the availability of qualified workers for almost all positions, especially those related to engineering.

Brazil's S&T capacity has come a long way, however, since the National Research Council (CNPq) and a second federal agency, Co-ordination for Training Higher Education Personnel (CAPES), were set up in the 1950s, followed by the São Paulo Research Foundation (FAPESP) in 1962. The early 1960s also saw the State of São Paulo make the landmark decision to step up academic research by creating the Full-time Regime for faculty to give professors ample time to do research. Scientific endeavour is less than a century old in Brazil. Even today, development tends to be concentrated in the country's south and southeast regions, home to the seven main universities, those of São Paulo (USP), Campinas (Unicamp), the State of São Paulo (UNESP), Minas Gerais (UFMG), Rio Grande do Sul (UFRGS), Rio de Janeiro (UFRJ) and the Federal University of São Paulo, all just half a century old.

Brazil thus faces three major challenges. *Firstly*, it needs to intensify business R&D, in order to drive innovation and competitivity. This requires creating an environment conducive to business R&D, including by encouraging greater interaction between the public and business research communities. *Secondly*, it needs to develop and internationalize its best universities to turn them into world-class centres of excellence. *Thirdly*, it needs to spread scientific excellence beyond São Paulo, Rio de Janeiro and other major urban centres to less privileged regions, such as the Amazon and the Northeast.

In the following pages, we shall analyse the shift in government S&T policy since 1999 from a quasi-exclusive orientation towards academic research to a policy of strengthening the role of business R&D. We shall describe the institutions that make up Brazil's innovation system, its demographics and investment pattern, heavily weighted towards the public sector. We shall then analyse Brazil's scientific productivity in terms of publications, patents, products and trade balance before concluding with a study of recent trends in international collaboration, including the emergence of new partners. We shall leave for last the discussion of the current policy environment, as most of the effects of the *Plan of Action in Science, Technology and Innovation for Brazilian Development* are yet to be reflected in the data.

Figure 1: Trends in GERD in Brazil, 2000–2008



Note: Private R&D includes private non-profit R&D, such as the share spent on research by private universities (0.02% of GERD).

Source: Ministry of Science and Technology, S&T Indicators, June 2010

R&D INPUT

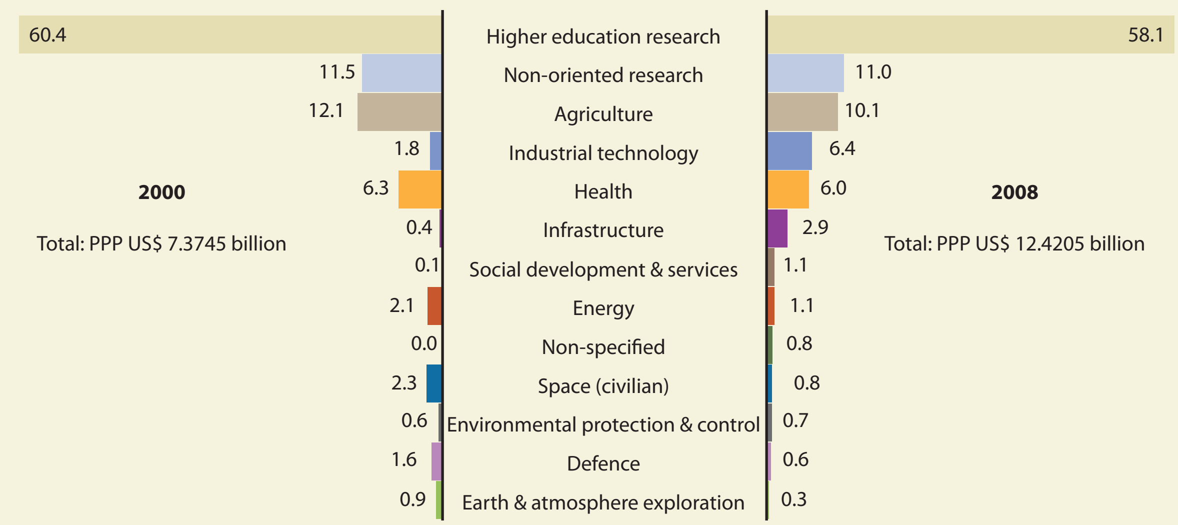
Trends in R&D expenditure

Between 2000 and 2008, GERD in Brasil grew, in constant 2008 values, by 28% from R$ 25.5 billion to R$ 32.8 billion. The GERD/GDP ratio progressed more modestly, from 1.02 to 1.09% of GDP (Figure 1).

Public R&D expenditure increased for almost every socio-economic objective between 2000 and 2008 (Figure 2). The exceptions were defenCe, energy, space and the exploration of Earth and the atmosphere. However, even some of those sectors which benefited from a monetary increase saw their 'priority status' diminish over this period. This was notably the case of agriculture, which represented 12% of the total public budget in 2000 but just 10% eight years later, a drop of 17%. Energy also saw its share whittled down by 41%, from 2% to 1% of the total budget. Although social development and services received a boost, this remained a fairly low R&D priority in 2008. Greater priority was also accorded in 2008 to infrastructure. In the case of industrial technology, the observed increase is in line with the stated objectives of S&T policies adopted since 1999, including the *Plan of Action in Science, Technology and Innovation for Brazilian Development* (2007–2010) discussed on page 118. However, the statistics for energy and space are at odds with the declared priorities of the Plan. The lower priority accorded agriculture should be especially troubling, considering the economic relevance of this sector for Brazil.

Public R&D expenditure is mostly directed towards academic R&D in Brazil, where it funds graduate school-related research and public research institutions to a large extent (Table 1).

Figure 2: Government expenditure on R&D by socio-economic objective, 2000 and 2008 (%)



Source: Ministry of Science and Technology, S&T Indicators, June 2010

Table 1: GERD in Brazil by source of funds, 2008
In PPP US$ millions

	Federal	State	Private	Total	%
Higher education	3 535.7	2529.2	497.6	6 562.5	29
Institutes and agencies	4 942.7	1 413.0	6 355.6	–	28
Business	155.0	–	9 946.3	10 101.3	44
Total	8 633.3	3 942.2	10 443.9	23 019.4	100
Share of total (%)	38	17	45	100	

Source: Ministry of Science and Technology, S&T Indicators, June 2010

At 1.09% of GDP (2008), Brazil's R&D intensity exceeds Latin American standards but lags well behind the average (2.28%) for the Organisation for Economic Co-operation and Development (OECD) and European Union (1.77%). In 2008, 55% of GERD was provided by the public sector, either through direct government spending or through expenditure on higher education. This puts the level of public investment in R&D at 0.59% of GDP. Some 45% of GERD thus comes from the private sector, a share that has remained stable over the past decade, compared to 69% for OECD countries and 65% for the European Union (Figure 3).

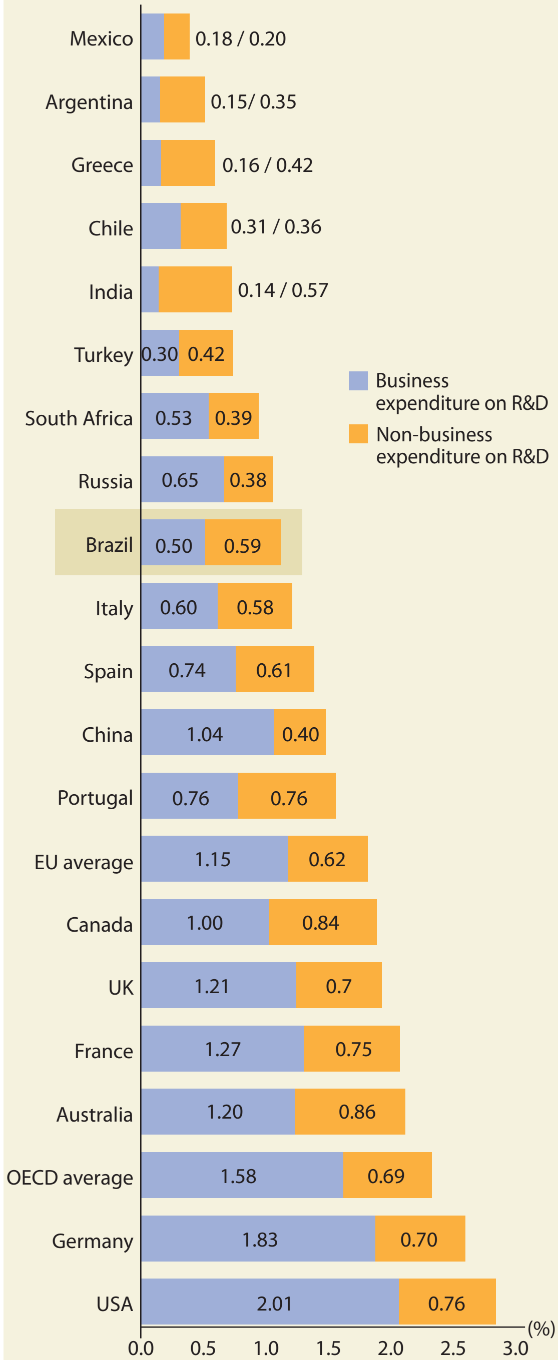
The difference in the share of GERD contributed by the business sector in Brazil and OECD countries is striking. Whereas non-business R&D expenditure in Brazil (0.59% of GDP) is only 15% less intense than the average for OECD countries, the Brazilian share of business R&D expenditure (0.48% of GDP) amounts to just 32% of the OECD average. This gap exposes one of the main challenges for the Brazilian national innovation system: creating the requisite conditions for the share of business R&D expenditure to increase by a factor of at least three to reach an intensity comparable to the OECD average and thereby maintain an adequate level of technical competitiveness for industry.

The creation of sectoral funds

The most important innovation in federal R&D funding in Brazil in the past 20 years has been the creation of the so-called sectoral funds, enacted by law during 2000–2002 (InterAcademy Council, 2006, p.79). These sectoral funds introduced targets for government-selected R&D projects of benefit to industry and cut back taxation to a fraction of the revenue of certain industries earmarked for privatization over this period.

The concept of sectoral funds sprang from the recognition that many of the state-owned companies due to be privatized were strong in R&D, mostly in the fields of telecommunications and energy, and that these activities deserved not only to be protected but also intensified. The sectoral fund model was created for Ronaldo Sardenberg, Minister of Science and Technology at the time, by the ministry's Executive Secretary, Carlos Pacheco. The sectoral funds would turn out to be a great success. Rather than creating any new tax, they redirected existing taxation and related contributions which were already part of the country's privatization strategy.

Figure 3: GERD/GDP ratio in Brazil, 2008 (%)
Other countries and regions are given for comparison



Source: Ministry of Science and Technology S&T Indicators accessed June 2010

In recognition of the heterogeneity of Brazil and its R&D system, the legislation passed between 1999 and 2002 specified that no less than 30% of the value of each sectoral fund was to be used to develop those regions with weaker R&D activities, namely the North, Northeast and Central West of Brazil.

The first sectoral fund was that created for oil and natural gas in 1999 (Table 2). Thirteen others followed over the next three years. Two of these 15 sectoral funds are unrelated to specific industries, namely:

- the R&D Infrastructure Fund is financed by a 20% contribution from each of the other funds and focuses on developing academic R&D infrastructure;
- the Green–Yellow Fund – a reference to the national colours of Brazil – is funded via 33% of the taxes paid by corporations that send funds abroad for technical assistance, royalties and specialized technical and professional services, plus (nominally) 43% of the recovered taxes from a progressively decreasing tax exemption awarded to the information technology (IT) industry to foster its development.

Each fund has a steering committee composed of members from academia, government and industry. This committee makes all decisions regarding expenditure, usually keeping a portfolio of projects that are expected to blend research proposals in the basic and applied sciences. It also oversees investment to make sure the funds are spent on projects related to the respective industry.

The sectoral funds injected new money into R&D funding in Brazil, even though the federal government continued to confiscate a fraction of the industrial revenue due to the funds in order to meet and exceed its fiscal surplus target. After this practice ceased in 2008, the National Fund for Scientific and Technological Development (FNDCT) reached an all-time high the same year, with expenditure tipping PPP US$ 1.4 billion. Figure 4 shows the steep rise in FNDCT expenditure after the creation of the first Sectoral Fund for Oil and Natural Gas in 1999 and another 13 sectoral funds in the next three years.

State-level R&D expenditure

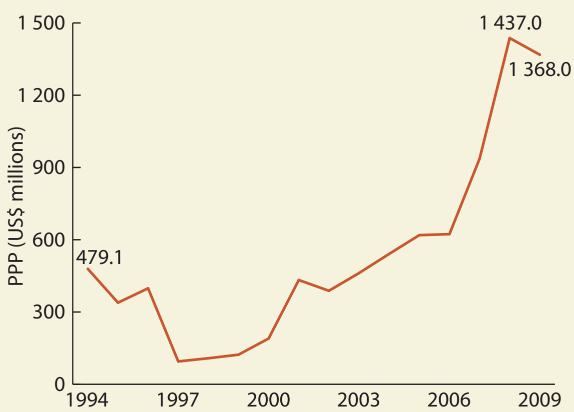
A substantial slice of government R&D funding comes from state governments, via foundations they fund, mission-oriented, state-owned institutes and state-owned

Table 2: Brazilian state industries targeted by sectoral funds, 1999–2002

CT-Aero	Aeronautics
CT-Agro	Agribusiness Sectoral Fund
CT-Amazônia	Amazon
CT-Aquaviário	Waterways and Naval Industry
CT-Biotec	Biotechnology
CT-Energ	Energy
CT-Espacial	Space
CT-Hidro	Hydroresources
CT-Info	Information Technology
CT-Infra	R&D Infrastructure
CT-Mineral	Mining
CT-Petro	Oil and Natural Gás
CT-Saúde	Health
CT-Transpo	Ground Transportation
CT-FVA	Green–Yellow Fund (industry–university cooperation)

Source: Brazilian Innovation Agency: www.finep.gov.br/fundos_setoriais/fundos_setoriais_ini.asp

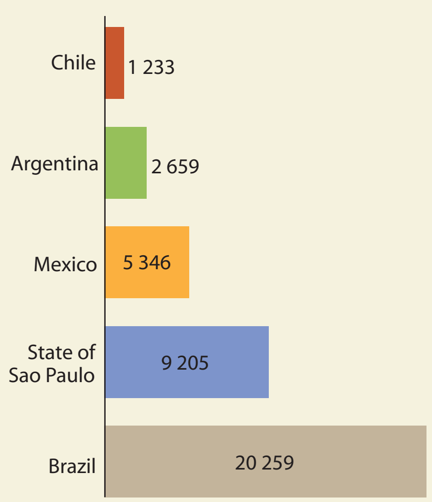
Figure 4: Evolution in Brazilian National Fund for Scientific and Technological Development (FNDCT), 1994–2009



Source: Ministry of Science and Technology; for the conversion of monetary amounts to PPP $US: Melo, L.M. (2009) *Revista Brasileira de Inovação 8* (1), pp. 87–120 institutions of higher education. In 2008, about 32% of public R&D expenditure originated from state funds. Some states have strong R&D systems, the main one being São Paulo where 64% of public R&D funding comes from the state (Figure 5).

The State of São Paulo generates 34% of Brazilian GDP and it has a long tradition of supporting higher education and research: the University of São Paulo dates from 1934 and the São Paulo Research Foundation was written into the State Constitution in 1947. Of all the states in Brazil, it is São Paulo which receives the most funding from federal agencies, normally 30–35% of the total. This is essentially because the state supports three world-class public universities which are among the 500 best in the world, according to the Institute of Higher Education at Shanghai Jiao Tong University, as well as the state-funded Foundation for the Support of Research in São Paulo (FAPESP) which has been operating since 1962. The state government's strong support makes São Paulo the second-biggest spender on R&D in Latin America. This underscores the relevance of regional R&D funding in a large federal system like that of Brazil.

Figure 5: The Brazilian State of São Paulo's contribution to GERD, 2007
In PPP US$ billions



Source: for Brazil: FAPESP (2010) *Indicadores de C&T&I em SP e Brasil 2010;* for other countries: RICYT database, June 2010

A sizeable portion of state investment in R&D comes from state foundations whose mission is to support research. These exist in almost all Brazilian states. Besides FAPESP, the main ones are FAPEMIG in Minas Gerais, FAPERJ in Rio de Janeiro, FAPERGS in Rio Grande do Sul, FACEPE in Pernambuco, FAPECE in Ceará and FAPESB in Bahia.

Business R&D expenditure

Of 95 301 companies polled in the Technological Innovation Survey (PINTEC) conducted by the Brazilian Institute for Geography and Statistics (IBGE) in 2005, only 6 168 reported having any type of R&D activities, permanent or otherwise. The full sample corresponded to a total revenue of US$1 097 billion. Of this, total R&D expenditure was reported of US$ 9 368 billion. The biggest spenders were the motor vehicle, trailers and semi-trailers industry (16% of total expenditure) and oil refining, ethanol and nuclear fuel (9 % of the total).

An interesting feature of business spending on R&D relates to the opportunities for attracting foreign direct investment. In 2006, US majority-owned corporations invested US$ 571 million in R&D operations in Brazil, 185% more than in 2001, according to the US Bureau of Economic Analysis.

Tax incentives for business R&D

Four federal laws provide tax incentives for business R&D (Table 3). Altogether, taxes waived in 2008 corresponded to US$ 3 643 billion, or 37% of business R&D expenditure.

Two other laws benefit academic institutions mostly. These laws have established an import tax waiver for scientific equipment and materials. The 2005 law on tax incentives for business R&D (Law 11196/05)[3] is considered by company representatives as being an improvement on previous legislation, since it simplifies the formalities required to benefit from these incentive measures. Although the 1991 law on tax incentives for information technology R&D (Law 8248/91) is used intensely by firms in the IT sector, non-IT companies use Law 11196/05 to a limited degree.

An important criticism by the business sector of this regime of incentives and subsidies is that there is an over-emphasis on the IT sector because of Law 8248/91.

3. In Brazil, laws do not bear names, only numerical references that include the year of adoption.

This regime is comparable in size to that of OECD countries but, in point of fact, few sectors are entitled to benefit from it. The difficulty stems from the fact that the IT incentive law is actually an internal equalization law to compensate for non-R&D incentives offered to IT companies to encourage them to locate in Manaus, in the Amazon (IEDI, 2010). Once the IT incentives are set aside, the incentives cum subsidies regime corresponds to just 13% of business expenditure on R&D.

In addition to tax incentives, government purchasing power through procurement is used in many countries to foster innovation, especially in defense- and health-related industries. This type of support for industrial R&D is still very limited in Brazil even in defense and health spending. The law on innovation of 2004 includes articles designed to foster more intense use of procurement. The government has come under unrelenting pressure from representatives of industry to adopt a more pro-active attitude in its procurement policies (Box 1).

Venture capital

The venture capital industry has grown in Brazil since the economy stabilized in the mid-1990s. The National Bank for Economic and Social Development (BNDES) has been active in this market since 1995, whereas relevant government initiatives date back to 1999. In 2000, the Ministry of Science and Technology launched an initiative called Inovar, led by the Brazilian Innovation Agency (FINEP), a federal agency with some investment bank-like attributes. The market responded well to this initiative and several venture fora were subsequently organized to present companies to potential investors. In 2005, BNDES announced the bank's return to venture operations, via a fund of approximately U$ 150 million for investment in partnerships to capitalize private funds. Legislation enacted on 15 February 2006 in a provisional decree known as Executive MP, or Executive Order, substantially reduced the tax burden on revenue from venture funds for foreign investors. However, most investment in venture funds tends to target 'non-technology-based' industries. A 2003 report concluded that 86% of venture operations in Brazil targeted these 'non-technology' sector industries (ABCR and Thomson Venture Economics, 2003).

Trends in R&D personnel

A shortage of PhDs

Although Brazil has managed to increase the number of doctorates granted each year to 10 711 in 2008, the country still faces a shortage, especially in engineering. The number of graduates may seem high but this translates into just 4.6 doctorates per 100 000 inhabitants,

Table 3: R&D tax laws and subsidies for business R&D in Brazil, 1991-2005

Focus of law	Year of adoption	Reference	PPP US$	Type of advantage
Tax incentive				
Tax incentives for the IT sector	1991	Law 8248/91	2 236.4	Tax incentives for IT sectors
Tax incentives for business R&D	2005	Law 11196/05	1 085.0	Tax incentives for all sectors
Subsidy				
Subsidies for business R&D in the form of government loans	2002	Law 10332/02	62.9	Interest rate equalization
		and Industrial Technology Development Plan (PDTI)	34.8	Other subsidy
Subsidies for business R&D	2004	Law 10973/04	224.1	General subsidy
Total (Incentives + subsidies)			3 643.3	
Business expenditure on R&D			9 946.3	
Share of incentives and subsidies in business expenditure on R&D			37%	

Source: IEDI (2010) *Desafios da Inovação - Incentivos para Inovação: O que Falta ao Brasil*

Box 1: Procurement policies to develop essential vaccines

Public buying policies are one of the mechanisms used globally to promote both science and the social appropriation of knowledge. The Brazilian vaccination and procurement policies have had a major impact over the last decade on both basic research and vaccine production. These policies promote immunobiological self-sufficiency and universal access to vaccines that are provided free of charge. Two centennial public institutions, the Butantan Institute and Oswaldo Cruz Institute, have built parallel research, development and vaccine production facilities that allow Brazil to be competitive both scientifically and technologically in the field.

The legal framework responsible for stimulating vaccine production by these twin institutions is based on Article 24 of Law 8666 of June 1993. This article regulates Article 37, Item XXI, of the Federal Constitution and institutes norms for the bidding process and award of contracts by the public administration, among other measures. Article 24 states that bidding in the procurement process may be dispensed with if a public entity acquires goods or services from another entity or body belonging to the public administration, as long as these goods or services were created for this specific purpose prior to the enactment of Law 8666 and providing that the contract price is compatible with the market price. This decision incited both the Butantan and Oswaldo Cruz Institutes to develop pilot plants for vaccine production, with the Ministry of Health as their key partner. The ministry played a vital role, as it guaranteed the institutes a main buyer and minimal threshold for production. It was evident, however, that these facilities would need to be accompanied by a parallel expansion of vaccine-related basic science.

Making a full scientometric analysis of progress in this area of basic science is a tricky exercise, since many biological fields are vaccine-related. Notwithstanding this, a search for publications produced in Brazil using 'vaccine' as a topic reveals that, over the past five years, the contribution of related basic sciences in Brazil has jumped from a 2% share of world literature to a 3% share. More importantly, the two vaccine producers, Butantan and Oswaldo Cruz, have been responsible for about 30% of all scientific output in Brazil in the field of vaccine development since 2004. In 2009, the Butantan Institute produced more than 200 million doses of vaccines using in-house technology, including those for diptheria, tetanus and pertussis (DTP), also known as whooping cough, and for Hepatitis B. The same year, Biomanguinhos, a manufacturing facility associated with the Oswaldo Cruz Institute, produced more than 170 million doses of vaccines for yellow fever, *Hemophilus influenza* type B and oral poliomielytis Sabin, among others.

Both the Butantan and Oswaldo Cruz Institutes are developing technology derived from in-house basic science and actively pursuing the launch of new state-of-the-art vaccines for the Brazilian and export markets via technology transfer agreements with private companies. Products in the pipeline from the Butantan Institute include vaccines for cell-culture rabies, dengue, rotavirus and influenza.

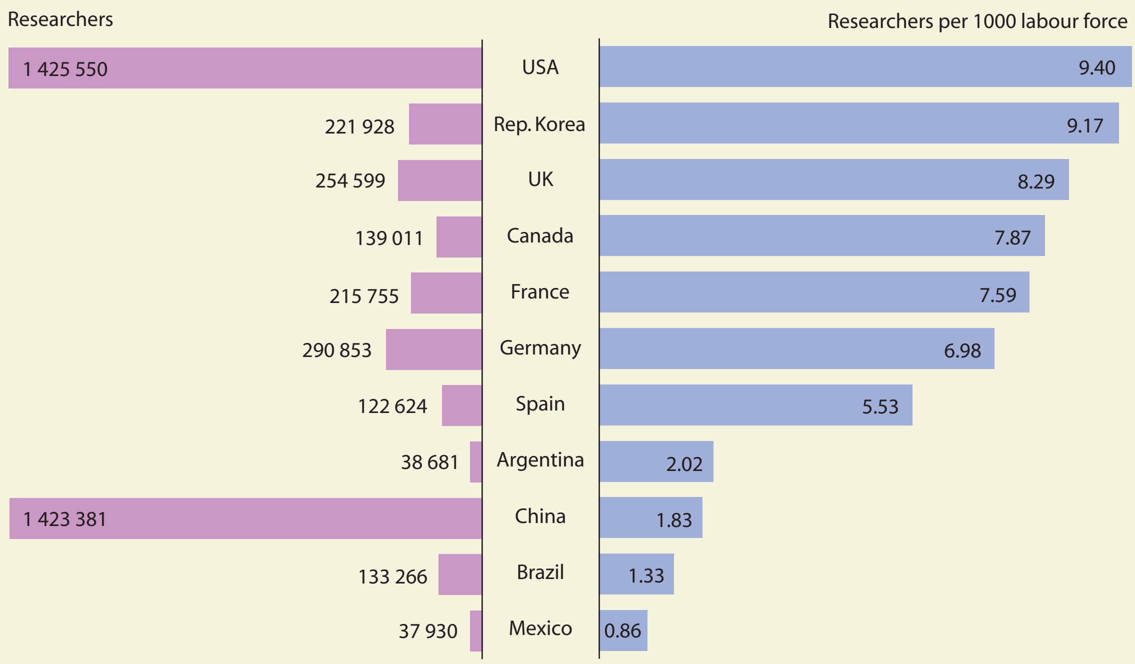
Source: authors

a ratio 15% lower than in Germany and roughly one-third that of the Republic of Korea (CAPES, 2005). At under-graduate level, Brazil faces an enormous challenge, since only 16% of youth aged 18–24 years were enrolled in higher education in 2008. This percentage will have to treble, if Brazil wishes to be on a par with the low end of the scale for OECD countries. The country's strategy so far has been to expand the number of private institutions offering 4–5 year courses, in tandem with fostering greater enrollment at public universities offering courses of the same duration. This strategy has not sufficed, however, to raise the enrollment rate to an internationally competitive level.

Most Brazilian researchers are academics

The lion's share of R&D is conducted by academic institutions in Brazil, as confirmed by the demographics (Figures 6 and 7). In most cases, it is easier to obtain precise information about the number of employees than about R&D expenditure, especially in the private sector. Researchers in Brazil occupy primarily full-time academic positions: 57% are employed by universities and another 6% by research institutes. That leaves just 37% in the business sector, which is consistent with the smaller portion of private R&D expenditure compared to public disbursements. The low number of scientists in the private sector is not without repercussions, as witnessed by the

Figure 6: Researchers in Brazil, 2008
Other countries are given for comparison



Source: Ministry of Science and Technology database, May 2010

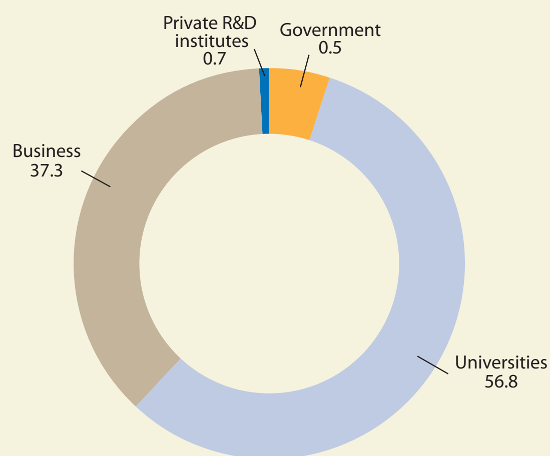
deficiency in patents generated by Brazilian industry. It is also one of the main obstacles to the development of stronger university–industry ties. Moreover, only 15% of Brazilian researchers in the business sector hold an MSc or PhD. In the Republic of Korea, this percentage is 39%: 6% hold a PhD and 33% an MSc. Government R&D funding agencies like CNPq, FINEP, FAPESP and others have created fellowship programmes for doctoral researchers in industry but these have shown limited results.

R&D OUTPUT

Scientific publications

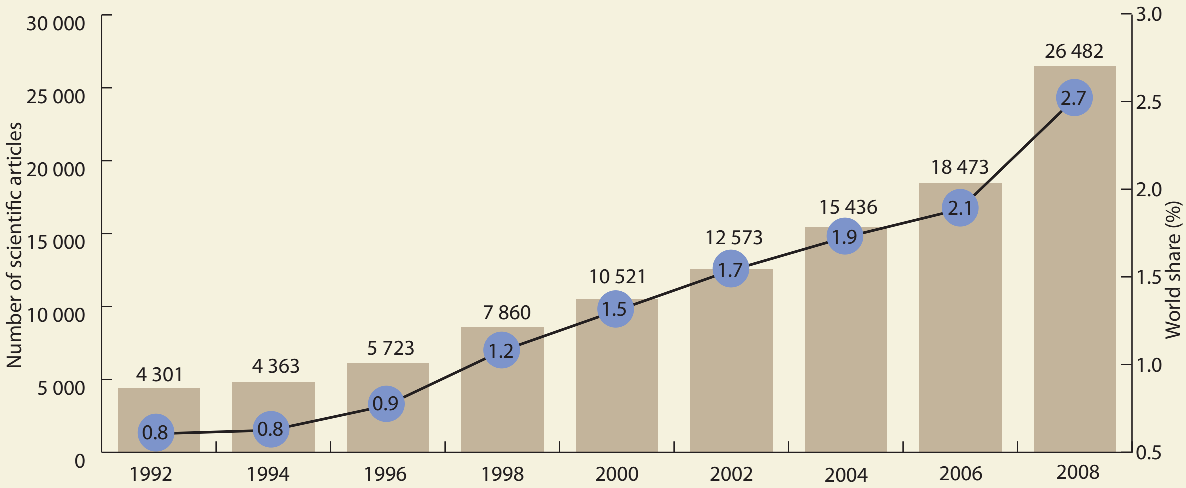
The number of scientific publications originating from Brazil has grown steadily over the past 26 years, culminating in 26 482 in 2008 (Figure 8). In parallel, Brazil's world share of articles has climbed from 0.8% in 1992 to 2.7% in 2008. There is a correlation between this increase and the growing number of PhDs awarded annually. Thanks to a consistently favourable policy for graduate education over the past 50 years or more, the number of PhD-holders has gone from 554 in 1981 to 10 711 in 2008.

Figure 7: Researchers in Brazil by performing sector, 2008 (%)
Full-time equivalent



Source: Ministry of Science and Technology database, June 2010

Figure 8: Scientific articles written by authors affiliated to Brazilian institutions, 1992–2008



Note: The evolution in scientific publications should inspire caution because the Thomson Reuters Web of Science changes the selection of journals over time. Some growth may thus be due to the inclusion of new journals, especially in 2008.

Source: Thomson Reuters (Scientific) Inc. Web of Science, (Science Citation Index Expanded), compiled for UNESCO by Canadian Observatoire des sciences et des technologies, May 2010

The impact of articles originating from Brazil has also grown: in 2000, there were 1.45 citations per article two years after publication,[4] compared to 2.05 citations for articles published in 2007. Brazil's presence has grown in all the major fields of science but articles are most common in agronomy and veterinary sciences (3.07% of the world total), physics (2.04%), astronomy and space science (1.89%), microbiology (1,89%) and plant and animal sciences (1.87%)[5].

The existence of a burgeoning scientific community has allowed special research programmes requiring a large pool of researchers to develop. A good example is the Genome Project implemented in São Paulo, which was the first to sequence the DNA of a phyopathogenic bacterium, *Xylella fastidiosa*. This programme was run in partnership with Fundecitrus (Citrus Producers Association).

4. Data collected by the authors using the Thomson Reuters Web of Science and counting those articles restricted to the category of 'articles' and citations recorded in the two years following publication

5. For a comparison with China and Índia, see Figure 8 on page 375.

In addition to producing advanced science, the Genome Project contributed knowledge that enabled researchers at Fundecitrus to devise ways of controlling a disease which attacked orange trees, Citrus Variegated Chlorosis. It also generated at least two spin-off companies in the fields of genomics and bioinformatics. Another example is the Biota Research Programme, one of the largest in the world in the field of biodiversity science (Box 2).

The data recorded in the Thomson Reuters database do not tell the whole story about Brazilian productivity, however. In developing countries, new knowledge frequently finds its way into local journals that often pass under the radar of Thomson Reuters' Science Citation Index, unless the journal has international circulation, which is rarely the case. Moreover, the language of most Brazilian scientific journals is Portuguese rather than English, especially as concerns articles in the humanities and applied social sciences. In order to enhance the visibility of Brazilian scientific production, FAPESP and the Latin American and Caribbean Center on Health Sciences Information

Box 2: Mapping biodiversity in São Paulo

Since 1998, a 'virtual institute of biodiversity' by the name of Biota has been mapping the biodiversity of the State of São Paulo and defining mechanisms for its conservation and sustainable use.

Being a virtual institute, it has no physical premises – participating researchers work in their own departments anywhere in the State of São Paulo. The 200 researchers and 500 graduate students who work for the institute are employed as faculty at 16 institutions offering higher education and research. FAPESP has thus avoided the risk of a major 'turf war' between rival institutions plaguing the programme. The virtual institute also employs about 80 collaborators from other Brazilian states and approximately 50 from abroad. Participation is open to anyone with a sound project that has survived the peer-review process managed by FAPESP.

In 11 years, the programme has supported 87 major research projects with an annual budget of approximately US$ 7.1 million. During that time, the programme has also trained 150 MSc and 90 PhD students, uncovered and stored information about approximately 10 000 species and managed to make data available from 35 major biological collections. This has translated into 464 published articles published in 161 scientific journals, 16 books and two atlases.

In 2001, the programme launched an open-access electronic peer-reviewed journal, *Biota Neotropica*, to communicate original research results on biodiversity in the Neotropical region. The journal is quickly becoming an international reference in its field.

In 2002, the programme launched a new venture called BIOprospecTA, in order to search for new compounds of economic interest for pharmaceutical or cosmetic applications. As a result, three new drugs have been submitted for patenting.

The programme has also had a considerable impact on public policy. The government of the State of São Paulo has drawn on the results of the programme to issue four Governor decrees and 11 resolutions concerning conservation of areas in the state. In January 2009, for example, the state government designated three large coastal Areas for Environmental Protection (APA Litoral Norte, APA Litoral Centro, APA Litoral Sul). Over the next ten years, the Biota–FAPESP Programme may produce data to improve management of these protected areas.

The international Scientific Advisory Board responsible for evaluating the programme has stated that 'science in most Biota projects is of a high quality that is either equivalent or exceeds that in other countries and, in several projects, it is of outstanding quality and on the cutting edge of international efforts'.

In 2009, the Biota programme began preparing a draft *Science Plan and Strategies for the Next Decade*, based on the recommendations of a workshop held in June the same year on Establishing Goals and Priorities to 2020.

Source: www.biota.org.br/; www.bioprospecta.org.br; www.biotaneotropica.org.br

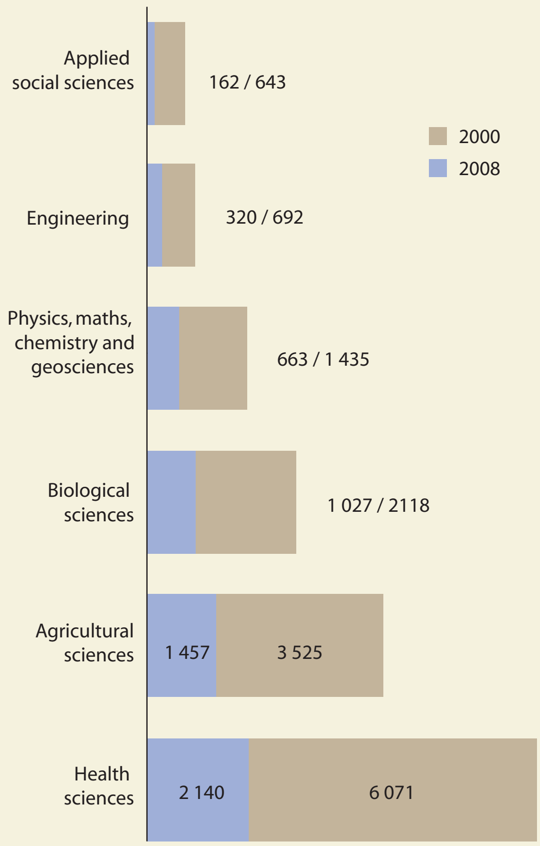
created an open access web portal in 1999, the Scientific Electronic Library Online (Scielo). In 2009, Scielo offered access to 203 peer-reviewed journals, including titles from Argentina, Brazil, Chile, Colombia, Cuba, Spain, Portugal and Venezuela. The same year, the Scielo website received 119 million visitors, who downloaded 15 759 articles. See Figure 9 for a comparison of the number of articles published in national journals in 2000 and 2008.

Most scientific production comes from public universities. Just seven universities accounted for 60% of articles published in international journals in 2009 (Table 4). Their share of the total increased from 60% in 2000 to 71% in 2007 before falling back to 60% in 2009. The University of São Paulo, with a full-time faculty of 4 670, produced 23% of the country's science in 2009, followed by the University of the State of São Paulo (2 889 full-time faculty) and Unicamp (1 538 full-time faculty), both with 8%.

Industrial and academic patents

In 2009, 103 utility patents for Brazilian inventions were issued by the United States Patents and Trademark Office (USPTO), almost the same number as five years previously (106). This is a dismal count, given the size of the Brazilian economy and its scientific infrastructure. Even if Brazil

Figure 9: Scientific articles published in Brazilian journals, 2000 and 2008



Source: Scielo Brazil database

outshines its Latin American neighbours for this indicator, it is dwarfed by India (Figure 10).

The small number of scientists working in the business sector directly affects the number of patents originating from Brazil, in the same way that dominant industrial sectors and export coefficients do. There may be a correlation between these low patent figures and the level of qualification of researchers employed in the business sector, given the small fraction with an advanced graduate degree (*see page* 109). Another factor may be a lack of audacity in the R&D objectives of most Brazilian industries, stemming from decades of operating in a closed market and an erratic economy. Changes in the economic climate since the 1990s have created a more open market, stronger competition and a stable economy. In turn, this is changing attitudes in many companies but the impact has not yet made itself felt in terms of the quantity and quality of business R&D.

Academic patenting has been gaining momentum in Brazil, especially since the feats of some institutions gained country-wide visibility, such as those of Unicamp and the Federal University of Minas Gerais. Unicamp has been strong in patents for more than two decades and has the largest stock of any Brazilian academic institution. In the period 2000–2005, it was awarded the most patents after Petrobrás, the Brazilian state-owned oil company. In 2002, the university founded the Unicamp Agency for Innovation encompassing a Technology Transfer Office, thereby demonstrating a strong penchant for licensing and the generation of revenue from its intellectual

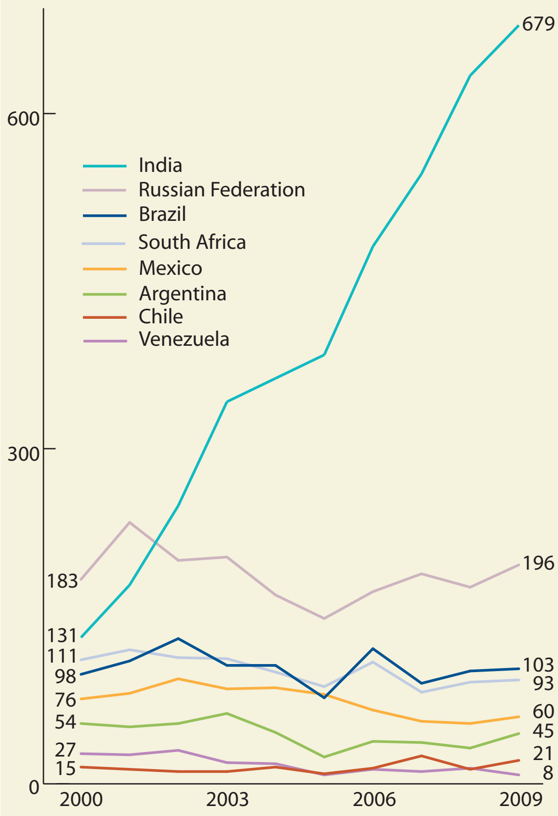
Table 4: Scientific articles published by Brazil's main research universities, 2000–2009

University	2000	2003	2006	2009
University of São Paulo (USP)	2 762	3 888	6 068	7 739
University of the State of São Paulo (UNESP)	772	1 104	2 065	2 782
University of Campinas (Unicamp)	1 190	1 498	2 386	2 582
Federal University of Rio de Janeiro (UFRJ)	1 080	1 253	1 778	2 357
Federal University of Rio Grande do Sul (UFRGS)	557	792	1 374	1 797
Federal University of Minas Gerais (UFMG)	597	810	1 392	1 685
Federal University of São Paulo (Unifesp)	433	659	1 251	1 561
Total for seven universities above	7 391	10 004	16 314	20 503
Total for Brazil	11 978	15 125	23 061	34 172
Share of seven universities above in total (%)	62	66	71	60

Source: SCOPUS, search restricted to articles, notes and reviews, August 2010

Figure 10: USPTO patents awarded to Brazilian inventors, 2000–2009

Other countries are given for comparison



Source: USPTO (Utility Patents)

property. Moreover, most of these licenses are exclusive, as in this case the licensee takes part in the development of the intellectual property through a co-operative R&D agreement.

Of the top 10 awardees of patents by the Brazilian Patent Office (INPI) in the period 2000–2005, three were academic institutions: Unicamp, FAPESP and the Federal University of Minas Gerais. This seems to indicate two things: *firstly,* that academic institutions have embraced the idea of protecting their intellectual property and are seeking opportunities to generate businesses with it; and, *secondly,* that efforts by industry to generate intellectual property remain ineffectual, since it is rare to find situations in which academic institutions generate more patents than industry among industrialized economies.

This said, very few research universities have, so far, been able to make more money out of licensing than they spend in the process (Mowery *et al.* 1999). The real motivation for a university to license its intellectual property should be in order to fulfill its mandate of diffusing knowledge throughout society and creating opportunities for its students. An exclusive fixation on financial benefits has thwarted many attempts by Brazilian universities to transfer technology and purchase it via licensing fees — and even attempts by R&D public agencies. There is still a lot to be learned in Brazil about the benefits to society of generating new businesses via excellent higher education, a sector in which Brazil has already obtained some important successes. One example is the Aeronautics Technology Institute, one of the best engineering schools in Latin America, which gave rise to the Brazilian Aeronautics Company (EMBRAER).

SUCCESS STORIES IN INNOVATION

Brazil can boast of some extremely successful cases of knowledge-based innovation. Take the example of jet aircraft, a highly competitive product of Brazilian R&D. Since being privatized in 1994 at a time of economic crisis, EMBRAER has gone on to become the third-largest aircraft manufacturer in the world. The first units of the 90-seater ERJ–190 have been flying commercially since early 2006 (*see page* 94). Moreover, a subsidiary of EMBRAER, the Neiva Aeronautics Industry, has produced the world's first alcohol-powered aircraft, the EMB 202 Ipanema. By 2006, Neiva had delivered more than 3 700 units, making the EMB 202 the most common agricultural aircraft in Brazil.

The agribusiness sector has also obtained outstanding results in both production and productivity. This sector benefits from public R&D investment via the Brazilian Agricultural Research Corporation (EMBRAPA) and other organizations within the national system of agricultural R&D. Soybeans, oranges and coffee are important export products, largely due to years of continual R&D.

Energy obtained from ethanol is another demonstration of the country's ability to create and use knowledge to generate opportunities. The ProAlcool National Programme (Alcohol Programme) launched in the 1970s is the world's most ambitious scheme today for using ethanol fuel in automobiles (Box 3). In 2005, 50% of

Box 3: Bioenergy R&D in Brazil

Since the launch of the ProAlcool National Programme in 1975, industrial, government and academic R&D have been making a considerable contribution to the development of the ethanol business in Brazil. A group of well- established research organizations like the Center for Sugarcane Technology (CTC), the Agronomical Institute of Campinas (IAC) and the Network for Sugarcane Improvement (Ridesa) have developed a large number of new varieties that have raised the average yield from 50 to 85 tons per hectare. Industrial R&D, often in association with universities, has improved industrial productivity from 55 to 80 litres of ethanol per ton of sugarcane. It has also obtained important results in the treatment of industrial residues.

The recent surge in international interest in bioenergy has intensified research in this field in many countries, causing Brazil to align its own strategy on competing in global markets. This strategy requires not only more R&D but above all cutting-edge R&D. Together with CTC and Central Alcool, FAPESP embarked on a project in 1999 to identify expressed genes in sugarcane and in functional genomics (SUCEST and SUCEST-Fun) and train human resources in this field. This effort contributed to an increase in the number of scientific articles about sugarcane in Brazil.

Given the potential for a massive scaling-up of production and the competitivity of Brazilian sugarcane ethanol, sustainability came to be an essential element of increasing productivity. In the past three years, a number of initiatives have been launched in Brazil to harness advanced science to sustainability and productivity targets. For instance, EMBRAPA, the state-owned company for agricultural research, has opened a division on agro-energy.

In addition, a new research centre was inaugurated in 2009, the Brazilian Bioethanol Science and Technology Laboratory (CTBE), in Campinas in the State of São Paulo. CTBE has three objectives: to perform competitive R&D to improve crops and conversion paths for bioethanol production from sugarcane; to partner other research organizations working in related areas, through a network of associated laboratories in universities and research institutes and; to act as a supplier of technology for the industry, providing strategic information of mutual concern.

A third initiative is the FAPESP Programme for Research on Bioenergy (BIOEN). BIOEN aims to create linkages between public and private R&D by using academic and industrial laboratories to advance and apply knowledge in fields related to ethanol production in Brazil. The BIOEN programme has five divisions:

- Sugarcane Plant Technologies, including plant improvement and sugarcane farming;
- Ethanol Industrial Technologies;
- Bio-refinery Technologies and alcohol chemistry;
- Otto Cycle Engines and Fuel Cells, ethanol applications for motor vehicles;
- Social and Economic Impact, Environmental Studies, Land Use and Intellectual Property.

The BIOEN Programme is well-equipped to support exploratory academic research on these topics and train scientists and professionals in essential areas for advancing the ethanol industry's capacities.

On top of this, BIOEN establishes partnerships co-funded by FAPESP and industry for co-operative R&D between industrial and academic laboratories at universities and research institutes. Other research agencies from the federal government and other state governments participate in the programme. They include CNPq and FAPEMIG. In 2009, BIOEN contracted its first round of 60 research projects.

A fourth initiative in progress in mid-2010 is the establishment of the São Paulo Bioenergy Research Center, with hubs in the three São Paulo State research universities (University of São Paulo, Unicamp and UNESP). The centre will set out to attract a greater number of scientists in the field of bioenergy to the three participating universities and will receive funding from FAPESP, the state government and the universities themselves to the tune of US$100 million over the next ten years.

In addition to these state or federal initiatives, companies have also stepped up their R&D efforts in bioenergy. Petrobrás has a programme on second-generation biofuels, which use waste from crops, and large companies such as Vale, Braskem and Oxiteno are also conducting a lot of bioenergy-related R&D.

Source: authors; www.cnpae.embrapa.br/; www.bioetanol.org.br/english/index.php; www.fapesp.br/en/bioen automobiles sold in Brazil were of the flex-fuel type and, by January 2006, as much as 74%. On top of that, the country adds 25% ethanol to gasoline to reduce carbon emissions and import costs. Automakers in Brazil have developed flex-fuel systems that can use from 0 to 100% of ethanol or gasoline. This technology is the brainchild of Brazilian R&D teams working in the country for foreign-owned auto-parts and automobile manufacturers who have developed a technology superior to that used anywhere else in the world (Bueno, 2006; Lovins *et al*., 2009). In 2008, Brazil was the world's second-largest ethanol producer (24.5 billion litres) after the USA, at a cost of US$ 0.19 per gallon, less than half the world average (US$ 0.40). Industry, government institutes and universities have developed better varieties of sugarcane and more efficient planting and harvesting methods, in tandem with more sophisticated ethanol refineries.

In each case, the main asset has been a stock of well-educated personnel trained in institutions which meet the world's best academic standards. All of these industries share another common feature: at some point, each has depended on policies which harnessed the government's purchasing power to stimulating technological development. The last ingredient in this recipe for success has been a fruitful public–private partnership to get the ideas to market.

One challenge the country has yet to overcome is that of diffusing this experience and skill in innovation through all sectors of industry. Years of a closed market and economic instability have taken their toll on attitudes towards innovation in the business sector. The sector has, however, responded quite well to incentive measures; during the 1990s when the Brazilian economy began opening up to the outside world, the federal government developed a country-wide programme for improving the quality of industrial products and processes that proved highly successful. More recently, both the government and leaders of industry have turned their attention to technological innovation. As a result, momentum has been building to develop this important area. For example, the National Confederation of Industry (CNI) initiated a Movement for Business Innovation (MEI) in 2009 to woo business leaders, a scheme that is already picking up speed.

INTERNATIONAL COLLABORATION

Brazilian international scientific collaboration has been steady for the past five years, according to Vanz (2009). However, at 30%, the share of internationally co-authored articles is substantially lower than the figure of 42% reported by Glanzel (2001) for the period 1995–1996.

US scientists are the main partners for Brazilians. A study by Adams and King (2009) found that 11% of scientific articles written by Brazilians between 2003 and 2007 had at least one co-author in the USA and 3.5% a co-author from the UK. Argentina, Mexico and Chile combined represented just 3.2% of co-authors of Brazilian articles.

International scientific collaboration is supported by both federal and state agencies via initiatives ranging from individual scholarships to multilateral programmes. CAPES, the main body responsible for supporting and evaluating graduate programmes, has a diverse portfolio of measures for financing international collaboration. In 2008, CAPES granted 4 000 scholarships to Brazilian graduate students abroad. CAPES also maintains bilateral collaboration programmes with Argentina, Cuba, France, Germany, the Netherlands, Portugal, Uruguay and the USA. In 2009, more than 500 joint research projects were financed under these agreements.

Through the Department of International Collaboration (ASCIN), the CNPq runs programmes ranging from individual scholarships for foreigners to regional programmes for scientific collaboration. Latin America and Africa, one of Brazil's priorities for regional collaboration, benefit from specific programmes: ProSul and ProAfrica. Other CNPq programmes focus on specific fields within a wider region. One example is the InterAmerican Collaboration in Materials involving Argentina, Canada, Chile, Colombia, Jamaica, Mexico, Trinidad and Tobago, Peru and the USA.

FAPESP itself has agreements for co-funding research with agencies in Canada, France, Germany, Portugal, the UK and USA. In fact, all the main Brazilian universities and research organizations offer services fostering international collaboration in research[6].

6. See page 96 for more information on Pan-American scientific collaboration.

Brazilian scientists and organizations serve on the governing bodies of the InterAcademy Panel, InterAcademy Council, InterAmerican Network of Academies of Science, International Council for Science, Academy of Science for the Developing World and several international disciplinary unions. Participation in these decision-making bodies has helped to integrate Brazilian science into global and local collaborative and large-scale projects, while offering Brazil's scientific community greater international exposure.

One example of a large-scale collaborative programme is that for the Southern Astrophysical Research (SOAR) Telescope commissioned in 2003. This 4.1-m aperture telescope has been designed to produce the best-quality images of any observatory in its class in the world. Funded within a partnership involving primarily Brazil, Chile and three US institutions, the National Optical Astronomy Observatory, Michigan State University and the University of North Carolina at Chapel Hill, SOAR is situated on Cerro Pachón at an altitude of 2 700 m, on the western edge of the peaks of the Chilean Andes. Brazilian participation in this project has contributed significantly to the growth of the scientific community and resulted in a rise in Brazilian publications in astronomy from 274 in 2000 to 404 in 2009. World-class instruments, such as an integral field spectrograph, have been designed and built in Brazil for installation in the SOAR facility.

Brazilian scientists are also collaborating with their Chinese counterparts on an ambitious project to develop and operate remote–sensing satellites for Earth observation (Box 4).

Another important programme for international S&T collaboration is led by the Brazilian Agricultural Research Corporation (EMBRAPA). EMBRAPA has set up laboratories in the USA, Netherlands, UK and Republic of Korea to throw bridges to the most advanced research in the world. EMBRAPA also has offices in Senegal, Mozambique, Mali and Ghana. These offices are part of the EMBRAPA Africa Programme, which strives to develop projects for scientific co-operation. The offices in Africa also interact with governments and local bodies to offer assistance in defining priorities, so that EMBRAPA laboratories in Brazil can propose contributions that address local needs.

AN ACTION PLAN FOR S&T

In 2007, the government presented a *Plan of Action in Science, Technology and Innovation for Brazilian Development* for the period 2007–2010.

Box 4: China and Brazil developing space technology together

The China–Brazil Earth Resources Satellites (CBERS) programme embraces a family of remote-sensing satellites built jointly by Brazil and China. This example of successful South–South co-operation in high technology currently includes five satellites which provide coverage of the world´s land areas. CBERS-1 functioned from October 1999 to July 2003, CBERS-2 from October 2003 to June 2008 and CBERS-2B from September 2007 to May 2010. CBERS-3 will be launched in 2011 and CBERS-4 in 2014. CBERS-3 and CBERS-4 are each equipped with four cameras with bands in visible, near-infrared, middle and thermal infrared (*see image page* 102).

Brazil and China share the responsibility for, and cost of, building the satellites. In Brazil, the National Institute for Space Research (INPE) designs half of the subsystems and contracts them to the Brazilian space industry. The Brazilian participation in the programme amounts to a total cost of about US$ 500 million, with 60% of investment taking the form of industrial contracts.

Data obtained from the CBERS satellites are released within a free and open data policy. From 2004 to 2010, more than 1.5 million images were delivered to users in Brazil, Latin America and China. These images have applications on forestry and agriculture assessment, urban management and geological mapping. Brazil uses the images to survey deforestation in Amazonia and to assess land use associated with cash crops such as sugarcane and soybeans and with large-scale cattle ranching.

China and Brazil have agreed on a joint strategy for facilitating international access to remote-sensing data in Africa. From 2012 onwards, African ground stations in South Africa, the Canary Islands, Egypt, and Gabon will receive and freely share CBERS data. The CBERS programme thus enables Brazil and China to contribute to global environmental policy-making.

Source: www.cbers.inpe.br/

The *Plan* is an important advance in that it groups most of the federal initiatives in S&T in a single document. This allows for a much better understanding and monitoring of the federal S&T system and, hypothetically, for an evaluation of the Plan's implementation. The *Plan* has been welcomed by the scientific community.

The Plan does have its shortcomings, however. For one thing, it fails to to integrate the various federal ministries that should be involved in fostering science, technology and innovation (STI). Federal initiatives are also poorly articulated with those at state level. Moreover, in many cases, those sectors defined as being strategic actually received a smaller share of funding in 2008 than in 2000, as we have seen on in Figure 2. This is the case of agriculture, energy and defence, for example. Nor has the goal of raising GERD to 1.5% of GDP by 2010 been attained. These shortcomings do not invalidate the usefulness of the *Plan*, however. Overall, it has been a positive initiative with most of its proposals being implemented to some extent. These shortcomings will need to be rectified, however, in future action plans.

The *Plan* has four thrusts:

- To expand, integrate, modernize and consolidate the national innovation system by improving co-ordination at the federal, state and municipal levels, as well as between these public entities and private enterprises. The focus is on strategic areas for national development and both the renewal and consolidation of international co-operation. Another important goal is to increase the number of scholarships and fellowships for under-graduates, master's and PhD students, postdoctoral students and senior researchers from 102 000 in 2007 to 170 000 by 2011.

- To improve and promote technological innovation in companies by nurturing an innovation-friendly environment within firms and by strengthening industrial, technological and export policies. The aim is to generate employment, raise income and add value to each stage of the production process. One priority is to increase the number of active researchers in the private sector while, in parallel, training human resources and developing a 'knowledge creation culture' in enterprises. Another goal is to create a structure for the Brazilian Technology System (SIBRATEC). SIBRATEC is a group of entities that helps companies across Brazil develop their businesses by providing services that include technology transfer and assistance. These services relate in particular to the Basic Industrial Technology (TIB) programme[7]. One goal is to increase the number of business incubators and technological parks. Another is to permit the creation of self-governing innovative enterprises.

- To strengthen R&D in strategic areas that include biotechnology, nanotechnology, agribusiness, biodiversity and renewable sources of energy. Specific goals are included for the nuclear, space, metrology, national security and defence sectors.

- To promote science popularization and improve science teaching, as well as technology diffusion for social inclusion and development. Social development is a major objective of current state policies. Key tools are the Mathematics Olympiads for Public Schools launched in 2005, which attracted 18 million participants in 2008; the promotion of National Science and Technology Week in October each year; support for the establishment of TeleCenters in rural areas to narrow the digital divide and fight poverty, a programme launched by the Ministry of Communication in 2007, and; the programme offering Research and Development Support for Nutritional and Food Security. The latter was launched in 2008 by networking Research and Technological Institutes of Food Sciences and now offers information and consultancy services to small and medium-sized enterprises, as well as to individual farmers and food producers.

CONCLUSION

It is evident from the foregoing that Brazil has developed a competitive academic base in science. Academia still faces a number of challenges, however. Although the number of scientific articles and doctorates granted annually has been rising, there remains a lack of homogeneity in the regional distribution of academic staff and the country's knowledge base: 60% of all scientific articles originate from just seven universities, four of which are in the State of São Paulo. There is also a lack of homogeneity in disciplinary fields. Efforts will be required in engineering and computer science, for example, to train more undergraduates and PhD-holders and expand Brazil's international presence. At the same time, the advancement of knowledge in Brazil might benefit from

7. This programme includes metrology, technical norms and standards, conformity to standards, intellectual property and design.

a more balanced governmental approach between directed and unfettered research. Recently, there has been a seemingly excessive tendency to direct calls for projects towards specific objectives. This penalizes curiosity-driven research, the cornerstone of a strong academic system.

Industrial R&D is in need of even greater attention than academic research. It still suffers from a lack of government support, even though the situation has improved radically over the past eight years. Recent measures like the law on innovation (2004) and its consequences, such as the refurbishing of tax-incentive legislation and the introduction of a policy of subsidies, are expected to have a big impact on industrial R&D. These measures fall within the framework of the national Industry, Technology and Trade Policy (PITCE) adopted in 2003. The emergence of the National Bank for Economic and Social Development (BNDES) as a funding source for technological development and industrial R&D is, possibly, the most important boost for industrial R&D in the country for many years.

As we have seen, research funding comes mainly from the public purse (55%). Brazil falls below the OECD average for both its GERD/GDP ratio (1.09%) and the share of GERD contributed by government (0.59%). To meet the OECD average for public funding of R&D, Brazil would have to invest an additional R$3.3 billion (PPP US$ 2.3 billion). This amount corresponds to roughly three times the budget of CNPq.

The largest gap of all with the OECD countries concerns business spending on R&D. Here, the OECD average (1.58% of GDP) is three times that of Brazil (0.48% of GDP). Catching up to the OECD would entail the Herculean task of raising private R&D expenditure from US$ 9.95 billion in 2008 to US$ 33 billion. This challenge calls for much more effective policy instruments than those employed thus far by the Brazilian state. Moreover, these must not be confined to financial instruments, such as government subsidies, tax breaks and procurement policies, but should also encompass the legal and political instruments necessary to create an environment conducive to private investment in R&D.

A final note is in order here to address a question that comes up frequently in political circles in Brazil, namely, 'Why should taxpayer money pay for R&D?' As a tentative answer, we would say that there are at least two equally valid justifications for this. One is that contributing to the universal pool of knowledge makes Brazilians more capable of determining their own destiny. Like people everywhere, Brazilians ask themselves, 'How did the Universe begin?' 'How does it work?' 'Why does society behave the way it does?' 'What drives human beings towards good or evil?' Understanding the classics of literature and appreciating nature and art are part of what makes us human. Studying these and an infinite number of other questions enriches us. This alone would be reason enough to use taxpayer money to find science-based answers – even incomplete ones – to fundamental questions and thereby improve our knowledge of the Universe and humankind. This endeavour is obviously much more the sphere of universities than industry or the private sector.

The other reason why taxpayer money should finance R&D seems far more popular nowadays than the first reason evoked above: the more knowledge a society obtains by employing the scientific method, the richer it becomes. This utilitarian view has strong appeal, especially since the discovery of the genome and atomic energy, and the invention of the transistor and Internet.

In our view, both reasons are complementary rather than antagonistic, since both perceive science as a productive force. This line of reasoning depends strongly on the capacity of industry and other enterprises to improve Brazilians' standard of living to make its case.

The challenge for Brazil will be to turn these dual reasons into a functioning tandem by creating conditions under which universities and private companies can, in the words of Francis Bacon[8], through 'good and sound research', make the country a better place and a full member in the concert of nations.

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His research interests include higher education, science, technology and innovation. He is a member of several learned societies, including the Brazilian Academy of Sciences, Latin American Academy of Sciences and the Academy of Sciences for the Developing World.

The development and production of pharmaceuticals in general – and biotechnological products in particular – is without doubt the most successful example of the Cuban scientific endeavour but it is not the only area of importance for R&D. Another important priority today is energy… Disaster monitoring and mitigation are also taking on a growing role, in light of the threat of stronger hurricanes, droughts, coral bleaching and flooding in future as a consequence of climate change.

Ismael Clark Arxer

6 · Cuba

Ismael Clark Arxer

INTRODUCTION

The Republic of Cuba is an archipelago comprising a main island and more than 4000 smaller islands and keys, for a total land area of 109 886 km^2 and a population of roughly 11 million. Cuba is located in the Caribbean Sea just south of the Tropic of Cancer. Its immediate neighbours are the Bahamas, Haiti, Jamaica, Mexico and the USA.

The youngest Hispano-American republic, Cuba was founded in 1902, after a 30-year war of independence against Spanish rule which ended in a four-year occupation by US troops in 1898. During the first half of the 20th century, Cuba was heavily controlled by foreign interests within a plantation and extractive economy. A report by the *ad hoc* Truslow Commission of the International Bank for Reconstruction and Development, which had travelled to Cuba to study the provision of loans, stated unequivocally in 1950 that 'in the field of applied research and labs, there was no development at all in Cuba' (Sáenz and García-Capote, 1989).

Just months after establishing a revolutionary government, President Fidel Castro made his first science policy statement in January 1960. 'The future of our country has to be necessarily a future of men [and women] of science, of men [and women] of thought', he said, 'because that is precisely what we are mostly sowing; what we are sowing are opportunities for intelligence' (Castro, 1960).

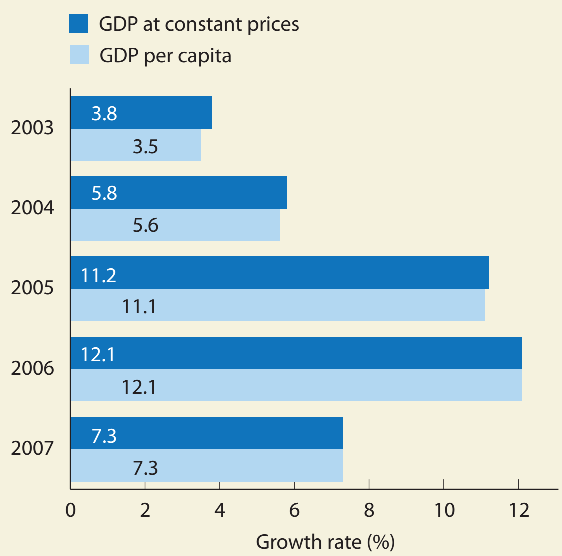
This has been the cornerstone of Cuba's scientific development ever since. Following the revolution, the development model evolved into a state-planned economy with education and scientific development as high priorities. Most of the research centres in Cuba today were born of research groups, or started out as institutes, in the decades immediately following the Cuban revolution in 1959. Some of these centres, like the National Centre for Scientific Research (CENIC) founded in 1965, played an essential role in training young science students at home and in the eventual establishment of many other research institutions.

By the dawn of the 21st century, Cuba was perceived as being a proficient country in terms of scientific capacity, despite having experienced more than four decades of a trade embargo and restrictions on scientific exchanges imposed by successive US administrations (Jorge-Pastrana and Clegg, 2008). In a study commissioned by the World Bank in 2001, Wagner *et al* of RAND, an S&T think tank in the USA, classified nations into four categories according to their scientific prowess: developed, proficient, developing and lagging. In Latin America and the Caribbean, only Brazil and Cuba qualified as 'proficient'.

Cuba is still recovering from the effects of the severe economic crisis caused by the collapse of its main trading partner, the Soviet Union, in the early 1990s: GDP dropped by about 40% in less than five years and new markets had to be found for up to 75% of foreign trade, under very difficult credit conditions.

Figure 1 shows a sustained, if modest, increase in Cuba's GDP between 2003 and 2007. The result is that the country's GDP, both overall and per capita, is now on a par with levels at the end of the 1980s. Today, Cuba ranks among medium-income countries. It is interesting to note the growth in the percentage of GDP contributed by community, social and personal services: this grew from 25.5% in 2002 to 34.5% in 2007. Cuba has also diversified its economic ties. In 2006, its main foreign trading partners were Venezuela, China, Spain and Canada, in descending order.

Figure 1: Growth in Cuba's GDP and per-capita GDP, 2003–2007 (%)



Source: ONE (2008) *Statistics Yearbook 2007*

Schoolchildren discovering a telescope

Photo: © Oscar Álvarez/ Cuban Academy of Sciences

ORGANIZATION OF RESEARCH

In the mid-1990s, a Ministry for Science, Technology and Environment (CITMA) was established with the aim of harnessing Cuban scientific knowledge to a more sustainable form of development. The ministry encompasses a dozen science centres of national interest; some of these are among the best in the country, like the Institute of Meteorology (Table 1). There are subordinate executive offices in each of the country's 14 provinces, as well as co-ordinators for the 169 municipalities.

In 1996, the Cuban Academy of Sciences was reorganized. After 35 years of working mainly as a support body for research and development (R&D), the members agreed to new statutes allowing the academy to return to its traditional role of primary scientific advisory body. The institution is now also responsible for recognizing excellence in research and for acting as the representative of the Cuban scientific community, both in Cuba and abroad. The academy has a very long tradition. It was one of the first merit-based national academies of science to be established outside Europe, in 1861, even though it languished for most of the first half of the 20th century for the reasons evoked above.

Table 1: Cuba's top 20 S&T research institutions*

Centre of Pharmaceutical Chemistry	www.cqf.sld.cu
Cuban Institute of Sugar Cane Derivatives	www.icidca.cu
Institute of Animal Science	www.ica.inf.cu
University of Havana	www.uh.cu
Centre of Genetic Engineering and Biotechnology	www.cigb.edu.cu
Institute of Tropical Medicine Pedro Kourí	www.ipk.sld.cu
Havana Technological University José A. Echevarría	www.cujae.edu.cu
Institute of Cybernetics, Mathematics and Physics	www.icmf.inf.cu
Centre of Molecular Immunology	www.cim.sld.cu
Finlay Institute (vaccines R&D)	www.finlay.edu.cu
Las Villas Central University Marta Abreu	www.uclv.edu.cu
National Centre for Plant and Animal Health	www.censa.edu.cu
National Centre of Scientific Research	www.cnic.edu.cu
National Institute of Agricultural Science	www.inca.edu.cu
Bioplants Centre – Ciego de Avila University	www.bioplantas.cu
Cuba Neuroscience Centre	www.cneuro.co.cu
Institute of Plant Health Research	www.inisav.cu
National Institute of Economic Research	www.inie.cu
Institute of Ecology and Systematics	www.ecosis.cu
Institute of Meteorology	www.insmet.cu

*Measured in terms of the number of prizes awarded by the Cuban Academy of Sciences over 1997–2006, on the basis of the number of papers published, the socio-economic benefit of a research result, etc.

Source: author

An overall *National Plan for Science and Technology* is prepared each year by CITMA. The *Plan* is followed up by specialized staff and the accomplishment of objectives and overall progress is periodically reviewed by expert groups organized by CITMA. Priority is given to projects within the National Research Programmes in Science and Technology which have been approved at the highest level of CITMA, according to a peer review process, and which are in turn funded by the state budget. Other ministries select and support sector-targeted S&T programmes in a similar fashion.

An analogous procedure is followed at the provincial level at the demand of territorial authorities. Delegate Offices of CITMA contribute to the selection of local projects and to follow-up processes. These local R&D projects are also funded by the state budget and usually implemented by university research groups or scientific centres located in the territory.

R&D INPUT

R&D expenditure

Gross domestic expenditure on R&D (GERD) in Cuba is more or less on a par with the mean for Latin America and the Caribbean, although regional spending has surged in recent years. The situation is more or less equivalent for overall S&T expenditure (Figure 2).

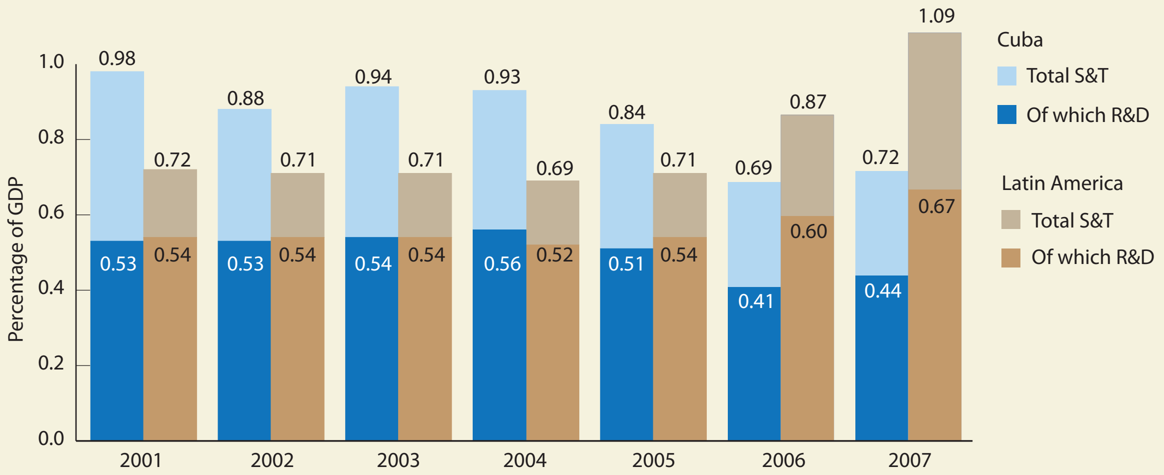
Most R&D projects with a direct link to the immediate demands of the productive sector are funded by enterprises (Figure 3). The share of business funding of R&D has declined in recent years (Figure 4).

Human resource issues

In 2008, 53.5% of all S&T professionals were women. Cuba is second only to Uruguay in Latin America for this indicator, according to RICYT (2010). This proportion will tend to increase, since 60% of graduates entering into a scientific career were women in 2008 (ONE, 2008).

Tertiary education in Cuba today comprises 65 centres of higher education, spread across more than 3500 campuses at the municipal level.

Figure 2: Cuban expenditure on S&T and R&D, 2001–2007 (%)



Source: RICYT (2010) *El Estado de la Ciencia*

First-year enrollment in higher education more than doubled between 2004/2005 and 2007/2008, from 361 845 to 743 979. The social sciences and humanities continue to attract the greatest number of vocations, followed by the medical sciences, with 187 690 first-year students in 2007/2008. A further 42 741 students chose engineering in 2007/2008. Enrollment in the natural sciences and mathematics has remained stable, with 3 970 first-year students in 2004/2005 and 3 922 in 2007/2008.

The total number of graduates has increased each year this century, with an impressive leap in 2007/2008 to 71 475, compared to 44 738 the year before. This performance is largely due to the surge in graduates in health-related disciplines, who numbered 8 396 in 2006/2007 and 24 441 just twelve months later. On the flipside, the number of graduates in the natural sciences and mathematics remains low: they numbered 601 in 2003/2004 and 559 in 2007/2008. Today, there are more than 900 000 university graduates in Cuba, out of a population of 11 million.

Scientists, engineers and technicians are employed in the 119 R&D institutions Cuba counts in its 14 provinces and in 34 other institutions performing S&T services. However, only a small minority (7.3%) of R&D personnel are employed as researchers. In 2006, the work of 7.1 Cubans in every 1 000 was related to S&T in one way or another, a ratio which had dropped to 6.4 by 2007 (RICYT, 2010).

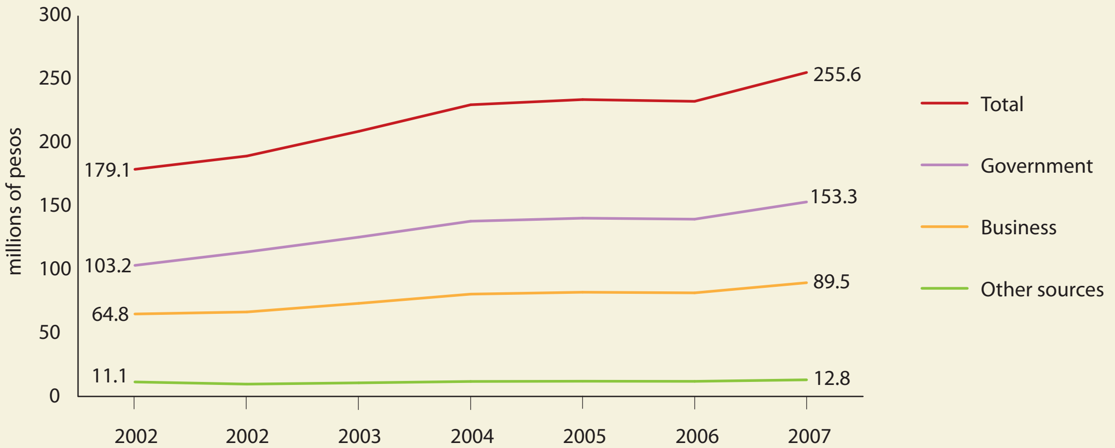
Cuba's National Research Programmes

National Research Programmes in Science and Technology (NRPs) in 2009 are listed in Table 2. Some of these date back to previous periods, as in the case of the Programme for Global Change and the Evolution of the Cuban Environment.

One of the new NRPs is devoted to Information and Communication Technologies (ICTs). In fact, since the end of 2002, computer science has been given a boost with the establishment of a large University of Informatics Science. The main campus is located in Havana, with three branches elsewhere in the country. In 2006, this university reached its designed capacity of 10 000 students, all of whom participate actively in the application of research in informatics to the Cuban economy and society. As part of efforts to spread computer literacy to all those interested to learn and in the perspective of progressive use of informatics in society, a network of local computer clubs has been put in place country-wide since 1990. This scheme has been renewed and duplicated online in the past five years. As of 2009, there were 602 cyber-clubs distributed across the country, interconnected through an Intranet service.

Internet access remains very low, at just 11.6% in 2007 according to the United Nations Statistical Division, although this is a great improvement over the previous year (2.1%). Gradual expansion of access to Internet will be dependent on the conditions under which connectivity can be assured. Expanding connectivity is restricted by the high cost of the

Figure 3: GERD in Cuba by source of funds, 2001–2007

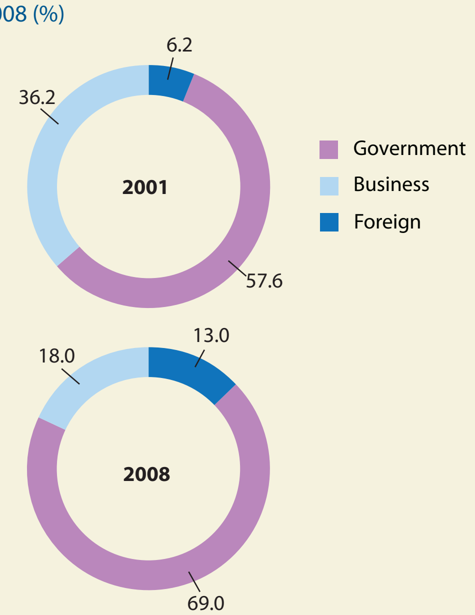


Source: UNESCO Institute for Statistics database, June 2010

satellite channels used – so far, the country's only available possibility. It is also restricted by the refusal up to now to allow Cuba to connect to Internet using an optic fibre cable via either Florida or Mexico, due to the US economic blockade, since both cables are managed by US companies.

Other important NRPs are devoted to neurosciences and to promoting basic research in mathematics, physics and computer science. Yet other programmes deal with previously well-established priorities, as in the case of plant biotechnology and sustainable food production. As a matter of fact, the impact of Cuban biotechnology on agriculture and food production has been significant. Several projects for the development of transgenic plants containing genes for resistance to pests and diseases were under development in 2009. The potential of transgenic plants as systems for the expression of recombinant proteins is being actively explored.

Figure 4: GERD in Cuba by source of funds, 2001 and 2008 (%)



Source: RICYT (2010) *El Estado de la Ciencia*

Social sciences are also part of the NRP. Particular programmes are oriented, for example, towards coping with specific features and problems of Cuban society or in identifying and analysing major trends in the global economy.

The scientific endeavour devoted to energy efficiency and the use of renewable energy sources does not qualify as an NRP but is nevertheless part of a huge State effort to rationalize energy consumption and promote savings. Particular attention is also being paid to the integrated management of water and soil resources, in order to cope with drought and its effects. As a number of projects under this scientific endeavour are considered a priority, they are included in the national S&T budget.

The same goes for nanosciences. The government is beginning to build capacity in this field by providing basic facilities and training personnel. Although nanosciences are not formally recognized as an NRP, some related R&D projects are being carried out within the framework of the NRP devoted to new materials.

Table 2: Cuba's National Research Programmes, 2009

National Research Developments in Neurosciences
Agricultural Production for Food Security
Energy Resources for Sustainable Development
Basic Research in Mathematics, Physics and Computer Science
Information and Communication Technologies
New Materials
The Sugar Industry
Agricultural Biotechnology
Pharmaceutical and Biotech Products
Human and Veterinary Vaccines
Sustainable Development of Mountain Region Ecosystems
Cuban Society: Challenges and Perspectives
The Cuban National Economy
Trends in the World Economy and International Relations
Global Change and the Evolution of the Cuban Natural Environment
Plant Breeding and Genetic Resources
Total: 21 million pesos (US$21 million)

Source: author

The priority given to biotechnology

In the early 1980s, Cuba stepped up its international exchanges. This in turn made it more vulnerable to some epizootics and epidemics. This would mark a turning point in Cuba's commitment to R&D: the combination of these two factors, coupled with the availability of a core human potential, would motivate Cuba to develop the scientific establishment further and expand its base into the national economy. This heralded the beginning of accelerated research in molecular biology and genetic engineering which would culminate in the founding of the Centre of Genetic Engineering and Biotechnology in 1986, one of Cuba's top R&D institutions.

Over a period of 20 years or so, the Cuban government invested around US$1 billion to develop the country's first and most important science node – that of West Havana – comprising of 52 institutions and enterprises related to biotechnology, covering research, education, health and economics. Ten institutions form the core of this node, in that they support the entire effort financially through their production capacities and exports.

In 2008, these 10 institutions were carrying out more than 100 research projects, mainly related to biotechnology applied to human health; these have generated a product pipeline of more than 60 new products. Most of these products are protected by intellectual property rights and more than 500 patents have been filed abroad. Several Cuban scientific results have been awarded the World Intellectual Property Organization (WIPO) Gold Medal.

The case of biotechnology is typical of Cuba's approach to R&D:

- the Cuban government is the source of investment;
- biotechnology is part of the national health system and, for this reason, national needs become a priority;
- success in biotechnology is essentially supported by Cuban scientists and professionals;
- biotechnology follows a 'closed cycle' from research to commercialization by fully integrated state institutions, with profits generated from sales in foreign markets, an important part of which is reinvested in R&D;
- national collaboration replaces competition among individuals as a driving force of Cuban biotechnology;
- 'spin off' state enterprises grow out of scientific institutions;
- success in product development has in turn improved Cuba's ability to access foreign markets, especially in the developed world, in terms of quality, production volumes, cost, novelty and joint ventures (López Mola *et al;* 2006). Two good examples are the licensing agreements signed in 2005 with China's Biotech Pharmaceutical Ltd for the joint development, production and marketing of monoclonal antibodies to treat auto-immune diseases and lymphomas, and, secondly, the agreement signed in 2004 with the American corporation CancerVax for technology transfer in vaccine production from Cuba to the USA to combat malignant diseases.

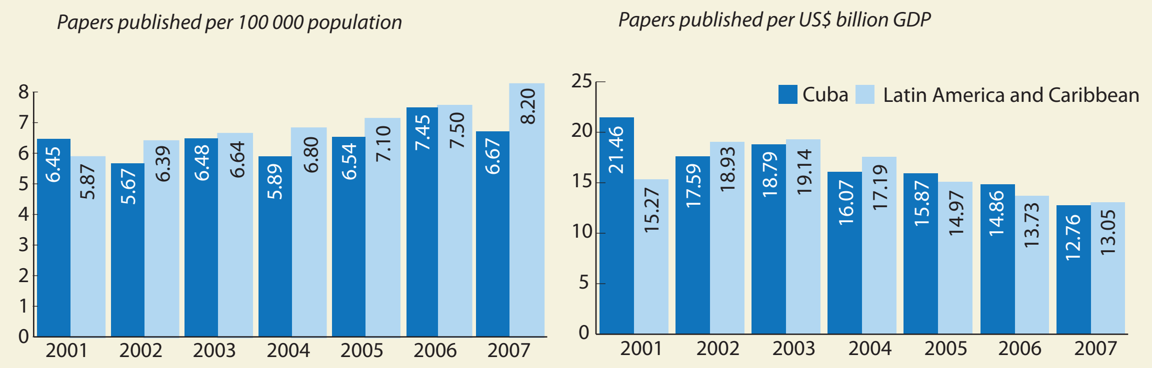
Other R&D piorities

The development and production of pharmaceuticals in general – and biotechnological products in particular – is without doubt the most successful example of the Cuban scientific endeavour but it is not the only area of importance for R&D.

Another important priority today is energy. R&D in this area is mainly related to wind energy production, hydropower, solar photovoltaic and – to a lesser extent – thermal energy from biomass. Generally speaking, priority is given to methods of saving energy and to the efficient use of every energy source.

Cuba began inventorying and evaluating its natural resources and ecosystems some decades ago. A comprehensive report updating the state of the environment was commissioned by

Figure 5: Cuban visibility in international scientific publications, 2001–2007



Source: RICYT (2010) *El Estado de la Ciencia*

CITMA and eventually released in October 2008, following the latest methodological guidelines established by the United Nations Environment Programme (CITMA–UNEP, 2008). More than 70 PhD holders from more than 50 national institutions participated in the study. The report covers such key areas as soils, water resources, biological diversity and the atmosphere; it provides a science-based approach to sustainable management of hydrographic basins, coastal areas and the urban environment, these being considered the main areas on which to focus management by the different authorities involved under the guidance of CITMA.

Disaster monitoring and mitigation is taking on a growing role, in light of the threat of stronger hurricanes, droughts, coral bleaching and flooding in future as a consequence of climate change. An evaluation was under way in 2009 of Cuba's vulnerability to extreme natural events, adaptation to these and mitigation of their effects. Early warning systems are constantly being improved. When Hurricane Gustav, the worst storm Cuba had seen for 50 years, struck on 30 August 2008, followed just days later by Hurricane Ike, approximately 2.7 million Cubans were evacuated. Economic losses totalled an estimated US$5 billion but, thankfully, there were almost no casualties.

R&D OUTPUT

Scientific output in Cuba, as expressed by scientific papers published in international journals, compares favourably with the mean for Latin America and the Caribbean. However, available data show that, whereas Cuba was slightly ahead of the rest of the region in 2001 in terms of papers per 100 000 population, the regional mean has since progressed. If we take the level of GDP into consideration in calculating scientific authorship, the data paint a similar picture for the first few years of the decade. However, both Cuba and the region begin losing ground from 2005 onwards (Figure 5).

Despite this modest numeric output in international publications, the results of Cuban research in several scientific disciplines are of a high quality. In vaccine development, Cuba is even at the forefront of research. One important detail is that these results have a high local social impact; all Cuban children are vaccinated, for instance, against 13 diseases and eight of these vaccines are produced locally.

Among Cuban pharmaceutical products, several should be highlighted. These include: the meningitis B vaccine, a recombinant vaccine for hepatitis B, a recombinant streptokinase thrombolytic agent, the cholesterol-lowering Atheromixol pill, recombinant human erythropoietin and colony-stimulating factors. The list is long. To it has recently been added a proprietary humanized antibody for the treatment of cancer.

In the diagnostic field, networks of neural diagnostics laboratories and ultra-micro Elisa systems (SUMA) for early infant diagnosis, blood safety and epidemiological surveillance have been established and continually improved and expanded since the mid-1980s. These offer coverage for the screening of the entire Cuban population that is unparalleled in the world.

The impact on the population's health is evident: meningitis epidemics have disappeared and hepatitis B is on the brink of being eradicated from the infant population. The entire Cuban population under 22 years of age is immunized against hepatitis B, the incidence of which is the lowest in the world.

INTERNATIONAL RELATIONS

The growing visibility of Cuban science

The visibility of Cuba in the international scientific community has increased somewhat in recent years. In July 2004, the American journal *Science* published a paper on the development at the University of Havana of a synthetic conjugate polysaccharide vaccine against *Haemophilus influenzae* type B. This bacterium is responsible for half of the bacterial infections in children under the age of five, including some of the most feared, like meningitis. In September of the following year, *Science* showcased María Guzmán, head of the virology department at the Tropical Medicine Institute Pedro Kourí (IPK) in Havana and a leading world expert on dengue fever. Guzmán was presented as one of 12 'global voices of science' in an issue commemorating the journal's 125th anniversary.

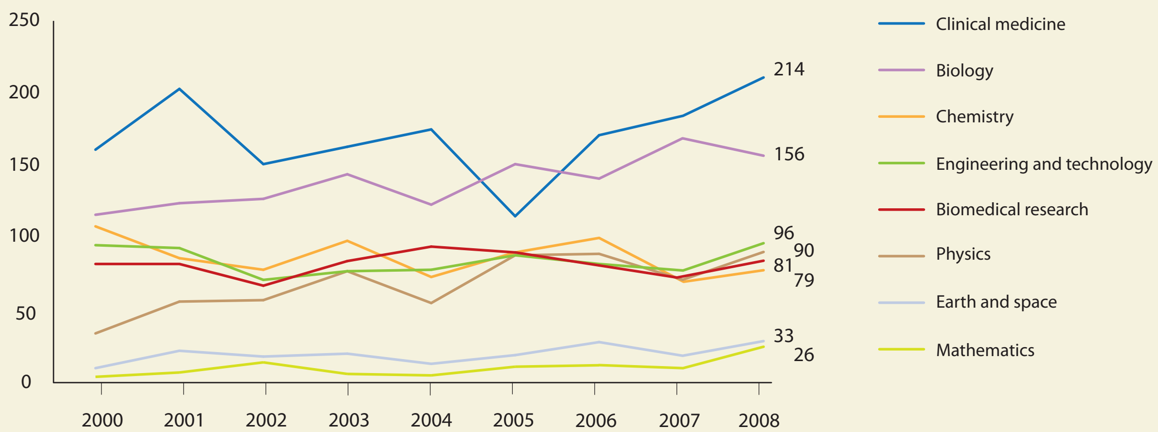
In 2008, the Cuban Academy of Sciences awarded a national prize for the development and commercial production of the first pentavalent vaccine produced in the developing world. The result of close co-operation among several Cuban centres of excellence, this new synthetic vaccine provides protection against *H. influenzae* infections, as well as tetanus, diphtheria, whooping cough and hepatitis B. In December of the same year, *Nature Biotechnology* published a review of the Cuban biotech industry.

Articles written by young Cuban authors in basic sciences are also being published in high-ranking international scientific journals like the *International Journal of Mathematics* and *Mathematical Sciences* (Abreu, 2005). According to data available at Thomson Reuter's Web of Knowledge, Cuban physicists were cited, on average, 60 times per year in 2004–2008, a significant increase. See also Figure 6.

International scientific co-operation

The Cuban scientific establishment is active in international co-operation, through bilateral agreements and by way of participation in international organizations. Bilateral agreements covering a wide range of research topics are in place with Argentina, Brazil, Colombia, Mexico and Venezuela. Beyond the region, China, India and Malaysia are the main partners. Cuba is an active member of the International Council for Science and the InterAcademy Panel for International Issues. It also belongs to regional bodies like the InterAmerican Network of Science Academies and the Caribbean Scientific Union. The embargo has not been effective in preventing international co-authorship of scientific publications, except as concerns co-operation with US scientists.

Figure 6: Publications in Cuba by major field of science, 2000–2008



Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Extended) compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

Ongoing medical assistance to developing countries
Cuba also provides medical assistance to developing countries confronted with an emergency. As a typical example, Cuba and Brazil both responded to a WHO request in 2007 to provide the large quantities of doses of A-C anti-meningococcal vaccine required by African countries facing health emergencies. The region at risk is home to 400 million people and covers 21 countries, including Burkina Faso, Ghana, Mali, Niger, Nigeria and Sudan.

Cuban medical co-operation goes back over 40 years but it changed into higher gear with the launch of the Comprehensive Health Programme (CHP) in 1998. This began as an emergency response to the international appeal for help formulated by the presidents of Central American countries devastated by Hurricane Mitch. Gradually, CHP developed into a regular assistance programme for Central American and Caribbean countries. At the request of their governments, the geographical scope of the programme was later broadened to include some African countries. As of 2009, Cuban collaborators working for the CHP had provided medical care to 95.4 million people and performed surgery on more than 2.2 million patients. At last count, Cuban personnel had vaccinated 9.4 million people.

CONCLUSION

By harnessing S&T to social needs over the past 40 years, Cuba has managed to eradicate illiteracy, extreme poverty, hunger and infant deaths due to preventive diseases. Today, the country ranks 51st in the UNDP's Human Development Index, placing it among countries with high human development (UNDP, 2009). Cuba's level of development is considered as being on a par with that of Uruguay (50th), Mexico (52nd) and Costa Rica (54th), and as distancing Brazil (75th). In the region, besides Uruguay, only Barbados (37th), Argentina (49th), Chile (44th) and Antigua and Barbuda (47th) rank higher. Moreover, according to the World Wide Fund For Nature's *Living Planet* report of 2006, Cuba is the only country with an acceptable 'ecological footprint' (WWF, 2006, page 19).

Where should Cuba go from here? Special care will need to go into updating and strengthening the technological infrastructure of its R&D institutions. For example, between 2005 and 2008, the Cuban government modernized the local Meteorological Service operated by the Institute of Meteorology by installing modern computing systems and other equipment. In 2009, this was still work in progress but there were already signs of a marked improvement in the efficiency of the early warning and hurricane-tracking systems. This modernization process should extend progressively to other branches of meteorological science like the mathematical modelling of potentially dangerous natural events. In the near future, it will be imperative to update the research technology of centres involved in other absolute priorities for R&D, such as food security or energy research.

Some strategic areas have been proposed as priorities for the short and medium term, to drive renewed investment in S&T infrastructure, which will of course be dependent on the country's possibilities for funding. These areas have been identified by means of a detailed consultation process conducted in 2007–2008 by CITMA, in which the Academy of Sciences took part. The process received input from more than 600 scientific experts, university professors and decision-makers, and includes contributions from territorial authorities and business leaders. The identified strategic areas can be summarized as follows:

- Innovation conducive to import substitution, a higher standard of living and more efficient production processes, such as in the areas of food production, construction technologies, water management, energy-efficient technologies and renewable sources of energy. By 2020, it is hoped that 18% of the country's total energy consumption will be provided by renewable sources.

- Competitive opportunities to attain a level of excellence in areas where Cuba has recognized capacities, or is developing such capacities, in order to enhance exports and improve living conditions: primarily, selected areas of biotechnologies, ICTs and advanced medical equipment; this includes the expansion of specialized value-added S&T services, as in the case of medicine.

- S&T fields in which Cuba must reach the forefront of knowledge or keep up with relevant new and convergent developments, such as materials science, bioinformatics and neurosciences. With regard to nanoscience and nanotechnology, a government endeavour is currently devoted to capacity-building, with special emphasis on training highly qualified human resources to work in the field.

- S&T problems that are especially relevant to Cuba's sustainable socio-economic development and to which significant contributions can be provided by the national STI system. Efforts in this area mainly focus on devising science-based measures to adapt to the impact of climate change, as well as applied research related to reducing vulnerability to natural disasters.

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Cuban National Statistical Office: www.one.cu

Ismael Clark Arxer was born in Havana in 1944. After graduating as a medical doctor from the University of Havana in 1967, he specialized in clinical biochemistry at the National Centre for Scientific Research. His work there was interrupted in 1975 when he took up a one-year fellowship at Friedrich-Schiller University in Germany.

Dr Clark Arxer has been linked to the Cuban Academy of Sciences since 1977, acting successively as General Scientific Secretary, Vice-President for Biology and Medicine, and as the Academy's First Vice-President. Following the creation of the Ministry for Science, Technology and Environment in 1994, he was appointed First Vice-Minister. Two years later, he was made President of the Cuban Academy of Sciences at the time of its reorganization.

He was the elected Chairman of the Caribbean Association of States' Special Committee for Co-operation in Education, Science and Technology, Health and Culture from 1996 to 1998, and he served from 2000 until 2005 as Secretary of the Caribbean Scientific Union.

Dr Clark Arxer is Full Professor at the University of Havana and at the Higher Institute of Technology and Applied Sciences (inSTEC). He is a member of both the Caribbean Academy of Sciences and of the Academy of Sciences of the Dominican Republic. Many of his articles have been published in Cuban journals and in specialized volumes in Mexico, Spain, Trinidad and Tobago and Venezuela.

One bright spot in an otherwise rather sombre tableau is the focus on higher education.

Harold Ramkissoon and Ishenkumba A. Kahwa

7 · The CARICOM countries

Harold Ramkissoon and Ishenkumba A. Kahwa

INTRODUCTION

Like elsewhere, the Caribbean region faces numerous challenges in a world that is becoming more and more interconnected. The peak in international prices of food and energy in 2007 and 2008 has further weakened the fragile economies of many countries. In Jamaica, for example, the import bill for petroleum products of roughly US$2 billion in 2007 was similar to the value of exports, which stood at nearly US$1.8 billion the same year; in 2006, the import bill had represented just 66% of export earnings (Government of Jamaica, 2006).

In such a climate, most governments in the region would find it difficult to augment their current investment in research and development (R&D), which has largely stagnated over the past decade at a dismal level of about 0.1% of GDP (Planning Institute of Jamaica, 2007). This is well below the target of 1% of gross domestic expenditure on R&D (GERD) that many developing countries agree they should strive for. This target is not unreasonable and has already been achieved by one of the smallest and poorest countries, Rwanda, which devotes 1.6% of GDP to science, technology and innovation (STI) [African Development Bank, 2007]. As a consequence, the Millennium Development Goals (Annex II) could remain largely unfilled, with most of the countries in the region unable to lift themselves out of the poverty trap.

The global recession that originated in the USA in 2008 has exacerbated the situation. The fragile tourism industry on which so many of the region's economies depend has been severely affected. For example, 83 460 tourists holidayed on the island of Tobago in 2006, compared to just 23 580 from January to June 2008, according to the Central Statistical Office of Trinidad and Tobago. The unofficial occupancy rate of hotels for the winter of 2008/2009 was about 30%, down from the normal rate of over 70%. In addition, both Jamaica and Guyana have experienced a drastic reduction in the flow of remittances from abroad, upon which they are so dependent: in Guyana, remittances contributed 22% of GDP in 2006. Even Trinidad and Tobago, the strongest economy in the region, has not been exempt from the 'meltdown'. In early 2009, the government had to rescue, via a financial bailout, one of the biggest private companies in the country, CL Financial, which reportedly contributed 25% of GDP and whose investments extended beyond the region. With weakening economies and the attendant rising unemployment, the immediate outlook for the region does not look bright.

In spite of this, the scientific community must pursue its efforts to persuade governments that many of the Caribbean's socio-economic problems cannot be solved without a dedicated push to develop and apply science and technology (S&T), particularly in the areas of renewable energy and food security (Box 1). The fate of the regional centre for renewable energy, which was to be hosted by Barbados until the project collapsed recently, does not send an encouraging signal. Governments must resist the temptation to put S&T on the back burner. The determination of President Obama to 'restore science to its rightful place and wield technology's wonders' may make the task of convincing governments a little easier.

In the larger countries, there are blocks to build upon. The governments of Jamaica and Trinidad and Tobago have both formulated long-term development plans, *Vision 2030* and *Vision 2020* respectively, which place STI capacity-building at their heart. Trinidad and Tobago's *Vision 2020* was devised in 2002. It rests on five pillars: enabling competitive business; developing innovative people; nurturing a caring society; investing in sound infrastructure and the environment; and promoting effective government. In 2006, the first operational plan was devised for 2007–2010. As for Jamaica, its *Vision 2030* will be the country's first long-term development plan. It was presented to Parliament in 2009. The plan is being implemented via three medium-term socio-economic policy frameworks, through which funding will be identified. The plan's strategic priorities include the development of human resources; international competitiveness; environmental sustainability; health; social protection; STI; effective governance; and law and order.

R&D INPUT

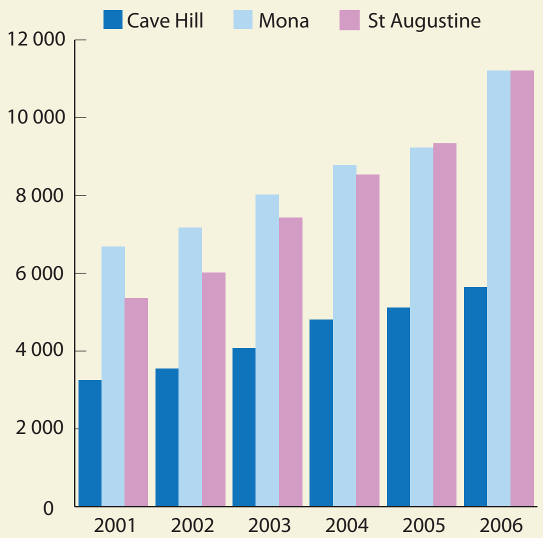
Trends in human resources

One bright spot in an otherwise rather sombre tableau is the focus on higher education. Over the last few years, two new universities have been established in the Caribbean; the state-owned University of Trinidad and Tobago (2004) and the private University of the Southern Caribbean (2006), also situated on the island of Trinidad. This brings the number of tertiary-level institutions in the countries of the Caribbean Common Market (CARICOM), with the exception of Haiti, to seven, for a population of about six million (Table 1): a ratio that compares favourably with other regions.

Students at the University of the West Indies

Photo: © University of the West Indies, St Augustine campus

Figure1: Undergraduate enrollment at the three campuses of the University of the West Indies, 2001–2006



Source: Harris, E. N. (2007) Personal communication. Report to Council Vice-Chancellor, University of the West Indies, 13 May

Moreover, thanks mainly to the introduction of free tertiary education in Trinidad and Tobago in 2006, student enrollment has increased substantially. For example, the three campuses of the University of the West Indies (UWI) have seen enrollment climb by, respectively, 65% (Cave Hill in Barbados), 68% (Mona in Jamaica) and 102% (Trinidad and Tobago) [Figure 1}. Growth in graduate enrollment has been less impressive over the same period and mainly confined to teaching, as opposed to research programmes.

While the rapid expansion of tertiary education in the region is most encouraging, it has led to one major problem. Generally speaking, the burgeoning student population has not translated into a proportionate increase in academic staff, resulting in additional teaching duties and space requirements. This has an adverse impact on efforts to create a vibrant research culture. To the credit of the UWI, 'semester leave' and research fellowships have been introduced to deal with this situation.

Another problem concerns sabbatical leave. This is meant to be accorded every six years so that staff can focus on

Table 1: Key socio-economic indicators for the CARICOM countries, 2008

	Population 2008 (thousands)	HDI ranking 2007	GDP per capita (PPP$) 2008	GDP annual growth 2007 (%)	GDP annual growth 2008 (%)	Public expenditure on education (% GDP) 2008	Public expenditure on tertiary education (% of all levels, 2008)	GERD/ GDP ratio 2007
Antigua and Barbuda	87 *	47 ↑	20 970	10.0	2.5	3.9^{-6}	6.7^{-6}	–
Bahamas	338	52 ↓	–	2.8	2.8^{-1}	–	–	–
Barbados 255		37 ↓	19 189	-2.1^{-5}	-2.1^{-5}	6.7	30.1	–
Belize	301	93 ↓	6 743	1.2	3.8	5.1^{-1}	0.7^{-1}	–
Dominica	67 *	73 ↓	8 706	3.4	4.3	4.8	–	–
Grenada	104	74	8 882	3.6	2.1	5.2^{-5}	9.8^{-5}	–
Guyana	763	114	3 064	5.4	3.0	6.1^{-1}	5.9^{-1}	–
Haiti	9 876	149	1 124	3.4	1.3	–	–	–
Jamaica	2 708	100 ↓	7 716	1.4	-1.3	6.2	15.7	0.06^{-5}
Montserrat	5 **-1	–	–	–	–	3.3^{-4}	–	–
St Kitts and Nevis	51*	62 ↓	16 467	4.0	8.2	9.3^{-3}	$–^{-6}$	–
St Lucia	170	69 ↓	9 836	0.8	0.5	6.3	–	0.36^{-8}
St Vincent and Grenadines	109	91 ↑	8 998	7.7	-1.1	7.0^{-1}	5.4^{+1}	0.15^{-5}
Suriname	515	97 ↓	7 401	5.2	5.1	–	–	–
Trinidad and Tobago	1 333	64 ↓	25 173	5.5	3.5	4.2**-6	–	0.06

-*n* = data refer to *n* years before reference year ↑↓ = change since previous evaluation * national estimation ** Unesco Institute for Statistics estimation

Source: for GERD and education: UNESCO Institute for Statistics, July 2010; for GDP per capita and GDP annual growth: World Bank; World Development Indicators, as of May 2010; for population: United Nations, Department of Economic and Social Affairs, Population Division; for population: UNDESA (2009), 2009; *World Population Prospects: the 2008 Revision*; for HDI ranking: UNDP (2009) *Human Development Report 2009*

Box 1: A centre of excellence to safeguard food security in Jamaica

In March 2008, at a time of escalating prices for cereal imports, the Jamaican Minister of Agriculture, Christopher Tufton, announced the establishment of a centre of excellence for agriculture at the Ministry's Bodles Research Station in St Catherine. The centre is being developed through a US$3 million provision from the Spanish Agency for International Development, in a drive to safeguard Jamaica's food security.

Essentially, the centre will be 'a facility that does applied research, practical research and training in the latest agricultural technologies in the world, based on our needs [and] our requirements', Dr Tufton outlined. These needs and requirements include the implementation of adequate and efficient irrigation mechanisms and systems, orchard development and greenhouse technology. He lamented the 'misuse and abuse' of water, noting that 'it's not that we don't have enough water, it's that we don't use it properly; we over-irrigate and we have to find a way to deal with that.'

The minister noted that citrus crops were the only established orchards in Jamaica. He stressed the need to do the same with other crops such as cashew, naseberry, mango and cacao. 'With orchards come risks', he said, 'because they are susceptible to diseases. We want to put some capacity in to anticipate some of those risks and deal with them.'

Dr Tufton said that, once the centre was established, he would be seeking to initiate collaboration with institutions like the University of the West Indies (UWI) to optimize the facility's resources. He had already advised the University of Technology, after it approached him regarding offering certification in agricultural research, to enter into discussions with the UWI on a possible partnership.

The new centre will be working on greenhouse expansion, greenhouses being a form of protected agriculture reputed for their high productivity. Jamaica sent 12 extension officers to Costa Rica for a month to study greenhouse technology in April 2008, under an agreement signed between the two countries earlier the same year.

Another initiative will consist of developing cassava, a drought-resistant crop, to reduce dependence on imported starches like rice, corn and wheat. The minister disclosed that approximately 2 000 acres of restored bauxite lands had been identified for the purpose of growing cassava, a project that would involve small-holder farmers. The ministry also plans to undertake test trials to determine the suitability of cassava as a substitute for corn-based livestock feed.

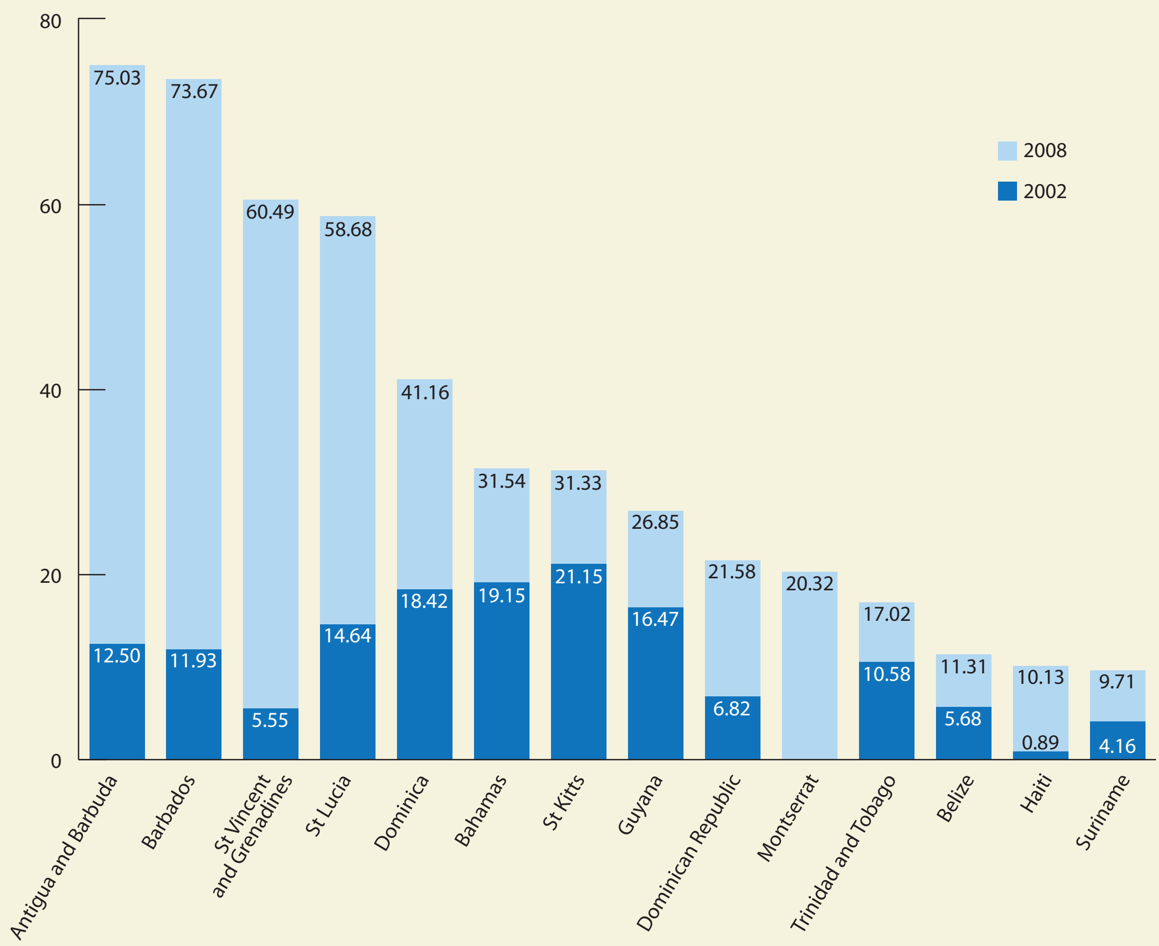
Source: Ministry of Agriculture, Government of Jamaica: www.jis.gov.jm/agriculture/

their research and recharge their scholastic batteries for a year. This benefits not only the individual but also the institution. However, for financial reasons, sabbatical leave is not a regular entitlement in the region. In some cases, it has even become an award for longevity, thereby defeating the very purpose for which it is meant. Universities thus need to revisit their policy for sabbatical leave.

There is another problem which this time affects Guyana and Suriname specifically. Although the salaries of academic staff have risen over the years in these countries, they still remain unattractive and uncompetitive, a situation that is hardly likely to change in the near future. This makes it difficult to recruit high-quality staff and, consequently, to mount competitive postgraduate programmes and create an enabling research environment. Together, Cariscience (Box 2) and the UWI are trying to help the national Universities of Guyana and Suriname improve their postgraduate and staff development programmes.

While some attempts have been made to address gender issues, the *status quo* has largely prevailed in recent years. There is still a paucity of senior women at both the professorial and decision-making level of S&T. The Faculty of Pure and Applied Sciences at the UWI, for example, counts just four full women professors out of a staff of over 150. The 'leaky pipeline' has not yet been repaired, with women renouncing posts of responsibility for a variety of reasons that include the conflict with family life and a certain discomfort with the science culture. In disciplines such as physics and computer science, women are still few and far between at the faculty level. There have been claims of disparities in remuneration and in the allocation of research funds and facilities. The situation is reversed when it comes to undergraduate and post-graduate enrollment, as here women continue to outnumber men. At the UWI's Mona campus, for example, about 73% of undergraduate students were women in 2005/2006 and 2006/2007. Policy- and decision-makers will have to intensify their efforts to address this gender imbalance.

Figure 2: Internet users per 100 population in the Caribbean, 2002 and 2008



Source: United Nations Statistical Division, Millennium Development Goals indicators

The migration of skilled labour is another key issue. The figures remain high for many CARICOM countries. For example, about 27 000 Jamaicans (1% of the population) migrated to the USA, Canada or the UK in 2007. This said, the increase in remittances from nationals working abroad has cushioned the impact of migration and softened its traditional image somewhat. Remittance inflows into Jamaica, for instance, stood at US$1.9 billion in 2007, close to export earnings of US$1.8 billion. This makes remittances Jamaica's top foreign-exchange earner. It is essential to determine how CARICOM countries can otherwise engage the diaspora in national development programmes. A number of organizations grouping the diaspora have been formed and in some cases have attracted large numbers.

It is in this context that the Caribbean Diaspora for Science, Technology and Innovation was officially launched in September 2008 in Port of Spain, at the 10th anniversary of Cariscience, by Fitzgerald Jeffrey, Minister of Science and Technology and Tertiary Education of Trinidad and Tobago. This is a commendable effort, particularly in light of the fact that chronic brain drain is not about to go away, given the unlikelihood of socio-economic conditions improving in the foreseeable future.

Trends in R&D expenditure

Adequate funding is a prerequisite for the creation of a dynamic research culture. The reality in the Caribbean is that investment in R&D by both governments and the private sector is grossly inadequate. This is the major difficulty encountered by regional scientists. Let us take the case of Trinidad and Tobago. By far the wealthiest of the Caribbean countries, with a booming economy based on natural resources, it spent a mere 0.06% of GDP in 2007 on R&D and an average of 0.12% over 2000–2005. At their annual meeting in 1999, the heads of government endorsed a proposal to establish a Caribbean Regional Research Agency. A decade later, this is yet to become a reality. Similarly, the share of business R&D in the total remains very low throughout the region, even if it has grown in Trinidad and Tobago from 13% in 2000 to 24% in 2005, according to the UNESCO Institute for Statistics.

The role of business

The main businesses in the region are associated with: (1) oil and gas, in Trinidad and Tobago; (2) alumina and bauxite, in Guyana, Jamaica and Suriname; (3) agriculture, in nearly all countries; and (4) tourism, nearly all countries.

Much of the region is no longer self-sufficient in food. In 1995, Belize, Dominica, Guyana, St Lucia and St Vincent and the Grenadines all exported more food than they imported, whereas Jamaica managed to balance food imports and exports. By 2004, only Belize and Guyana were still exporting more food than they imported and Jamaica was importing over 60% of staple foods, according to the Minister of Agriculture. The growth in tourism may have contributed to this situation, as it has intensified the demand for food not grown in the region (FAO, 2007).

R&D is conducted mainly in parent countries beyond the region. However, a disturbing trend, albeit one which may be justified by economic competitive environments, is that some major *local* companies have established R&D facilities in their overseas operations to respond more effectively to market realities abroad and at home. For example, GraceKennedy, a large indigenous Jamaican company, established an R&D outfit in Canada in 2006 to develop new products for its domestic and foreign markets (Meikle, 2006).

In response to this new reality, Kahwa (2003) proposed a model of R&D for developing countries that find their R&D skills underutilized at home. Dubbed 'Strategic Decoupling', the model seeks to focus the R&D effort of a researcher from a developing country on competitive global R&D opportunities. The model rests on success in the international R&D arena earning researchers from developing countries serious attention at home, thereby spawning confidence in their abilities at all levels. Indeed, the success of the small but growing pharmaceutical R&D operations undertaken by the UWI campuses in Barbados and Jamaica is indicative of the potential effectiveness of the Strategic Decoupling model.

These developments notwithstanding, a healthy level of innovation seems to be taking root in some businesses. The chicken and egg industry in the region is vibrant and vertically integrated, with a fairly large small-farmer base producing high-quality poultry products. This said, the process by which this has been achieved needs to be carefully studied and documented, so that lessons learned therefrom can be replicated in other sectors.

For the most part, innovation in the productive sector is, according to *Science, Technology and Innovation Policy Review, Jamaica* (UNCTAD, 1999), hampered by a disconnection between the R&D effort and critical industry needs. The productive sector is not investing enough in R&D (in-house or otherwise); there is thus little incentive for researchers to pay the requisite attention to the problems of industry. There is a need for policy innovation to create an integrated environment in which R&D institutions, the government and the private sector all work together to bring S&T to bear on economic growth, poverty reduction and job creation and in raising the standard of living.

Some business incubation is going on in Jamaica at the University of Technology and at the country's Scientific Research Council. The UWI has also established the Mona Institute of Applied Sciences (in 2001) to spearhead its efforts to transfer technology and commercialize the fruits of research. Success is slow in coming, however; this is largely due to the lack of mechanisms for venture capital, combined with weak linkages – even non-existent in some cases – between universities, public research institutes and the private sector in national systems of innovation.

Box 2: Cariscience

Cariscience is a sub-regional network of scientists bent on upgrading the academic excellence of graduate, postgraduate and R&D programmes in the Caribbean. An NGO affiliated to UNESCO, Cariscience was launched in June 1999 in Jamaica.

The network strives to strengthen theoretical and practical knowledge in basic and applied sciences in the Caribbean, to increase the number of postgraduate and R&D programmes, and to foster ties between these programmes. Cariscience is also supporting the development of an accreditation and evaluation system for postgraduate science programmes. Cariscience co-ordinates exchanges between researchers, teachers and students, organizes joint research projects and regional courses, and supports curriculum development and the training of science teachers. In 2007, it organized the first Caribbean Summer School in Mathematics and Physics, to introduce postgraduate students and researchers to frontier science in these disciplines. The ultimate goal is to improve science education and create a pool of young internationally competitive research scholars. This includes fostering linkages with the productive sector.

In recent years, Cariscience has gone beyond its original mandate to embrace the environmental sciences. It has undertaken a water project funded by UNESCO, for example, and organized a workshop on coastal erosion in 2005.

Since 2006, Cariscience has initiated and supported all the major regional meetings. The first was Harnessing Science and Technology for Caribbean Development (Trinidad and Tobago) in 2006, which drew participants from government, academia and industry. As part of the *Plan of Action*, a working group on science education was set up which recommended 'that our education systems make concepts of entrepreneurship and the use of STI part of the education curriculum from the primary-school level.' Cariscience went on to organize a CARICOM Science Education Conference in Jamaica in November 2007, sponsored by UNESCO, the InterAmerican Network of Academies of Sciences and the Caribbean Academy of Sciences.

In September 2007, Cariscience organized a four-day conference in Tobago on renewable energy in the Caribbean. This led to the creation of the Committee on Caribbean Education and Capacity-Building for Sustainable Energy in 2008, overseen by Cariscience.

Source: author

Download the Cariscience brochure (2008): www.unesco.org/science/psd/thm_innov/cariscience.shtml

For details: www.sta.uwi.edu/fsa/dmcs/cariscience

R&D OUTPUT

CARICOM publications

Although there are some encouraging developments in terms of R&D output, progress is still painfully slow in the Caribbean. There are also persistent reports of a disconnection between the output of researchers, on the one hand, and the R&D needs of the productive sector, on the other. In 2008, Prime Minister Golding of Jamaica asserted that 'research has been too academic' and demanded that it be 'synchronized with growth objectives'. Although he makes a critically important point, research has still not been planned and resourced to perform this role in any of the CARICOM countries.

Indeed, the citation rate in the international literature for original research articles from the region shows only modest growth of roughly 22% over 2001–2005 and even a worrisome downturn in 2006. Furthermore, articles in basic sciences tend to be stagnating at about 150 per year for the 2001–2007 period, save for a peak in 2005 (Figure 3). The majority of original research articles come from medical and allied fields due, in part, to the effectiveness of the *West Indian Medical Journal* in nurturing research and publication skills (Figure 4). The participation rate in original research publishing is more encouraging. Whereas Jamaica, Trinidad and Tobago and Barbados have traditionally dominated CARICOM publications in international literature, every CARICOM country except Montserrat has shown some research and publishing activity during 2001–2007. Newcomers Bahamas, Belize and Grenada, in particular, are showing some promise (Figure 5).

The dominant institution in higher education for the past 60 years has been the UWI. While this is still the case, with over 70% of CARICOM articles stemming from the UWI, other institutions have also come on the scene (Figure 6).

Their publication rates remain modest but that of St Georges University in Grenada is showing considerable promise; its publications are dominated by the medical sciences. The governments of Guyana and Suriname will need to invest more in their national universities to turn their scholarly productivity around.

CARICOM researchers exhibit considerable readiness to collaborate, especially with their counterparts in the USA, Canada and the UK who co-authored 29%, 11% and 6 % respectively of CARICOM papers over 2001–2007. This is an important step in the process of adaptation, diffusion and adoption of S&T by the developing countries that make up CARICOM.

Intellectual property issues are usually settled by researchers with the assistance of specialized offices and policies established at their universities and research institutions. There are potential sources of intellectual property in medical, agricultural, engineering and basic research. The protection of intellectual property is frequently hampered by a shortage of funds and researchers also tend to resort to authoring a research paper rather than doing all they can to bring their work to patentable levels. These are strategic issues that the region will have to tackle.

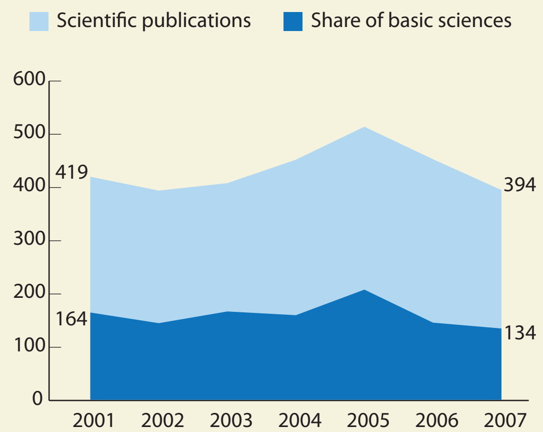
CARICOM patents

The picture with regard to CARICOM patents is a little murky but it does show some improvement in innovation in Jamaica and Trinidad and Tobago (Figure 7). In Jamaica, the number of patents granted to local inventors increased from zero in 2001 to nine in 2005 and 2006. The number of applications received by the Jamaica Intellectual Property Office is increasing, largely due to external interest. Jamaican applicants numbered in the range of 4–21 annually over the 2001–2007 period.

The patent situation in Trinidad and Tobago shows considerable interest from foreign applicants, which augers well for the country's efforts to make the economy knowledge-driven. However, in its drive for a knowledge-intensive economy, it will be important for Trinidad and Tobago to cultivate home-grown inventions, achieve the Millennium Development Goals and realize its own ambitions of obtaining developed-country status by 2020.

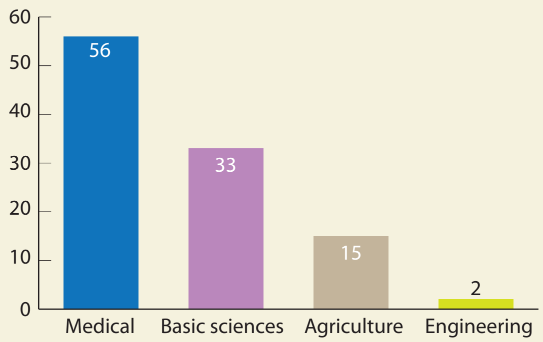
The Intellectual Property Office of Trinidad and Tobago reports that there are fewer than two applications per year from local inventors. Barbados' patents are even rarer and have mostly been granted to foreign applicants. The region's inventors have been somewhat successful with their patent applications in the USA, especially the Bahamanians, who secured 32 patents from the US Patents and Trademark Office (USPTO) over 2002–2007. Other countries having secured USPTO patents over the same period are: Barbados (7); Jamaica (6); St Lucia (2); and Trinidad and Tobago (6).

Figure 3: Articles published in the basic sciences in the CARICOM countries, 2001–2007



Source: Thomson Reuters (Scientific) Inc. Web of Science, Science Citation Index Expanded

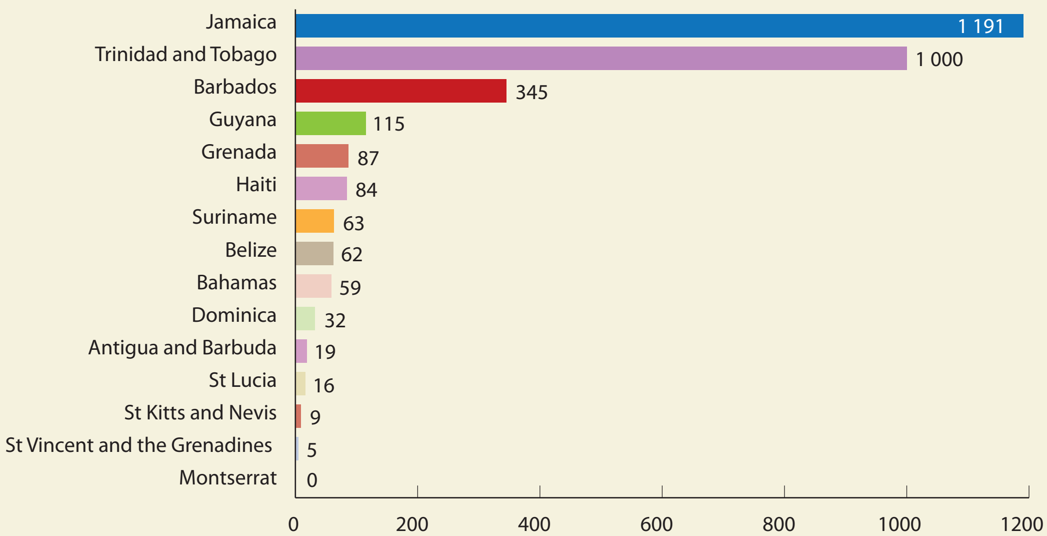
Figure 4: Scientific publications in the CARICOM countries by broad discipline, 2001–2007 (%)



Note: The combined total is greater than 100% because some publications relate to more than one discipline

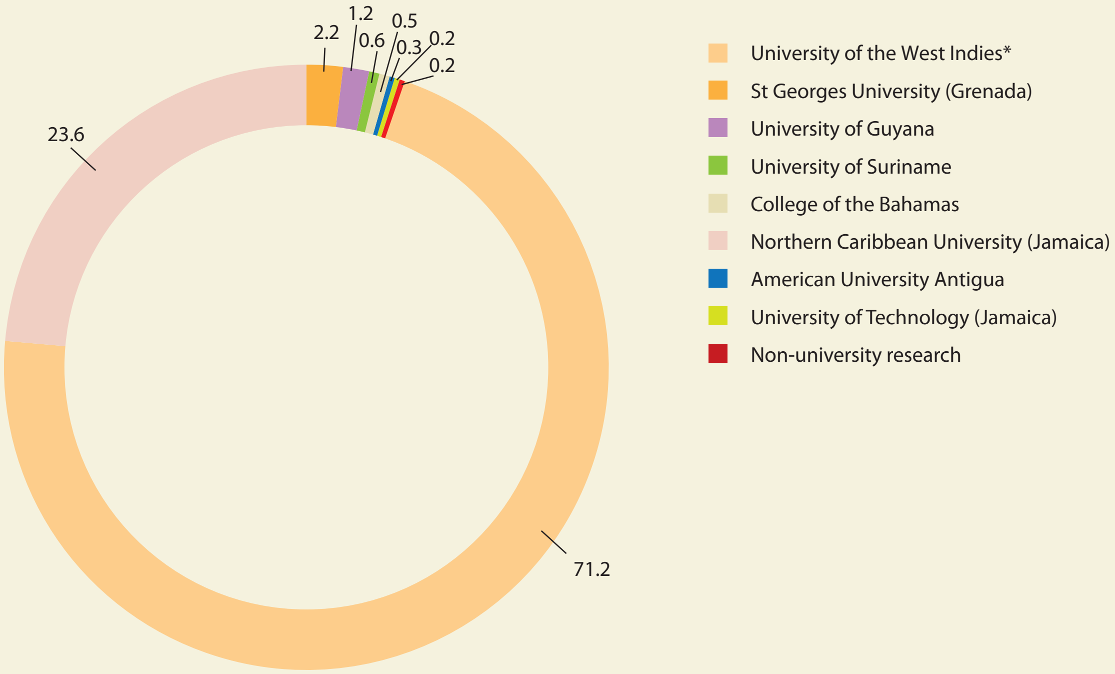
Source: Thomson Reuters (Scientific) Inc. Web of Science, Science Citation Index Expanded

Figure 5: Cumulative number of scientific publications in the CARICOM countries, 2001–2007



Source: Thomson Reuters (Scientific) Inc. Web of Science, Science Citation Index Expanded

Figure 6: Scientific publications by university in the CARICOM countries, 2001–2007 (%)
As a share of total research



*Serving all CARICOM countries except Guyana and Suriname

Source: Thomson Reuters (Scientific) Inc. Web of Science, Science Citation Index Expanded

THE ROLE OF REGIONAL BODIES

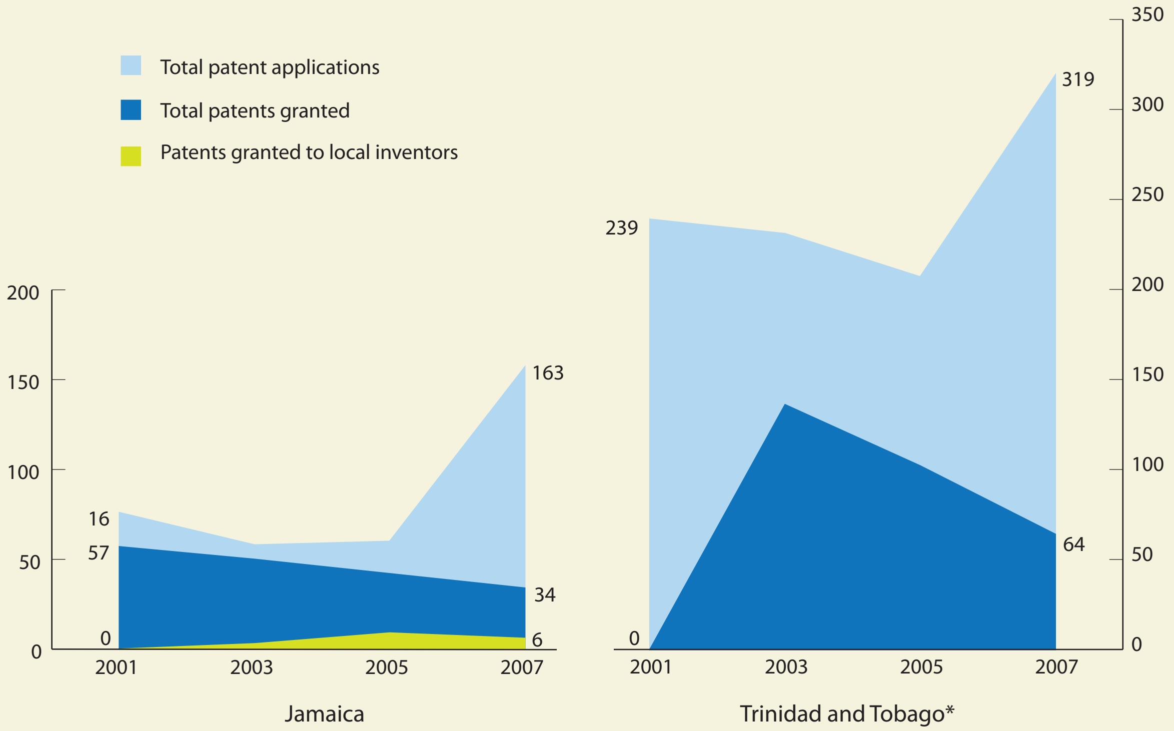
There are two major regional NGOs in the region, the Caribbean Academy of Sciences (CAS) and Cariscience. Founded in 1988, CAS has had a new lease of life in recent years. It has mounted major scientific meetings in Guadeloupe (2006), on the theme of Science and Technology in a Caribbean Environment and, in Grenada (2008), on Science and Technology: Vehicles for Sustainable Economic Development in the Caribbean. CAS has also obtained a grant from the European Union for a project to raise awareness of ICT issues. Within this project, CAS organized a Caribbean Conference on Information and Communication Technology: Research, Applications and Policies, at the Mona Campus of UWI in March 2009, immediately followed by an awareness-building workshop. Despite the EU grant, CAS continues to be plagued by funding shortages.

CAS has considerable potential for mobilizing scientists in the region. It reaches out to the wider scientific community through its membership of the Caribbean Scientific Union, the Academy of Sciences for the Developing World (TWAS), the InterAmerican Network of Science Academies and the InterAcademy Panel (IAP). It is hoped that the support it enjoys from international scientific academies will strengthen its regional position and attract funding from within the Caribbean.

Cariscience enjoys close ties to UNESCO and its Abdus Salam International Centre for Theoretical Physics in Italy; to the Organization of American States; and to the International Centre for South–South Co-operation in Science, Technology and Innovation launched in Malaysia in 2008. For a region as small as the Caribbean, these links are essential if it is to maintain a dynamic scientific community.

As for the Caribbean Council of Science and Technology (CCST), an intergovernmental organization, it continues to operate with support from only a handful of governments. Mokhele (2007) has noted the operational difficulties faced by the CCST since its inception and recommended that its fate be decided by the authorities.

Figure 7: Patent applications in Jamaica and Trinidad and Tobago, 2000–2007



* Local applicants in Trinidad and Tobago are fewer than two per year.

Source: Jamaica Intellectual Property Office (2008), Intellectual Property Office of Trinidad and Tobago (2006) with update January 2009

STRENGTHENING REGIONAL CO-OPERATION

The lack of a critical mass of scientists in any of the Caribbean countries, coupled with weak and fragile economies with the notable exception of Trinidad and Tobago, makes regional co-operation a necessity. Even in Trinidad and Tobago, there are just 477 scientists per million population.

A number of events have been held in recent years to strengthen co-operation in the Caribbean. In 2006, a major conference on Harnessing Science and Technology for Caribbean Development was held in Trinidad and Tobago under the auspices of CARICOM and the patronage of then Prime Minister of Grenada, Keith Mitchell, who at the time served as Head of Government with responsibility for S&T within CARICOM. The conference's main sponsors were UNESCO and Cariscience. Emanating from this Conference were the *Tobago Declaration* and an accompanying *Plan of Action*. A Steering Committee was subsequently established by Prime Minister Mitchell to drive implementation of the *Plan of Action*.

UNESCO agreed to provide a consultant to visit the region, assess the status of S&T and assist in providing the necessary platform for implementing the *Plan of Action*. The consultant, Dr Khotso Mokhele, visited the region in late 2006 before submitting a report to UNESCO early the following year. Known as the Mokhele Report, it was presented by UNESCO to high-level government and CARICOM officials in September 2007 (Mokhele, 2007). A high-level meeting involving ministers of science and technology and education, heads of tertiary institutions and captains of industry was convened by the Office of Prime Minister Mitchell in April 2008 to discuss the Mokhele Report (Box 3).

Box 3: The Mokhele Report

In 2007, a report entitled *Using Science, Technology and Innovation to Change the Fortunes of the Caribbean Region* was prepared by Dr Khotso Mokhele, former President and Chief Executive Officer of the National Research Foundation of South Africa, under a consultancy commissioned by UNESCO and the CARICOM Steering Committee on Science and Technology.

Higher education

The report noted that there were competent higher education institutions in the CARICOM countries but virtually no funding to support full-time postgraduate studies, with the possible exception of Trinidad. Mokhele observed that this situation was aggravated by the progressive loss of the regional character of the UWI by the devolution of authority to national authorities in a few major territories. Mokhele argued that political devolution would undermine the impetus towards regional integration, at a time when integration was being pursued by other major global geographical blocks, especially as academic research was best advanced in small island states by regional collaboration. He further intimated that the territories without a UWI campus needed urgent attention.

Economic structure

Mokhele observed that the region's economy was mainly mercantile and service-oriented, with mining and agriculture being in decline. The lack of a push–pull relationship between S&T and production tended to discourage youth from studying science, at a time when this was essential for development.

This disconnect between S&T and society had led to a propensity to criticize without proposing solutions, he observed. It had also created a schism between the leaders of society and the S&T community. The former criticized the unwillingness of researchers to tackle the needs of society and the latter felt their work was misunderstood.

Funding and implementation

The report stressed that government spending on S&T and R&D was miniscule, even though investment in research and innovation was the best path for lifting countries out of underdevelopment. Mokhele urged governments to forge international partnerships but pointed out that this did not mean they should relinquish responsibility for stimulating STI at home. He noted that the bureaucratic and consensual nature of government bodies prompted the belief that agencies formed and funded by them should be operated at arms length for flexibility and efficiency. On the contrary, stated Mokhele, these institutions needed to

The principal recommendation from this meeting was 'that an overarching broad-based agency called the Caribbean Science Foundation be established as soon as possible to develop S&T and build the requisite capacity to harness S&T for the region's development'. This is an opportunity for the scientific community to deal with its problem of fragmentation and unite under one umbrella to transform the region's S&T landscape.

However, this can only be achieved if there is the political will to move forward and the active co-operation of all stakeholders. In this regard, it is heartening to see that the strongly recommended Caribbean Science Foundation has now become a reality. It was officially launched on 21 September 2010 at the Caribbean Science Forum. The premonitory theme of the forum was Science, Technology, Innovation and Entrepreneurship – the Way Forward for the Caribbean.

CONCLUSION

The CARICOM region enjoys a certain measure of stability. It also has a reasonable infrastructure in place for education, information and communication, together with a group of dedicated scientists. The region therefore possesses the foundations on which to build its capacity to harness S&T more effectively to the socio-economic development of the Caribbean.

be more accountable than government bodies.

Recommendations

The report recommended a supranational approach to higher education and R&D. It called for the setting up of a regional Research and Innovation Agency, the medium- to long-term funding of which would need to be assured by the government and banking sector, via soft loans, grants and so on. The agency would be mandated to foster ties between bright young entrepreneurs and young scientists, technologists and engineers, to make the best use of knowledge to create new businesses and jobs.

The report also recommended developing 'a truly Caribbean university'. In parallel, it called for a fund to be set up within the agency to allow for full-time postgraduate study and post-doctoral fellowships to make the university more inclusive. The fund could be administered by the Research and Innovation Agency.

It also recommended the launch of an R&D survey to reveal the true state of affairs and provide data of use for international comparisons.

Another key recommendation was for NGOs like the Caribbean Academy of Sciences and Cariscience to be strengthened, as these were considered vital for providing up-to-date information and analysis of the influence of global S&T on the Caribbean region. This was all the more important, noted Mokhele, in that there was no regional 'think-tank', nor any science advisors to the prime ministers or parliaments, with the exception of Jamaica and Guyana.

Reception of the report

Many of the report's findings were endorsed at a meeting of the CARICOM countries in Grenada on 9 April 2008, convened specifically to discuss the report. In commenting on its findings, Dr Arnoldo Ventura of the Office of the Prime Minister in Jamaica acknowledged that clear economic demand for S&T was largely non-existent in the Caribbean, despite the fact that both demand and supply were important to trigger innovation. He observed that 'in our region, there is reasonably good R&D but pilot plants, scale-ups, repair, design, maintenance and engineering capabilities are weak and often absent. This has to be remedied.'

The meeting recommended the establishment of the Caribbean Science Foundation 'as soon as possible to develop STI … for the region's development'. Among other functions, the foundation would be responsible for strengthening the weak link between the private sector and academia by fostering collaborative R&D.

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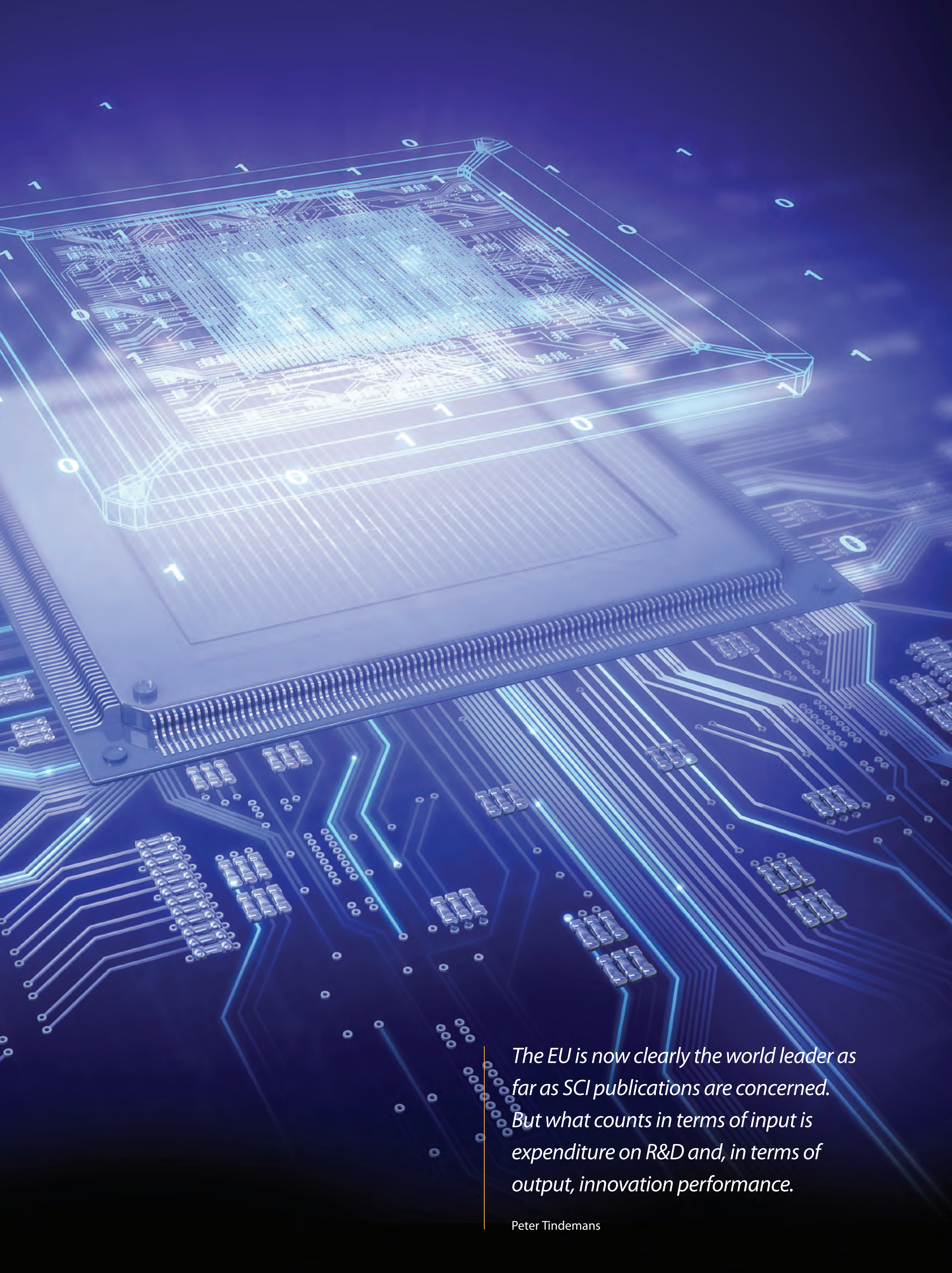
Prof. Kahwa was born in Tanzania in 1952. After obtaining an MSc in inorganic chemistry from the University of Dar es Salaam, he went on to complete a PhD at Louisiana State University in the USA in 1986. Four years later, he set up a laser laboratory at the UWI to study the electronic behaviour of novel molecules with supramolecular aggregations and potential new applications in biomedical diagnostics and therapeutic, catalytic and nano-mechanical systems.

In addition to chemistry, Prof. Kahwa has a keen interest in both environmental research and policy and the interactions between society and the science–technology–innovation triad. This dual interest led him to form a broad-based team which developed and launched a set of study programmes in Occupational and Environmental Safety and Health at the UWI in 2006.

Harold Ramkissoon was born in 1942 in Trinidad and Tobago. He was educated first at the University of the West Indies then at the Universities of Toronto and Calgary in Canada. A mathematician, he is currently Professor Emeritus at the University of the West Indies in Trinidad.

Prof. Ramkissoon has made notable contributions to understanding of micropolar and microcontinuum fluids and Marangoni instabilities and has played a pivotal role in the advancement of science in the Caribbean region. He has been the recipient of several awards, including the Chaconia Gold Medal, Trinidad and Tobago's second-highest national award; the Academic Gold Medal from Simón Bolívar University in Venezuela; and the First CARICOM Science Award.

Prof. Ramkissoon is a Fellow of both the Caribbean Academy of Science and the Academy of Sciences for the Developing World (TWAS), as well as a Corresponding Member of the Cuban Academy of Sciences and the Venezuelan Academy of Sciences. He is also Executive-Secretary of Cariscience.



The EU is now clearly the world leader as far as SCI publications are concerned. But what counts in terms of input is expenditure on R&D and, in terms of output, innovation performance.

Peter Tindemans

8 · European Union

Peter Tindemans

INTRODUCTION

The European Union (EU) now counts 27 member states. Since the previous enlargement embraced 10 new countries[1] on 1 May 2004, Bulgaria and Romania have joined the fold, on 1 January 2007. The total population of the EU-27 stood at 495.5 million in 2008, versus 486.6 million five years earlier for the same 27 countries. Negotiations with three more candidate countries are ongoing: Croatia, the Former Yugoslav Republic of Macedonia and Turkey.

Eleven countries have concluded co-operation agreements in science and technology (S&T) that involve contributing to the budget of the EU's Seventh Framework Programme for Research and Technological Development (FP7), covering 2007–2013. These include the four remaining members of the European Free Trade Area (EFTA), Iceland, Liechtenstein, Norway and Switzerland, as well as Israel and Turkey. The others are Albania, Bosnia and Herzegovina, Croatia, the Former Yugoslav Republic of Macedonia, Montenegro and Serbia. These 11 countries participate in the FP7 on the same footing as the EU member states. In describing developments and performance in the EU member states over the coming pages, some information on the EFTA countries in particular will thus be included. Neither Turkey nor those countries in Southeast Europe which are not EU members will be discussed, however, as they are the object of separate chapters (*see pages* 183 *and* 201).

Real growth in GDP for the EU-27 came to 11.9% for the cumulative five-year period to 2008, resulting in an estimated GDP per capita in purchasing power parity (PPP) of €25 100 in 2008 (Table 1). Obviously, growth rates vary greatly among the 27 member states. Slovakia, Latvia and Lithuania lead the pack with five-year real growth rates of as much as 40–43%. At the other end of the scale, Italy and Portugal report lagging five-year growth rates of 5–6%. Clearly, the newer member states are catching up in economic terms, although there remain yawning absolute differences. Estimated GDP per capita (in PPP) in 2008 is lowest in Bulgaria and Romania, at €10 000 and €11 300 respectively, followed by Poland and Latvia at €13 800 and €13 900. Apart from the exceptional case of Luxembourg, where GDP per capita was a whopping €67 600 in 2008, the 'normal' high scorers are Ireland, the Netherlands and Austria at €36,300, €33 400 and €31 300 respectively.

That was before the recession. There is little doubt that the next *UNESCO Science Report,* looking back on the years 2010–2014, will paint a very different picture. The economic recession that has been hurting countries deeply all over the world since the last quarter of 2008 will have a widely varying impact on individual EU member states. That much is clear from the May 2009 forecasts for GDP growth – or rather shrinkage – with estimates of a contraction of more than 10% in 2009 for some countries. Ireland has been one of the first casualties; after decades of 'an economic miracle',

Table 1: Population and GDP in the EU, 2008

Country	Population 2008 (million)	5-year GDP growth rate (%)	2008 GDP per capita (PPP €)
EU-27	497.5	11.9	25 100
Austria	8.3	14.5	31 300
Belgium	10.7	12.4	29 500
Bulgaria	7.6	35.5	10 000
Cyprus	0.8	22.0	23 200
Czech Republic	10.4	31.3	20 900
Denmark	5.5	10.7	30 100
Estonia	1.3	32.8	16 200
Finland	5.3	17.6	28 900
France	63.8	10.0	27 200
Germany	82.2	9.1	29 100
Greece	11.2	20.7	24 300
Hungary	10.0	15.3	15 500
Ireland	4.4	22.8	36 300
Italy	59.6	4.9	24 900
Latvia	2.3	41.6	13 900
Lithuania	3.4	40.1	15 200
Luxembourg	0.5	26.1	67 600
Malta	0.4	14.1	19 600
Netherlands	16.4	13.8	33 400
Poland	38.1	30.2	13 800
Portugal	10.6	5.8	18 900
Romania	21.5	38.7	11 300
Slovakia	5.4	42.8	17 600
Slovenia	2.0	28.5	23 100
Spain	45.2	16.7	26 200
Sweden	9.2	14.7	30 900
United Kingdom	61.2	11.9	29 600

Source: Eurostat

Computer chip. In February 2010, Researchers at the Tyndall National Institute in Cork, Ireland, announced a breakthrough in transistors with the design and fabrication of the world's first junctionless transistor. These can be produced at 10-nanometer scale using existing fabrication techniques.

Photo: © Andrey Volodin/ iStockphoto

1. Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia

the Irish economy contracted by 8.5% on an annual basis in the first three months of 2009, according to the Irish Central Statistics Office.

Although several countries have stated individually and collectively that investment in research and education will be essential to overcome the crisis and even consolidate their position afterwards, neither the recovery packages put together by both individual countries and the EU, nor the budgetary forecasts for research and education seem yet to warrant great optimism, in marked contrast to the USA. One example is the United Kingdom; in its 30 April 2009 issue, the British journal *Nature* reported that, apart from an additional £1.4 billion for low-carbon business and technology, the UK's recovery package provided few incentives for research and development (R&D). One measure amounted to swapping £103 million from the research councils' budget for 'blue-skies' research[2] for research in key areas of economic importance. This finding seems to tally with the much less optimistic, more passive view among companies in Europe than their counterparts in the USA and China, or even in wider Asia. The biannual Survey[3] of 1 309 Chief Financial Officers of companies in the USA, Europe, China and the rest of Asia on their expectations for the second quarter of 2009 found that European companies still regarded their future with pessimism. They chose to focus on reducting costs and investment in R&D, in preference to redefining their business model, markets or strategies.

From a global perspective, by far the most important political development in relation to R&D in recent years will have been China's rapid move centre stage. Collaboration with individual researchers, between universities or between funding agencies is on the rise and, in policy discussions on research infrastructure, China is considered a global player, yet another manifestation of its omnipresence. Meanwhile, Europe still lacks the necessary co-ordination mechanism to co-operate on a large scale with a country like China. We shall examine China's rising star towards the end of the present chapter (*see page* 177).

2. Scientific research that has no immediate application in the real world; also known as 'curiosity-driven research' and at times employed interchangeably with the term 'basic research'.

3. The survey of European Chief Financial Officers is conducted by Tilburg University in the Netherlands: www.cfosurveyeurope.org

SOME KEY POLICY ISSUES

There is growing recognition in Europe that, without some fundamental changes in the way member states and the EU institutions define their responsibilities in science, technology and innovation (STI), Europe will not easily achieve its goal of becoming the most competitive and dynamic knowledge-based economy in the world by 2010. The *Lisbon Strategy*, as it is known, was adopted by heads of state and government in the Portuguese capital in 2000. Two years later in the Spanish city of Barcelona, they would fix a target for achieving this eldorado: each country would strive to devote 3% of GDP to expenditure on research and development (GERD) by 2010, with the private sector expected to contribute two-thirds of this effort. It is no secret today that this target will not be met.

The concept of the European Research Area dates back to the adoption of the *Lisbon Strategy* in 2000 (*see page* 194). The concept has since been revitalized by the European Commission, the Council of Ministers and the European Parliament to express the idea that Europe as a whole must make big strides in six areas:

- Europe must have a sufficient number of researchers who must be well-trained and mobile;
- research infrastructure is vital to facilitate research in all areas of S&T;
- excellent institutions of higher learning and research are needed;
- knowledge sharing across research bodies – including the private sector – is a key prerequisite for success;
- co-ordinated research programmes must form a glue for dispersed national efforts;
- last but not least, Europe must be open to the world in its STI efforts.

The EU's Framework Programmes and Europe's national programmes cannot continue to operate in the relative isolation from one other that has become their hallmark. This includes the programmes of the national funding agencies, which are all the more important in that they constitute most of the flexible funding for research. Co-ordination between national programmes has always been part of European rhetoric but it is now being admitted that the slew of mechanisms embraced successively to bring about co-ordination have not worked well. Part of the reason for this was no doubt the adoption of a far too comprehensive and insufficiently focused approach to co-ordination, without asking where and when co-ordination was actually most urgently needed or whether key stakeholders would be willing to accept co-ordination.

The Joint Technology Initiatives discussed farther down may be a step forward, as they involve both EU funding and national funds, even if their complexity is daunting (*see page* 163). Indeed, the Joint Technology Initiatives, combined with the European Research Council and intense discussion on research infrastructure, might well trigger a fundamental reconsideration of the framework programmes and introduce a shift away from a very large number of small projects towards funding of a few major mechanisms. Greater funding for a truly independent European Research Council, a theme which will also be dealt with later, or maybe even more councils for different fields of science, could be a better way of spending research funds at the European level. Similarly, funds could be better spent on large research facilities and on concentrated, large-scale missions to tackle challenges for Europe as a whole. A stronger European Research Council will, of course, make the issue of the council's relationship to the national funding agencies and the consequences for academically oriented research unavoidable. This issue could have been conveniently dealt with at the time the European Research Council was founded in 2006.

INSTITUTIONAL REFORM

Ratification of the Lisbon Treaty

The role of the EU in R&D has been defined in the various treaties that have successively shaped the EU over the past 50 years. The seeds of the EU were sown with the European Coal and Steel Community and the European Atomic Energy Community of the 1950s. These defined very specific responsibilities in coal and steel and nuclear research. Only in the 1980s and 1990s did amendments to existing treaties extend the EU's responsibilities beyond industrial competitiveness.

The Lisbon Treaty was finally ratified by the last of the 27 EU member states in November 2009. This treaty adds one major responsibility: 'The European Union shall draw up a European space policy and measures to that effect may take the form of a European space programme.' How this will work out in relation to the intergovernmental European Space Agency will be a key issue for the next five years.

Those member states which finance the European Space Agency have accepted this new role for the EU, some allegedly in anticipation of receiving financial contributions from the EU for the functioning of the agency. This enlargement of the scope of the EU's responsibilities has gone hand in hand with an increase in budgets (*see page* 160).

One European reform that has been stalling is that concerning patents. Everyone agrees that a community patent is vital – that is, a patent filed with, and granted by, the European Patent Office that would be valid throughout the EU and offer the possibility of appealing a patent or litigating for infringement via a single court preferably. Such a patent has been under discussion since the 1970s and, in the past few years, the European Commission has introduced proposals to establish a community patent. However, problems over language and jurisdiction have remained unsurmountable hurdles: a national court has jurisdiction and, up until recently, every member state could insist on an official translation of any patent granted. With 27 members, these requirements are no longer a viable option but not all countries are prepared to admit this. Some progress has been made in the area of translation especially: the 2008 London Agreement is an optional agreement among members of the European Patent Convention which limits the number of translations of a patent. A community patent nevertheless remains a distant prospect. However, in December 2009, ministers reached a political agreement on a European patent including a European jurisdiction, although some details will still have to be negotiated.

Reform of higher education

The Bologna Process

In many European countries, vast reforms have taken place in the past decade. In others, they are still in progress. These reforms affect the university sector in particular, within the Bologna Process which intends to create a European Higher Education Area by 2010 (Box 1). The reforms include changes in funding mechanisms and in university ties to enterprises. Key issues concern how to foster diversity among universities, autonomy, quality, quality assurance and evaluation, an outward orientation[4]

4. Universities with an outward orientation look for inspiration in research to the key challenges societies are facing. They renew curricula with the same perspective in mind and engage with companies and societal organizations on the role universities should play. They also pay more attention to the non-academic skills people need, such as communication skills, a team spirit, entrepreneurial skills, etc.

Box 1: The Bologna Process

The Bologna Process aims to create a European Higher Education Area by 2010. The process got under way with the adoption of the *Bologna Declaration* in the Italian city of the same name in June 1999. The three priorities of the Bologna Process are: the introduction of the three-cycle system (bachelor's + master's + doctorate); quality assurance; and the recognition of qualifications and periods of study across Europe.

Every second year, ministers responsible for higher education in the 46 'Bologna countries' meet to measure progress and set new priorities. After Bologna (1999), they met in Prague, Czech Republic (2001), Berlin, Germany (2003), Bergen, Norway (2005), London, UK (2007) and Leuven/Louvain-la-Neuve, Belgium (2009). The latter meeting focused on the importance of lifelong learning, widening access to higher education and mobility. It was here that the 2020 target was fixed for ensuring that at least 20% of those graduating in the European Higher Education Area spend time abroad studying or training.

Steered by European ministers responsible for higher education, the Bologna Process is a collective effort; it also involves public authorities, universities, teachers and students, employers, quality assurance agencies, international bodies and institutions. Although the process extends beyond the EU's borders, it is closely connected with EU policies and programmes. For the EU, the Bologna Process is part of a broader effort to drive a 'Europe of knowledge'.

In May 2006, the European Commission urged 'member states to press on with the modernization of Europe's universities.The aim is to increase our universities' contribution to the Lisbon Agenda for more growth and more and better jobs,' they said. 'Europe's 4 000 universities have enormous potential, much of which unfortunately goes untapped because of various rigidities and hindrances. The Commission is urging member states to free up the EU's substantial reservoir of knowledge, talent and energy with immediate, in-depth and co-ordinated change: from the way in which higher education systems are regulated and managed to the ways in which universities are governed.'
The EU is supporting a broad range of measures to modernize the content and practices of higher education in the 27 member states and the EU's 28 neighbouring countries. This support includes the Lifelong Learning Programme, the Instrument for Pre-accession Assistance, the European Neighbourhood and Partnership Instrument and the Development Cooperation Instrument, the Tempus programme and the EU's programme for worldwide academic co-operation, Erasmus Mundus.

The EU is also supporting the agenda for modernizing universities through the implementation of FP7 and the Competitiveness and Innovation Programme, as well as via the structural funds and loans from European Investment Bank.

Source: http://ec.europa.eu/education/higher-education/doc1290_en.htm

Official website of the Bologna Secretariat: www.ond.vlaanderen.be/hogeronderwijs/bologna/

and flexibility. These issues are clearly related. For example, greater autonomy requires a better quality assurance system. Similarly, a stronger outward orientation and responsiveness are difficult to achieve without greater autonomy and flexibility.

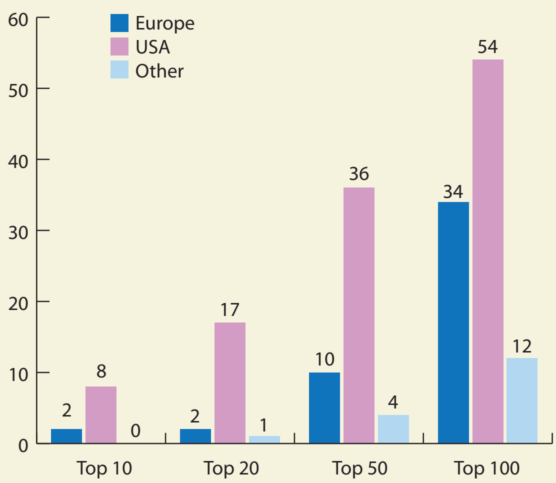
In Europe, there tends to be a general adhesion to the idea that universities need greater autonomy. There is unease in France, however, that this will translate into a power shift from the professors to university management, with administrators rather than faculty deciding on the appointment of professors or on the allocation of research funding. These concerns are unfounded and reflect a lack of knowledge of successful university systems abroad. Some have pointed out that true autonomy can only come from the financial autonomy obtained by a university that succeeds in raising funds from private industry and other sources.

Most European universities have been built upon, or adopted, the Humboldt model. This model is named after Wilhelm von Humboldt (1767–1835), who designed the Prussian education system which would later become a model for university systems in Europe, Japan and the USA. The Humboldt model advocates a unity of teaching and research at the institutional, personnel and student levels. Under the Humboldt model, academic training is hardly conceivable without some involvement in research, with the consequence that acquiring a university degree can take many years. Of course, the expansion of university systems to provide tertiary education to growing numbers of students, combined with the need for greater efficiency and cost-effectiveness, has inevitably led to changes. The rhetoric emerging from many discussions on universities, however, still reflects an attachment to the Humboldt model, despite the fact that it may not be sustainable.

A comparison with the US higher education system makes this abundantly clear. A good starting point is the now well-known ranking of universities worldwide by Shanghai Jiatong University. There is no need to discuss here in detail the merits or demerits of this ranking, or for that matter of any ranking. What matters is that the criteria used for the Shanghai Jiatong ranking are based on research capacity. When it comes to research, all ranking systems would demonstrate that Europe spreads its resources relatively thinly compared to the USA.

It is obvious that American universities dominate international rankings (Figure 1 and Table 2). Only when we take into account the universities placed 51st to 100th do we find a much better balance between Europe and the USA. A more detailed comparison of two world-class US universities (Stanford and the Massachusetts Institute of Technology) with three top-tier European universities (Cambridge in the UK, Eidgenössische Technische Hochschule in Switzerland and Karolinska in Sweden) suggests one important reason. Although the research budgets of European universities are certainly considerable, the budgets of the two US universities are larger still. As a matter of fact, the National Science

Figure 1: Number of top European and US universities



Source: Shanghai JiaoTong University

Table 2: Comparison between key US and European research universities, 2006

	Massachusetts S Institute of Univ Technology, USA	**tanford ersity, USA**	**Eidgenössische Technische Univ Hochschule Zürich (ETH), Switzerland**	**Cambridge ersity, UK**	**Karolinska Institutet, Sweden**
Scope	Broad	Broad	Science and engineering	Broad	Medical
Budget, excluding construction	US $1.4 billion	US $2.6 billion	€750 million	€780 million	€440 million
Number of students	10 200	14 900	12 700	17 800	8 000
Proportion of undergraduate to graduate students	2:3	45:55	2:3	2:1	3:1
Budget for research	US $660 million in sponsored R&D	US $900 million sponsored R&D	€430 million	€285 million in research grants	€370 million
Research contracts from industry	~15%	<5%	~9%	10–15%	~9%

Note: Budget data are typically for 2006 or prospects for 2007

Source: Tindemans *et al.* (2007) *The European Institute of Technology: a Feasibility Study for the European Parliament*

Foundation's statistics on research at US universities reveal that about 200 universities account for almost all university research in the USA. Liberal arts colleges, community colleges and others provide the bulk of tertiary education (*see page* 45).

The situation is very different in Europe. The ambition of many universities is to become a research university, in line with the prevailing ideal of what a university should be, based on the Humboldt model. One example is Poland, which has 147 universities performing research, according to ERAWATCH. The consequence of this is much fewer resources for the average university. Jamil Salmi, Tertiary Education Co-ordinator within the World Bank's Human Development Network, concluded in a recent global analysis that world-class universities share three key factors (Salmi, 2009). *Firstly*, they have a concentration of top talent, both among faculty and among students. *Secondly*, they have abundant resources. *Thirdly*, they have appropriate governance systems.

Europe thus needs to foster greater diversity among its universities and other institutions of higher learning. Many of the reforms European countries have witnessed over the past decade have diversification as their goal, sometimes explicitly, more often implicitly. Diversification has several components, including the concentration of research funding. European countries are still very reluctant to embrace this. Just as the EU's Framework Programmes have relied in many ways on creating networks and other forms of collaboration to create supposedly a critical mass, so too do most national programmes and policies. Only in the UK has there been a deliberate policy of augmenting the concentration of research resources, as will be explained shortly. Even within the UK, there has been a lot of opposition from the regions. The policy has been diluted in any case since the distinction between polytechnics and universities was abandoned in the early 1990s.

Eventually, the concentration of research funding in selected universities will have to be accompanied by many universities redefining themselves as the equivalent of liberal arts colleges. This form of differentiation is certainly made easier by the generalization of the bachelor's and master's degree programmes at the heart of the Bologna Process, which was adopted by European countries a decade ago and is gradually being implemented in many countries. However, in most countries, a bachelor's degree is still not regarded as a full university education by students, parents and employers alike.

A third dimension of differentiation is quality. Of course, no one wants to be a low-quality institution. Currently, quality assurance schemes are being introduced in most countries to increase quality. However, it is simply impossible for every university to belong to the top tier of research universities. Moreover, there are some very good reasons for choosing a different mission, for example to provide a region with good-quality tertiary education. One very interesting example of a country trying to increase institutional differentiation is Germany with its '*Exzellenz Initiative*'. Responsibility for higher education in Germany rests with the states. The federal government therefore has to manoeuvre carefully to introduce policies and schemes affecting higher education. Thus, when the federal government arrived at the view that the international competitiveness of German universities required greater differentiation, it took lengthy discussions with the states before they would agree, in 2005, to adhere to the *Exzellenz Initiative*. In two rounds in 2005 and 2006, universities were invited to submit three types of plan for total additional funding of €2 billion. Relatively speaking, that is perhaps not such an enormous amount but, in the complex world of German policy-setting, and given the very traditional position and organization of German universities, the *Exzellenz Initiative* marks a significant evolution that is representative of what is happening in other countries. Graduate schools were introduced some 25 years ago as a means of formalizing and improving PhD training. One component of the *Exzellenz Initiative* was thus to select 39 excellent graduate schools over time. A second component focused on clusters of excellence: research groups in several disciplines and institutions within a region were to create strong regional clusters. Thirty-seven such clusters have been selected. These include a Nanosystems Initiative in Munich, for instance, but also a cluster in Heidelberg on Cultural Exchange in Europe and Asia in a Global Context. The third and last component invited universities to submit strategic plans for their institution as a whole. Only nine universities have received this recognition. Some five or six universities clearly stand out in terms of the number of awards they have received for the three components of the *Exzellenz Initiative*.

Whatever one's mission, appropriate governance systems are vital for effectiveness. Autonomy is a key factor in this regard. In a study carried out by the Bruegel Foundation, the performance of European universities was analysed and relations between governance, spending and performance investigated (Aghion *et al*., 2007). The conclusion was straightforward. European universities must become more autonomous, in particular with regard to budgets but also when it comes to hiring faculty, remuneration, course design and student selection, particularly at the master's level. This process towards more autonomy is ongoing.

ERAWATCH regularly collects data on developments in the STI systems and policies of the EU member states on the basis of reports by national correspondents. The 2008 ERAWATCH report summarizes key recent university reforms. Covering a period between 2001 and 2008, it lists formal legal reforms for 21 EU countries. Of these, 16 explicitly mention autonomy as one of their objectives or principles. Some examples follow:

- The Danish University Act of 2003 stipulated larger autonomy for universities and the 2007 major restructuring of Danish universities gave them greater flexibility in the recruitment of researchers.
- In Spain, the Organic Law for universities of 2001 likewise increased the autonomy of universities.
- In Lithuania, higher education is currently undergoing a reform that should be complete in 2010. The move is towards greater autonomy, even though a high level of regulation reportedly persists.
- The 2005 Act on Higher Education in Poland brought a much higher level of institutional autonomy.
- The French Law on University Responsibilities and Freedom of 2007 afforded universities greater power and responsibility for hiring staff; 20 universities were the first to become autonomous in 2009.
- The Higher Education Law of 2002 in Slovakia introduced a major reform implying, *inter alia,* greater institutional autonomy. This resulted in universities becoming self-governing, self-organized entities.
- In Finland, the government response to concerns about the lagging performance of Finnish universities has been to introduce a development plan with greater autonomy as one of its pillars, next to the merger of institutions, for example.
- The one exception which proves the rule seems to be Slovenia, where the government proposed augmenting its involvement in matters such as nominations or even the promotion of staff in a draft bill in 2007. Strong opposition led to the minister's resignation, however, so Slovenia may eventually lose its status as the exception to the rule.

Autonomy goes hand in hand with accountability and mechanisms for quality evaluation and quality assurance. In practically all countries, government funding for university research follows a dual approach. Next to institutional funding, usually flowing directly from the government to the universities, there is competitive funding provided by one or more research councils or national funding agencies. The balance between the two types of funding can be very different from one country to another. In the United Kingdom, for example, about £2.8 billion is funded by the research councils and £1.5 billion comes in the form of institutional funding through the higher education research councils. To take another example, France created a National Research Agency (*Agence nationale de recherche*) in 2005 for funding exploratory research projects within government-set priorities on a competitive basis. The aim is to arrive at 20% competitive funding by 2010. Many of the examples and data presented here are based on the ERAWATCH 2008 country reports.

Performance agreements

The focus in the present section has been on institutional funds and attempts by countries to relate this funding in some way to performance. For competitive funds, such a relation is self-evident. Throughout the EU, we find a variety of mechanisms. Performance agreements are one example. Concluded for a period of three to five years, these agreements have been introduced in recent years in Austria, Denmark, Finland and Luxembourg, for example. In the latter case, a performance agreement was concluded at the time of the founding of the University of Luxembourg, the country's first university. In each case, the minister and the university agree on a sometimes vast number of targets which the university accepts to achieve. These may be quantitative and relate to education, research, technology transfer and ties to industry, patents and so on. As an example, Table 3 describes the Development Contract for 2008–2010 signed by Aarhus University and the Danish Minister for Science, Technology and Innovation.

For education, the budget the ministry provides can often be related to some unit price, for example the estimated

Table 3: Development contracts for Aarhus University in Denmark, 2006 and 2010
Selected activities

Activity	Indicator	2006	2010
Research			
Research production	Number of research publications	5 091	5 575
Internationalization of research	Number of foreign researchers attracted	149	220
Attraction of external non-government funds	EU funds Private Danish and foreign funds	US$ 17.8 million US$ 71.6 million	US$ 26.4 million US$ 82.4 million
PhD activity	Number of degrees conferred	223	391
Degree programmes			
New enrollments	Newly enrolled students	Bachelor's: 4 955 Master's: 3 440	Bachelor's: 5 467 Master's: 4 370
Drop-outs	Drop-out percentage	Bachelor's: 35.9% Master's: 11.2%	Bachelor's: 30.4% Master's: 8.0%
Completion time	Percentage of students completing studies in prescribed time	Bachelor's: 39.0% Master's: 11.5%	Bachelor's: 41.2% Master's: 28.1%
Quality assurance of degree programmes	Number of completed degree programmes for which evaluation of teaching is published on web	50%	100%
Dissemination of knowledge			
Continuing and further education	Number of course participants	6 050	6 400
Participation in public debate	Number of written contributions to popular media	1 746	2 750
Collaboration with business community	Number of collaboration agreements Number of reported inventions	276 59	350 110
Research-based advice to the authorities			
Research-based advice to authorities	Income from advice to authorities	US$ 90.8 million	US$ 103.4 million

Source: Aarhus University

costs of training a bachelor in a three-year course. For research, that is impossible and therefore the institutional research budget is usually a lump sum resulting from negotiations with the ministry on the basis of incremental changes. As these agreements have only been introduced recently, no evaluations have so far been carried out.

A very different scheme has been in use in the United Kingdom since the early 1990s. In 2008, the latest in a series of Research Assessment Exercises was held to decide about the allocation to universities of the £1.5 billion pounds per annum available as institutional research funding. This is a highly competitive scheme with very strong incentives for winners and penalties for losers. No country has so far followed anything similar to the UK's Research Assessment Exercise. Even in the UK, the debate continues, as the swings in funding from one period to the other can be significant and therefore lead to effects that not everyone considers beneficial in the long run. On the other hand, the scheme does promote competition and a concentration of research funding, both hallmarks of research in the top league. In the Research Assessment Exercise, universities choose the units of assessment (such as cardiovascular research) in which they wish to submit proposals. In 2008, these units numbered 67. A proposal consists of a number of researchers identified by name, plus evidence of their quality as researchers in the form of papers, citations or the number of PhD students supervised, for example. There is no requirement to submit all researchers active in a particular unit of assessment. The Higher Education Funding Councils have set up panels to assess the individual researchers using a 'star system' ranging from four to zero stars. The upshot is that a group ranked highest (four stars) gets seven times as much as a group with an average ranking (two stars). As for groups with a low ranking, they get nothing.

Only Poland has a system bearing some resemblance to that of the UK. Institutional research funding is based on an external assessment system. A fixed set of indicators is used to evaluate performance over three years. Research units are benchmarked against similar units in the same discipline then ranked in five categories. Relatively less money is involved, however, and the system is not as severe, nor apparently as automatic, as the UK system.

In most countries, however, there is only an indirect link between institutional funding of university research and performance. Moreover, when some form of formula funding is used, this may involve, for example, the number of PhD degrees conferred. That is the case, for instance, in the Netherlands where institutional research funding for universities is basically frozen at some historical level but where around 25% is proportional to the number of PhD degrees awarded by the university. That does not mean that countries have not set up extensive evaluation mechanisms. Indeed, this is one of the key developments of recent years. Here again, some examples serve to illustrate the trend: Italy has evaluated the research results of universities and public research bodies from 2001 to 2003 but their impact on policy and funding has been shown to be limited as yet. This evaluation was carried out initially through a committee established by the Ministry for Universities and Research that has since been superseded by a National Agency for the Evaluation of Universities and Research since 2008. Once it becomes operational, the agency's findings should guide the allocation of public funds for research.

France, too, has moved away from a scattered evaluation system towards the creation of a central Agency for Evaluation of Research and Higher Education. This agency will evaluate research at three levels: *firstly*, institutions will be assessed, including their internal rules for staff evaluation; *secondly,* the research units of both universities and public research bodies will be evaluated to the tune of around 1 000 per year; and *thirdly*, degrees and diploma structures will be reviewed and lead to some sort of accreditation of the programmes. How this will affect institutional research funding remains to be seen. Up until now, the universities have negotiated four-year contracts with the ministry.

The Netherlands also has a national system for evaluating research at universities and at the institutes conducting academic research under the umbrella of the Royal Academy for Arts and Sciences (KNAW) and the Netherlands Organisation for Scientific Research (NWO) but the system operates in a different way. The Association of Dutch universities, KNAW and NWO agreed on a common protocol in 2002: they accept evaluations, done at the level of research groups, whenever a research group straddles both a university and a research institute or could be evaluated in two different scientific areas; they have established a common cycle so that research groups in each discipline are assessed once every six years. Moreover, there is a facilitating organization they are at liberty to invite to organize the evaluations. It is up to the management of a given university, KNAW or NWO, however, to decide whether universities are to have their research groups in a particular discipline evaluated by the same international visitation committee or whether they prefer a separate evaluation for their institution only. Any financial consequences are the sole responsibility of these management bodies. A university's institutional research budget being fixed without room for negotiation with the ministry, management has to decide whether to reallocate research budgets internally. This has been done to a significant degree in recent years. In an interesting development, the universities, KNAW and NWO have all agreed recently to experiment with a broader assessment protocol that explicitly measures not only the economic impact but also the societal impact of research for those groups and institutes with an explicitly societal mission.

In Germany, there is no national system for evaluating university research but, for all other public research, it is the German Science Council which carries out evaluations. All institutes belonging to renowned German research umbrella organizations like the Max Planck Society are regularly evaluated. In 2009, the Science Council was in the process of completing an evaluation of the 50 or so government research institutes. The Science Council's assessments are usually taken very seriously by research bodies.

Finland is another country that has a thoroughly developed system of research evaluation. Here, the Academy of Sciences is responsible, next to the Technology Foundation (TEKES), for technology development and innovation support programmes. The Finnish academy is the equivalent of the research funding councils or agencies in other countries. Once every three years, the academy carries out an evaluation of the entire research system in Finland, with publication output being an important indicator. The Finnish academy also assesses research at the programme level and is increasingly looking not only at the immediate output but also the longer-term impact of research. The academy also evaluates scientific disciplines using a method similar to that employed in the Netherlands: foreign expert panels assess a large number of research groups on past performance.

The results of the various assessments serve as input for the performance contracts that accompany institutional government funding but there are no algorithms involved. Many more examples could be given for most of the EU member states but the trend is clear from just this handful of countries: more explicit evaluations; evaluations at various levels, such as research groups, programmes, disciplines or institutions; a variety of mechanisms to link performance to institutional research budgets; and, increasingly, attempts to extend the scope of evaluations to the longer-term and societal impact.

EUROPEAN CO-OPERATION AND INTEGRATION TAKE OFF

In this section, we shall be describing a number of European schemes for collaboration and issues like the development of research infrastructure which are based on agreements between governments or between national funding agencies. We shall then move on to the EU's role in fostering collaboration in R&D.

The region continues to develop the European dimension of what, in the past, were purely national landscapes of universities, research institutes, companies, research funding agencies, policies and regulations. Over the past two decades, Europe has witnessed a much greater degree of co-operation among researchers in different European countries. The EU's Framework Programmes, about which more will be said later, have played a key role in this respect. The new European Research Council is an important development at the institutional level, although it is not yet a complete success. The jury is also still out on another institution, the European Institute of Innovation and Technology. Major S&T-based services and industries have also often acquired a European flavour.

One very visible example of pan-European research is the aircraft manufacturer Airbus. The company is the result of a merger by the formerly independent aircraft companies of four European countries, France, Germany, Spain and the UK. Airbus employs about 57 000 people. It produces about half of the world's jet airliners and is credited with designing the biggest airline jet in the world, the A380, which, despite delays, was delivered to its first customer in 2007. The company has subsidiaries in China, Japan and the USA.

Also in the transport sector, high-speed train services are spreading their net ever wider across Europe. These are one of the transeuropean networks that have been identified in the EU treaties as essential infrastructure for Europe. Of course, operational costs and investment in these railways are borne by the rail companies concerned.

Information infrastructure is another area in which pan-European co-operation is bearing fruit. GÉANT is the pan-European data communication infrastructure via which all the national research and education networks (NRENs) in Europe co-operate. Through it, they are connected to each other and to like networks around the world. The third phase was launched in December 2009. It promises to provide Europe with highly advanced networking services for education and research for the coming years. Its development, construction and operating costs are half funded by the NRENs themselves and half by the EU through its FP7.

One sector to watch in coming years will be nuclear energy. With the energy crisis and current concerns about global warming, governments seem to be reassessing their position on nuclear energy, which they now see as a realistic option. How the EU nuclear reactor industry positions itself will be a vital question. So far, the nuclear reactor industry has been dominated by Areva in France and Siemens in Germany, two companies which co-operated until early 2009 via a joint venture. Areva and Siemens have both put a lot of effort into what was first termed the European Pressurized Water Reactor then the Evolutionary Pressurized Reactor and now simply EPR. However, the first two EPR reactors under construction, one in Finland and the other in France, are facing very costly and lengthy delays linked to the redesigning of part of the reactor.

The EU has vowed to slash carbon emissions by 20% compared to 1990 levels by 2020 and indicated that it would be prepared to commit to greater cuts if other high emitters like the USA and China do the same. The EU will essentially have recourse to the carbon trading mechanism to meet this target. However, everyone seems to agree that, if we are serious about keeping global temperature rise this century to a manageable 2 °C, this will mean cutting back emissions by 80–90% by 2050 then achieving negative emissions by 2080. The latter target is not impossible but would require drastic measures. If the EU follows this more ambitious path, it will need to invest massively in R&D in the coming years to develop clean energy technologies that can be deployed on a large scale.

One recent development at the European level will have major repercussions for the chemicals industry. On 1 January 2007, the European Community adopted the Registration, Evaluation, Authorisation and Restriction of Chemical Substances (REACH). The aim of REACH is to improve the protection of human health and the environment by obliging chemical companies to declare the intrinsic properties of chemical substances. In parallel, REACH sets out to enhance the innovative capability and competitiveness of the EU chemicals industry. Information is amassed in a central database run by the European Chemicals Agency in Helsinki, Finland.

After many years of deliberations, the EU has also reached a decision, at last, as to the fate of Galileo, a state-of-the-art, autonomous global satellite navigation system which will provide autonomous navigation and positioning services, interoperable with the Global Positioning System (GPS) and the Global Navigation Satellite System (GLONASS). The first Galileo test satellite was launched by the European Space Agency in September 2009.

Europe's international research organizations

Various countries in Europe have built up large research organizations since the Second World War (Table 4). The founding of these centres was partly politically motivated but also responded to an economic reality underlying the scientific arguments: in many areas, investment in R&D had simply become too expensive for individual countries to bear. The one exception to the rule is the European Molecular Biology Laboratory. Here, the problem was not the size of the investment required but rather the disciplinary rigidity of university structures, which meant they had difficulty accommodating the new 'interdiscipline' of molecular biology.

The seven largest laboratories are the European Organization for Nuclear Research (CERN); European

Table 4: International research organizations in Europe

Organization	Field of research	Year established	Annual budget (millions of euros), 2007
European Organization for Nuclear Research (CERN)	Particle physics	1954	700
European Space Agency (ESA)*	Space research, micro-gravity, Earth observation	1975	800
European Southern Observatory (ESO)	Astronomy	1962	148
Institut Laue Langevin (ILL)	Neutron research	1967	79 (2008)
European Molecular Biology Laboratory (EMBL)	Molecular biology	1974	71
European Synchrotron Research Facility (ESRF)	Synchroton radiation research	1984	80
European Fusion Development Agreement (EFDA)**	Fusion research and development	1999	–

* The European Space Agency was established by the merger of the European Space Research Organisation and the European Launcher Development Organisation. The annual budget of €800 million covers only the programmes for science, Earth observation and microgravity; ESA's total budget is €3 694 million.

** The EFDA combines the EU's fusion programme and the national fusion programmes co-ordinated in this EFDA and is the continuation of long-standing co-operation based on the European Atomic Energy Community (EURATOM), one of the three original European Communities that are now all integrated in the EU. The Joint European Tokamak has been the main facility for fusion research up until now; the next stage will be the International Thermonuclear Experimental Reactor (Box 2).

Source: author

Box 2: The International Thermonuclear Experimental Reactor

The project for an International Thermonuclear Experimental Reactor (ITER) involves China, the European Union, India, Japan, the Republic of Korea, Russian Federation and the USA. The most ambitious collaborative project in science ever conceived, ITER is developing a reactor which will cost €10 billion to construct and run for its anticipated lifetime.

Once operational, this experimental reactor will be powered by nuclear fusion, a technology which could change the face of nuclear power, Nuclear reactors currently use nuclear fission which, unlike nuclear fusion, produces radioactive waste.

However, nuclear fusion has yet to be fully mastered. This is because nuclei strongly resist being brought close together, owing to of their positive charge induced by their protons. The ITER reactor would need to accelerate the nuclei to high enough speeds to overcome this electromagnetic repulsion until the nuclei came close enough to achieve fusion.

In 2006, the project partners opted to build the reactor in the town of Cadarache in France, reflecting Europe's leading role in thermonuclear fusion. Construction should be completed by about 2018.

For details: www.iter.org

Fusion Development Agreement; European Molecular Biology Laboratory; European Space Agency; European Organisation for Astronomical Research in the Southern Hemisphere; European Synchrotron Radiation Facility; and the Institut Laue Langevin. A couple of years ago, these organizations formed EIROforum, a platform for improving their visibility in European policy discussions, among other goals.

These laboratories are considered to be among the best in the world. With the exception of the European Space Agency (ESA), they are all dedicated R&D organizations. In tandem with its specific research mission, ESA is, of course, like all major space agencies, involved in technology development, the construction and operation of launchers and spacecraft, and in supporting European space policy.

All but the European Fusion Development Agreement are intergovernmental bodies. That is, they have been established by an *ad hoc* group of countries whose governments have concluded an international agreement to establish a research organization, with representatives of these governments forming a council which acts as the supreme administrative and strategy-determining body.

Thermonuclear fusion is the only area in which the European Commission has real authority. It is also the only area in which a substantial part of European R&D budgets are concentrated within EU mechanisms. Since the 1950s, national fusion programmes have been co-funded and strongly co-ordinated by this central mechanism. This has given Europe a leading position in developing and now also hosting the €10 billion International Thermonuclear Experimental Reactor currently being built in France (Box 2). EFDA is now is focusing on co-ordination, including the collective use of the Joint European Tokamak for as long as this, the largest current R&D fusion facility, remains operational.

As far as the other intergovernmental European research organizations are concerned, the major event of the past five years has no doubt been the inauguration of CERN's Large Hadron Collider in the autumn of 2008. This new accelerator is also a global collaborative effort and will be the world's leading particle physics facility for the next 15 years or so with operations having resumed in late 2009 after initial technical problems.

One other European research laboratory stands out, the Joint Research Centre of the EU with five locations in Ispra (Italy), Karlsruhe (Germany), Mol (Belgium), Petten (Netherlands) and Seville (Spain). It differs from the EIROforum research organizations in that it is not concerned with operating large user research facilities. More will be said about it in the section on funding R&D in the EU (*see page* 160).

A road map for research infrastructure

The policy discussion on new research infrastructure has become intense in Europe. In 2002, the EU member states and the European Commission decided to establish a European Strategy Forum on Research Infrastructure (ESFRI). ESFRI consists of high-level officials from the EU member states and the Commission. Taking the 20-year *Facilities Outlook* of the US Department of Energy as an example,[5] ESFRI published a *Road Map* of 35 new research facilities or upgrades to existing ones in 2006, 'research infrastructures' in the European jargon. The construction of these new facilities was considered as being vital for consolidating Europe's competitive edge in R&D. The ESFRI *Road Map* was updated in December 2008 and now contains 44 facilities. The coverage is much wider than for the US report: materials and analytical facilities for physical and engineering sciences; facilities for the medical and biological sciences; infrastructure for social sciences and humanities, as well as for energy, environmental sciences and so on.

Much of this infrastructure will be distributed. An example is a project in which biobanks across Europe form effectively one big European biobank. For all these reasons, construction and operating costs vary widely. Next to traditional facilities for neutrons, synchrotron radiation or astronomy, which would each cost €1 billion or more to build, the *Road Map* contains projects like the European Social Survey, a collaboration for continuing the co-ordinated, harmonized gathering of survey data to monitor social attitudes and value changes in a large number of European countries, a project measured in only a few tens of millions of euros.

Only two of the major new facilities featuring on the *Road Map* have been decided so far, the X-ray Free Electron Laser Synchrotron (X-FEL) in Hamburg, Germany, and a facility for studying rare isotope radioactive beams, also in Germany. A third, the European Neutron Spallation Source (ESS), which will be built in Lund in Sweden, was at an advanced stage of the decision-making process in November 2009.

This shows that the basic problem in Europe remains unresolved. There is no mechanism in place yet for deciding on investment in large research infrastructure that is financially beyond the reach of individual countries in a reasonably transparent and efficient manner. Many governments are unwilling to create a substantial role for the EU, the European Commission is not always eager to accept such a role and national funding agencies haven't found a structural way of co-operating in these matters either. One consequence is that no EU money is currently available to contribute to funding new research facilities.

5. Published in late 2003, the *Facilities Outlook* contained a priority list of 28 new user facilities or upgrades to existing facilities, ranging from ITER to accelerators, neutron and synchrotron sources, facilities for nuclear magnetic resonance and high performance computers.

European Science Foundation

The European Science Foundation (ESF) differs not only from the intergovernmental research bodies described above but also from its US namesake, the National Science Foundation. With an annual budget of only about €50 million, it doesn't really fund research. The European Science Foundation is an association of 80 members composed of national funding agencies, academies of sciences and arts and so-called research performing bodies like the Max Planck Organization in Germany. It has positioned itself as the agenda-setting body for science in Europe, via foresight studies. It also stimulates co-operation among scientists to implement these science agendas through various programmes. One example is EUROCORES, a programme which brings together national funding that is thus not included in ESF's €50 million budget.

The ESF also operates the COST programme, which consumes the lion's share of the ESF's €50 million budget. Officially, COST is an intergovernmental programme which funds co-ordinating activities like workshops in specific areas agreed upon by the COST High Level Group. In practice, however, the intergovernmental aspect seems to be rather irrelevant, like the EU Community aspect. Partly within, partly without the ESF, the heads of the national funding agencies have created a mechanism for strengthening co-operation among themselves. They themselves are known as the European Heads of Research Councils (EUROHORCS). This is a source of persistent confusion but the problem will have to be resolved in the broader context of a debate on the mutual roles of the ESF, the recently established European Research Council – much more comparable to the National Science Foundation in the USA than the ESF – and the national funding agencies or research councils. More will be said later about this issue.

EUREKA

EUREKA was established in 1985. It was initially a French response to US President Reagan's 'Star Wars' Strategic Defense Initiative. EUREKA has since developed into a pan-European mechanism for stimulating innovation in industry through close-to-the-market collaboration between small, medium-sized and large enterprises, universities and research institutes. It is another intergovernmental initiative in which the European Commission is just one of several partners. The relationship between the EU and EUREKA continues to be a bone of contention.

Table 5: EUREKA projects, 2010

Number of running projects	722
Total budget for projects	€1.3 billion
Organizations involved in EUREKA projects	2 640
Large companies	476
Small and medium-sized enterprises	1 174
Universities	459
Research institutes	491
Government/National administration	40

Note: EUREKA is a pan-European intergovernmental initiative to support the competitiveness of European companies by fostering market-oriented R&D via international collaboration.

Source: EUREKA website, September 2010: www.eureka.be

Companies and research bodies are invited to propose innovative projects for the EUREKA label, formally granted by the EUREKA ministers, and for limited government financial support. The latter is awarded strictly on a national basis, with levels of support and conditions for attribution differing widely. The EU does provide some additional financial support but always on a case-by-case basis, despite repeated attempts to come to an agreement on a general support scheme.

EUREKA functions along two lines: bottom-up projects proposed by individual companies, and strategic projects, of which there are two types, EUREKA clusters and umbrellas. The latter involve collaboration among a number of countries, which invite companies and research bodies to develop and submit proposals in specific areas. EUREKA clusters are strategic associations of usually large companies, small and medium-sized enterprises (SMEs), universities and research institutes (Table 5).

European Institute of Innovation and Technology

Something must be said about the European Institute of Innovation and Technology, simply because it has been a focus of policy attention since 2005. Conceived by the president of the European Commission as a direct counterpart to, and copy of, the Massachusetts Institute of Technology (MIT) in the USA, the European Institute of Innovation and Technology has provoked much debate. The underlying assumptions of both the European and US reality have been questioned with great passion. Tindemans *et al*. (2007) provide an in-depth discussion on this subject. Does Europe really lack an 'MIT'? Is it true that industry contract funding is the defining difference between US and European university research funding? Doesn't Europe have very good examples of its own of institutions integrating research, education and conditions for innovation? The answer to all these questions is 'no'.

As a backdrop to this debate, Table 2 provides some interesting data. Science parks such as those in Cambridge (UK) and Leuven (Belgium) further substantiate the idea that the rationale behind the European Institute of Innovation and Technology, namely that a solid institution linking training, research and the promotion of innovation is missing in Europe, is not that straightforward.

It was nevertheless decided in 2007 to establish the European Institute of Innovation and Technology as a distributed organization where the activities would take place at many locations across Europe. The European Institute of Innovation and Technology's key units will be so-called Knowledge and Innovation Communities. Each of these communities will consist of a number of teams formed from companies, universities and research institutes. Each member of a team is not supposed to work from his or her own home base but rather cluster at a few specific locations. Strong leadership and management should make the difference with other mechanisms of decentralized co-operation. A Governing Board has been appointed and the institute's headquarters are being set up in Budapest, Hungary. Three proposals for creating Knowledge and Innovation Communities were selected in December 2009 on a competitive basis in three areas: climate change mitigation and adaptation; sustainable energy; and the future information and communication society. So far, €300 million has been made available as additional funding from the EU for the first five-year phase. The remainder of the estimated €1.5 billion or so will have to come from partners and from competitive European or national funds.

The EU's role in fostering R&D

In recent decades, the EU has built up a considerable position in funding R&D in Europe. The real take-off took place in the early 1980s when the ESPRIT programme was set up to lure the 10 or so largest European companies in micro-electronics and information technology into a mode of co-operating in pre-competitive research. Soon afterwards, the idea of a Framework Programme was conceived to simplify the political decision-making process. In the past, the Council of Ministers, with the involvement of the European Parliament, had to agree unanimously on each separate programme in information technology (IT), telecommunications, health and so on. Successive Framework Programmes, the first six each covering a four-year period, the current seventh a seven-year period to 2013, have each been intended to embrace virtually all of the EU's R&D efforts.

There are two more programmes from which R&D-related projects can be funded. One is the Competitiveness and Innovation Framework Programme. It focuses largely on helping SMEs to find venture capital and other forms of funding, adopt advanced solutions using information and communication technologies (ICTs) and increase both energy efficiency and innovative approaches to renewable energy. Given its scope and the fact that it represents only about 7% of FP7, it will not be dealt with further.

That is also the case for the second additional mechanism. For a long time, European structural funds have been part and parcel of the European integration machinery. Their basic purpose is to help lagging regions in both new and older member states catch up and thereby, as the jargon goes, increase cohesion throughout the EU. Although allocating money to this cohesion policy is always a highly politically charged decision, there is an underlying rationale: to identify those regions that are eligible for support using criteria such as income or industrial decline. Countries have a relatively free hand in establishing a programme of activities for receiving support. Moreover, countries are increasingly using these funds to help improve their knowledge infrastructure by investing in universities, science parks or even research facilities. The innocent traveller should not be surprised to come across a sign saying 'Co-funded by the European Regional Fund' in sometimes rather improbable places. No detailed comprehensive information is available, however, on the extent to which R&D activities or investment are funded in this way. The rest of the discussion will thus be concentrated on the Framework Programme.

Most EU funding is competitive and meant for research by companies, universities or research institutes throughout the EU member states, the candidate member countries and countries that have signed association treaties with the EU. The latter basically implies that, once these countries have paid up what would be their GDP-proportional share of the Framework Programme budget, they are then free to compete for projects. Part of the budget is for the EU's own in-house Joint Research Centre.

The philosophy behind the Framework Programme has never been simply to fund the best and/or most relevant research. There have always been two meta-goals, as it were. Stimulating co-operation between researchers and between companies, universities and research institutes across the participating states was one such goal and co-ordinating national research efforts and policies was the other. As a consequence, much emphasis has always been placed on conditions that researchers often did not feel comfortable with. The obligation to include researchers from several member states led to the formation of very large teams and it was not evident that these comprised the best people for the task at hand. The idea of co-ordination was translated to mean copious support for all sorts of networks with all their trappings: co-ordination meetings, workshops and so on.
The current FP7 consists of six big chunks: Co-operation; Ideas; People; Capacities; Civil Nuclear Activities (fusion, fission, radiation protection); and Non-nuclear Activities of the Joint Research Centre.

Table 6 shows the structure and the budget of FP7. Formally, the nuclear activities, including fusion, are part of a separate legal mechanism but that distinction is irrelevant here. To put the EU funding in perspective, it is helpful to compare the budget of FP7 to total public funding for R&D. The national governments' budget appropriations for R&D (GBAORD) for the EU-27 amounted to €81.3 billion in 2005. The total budget of FP7 has two components: €50.5 billion is allocated for a seven-year term and €2.7 billion for a five-year term. By extrapolation, this amounts to an annual average of about €7.7 billion, or approximately 8–8.5% of public funding for R&D. The average annual budget involved with the Framework Programme and the large intergovernmental research organizations mentioned previously amounts to about 10–10.5% of public funding. This underlines the point that national funding still dominates, even though EU funds are usually required to match national funding. The same point is illustrated by the fact that the budgets of the national funding agencies like the UK research councils or the German Research Association

Table 6: Structure and budget of EU's 7th Framework Programme for Research, 2007–2013

Area of co-operation	Budget (in millions of euros)*
Co-operation	
Health	6 100
Food, agriculture and fisheries, biotechnology	1 935
Information and communication technologies	9 050
Nanosciences, nanotechnologies, materials and new production technologies	3 475
Energy	2 350
Environment (including climate change)	1 890
Transport (including aeronautics)	4 160
Socio-economic sciences and humanities	623
Space	1 430
Security	1 400
Co-operation total	32 413
Ideas	7 510
People	4 750
Capacities	
Research infrastructure	1 715
Research for the benefit of small and medium-sized enterprises	1 336
Regions of knowledge	126
Research potential	340
Science in society	330
Coherent development of research policies	70
Activities of international co-operation	180
Capacities total	4 750
Non-nuclear activities of EU's Joint Research Centre (JRC)	1 751
Nuclear activities of EU's JRC: fusion**, fission and radiation protection	2 700

* Budgets cover the seven-year period 2007–2013, with the exception of the budget for the nuclear activities of the JRC, which covers 2007–2011.
** includes the contribution to ITER (Box 2)

Source: Final agreement between EU Council of Ministers and European Parliament, 2006

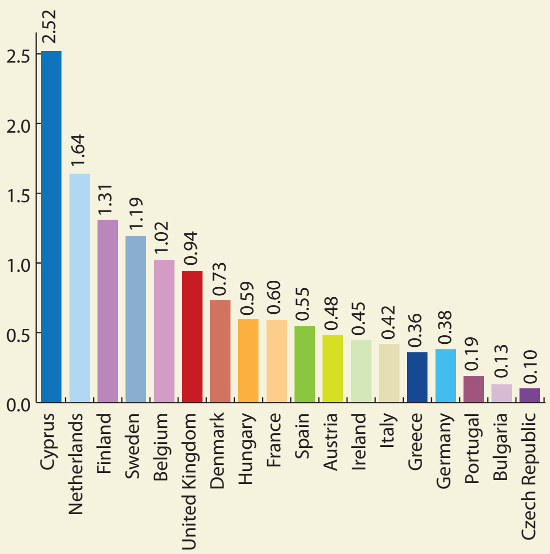
combined are of the order of 25% of public funding for R&D. This highlights a key policy issue within the EU which has so far been largely ignored: what should the role of the EU really be in relation to national funding sources and what should the role of national funding agencies be in achieving co-ordination between national funding sources?

European Research Council

Despite the still relatively limited role of the EU budgets for R&D, important developments are taking place which are at the heart of current policy debates in the EU. The major debate concerns the European Research Council (ERC), formally established in December 2006 when its seven-year budget of €7.5 billion was approved as part of FP7. The ERC is a genuine funding agency. Although it is still run as a formal Executive Agency of the EU, it is led by an independent Scientific Council consisting of some 20 scientists. The council sets policy, defines the scientific strategy and establishes the methods for reviewing the applications for funding.

Currently, the ERC has two funding schemes, Starting Grants for young researchers setting up a small research group and Advanced Grants for established researchers. For the first time, Europe has recognized that the promotion of scientific research of the highest calibre requires a European-wide competition, as opposed to national competitions. Moreover, the way in which these funding schemes operate is fundamentally different from the 'normal' FP7 programmes: scientific excellence is the only criterion; there is no requirement to collaborate with other researchers from different countries and the contributions

Figure 2: Starting grants from European Research Council per million inhabitants, 2007



Note: The data concern the first round of grants in 2007. A recipient is associated with the country where his or her institution is located, irrespective of nationality. No grants were awarded in 2007 in those EU countries not listed here.

Source: European Research Council

are grants rather than contracts with deliverables. The ERC has by now financed one round of some 300 starting grants for an average amount of €1 million and one round of an equal number of advanced grants for an average of about €2 million. As could be expected, the distribution of these grants over the various countries is very uneven. As an example, Figure 2 shows the number of starting grants per million inhabitants of the host country of the institution at which the principal investigator works.

The Joint Technology Initiatives

The Joint Technology Initiatives (JTI) build on the technology platforms which were formed on a competitive basis in the EU's Sixth Framework Programme (FP6). Each initiative is an alliance among what tends to be a large number of companies, universities and research institutes throughout Europe, with the aim of establishing a strategic research agenda in a particular domain. In order to create strong public–private partnerships to implement a few of these agendas in strategic areas, the European Commission and the member states have defined six Joint Technology Initiatives. A large impact on industrial competitiveness and growth; important contributions to broader policy and societal objectives; a strong financial and resource commitment from industry; and the capacity to attract additional national support were among the criteria used to identify the following JTIs: Innovative Medicines Initiative (IMI), Embedded Computing Systems (Artemis), Aeronautics and Air Transport (Clean Sky), Nanoelectronics Technologies 2020 (ENIAC), the Hydrogen and Fuel Cells Initiative (FCH) and Global Monitoring for Environment and Security (GMES).

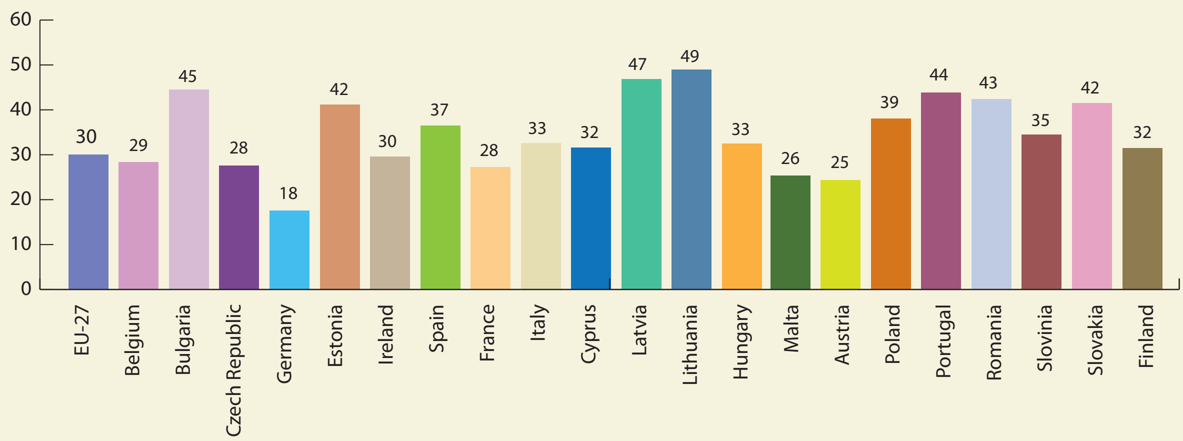
A JTI is known as a 'joint undertaking', a rather complicated European legal structure. On top of that, it is cumbersome to create, one reason being that ordinary citizens, companies or organizations cannot decide by themselves to create a joint undertaking; the Council of Ministers and the European Parliament have to be involved. Yet companies on the whole are of the opinion that JTIs could be an important step forward in establishing the necessary critical mass and helping to leverage national funding. Take the example of Artemis. About 20 countries participate in Artemis, as well as the European Commission and a dedicated industrial foundation of some 100 members, 50% of which are companies. A 10-year R&D programme costing €2.5 billion has been defined, with funding from the participants and national governments, together with some €500 million from FP7. The Board of the Artemis Joint Undertaking will select projects for funding from proposals submitted by groups of members of the foundation. JTIs might mark a new phase in the efforts to increase co-ordination between national programmes and funding mechanisms, something which has always been an elusive goal of official EU policies for STI.

NATIONAL AND REGIONAL DIFFERENCES IN R&D

Differences in gender balance

Within the EU, there are yawning differences between countries when it comes to the share of women among researchers, be it in industry, academia or government institutes. As we can see from Figure 3, the range extends from fewer than 25% of researchers being female to about 50%. There has been little improvement in the EU-15 countries over the years. However, the countries which acceded to the EU in 2004 have now set a faster pace, particularly the Baltic States and countries of Central and

Figure 3: Share of women among European researchers, 2006 or latest available year (%)
Measured as a headcount



Source: European Research Council

Eastern Europe, with the notable exception of the Czech Republic. In traditional R&D strongholds like Germany or France, the participation rate of women in R&D is even much lower than the EU average.

Differences in GERD

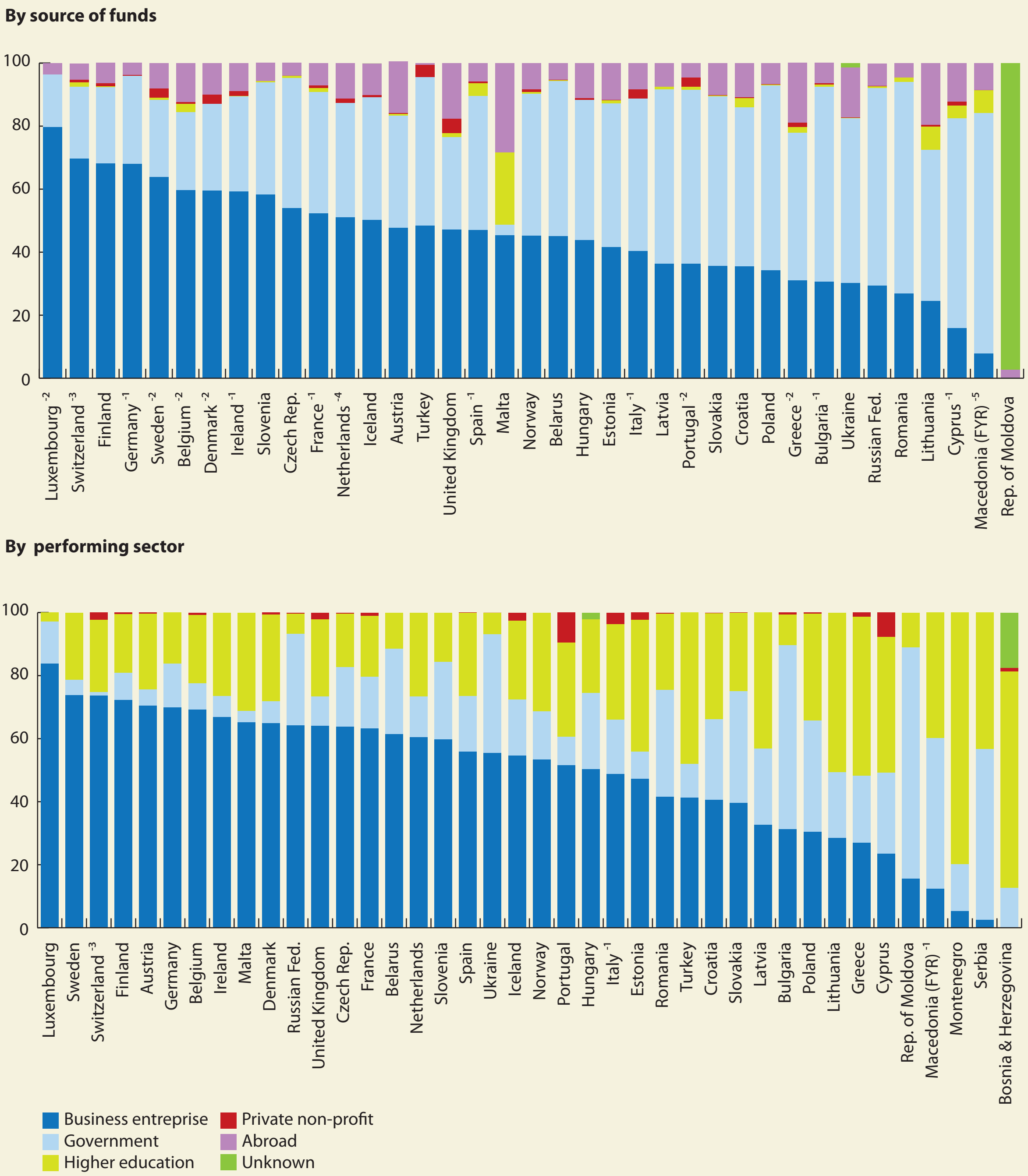
There are also large variations between countries when it comes to funding R&D. Incidentally, it should be noted that all of the organizations, laboratories or research funding programmes at the European level are taken into account in the data on GERD, research personnel, patents and so on collected on a per-country basis, as there is no separate geographical administrative domain beyond the countries in Europe.

As Figure 4 and Table 7 demonstrate, the GERD/GDP ratio varies from less than 0.5% in Bulgaria, Cyprus and Slovakia to more than 3.4% in Finland and Sweden. The share of R&D financed by industry represents less than 30% of GERD in some countries and almost 70% in others. It is no accident that the GERD/GDP ratio is highest precisely in those countries where industry contributes much more than 50% of GERD: Sweden, Finland, Germany and Denmark. Austria is the only real exception. So is Luxembourg, in fact, but Luxembourg is statistically an exception in many respects. In most of the newer member states, the share of industry is negligible, with the notable exception of the Czech Republic and Slovenia. We can see a similar pattern when it comes to the performance of R&D. Here, industry shares tend to be somewhat higher than for R&D funding, since public support for R&D in industry usually outweighs industry outsourcing to universities, for example.

Many of these differences in GERD and related indicators should be nuanced, however. They should come as no surprise and need not be a cause for concern. One simply cannot expect all countries to devote the same share of GDP to R&D. Nor is this the case within countries, as shall become apparent later from the regional innovation index (*see page* 169).

Europe should compare itself to the USA, China or Japan. Natural comparative advantages like lying on the seaboard and historical developments have been the cause of wide regional differences. As far as R&D is concerned, the federal funding sources continue to be a critical factor in keeping the US R&D system fairly concentrated both in terms of institutions and geography. The same can be said for the private equivalent of federal funding sources in the form of large private foundations. In Europe, it is understandable but unsustainable for almost all countries (and often regions within countries) to have a tendency to build their national systems on research-based universities and research institutes, to copy each other's priorities and to want to host large research facilities. This situation does define a key policy

Figure 4: GERD in the EU by source of funds and performing sector, 2007 or latest available year (%)



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

Source: UNESCO Institute of Statistics, September 2009 issue for the EU countries. How can they arrive at a balanced but differentiated approach to knowledge concentrations in the traditional sense of major research universities, research-intensive companies, vast amounts of venture capital and so on?

Table 7: GERD in the EU-27, 2004 and 2007 (%)

	GERD/GDP ratio, 2004	GERD/GDP ratio, 2007*	Industry-financed share of GERD, 2007*
EU-27	1.82	1.83	54.5
Austria	2.26	2.56	47.7
Belgium	1.87	1.87	59.7
Bulgaria	0.50	0.48	30.6
Cyprus	0.37	0.45	15.9
Czech Republic	1.25	1.53	54.0
Denmark	2.48	2.55	59.5
Estonia	0.86	1.14	41.6
Finland	3.45	3.47	68.2
France	2.15	2.08	52.4
Germany	2.49	2.53	68.1
Greece	0.55	0.57	31.1
Hungary	0.88	0.97	43.9
Ireland	1.24	1.31	59.3
Italy	1.10	1.14	40.4
Latvia	0.42	0.63	36.4
Lithuania	0.75	0.82	24.5
Luxembourg	1.63	1.63	79.7
Malta	0.53	0.60	45.4
Netherlands	1.78	1.73	59.0
Poland	0.56	0.56	33.1
Portugal	0.77	1.18	36.3
Romania	0.39	0.53	26.9
Slovakia	0.51	0.46	35.6
Slovenia	1.40	1.58	60.3
Spain	1.06	1.27	47.1
Sweden	3.62	3.64	65.7
United Kingdom	1.69	1.76	45.2

*or latest available year

Source: OECD (2008) *Main Science and Technology Indicators 2008-2*

Differences in innovation performance

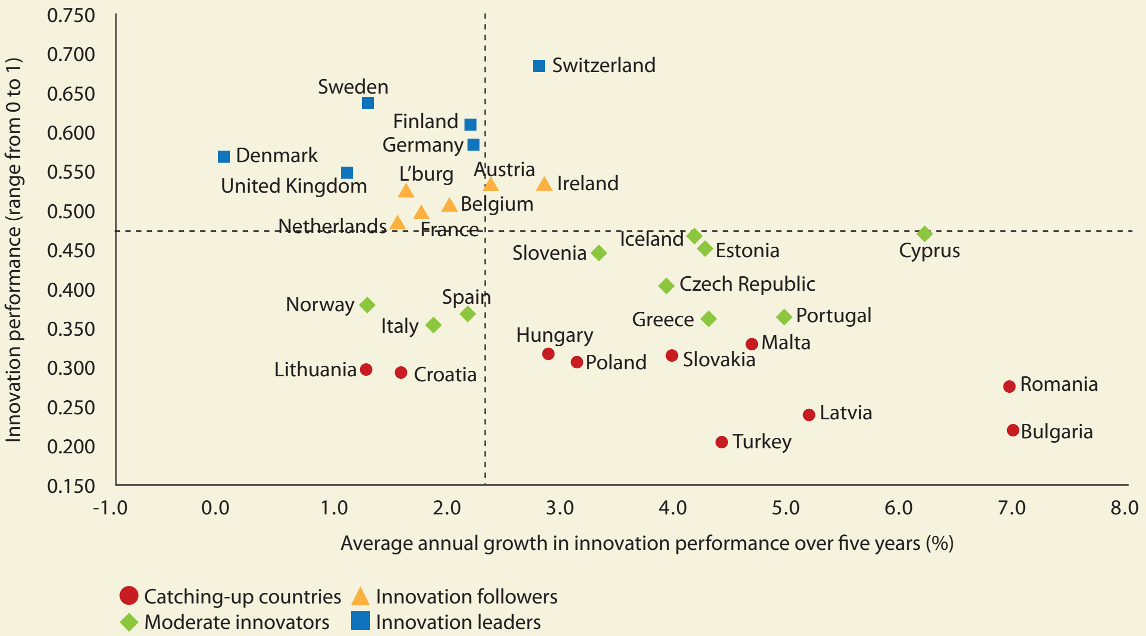
In the meantime, it is now possible to describe the differences between EU member states in a much more sophisticated way than before, thanks to the Summary Innovation Index (opposite). Following work carried out by the Organisation for Economic Co-operation and Development (OECD) in the 1990s to develop indicators that measure R&D input, throughput and output, and later the innovation process, a methodology was developed to try to capture the relative position of countries, the Summary Innovation Index. This index is modified slightly each time it is put together but the methodology is now stable enough to allow comparisons over a number of years.

If one looks at the performance of the innovation leaders, followers, moderate innovators and catching-up countries, the differences between the four categories are fairly consistent: innovation followers score less than leaders for each of the components and so on (Figures 5 and 6). The two figures may also be used to illustrate that scoring high on innovation is not *per se* the only route to prosperity. Norway is the obvious example. Its score shows that high income from natural resources can go hand in hand with an advanced economy and a highly educated population.

A correlation between specialization and public R&D funding

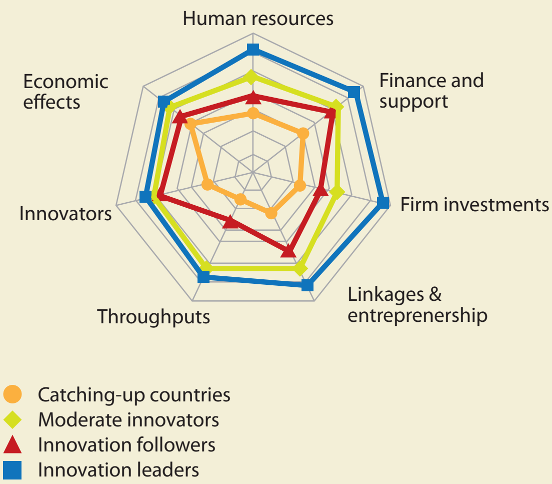
Innovation performance is a generic characteristic of a country's economy and does not look at the strength of individual sectors. But most countries do have a certain specialization, of course (Table 8). Finland, for example, is extremely strong in ICTs. Does government expenditure on R&D reflect this? Data can show government spending on R&D, known in EU jargon as Government Budgetary Appropriations for R&D (GBAORD), broken down by socio-economic objective. However, a key problem is whether to classify medium- or longer-term strategic or application-oriented research as 'non-oriented' or even as 'research financed from general university funds' or as sector-related research. For the most recent year for which data are available, Hungary identifies just 14.1 % of government expenditure on R&D as being financed from general university funds and non-oriented research combined, whereas, in many countries, these two categories alone account for more than 60% of the total (Table 9). Clearly, such a discrepancy between countries in reality is unlikely. Yet it is possible to see some sector realities reflected in the data.

Figure 5: Summary Innovation Index for EU-27, 2007 or latest available year
Other European countries are given for comparison



Source: Source: InnoMetrics (2009) *European Innovation Scoreboard 2008. Comparative Analysis of Innovation Performance.* January. European Commission; prepared by H. Hollanders at UNU-MERIT, Maastricht

Figure 6: Performance of EU-27 countries for seven components of innovation, 2007



Note: Data refer to 2007 or latest available year.

Source: Source: InnoMetrics (2009) *European Innovation Scoreboard 2008. Comparative Analysis of Innovation Performance.* January. European Commission; prepared by H. Hollanders at UNU-MERIT, Maastricht

Elements comprising the Summary Innovation Index

ENABLERS

Human resources
Graduates in science and engineering, social and human sciences
PhDs in science and engineering, social and human sciences
Tertiary education
Life-long learning
Youth education

Finance & support
Public R&D expenditure
Venture capital (three-year average)
Private credit
Broadband access by firms

FIRM ACTIVITIES

Firm investments
Business R&D expenditure
IT expenditure
Non-R&D innovation expenditure

Linkages & entrepreneurship
SMEs innovating in-house
Innovative SMEs collaborating with others
Firm renewal (SMEs entries + exits)
Public–private co-publications (two-year average)

Throughputs
EPO patents
Community trademarks
Community designs
Technology Balance of Payments flows

OUTPUTS

Innovators
Product/process innovators (SMEs)
Marketing/organizational innovators (SMEs)
Resource efficiency innovators
– Reduced labour costs
– Reduced use of materials and energy

Economic effects
Employment in medium-high/high-tech manufacturing
Employment in knowledge-intensive services
Medium/high-tech manufacturing exports
Knowledge-intensive services exports
New-to-market sales
New-to-firm sales

Trends in funding defence research
Defence research tends to be relatively easy to identify, with marked differences among the EU member states reflecting the importance each country accords to its defence industry. For the EU-27 overall, 13.3% of government spending on R&D is classified as 'defence' spending but four countries spend substantially more than the others: the UK (31.0%), France (22.3%), Sweden (17.4%) and Spain (16.4%).

Trends in funding research on agricultural production and technology
Agricultural production, which includes hunting, forestry and fisheries, is still relatively important for many of the countries that acceded to the EU in 2004. According to Eurostat (2008), the annual growth rate of added value at constant prices over 2000–2006 averaged 6.7% in Hungary, 10.9% in Slovakia and 3.8% in Poland, for example, whereas, in most of the older member states, production either declined or remained relatively stable. Government spending on 'agricultural production and technology' is on average much higher in the new member states: Cyprus (23.5%), Latvia (17.5%), Hungary (16.4%) and Slovakia (11.5%). Noteworthy is that Poland is an exception to the rule, at 1.3%, but then Poland classifies a full 77% as research financed from general university funds. Among the old member states, only a handful devote a considerable percentage of expenditure to agricultural research. Unsurprisingly, these are Ireland, the Netherlands and Denmark but also Iceland, Portugal and Greece (on Greece, *see page* 190). The percentage for Iceland is even 21.3%.

Trends in funding energy research
Turning to energy research, even though it seems likely that budgets will be rising in the near future, the 2005 data show only small amounts of funding for the 'production, distribution and rational utilization of energy'. A few countries stand out, however: Hungary devotes 10.4% to this sector but this is probably relatively distorted, *firstly* because of the very small amount of 'research financed from general university funds' and, *secondly*, in light of the percentages for non-oriented research. Other examples are Finland (4.8%), France (4%) and Italy (4.0%). By contrast, Germany's share is low, at 1.8%, and that of the UK even lower: 0.4%. The nuclear industry and nuclear power as such no doubt have much to do with these differences, although in the case of the UK, there may be a grey area between identifying research as 'energy' or 'defence'.

Trends in funding industrial production and technology
The data for 'industrial production and technology' and for 'protection and improvement of human health' are,

Table 8: EU publications by major field of science, 2002 and 2008
*For the countries with the highest GERD/GDP ratio**

Country / Territory	Biology		Biomedical reseach		Chemistry		Clinical medicine	
	2002	**2008**	**2002**	**2008**	**2002**	**2008**	**2002**	**2008**
Austria	493	682	979	1 273	647	765	2 955	3 515
Belgium	807	1 278	1 443	1 740	1 079	1 197	3 512	5 030
Czech Republic	532	1 040	619	986	871	1 102	726	1 473
Denmark	882	1 015	1 301	1 569	504	558	2 612	3 674
Finland	755	871	1 057	1 189	562	591	2 562	2 835
France	2 988	3 865	6 550	7 169	5 401	6 090	13 068	16 034
Germany	3 847	5 155	8 733	10 006	7 399	8 344	20 777	24 708
Netherlands	1 370	1 654	2 728	3 273	1 421	1 378	7 125	10 374
Slovenia	90	231	172	242	252	341	281	692
Sweden	1 127	1 268	2 404	2 453	1 161	1 143	5 492	6 263
United Kingdom	4 517	4 975	9 584	10 789	5 469	5 352	22 001	26 754

* Luxembourg does not feature in this table despite its high GERD/GDP ratio because its productivity is low, just 192 scientific articles across all major fields of science in 2006.

however, much more equivocal and probably marred by classification problems. Take the case of 'industrial production and technology'. It is no accident that the very high figures for Belgium (33.4%), Finland (26.1%), Lithuania (21.0%) and Hungary (19.6%) seem to coincide with the relatively low to very low percentages for 'research financed from general university funds' and 'non-oriented research' combined. Germany, Sweden and the UK would be expected to occupy a strong position but the first two have considerably higher levels of 'research financed from general university funds' and 'non-oriented research' figures than those for industrial production and technology, even though Germany's share, at 12.6%, is still considerable. In the case of the UK, its very high defence research component may partly explain the difference. In a similar vein, it is hard to believe that the widely varying figures for 'protection and improvement of human health' in the UK (14.6%), but extremely low figures for Sweden (1.0%) or Belgium (1.9%), reflect realities in health care.

Regional differences in innovation

The analysis of innovation performance along the lines of the Summary Innovation Index has been extended to European regions (Hollanders, 2006). Several words of caution are in order at this point, pertaining to the incomparable administrative definition of regions in different countries. In Belgium, for example, the whole of Flanders and the whole of the Walloon Region are counted as a single region, whereas, in the Netherlands, 12 provinces are each considered to be a region. Nevertheless, two key results stand out. In the first place, it becomes evident that there is an enormous variety within each of the EU member states. Whether one considers countries scoring high on the Summary Innovation Index for the country as a whole, such as Sweden or Finland, or countries that fare less well in this respect, such as the moderate innovators Greece and Portugal, the variation between regions within each country remains considerable. This illustrates the fact that striving for a homogeneous performance in innovation is a totally unrealistic goal and not necessary for a relatively homogeneous distribution of prosperity in a country. Secondly, regions that are performing very well can be found throughout the EU and not just in the old member states. Prague and Bratislava score as high as the best-performing region in the Netherlands, Noord-Brabant, which owes part of its score to the fact that several large companies – and Philips first and foremost – have installed large research laboratories in the region. This illustrates the point that making a judicious choice of specialization and sticking to it does pay off.

Earth and space		Engineering and technology		Mathematics		Physics		Total	
2002	2008	2002	2008	2002	2008	2002	2008	2002	2008
420	748	763	1 070	241	444	962	1 159	7 460	9 656
604	951	1 039	1 483	310	531	1 421	1 563	10 215	13 773
262	510	542	969	214	413	934	1 072	4 700	7 565
643	757	526	724	149	180	851	839	7 468	9 316
501	709	807	955	156	226	760	952	7 160	8 328
3 455	4 899	5 249	7 123	2 389	3 113	8 100	8 840	47 200	57 133
4 251	5 978	7 008	7 746	1 900	2 725	11 573	11 706	65 488	76 368
1 345	1 764	1 686	2 051	360	507	1 998	1 944	18 033	22 945
42	124	401	588	112	158	259	390	1 609	2 766
859	1 228	1 495	1 614	273	404	1 872	1 695	14 683	16 068
4 675	6 079	6 713	7 612	1 383	2 197	6 719	7 544	61 061	71 302

Source: Thomson Reuters (Scientific) Inc. Web of Science, Science Citation Index Expanded, compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

Table 9: EU government expenditure on R&D by socio-economic objective, 2005

In millions of euros and as a percentage of the total

	Exploration and exploitation of Earth (%)	Infrastructure and planning of land-use (%)	Control and care of environment (%)	Protection and improvement of human health (%)	Production, distribution and rational utilization of energy (%)	Agricultural production and technology (%)
EU-27	1.7	1.7	2.7	7.4	2.7	3.5
Austria	2.1	2.2	1.9	4.4	0.8	2.5
Belgium	0.6	0.9	2.3	1.9	1.9	1.3
Cyprus	1.9	1.5	1.1	10.4	0.4	23.5
Czech Republic	2.3	4.1	2.9	6.8	2.4	5.0
Denmark	0.6	0.9	1.7	7.2	1.7	5.6
Estonia	0.3	8.1	5.4	4.3	2.2	13.5
Finland	1.0	2.0	1.8	5.9	4.8	5.9
France	0.9	0.6	2.7	6.1	4.5	2.3
Germany	1.8	1.8	3.4	4.3	2.8	1.8
Greece	3.4	2.2	3.6	7.0	2.1	5.4
Hungary	2.9	2.1	9.7	13.1	10.4	16.4
Ireland	2.4	0.0	0.8	5.3	–	8.9
Italy	2.9	1.0	2.7	9.9	4.0	3.4
Latvia	0.6	2.3	0.6	4.0	1.7	7.3
Lithuania	2.6	1.8	6.8	12.4	3.4	17.5
Luxembourg	0.5	3.4	3.1	7.8	0.6	1.8
Malta	–	0.0	–	–	0.1	5.6
Netherlands	0.3	3.6	1.2	3.8	2.2	6.1
Poland	1.8	1.2	2.4	1.9	0.9	1.3
Portugal	1.6	4.5	3.5	7.6	0.9	9.9
Romania	1.2	3.4	2.1	4.4	0.9	4.3
Slovakia	0.6	1.0	3.3	1.6	11.5	5.0
Slovenia	0.4	0.8	3.1	2.0	0.5	3.2
Spain	1.6	5.5	3.0	8.2	2.2	6.3
Sweden	0.7	3.8	2.2	1.0	2.3	2.2
United Kingdom	2.3	1.1	1.8	14.7	0.4	3.3

Note: Government expenditure on R&D in the EU is known as government budget appropriations or outlays on R&D (GBAORD). Data are unavailable for Bulgaria.

Source: Wilen (2008) *Statistics in Focus*. Eurostat: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-08-029/EN/KS-SF-08-029-EN.PDF

Industrial production and technology (%)	Social structures and relationships (%)	Exploration and exploitation of space (%)	Research funded from general university funds (%)	Non-oriented research (%)	Other civil research (%)	Defence (%)	Total government spending (millions of euros)
11.0	3.1	4.9	31.4	15.1	1.6	13.3	81 328
12.8	3.4	0.9	55.0	13.1	0.9	0.0	1 593
33.4	4.0	8.4	17.8	24.2	2.9	0.3	1 788
1.3	8.2	–	28.7	22.9	–	–	44
11.9	2.8	0.8	25.4	27.3	5.7	2.5	552
6.3	6.3	2.0	45.3	20.6	1.2	0.7	1 482
5.8	6.4	0.0	–	49.2	4.0	1.0	45
26.1	6.1	1.8	26.1	15.2	–	3.3	1 614
6.2	0.4	9.0	24.8	17.8	2.3	22.3	15 950
12.6	3.9	4.9	40.6	16.3	0.7	5.8	17 221
9.0	5.3	1.6	42.2	17.0	0.8	0.5	635
19.6	9.1	2.3	9.1	5.0	0.3	0.1	329
14.2	2.4	1.5	64.3	0.1	–	–	751
12.9	5.3	8.0	40.3	5.8	0.1	3.6	9 577
5.1	1.7	1.1	74.6	–	1.1	–	25
6.0	20.1	–	–	–	29.3	0.2	8 74
21.0	16.4	–	16.4	25.6	3.4	–	95
–	6.9	–	86.9	–	0.6	–	9
11.5	2.1	2.5	49.0	10.8	4.6	2.2	3 557
5.9	0.9	0.0	5.3	76.9	0.2	1.3	719
15.1	3.4	0.2	38.8	10.4	3.4	0.6	1 082
10.7	0.3	2.4	–	40.9	27.8	1.7	174
–	3.6	–	25.6	35.9	3.5	8.3	108
22.6	2.7	–	–	59.7	0.2	4.9	167
18.5	2.2	3.5	17.8	11.0	3.7	16.4	7 634
5.4	5.0	1.2	46.1	12.7	–	17.4	2 561
1.7	3.5	2.0	21.7	16.0	0.5	31.0	12 950

Catching up within the EU: spotlight on the newcomers

The position of the last 12 newcomers to the EU has already received some attention in earlier sections but, here, we shall examine their situation a little more closely. Table 10 highlights the situation for some key indicators. In most cases, the newcomers show relatively high GDP growth rates. Otherwise, no consistent picture emerges. Countries are simply too different to appear in an orderly, homogeneous way in such a comparison. Yet a few conclusions do seem possible. Estonia and Latvia in particular, but also the third Baltic country, Lithuania, as well as Cyprus, have done very well for all the indicators in Table 10. For the Baltic countries, the question is whether and how these trends will continue, as these countries are among the hardest hit by the current global economic recession.

Business expenditure on R&D is growing considerably in most countries. Of course, this growth is starting from a very low level in almost all cases and, in several countries, foreign subsidiaries account for much of the investment in R&D. Nevertheless, the data show that private-sector investment in R&D has taken hold, with the remarkable exception of Slovakia and, less surprisingly, Romania, which faces demanding challenges.

The GERD/GDP ratio has increased in most of the 12 new EU countries but not in Slovakia, given the considerable decline in business expenditure, nor in Bulgaria or Poland. Doctoral degrees are on the rise in all but two countries: in Malta, they are down considerably but, for such a small country, there could be many explanations; in Hungary, this unexpected situation may be related to the reduction in public expenditure on R&D.

One particular area in which most of the most recent member states still have a long way to go concerns linkages between universities and public research institutes with private enterprises. That should come as no surprise. For most of the countries formerly belonging to the Council of Mutual Economic Assistance (COMECON)[6] in the era of state enterprises, there were few ties, as they relied on their own state laboratories and private enterprises were scarce. As for Cyprus and Malta, these are small countries with economies which are not strongly based on innovation and technology. Among the indicators used for the European Innovation Scoreboard, only one really captures these linkages between universities or public research institutes and private enterprises. This is the number of public–private co-publications, that is, publications where one or more authors from a university or a public research institute are

Table 10: Growth in R&D expenditure and PhDs in the 12 newest EU member states, 2003–2007 (%)

	Average annual growth rate for public R&D, 2003–2007	Average annual growth rate for business R&D, 2003–2007	Average annual growth rate for GERD/GDP, 2003–2007	Growth rate for PhDs, 2003–2007
Bulgaria	-4.7	10.7	-4.0	11.2
Cyprus	6.6	9.3	21.6	18.0
Czech Republic	3.5	6.6	23.2	7.0
Estonia	4.8	20.0	32.6	12.4
Hungary	-1.1	9.6	10.2	-1.1
Latvia	13.8	12.7	50.0	25.7
Lithuania	2.3	13.2	9.3	1.1
Malta	3.9	2.7	13.2	-16.8
Poland	-0.6	4.7	-3.6	12.2
Romania	18.0	0.0	35.9	2.1
Slovakia	0.9	-13.4	-9.8	7.7
Slovenia	7.5	3.8	9.3	2.6

Source: InnoMetrics (2009) *European Innovation Scoreboard 2008. Comparative Analysis of Innovation Performance.* European Commission; prepared by H. Hollanders at UNU-MERIT, Maastricht involved and at least one from a private enterprise. Table 11 reveals the current position of the latest 12 member states for this indicator and growth rates over the past five years. The number of public–private co-publications per million inhabitants should be put in perspective by comparing these figures with the performance of the highest-ranking EU countries: Sweden (116.1), Denmark (108.7), the Netherlands (83.7) and Finland (83.1). Slovenia is not far off the EU-27 average of 31.4 and Hungary, Estonia and the Czech Republic are well on their way to achieving this target but all the other countries are far behind. Nor would it be kind to compare these scores with Switzerland's score of 193.1 per million inhabitants. Nevertheless, growth rates among the newcomers are mostly positive to very positive.

A boost from EU structural funds

Making available EU structural funds is one of the key mechanisms by which the EU is helping new member states, as well as poorer regions in older member states. The newcomers usually have a lower GDP per capita and often major problems with their socio-economic structure. While comprehensive information on the use and impact of EU structural funds is not easy to obtain, they do now represent a significant impulse for building and modernizing the STI infrastructure.

Table 11: Public–private co-publications in the 12 most recent EU countries, 2007

	Number per million inhabitants (2007)	Annual growth rate over 2003–2007(%)
Bulgaria	0.5	19.4
Cyprus	9.1	11.0
Czech Republic	12.6	7.8
Estonia	14.5	17.3
Hungary	16.9	7.7
Latvia	0.4	–8.1
Lithuania	0.0	0.1
Malta	0.0	0.0
Poland	1.3	20.6
Romania	3.1	6.4
Slovakia	4.5	10.5
Slovenia	28.1	2.4

Source: European Innovation Scoreboard 2008

It is important to know that the budget ceilings for the EU budget as a whole and for the large subcomponents, the so-called Financial Perspectives, have been fixed for the seven-year period to 2013. That is why, in the following discussion, this period figures frequently. Of course, much of the money involved in the structural funds is used for physical infrastructure, utilities or labour market measures but, in most of the newest member states and some of the older ones as well, part of funding targets infrastructure for research and innovation, and the building-up of human resources. In fact, compared to the first period of structural fund support to the newest member states from 2004 to 2006, the programmes for 2007–2013 show a marked increase in support for R&D and innovation. Even though only a small number of countries have agreed special operational programmes dedicated to R&D and innovation,[7] in most countries there are now special priority components within these operational programmes which are agreed between a country and the European Commission as implementation vehicles for the policies governing structural funds. The information presented below again comes from the ERAWATCH country reports of 2008. It is not always clear whether the amounts mentioned concern only additional EU funding. A programme for a particular country involves some national co-funding but, in the case of R&D and innovation, this usually represents a small percentage (10–15%).

In Bulgaria, two of the seven operational programmes are dedicated to Competitiveness and Development of Human Resources. The first comprises a grant scheme for improving the R&D infrastructure of research organizations and for providing innovation services to companies. Another provides support to small and medium sized enterprises wishing to hire researchers to strengthen their innovation potential. In 2008, some €90 million was spent on these measures, a considerable sum: it represents three times the budget of the National Science Fund, for example (*see also page* 193). Cyprus intends to use part of the structural funds for basic infrastructure, such as incubators or a technology park. In the Czech Republic, the structural funds covering 2007–2013 will be one of the main sources of funding for R&D infrastructure and for training researchers.

6. From 1949 to 1991, COMECON served as the Eastern Bloc's answer to Europe's formation of the Organization for European Economic Co-operation.

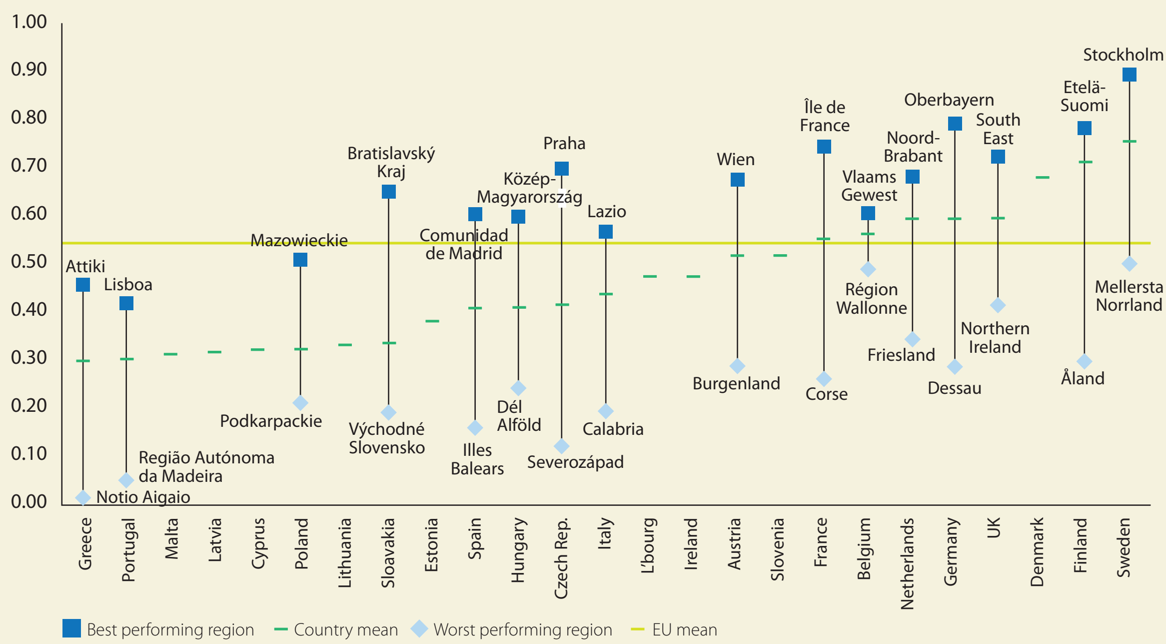
7. These are the European Fund for Regional Development and the European Social Fund, the two components of the structural funds.

The two dedicated operational programmes, R&D for Innovation and Education for Competitiveness, will provide €3.8 billion over 2007–2013. This is a significant addition to national public expenditure on R&D, which amounted to just €0.8 billion in 2007. Important as these funds are, they do have a potentially distortive effect. In the Czech case, the bulk of the funds will be spent outside the Prague region where the bulk of R&D capabilities are currently concentrated. This is because structural funds cannot be spent at will across a country's territory; they are linked to a region's socio-economic position. There is a risk that measures to support infrastructure development will be diluted, especially when it comes to R&D and innovation. As was argued earlier in the present chapter, Europe should be careful not to spread its resources for R&D too thinly. That applies first and foremost to countries. In EU reviews, countries can earn good marks for vowing to accept the Lisbon (2000) and Barcelona (2002) goals of the *Lisbon Strategy*, which imply devoting 3% of GDP to GERD, if not by 2010 then slightly later. It is a dubious assumption that Europe will be better off economically with such a homogeneous distribution of R&D.

If this is true for countries, it also applies to the situation within countries. Figure 7 shows that large differences exist in all countries when it comes to their regional innovation performance. The special Operational Programme on Competitiveness for Prague will support science parks, incubators, innovation centres and centres of excellence, linkages between companies and universities, or between companies and research centres, as well as the innovation capacity of enterprises. This focus on an already dynamic area for R&D may indicate that countries are aware of the risk.

In Estonia, one finds a similar heavy reliance on structural funds for investment in R&D infrastructure. Via two priority programmes, €365 million will be spent over 2007–2013 on research programmes and modernization of establishments for higher education and research. A further €120 million will go towards developing human resources for R&D. The same is happening in the other two Baltic countries. Latvia will spend some € 238 million on R&D and €202 million on innovation. In Lithuania, 46% of the funds for economic growth will go to R&D for business

Figure 7: Regional Innovation Index for regions within EU-27 member states, 2005 or latest available year



Note: The Regional Innovation Index 2006 uses the same methodology as the Summary Innovation Index described earlier but a more limited set of indicators.

Source: European Trendchart on Innovation (European Commission DG Enterprise and Innovation); prepared by Hugo Hollanders, UNU-MERIT, 2006: www.proinno-europe.eu/ScoreBoards/Scoreboard2006/pdf/eis_2006_regional_innovation_scoreboard.pdf innovation, of which €386 million is earmarked directly for investment in R&D, especially R&D infrastructure.

In Hungary, expenditure on research, technological development and innovation covers such projects as R&D centres, innovation and technology parks or complex technological developments in enterprises. This expenditure is funded via the Operational Programme on Economic Development. Similarly, the development of research infrastructure in institutions of higher learning is funded via an Operational Programme on Social Infrastructure. Together, these two programmes constitute an annual amount of some €200 million.

Malta, with its small population of about 400 000, will nevertheless spend €45 million on R&D infrastructure and human resources training, in addition to funds for stimulating R&D in industry.

Poland presents a stark contrast. With a population of about 38 million, it is by far the largest of the 12 member states that have joined the EU since 2004. The EU structural funds for Poland are thus incomparably larger. Notwithstanding this, their relative impact is very considerable indeed. The ERAWATCH country report of 2008 for Poland mentions that, in the 2004–2006 period, of the €133 million spent on strengthening co-operation in Poland between universities or research institutes and enterprises, a full €100 million was EU funding. For the 2007–2013 period, in the context of the Operational Programme for the Innovative Economy, of the total €9.7 billion, some €1.3 billion supports R&D in modern technologies and a further €1.3 billion research infrastructure. Incidentally, this is a case where the EU contribution is explicitly stated: of the €2.6 billion involved in the two aforementioned components, €2.23 billion is EU funding.

Romania is the one country where the use of structural funds for strengthening the R&D system is so far not working so well; the country has yet to develop the capacity to absorb such considerable sums (*see page* 191).

Slovenia would not suffer from this handicap. However, spending structural funds on R&D and innovation is apparently of lesser priority for Slovenia than for the other countries discussed here (*see also page* 190).

Last but not least, Slovakia has a special Operational Programme for Research and Development that supports R&D in universities and other higher institutions of higher learning, as well as co-operation between these institutions or research centres and industry.

Clearly, in many countries, structural funds will be a key component of their strategies for R&D and innovation for years to come. Apart from spending these funds wisely by not falling into the trap of spreading them thinly, for example, a major challenge will be to build a financially sustainable STI system by 2013 – for it needs few predictive powers to foresee that available structural funds will be thinner on the ground after 2013.

PUBLIC ATTITUDES TO S&T

European citizens are regularly polled on their attitude to S&T. These surveys include issues related to scientists and policy-making. The latest EUROBAROMETER survey published by the European Commission (2005)[8] is based on 30 000 interviews. Here, we shall give a brief overview of the illuminating answers to some of the questions.

Of the respondents, 30% on average said they were very interested in new inventions and technologies and 48% moderately interested. The same percentages apply to scientific discoveries. However, the figures vary greatly across Europe. In Lithuania, only 14% said they were very interested in new inventions and technologies, with similar proportions in Romania (15%), Italy (16%), Bulgaria (17%) and Portugal (18%). In Cyprus, the figure was as high as 54%, followed by Malta (46%), the Netherlands (42%) and Greece (41%).

There is a marked difference between males (40%) and females (21%), although the gender difference contracts when it comes to the level of interest in new scientific discoveries: 36% versus 25%. When asked which areas of science were of most interest, 61% of respondents (but 73% of females) cited medicine and 47% the environment (in equal proportions).

On the question of whether people regularly read articles on scientific topics in newspapers, magazines or on the Internet, the smaller countries in north and northwestern

8. A more recent survey in 2008 polled young people aged between 15 and 25 years. However, the methodology and questions had changed in this second survey, making it impossible to compare the opinions and views of the respondents to the 2005 and 2008 surveys.

Europe emerged with a clear lead: in descending order, from 38% to 26% of respondents in the Netherlands, Luxembourg, Belgium, Sweden, Denmark and Finland answered this question in the affirmative. Switzerland, Norway and Iceland also scored in the high twenties. The highest score for the larger countries went to France, with 25%. Italy could manage only 10%, Bulgaria, Romania and Portugal 11%. The differences shrink if one combines the answers for regular and occasional reading.

When asked to rank subjects on a scale of 1 (not at all scientific) to 5 (very scientific), 89% of respondents said they found medicine to be very scientific and 83% physics. But 41% were of the opinion that astrology was very scientific (compared to 40% for astronomy), 33% held the same view for homeopathy and 40% held economics in a similar regard.

Knowledgeability about science was surveyed by asking 10 quiz questions, such as whether the statement that 'lasers work by focusing sound waves' was false or whether it was true that 'human beings, as we know them today, developed from earlier species of animals'. On average, 66% of respondents (70% of men and a 62% of women) gave correct answers, with extremes of 78% for Sweden and 48–52% for a group of countries that includes Bulgaria, Cyprus, Romania, Malta, Lithuania and Portugal. The question on human evolution was answered correctly by 70% of respondents throughout the EU. There is some variation between men and women but it is insignificant. Perhaps more remarkable is that the average score for correct answers was still only 78% for those whose education ended after their twentieth year.

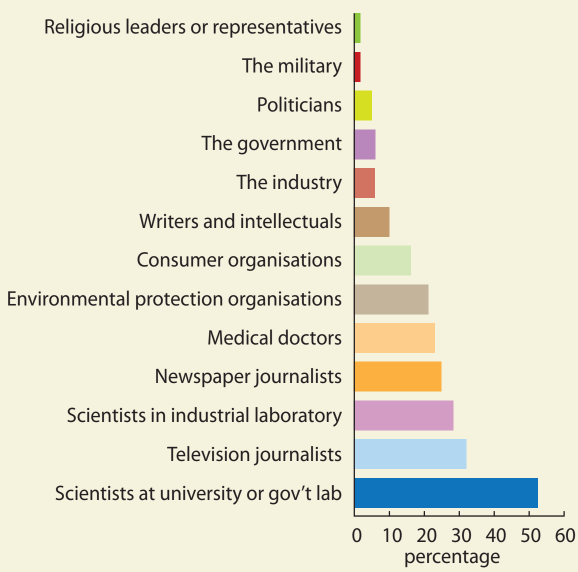
As to which three professional groups or institutions were most trusted to explain the impact of S&T developments on society, this question produced some interesting results (Figure 8). Scientists working for a university or in a government laboratory were most trusted by far, followed by television journalists, who had an edge over their newspaper colleagues. Somewhat surprisingly, medical doctors scored rather poorly but this may be because the questionnaire confined answers to three categories of person or organization. Again, one finds large variations from one European country to the next. For example, scientists working at a university or in a government laboratory scored 52% on average but between 68% and 76% in Slovakia, Cyprus, Greece and the Czech Republic.

In Portugal, on the other hand, only 38% of respondents mentioned this category as being among the three most trusted and in Denmark only 39%.

When it comes to the power respondents ascribe to science, remarkable differences arise. Asked whether science would one day give a complete picture of how nature and the Universe work, 24% of respondents in Iceland, 27% in Norway and Finland, 31% in the Netherlands and 37% in Switzerland agreed with the statement. The figure was even as high as 73% in Malta, 70% in Greece and 59% in Italy.

As for expectations as to whether S&T progress would solve social problems, a massive 88% of respondents agreed that this would help to cure such illnesses as HIV/AIDS or cancer. The Netherlands, Norway and Iceland scored highest, 97%, 95% and 94% respectively. At the other end of the scale came Slovenia and Lithuania, with a score of 75%. Of course, this heady level of optimism about what S&T can do does not extend to all social problems. Only 39% of respondents in the EU agreed that S&T would help eliminate hunger and poverty in the world and not more than 21% that

Figure 8: Professions trusted by the European public to explain the impact of S&T on society, 2005 (%)



Note: Survey in 2005 of 30 000 respondents in the EU-25, Bulgaria, Romania, Croatia, Turkey, Iceland, Norway and Switzerland

Source: Special EUROBAROMETER 224

S&T could sort out any problem. There were even deep lows of 7–9% in the Netherlands, Sweden, France and Denmark. One might perhaps take the view that having 21% of respondents believe in the omnipotence of S&T is a healthy score. Overall, 52% of respondents were of the view that the benefits of science outweighed any harmful effects it might have.

Questions were also asked about whether S&T were the *cause* of social problems. More than half (57%) of respondents held S&T responsible for most of today's environmental problems and, on a very contentious issue, 54% of respondents were of the opinion that genetically modified food was dangerous. Percentages for this question ranged from 88% and 80% in Cyprus and Greece respectively to 30% in the Netherlands, 33% in the UK and 39% in Sweden. Similarly, 59% of respondents agreed with the statement that, owing to their knowledge, scientists had a power that made them dangerous.

The majority of repondents subscribed to the view that governments ought to support scientific research that contributes to knowledge: 76% on average for the EU, the lowest score of 54% going to Austria. The latter result is surprising, given that Austria is one of only a handful of the 'old' EU countries that has seen its R&D effort rise considerably in recent years, thanks to a hike in public funding.

That the general belief that governments must support research can be at odds with other expectations of government is illustrated by the answers to the question as to whether governments should spend more money on scientific research and less in other areas. Here, the Netherlands scored lowest, with only 25% of respondents agreeing with this statement. In Malta and Finland, though, only 30% of those interviewed gave priority to an increase in government funding of science.

Respondents clearly expected scientists to abide by ethical standards. As many as 79% felt governments should formally oblige scientists to respect ethical standards. This seems to be in line with the view held by only 36% of respondents that there should be no limit to what science was allowed to investigate. If, on the other hand, scientists respected ethical standards, they should be free to do whatever research they wanted, opined 73%.

THE EU'S PLACE IN THE WORLD

We are now going to look beyond the EU's borders to its competitors. There is no doubt that the EU is one of the leading regions in the world in STI. However, the total amount of R&D carried out in the EU-27 measured as a percentage of GDP remains substantially less than the comparable amounts in the USA and Japan. Moreover, China is rapidly catching up to the EU, although the absolute amount spent on R&D is of course still much smaller (Table 12).

A number of non-financial indicators show a more balanced picture. There are now virtually as many full-time equivalent (FTE) researchers in the EU-27 as in the USA, with China not far behind. But perhaps the more interesting indicator is that for the number of researchers per 1000 labour force. Here, Japan leads, followed by the USA, with China still lagging behind (Table 13).

Not surprisingly, the same scenario repeats itself for the number of triad patent families. A patent family is a patent for which protection has been sought in many countries. A triad patent family means that a patent has been filed with the European and Japanese Patent Offices and granted by the US Patents and Trademark Office. The Triad is almost on a par for this indicator, which showed little progression between 2003 and 2006 (Figure 9).[9] China, on the other hand, has of course started at a much lower level but is displaying an extremely rapid growth rate.

The number of PhD degrees conferred is another interesting parameter. Here, the EU produces many more PhDs than the USA and it is Japan that is trailing behind. To get a better feeling for what these numbers mean, we need to take the size of the population into account. The 2008 OECD *Review of Innovation Policy in China* does this by relating the number of doctoral degrees conferred in all fields in 2004 to the number of people at the typical age of graduation. In the 19 EU countries included in the study, 1.4% of those in this age cohort received a doctoral degree, compared to 1.3% in the USA, 0.8% in Japan and 0.1% in China.

9. This trend will have been calculated for the same number of European countries for 2003 and 2006.

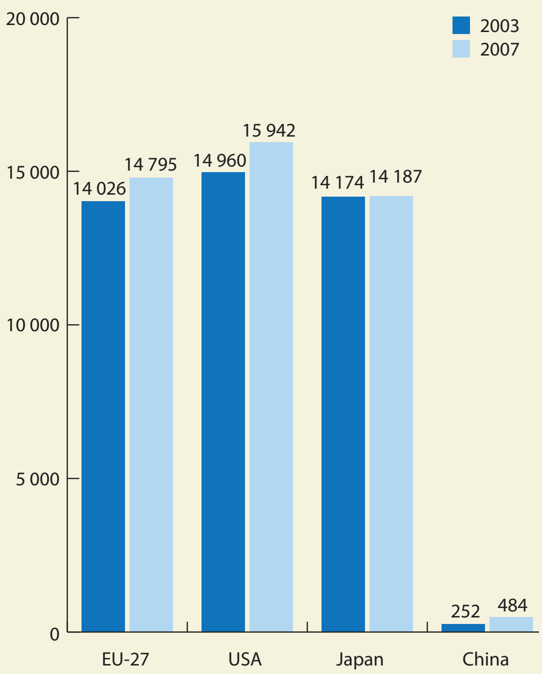
Table 12: Trends in GERD for the Triad and China, 2003 and 2007

	GERD in billions of current PPP US$	GERD/ GDP ratio (%)		Industry- financed (%) share of GERD		Government- financed (%) share of GERD		Defence (%) GERD/GBAORD**	
	2007	2003	2007	2003	2007	2003	2007	2003	2007
EU-27	244.7	1.76	1.77	0.94	0.97	0.63	0.60	14.0	13.3^{-1}
USA	368.8	2.66	2.68	1.71	1.78	0.80	0.74	54.9	56.6
Japan	138.8	3.20	3.39	2.39	2.62	0.58	0.55	4.5	5.2
China	86.8	1.13	1.42*	0.68	0.98	0.34	0.35	–	–

n = data refer to *n* years before reference year
** Government Budget Appropriations or Outlay on R&D. The industry-financed and government-financed shares of GERD are expressed in percentages of GDP.

Source: OECD (2008) *Main Science and Technology Indicators 2008-2*

Figure 9: Triad patent families, 2003 and 2007



Note: Patent families are defined as patents filed with all three of the following: European Patent Office, Japanese Patent Office and United States Patents and Trademark Office. The year is the so-called priority year, i.e. the date of the first international filing. China is added to show that this country is rapidly catching up in terms of absolute R&D expenditure, GERD/GDP ratio and the number of researchers but not yet in terms of patents. There is no doubt that every year to come will see significant increases.

Source: OECD (2008) *Main Science and Technology Indicators 2008-2*

Turning to the Science Citation Index (SCI), the total number of publications recorded by Thomson Reuters in all fields of natural sciences and engineering clearly places the EU in the lead for this indicator, with 36.5% (39.6% in 2002) of world publications in 2007, ahead of the USA at 27.7% (30.9% in 2002), Japan at 7.6% (10.0%) and China at 10.6% (5.2%) [*see page* 10]. Put another way, China's world share has nearly doubled in just five years, largely to the detriment of the Triad.

If the EU also occupies an enviable position in terms of scientific articles published within international collaboration, here we must of course take into consideration that there are 27 countries within the EU, giving these data only limited comparative value.
The distribution over the various subfields shows that biology, biomedical sciences and clinical medicine account for more than 50% of all European publications in the natural sciences and engineering (Table 14). For the USA, the equivalent figure is even higher than 60% and for Japan slightly below 50%. Quite appropriately, it has been said that the 21st century will be the century of the life sciences. One is inclined to say that Europe's higher shares than the USA (Japan looks more like Europe, with the exception of mathematics) in physics, chemistry and mathematics, engineering and technology either reflect a more traditional, less flexible academic research climate or a greater emphasis on more traditional industries, or possibly both. One must be extremely careful, however, not to draw inferences from generic publication data that are too general. Not unexpectedly, China differs markedly from the EU in its publications pattern: biology, biomedical sciences and clinical medicine account for some 25% of all publications, whereas the two categories

Table 13: S&T personnel in the Triad and China, 2007

	FTE researchers (thousands) 2007	FTE researchers per 1000 labour force (%) 2003	2007	Female researchers (head count) (%) 2006	Number of PhDs 2007	Share of PhDs in science and engineering, (%) 2007
EU-27	1342.1	5.8	6.4	33.0	100 347	40.7
USA	1425.6^{-1}	10.2	9.7^{-1}	28.0*	52 631	35.7
Japan	710.0	10.6	11.0	12.4	15 286	37.6
China*	1423.4	1.2	1.8	–	–	–

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

* percentage of full-time tenured or tenured-track faculty; women constitute 37% of all scientists and engineers (not only researchers) in business and industry in the USA

Source: for researchers: OECD (2010) *Main Science and Technology Indicators 2009-2*; for female researchers in the USA: data from Scientists and Engineers Statistical Data System of US National Science Foundation; for share of PhDs: Eurostat (2008) *Science, Technology and Competitiveness Report 2008/2009*

Table 14: Publications in the Triad by major field of science, 2008

	Biology	Biomedical research	Chemistry	Clinical medicine	Earth and space	Eng. and technology	Mathematics	Physics	Total
EU-27	29 516	45 815	36 221	119 230	26 095	44 182	15 239	43 693	359 991
USA	21 234	45 125	18 984	103 835	19 819	28 572	9 356	25 954	272 879
Japan	5 479	9 771	9 809	21 729	3 552	10 194	1 661	12 423	74 618
China	5 672	9 098	23 032	13 595	5 746	22 800	5 384	19 641	104 968
World	84 102	123 316	114 206	307 043	60 979	139 257	37 397	119 799	986 099

Note: The individual amounts do not add up to the total because international authorship means some publications are counted more than once.

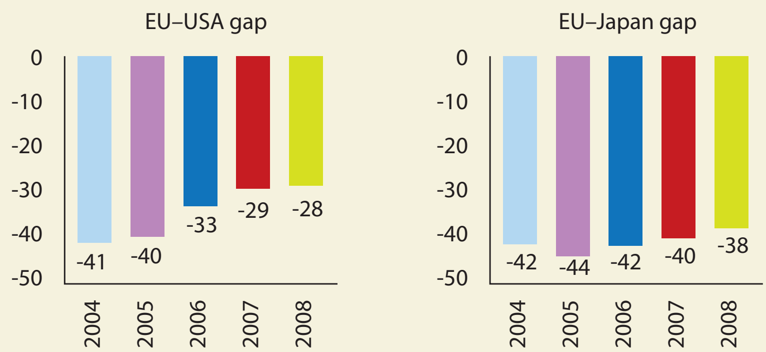
Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

of chemistry and engineering and technology represent much higher shares. When differences are this big between the life sciences and other major fields of research, this tends to reflect different stages of development.

We obtain a more comprehensive comparison between Europe, the USA and Japan if we widen the scope beyond input, throughput and output in R&D to indicators that try to measure the outcome in terms of innovation and also take into account factors conducive to innovation. An example of the former would be the relative amount of products new to the market, or at least new to the country or region concerned. The amount of venture capital available relative to the size of the economy would be an example of a stimulating condition. In the wake of efforts to capture the innovative performance of individual EU countries and even regions, the European Commission has begun comparing Europe with the USA and Japan (Figure 10). A set of 17 indicators is used in three broad categories: Enablers, Firm Activities and Outputs. The methodology is similar to that for the Summary Innovation Index (*see page* 167).

The EU Innovation Scoreboard of 2008 concludes that, for these 17 indicators, the USA and Japan still perform considerably better when it comes to innovation. Nevertheless, the EU-27 has been inching closer to the USA since 2004 and, to a lesser extent, to Japan. It is a little soon to rejoice, however, as the gap is not closing for three key indicators: business R&D, patents filed with the European Patent Office and those filed under the Patent Cooperation Treaty. For these three indicators, Japan is even increasing its lead over the EU.

Figure 10: The EU Innovation gap with the USA and Japan, 2004–2008 (%)



Note: Illustrated is the percentage by which the USA and Japan outperform the EU on average for the indicators listed on page 167.
Source: European Innovation Scoreboard 2008

CONCLUSION

We can see from the foregoing that the EU is now clearly the world leader as far as SCI publications are concerned. But what counts in terms of input is expenditure on R&D and, in terms of output, innovation performance. A lot of work lies ahead for Europe, as witnessed by the EU effectively having abandoned the Lisbon and Barcelona targets. The EU is of course not a homogeneous whole. The Summary Innovation Index, which offers a one-figure comparison of countries, shows that there are, in fact, three groups of countries: the leaders, the followers and the stragglers.

Interestingly, the statistics reveal that performing well in innovation is not a privilege reserved for the 'old' member states. More generally, the 12 new member states which acceded to the EU in 2004 and 2007 are for the most part making a valiant effort to renew and modernize their research and innovation systems. A danger is, though, that each of these countries will be inclined to apply the Barcelona target of devoting a 3% share of GDP to GERD to their own domestic situation, even though the example of the USA illustrates that broad regional differences are the norm.

European scientists, funding agencies and governments – not to mention companies – have long since realized that, when it comes to research and innovation, capabilities sometimes need to be pooled. This realization has led, for example, to large European multilateral research organizations like CERN which involve collaboration among several individual countries. It has also led to the EU's Framework Programmes. But a slew of other organizations and initiatives have also been established: the European Science Foundation and EUREKA are just two examples. Setting up the European Research Council (ERC) as a veritable continental funding agency has been the most important step taken in Europe for a long time. It is one reason why this council has triggered a much more fundamental debate than we usually see in Europe. What should be done at the European level? What is the role of the European Commission (or the EU), the national governments, the national funding agencies and the ERC? This is a discussion which has far-reaching implications.

Shouldn't the EU's Framework Programme focus much more on a limited number of genuine European challenges, such as developing a much stronger ERC, investing in key research infrastructure and funding a limited number of major European missions in the fields of energy, environment, health and so on? Or should the EU ignore these options and continue to fund a large number of relatively small projects that place centre stage the idea of collaboration between often large research groups spread across Europe? What future lies ahead for the EU's ambition of co-ordinating all national research, an ambition that has in practice always been thwarted?

The institutional reforms of universities, research institutes and organizations in Europe are part and parcel of this agenda for change. However, providing a more effective funding system in future is one thing; ensuring that the institutions carrying out research are positioned and resourced in the best way possible is quite another. What is certain is that these twin challenges will need to be tackled simultaneously.

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WEBSITES

Artemis and ENIAC Joint Technology Initiatives: *http://ec.europa.eu/information_society/tl/research/priv_ invest/jti/index_en.htm*

Bologna Secretariat: *www.ond.vlaanderen.be/hogeronderwijs/bologna/*

ERAWATCH: *www.erawatch-network.eu/*

EUREKA: *www.eureka.be*

Thematic Portal on Europe's Information Society: *http://ec.europa.eu/information_society/tl/research/index_en.htm*

European Institute of Innovation and Technology: *www.eit.europa.eu/*

European Research Council: *http://erc.europa.eu/*

European Science Foundation: *www.esf.org*

Peter Tindemans was born in 1947 in Nederweert in the Netherlands. After obtaining a PhD in Theoretical Physics from Leiden University in 1975, he switched from physics to science policy. He was responsible for co-ordinating the first comprehensive Dutch Innovation Policy in 1979 and, from 1991 to 1998, for research and science policy in the Netherlands.

Since 1999, he has been an independent consultant, working with the World Bank, UNESCO and governments in Africa, South and Central America, and Asia on STI policies. Within European countries, he has also worked with regional governments, universities and companies on regional innovation policies, including open innovation campuses. He has also chaired the European Spallation Source, a €1.4 billion neutron facility.

Dr Tindemans has been involved in key European initiatives, such as the EUREKA programme and the COSINE policy group which established the backbone of the first pan-European data network. He is actively engaged in debates on the future of science, technology and innovation policies in Europe. He was Rapporteur general of the World Conference on Science, organized in 1999 by UNESCO and the International Council for Science. He chaired the OECD Megascience Forum from 1992 to 1999 and was Rapporteur general of a joint OECD–United Kingdom conference on genetically modified food in 2000.

Dr Tindemans is a member of the Governing Board of Euroscience, a grass-roots organization for scientists, and of the Supervisory Board for the biennial Euroscience Open Forums, the European counterpart of the annual conferences organized by the American Association for the Advancement of Science in the USA. He is also a member of the Steering Group for the Initiative for Science in Europe.

The bottleneck caused by little domestic demand for R&D and a weak private sector in all but Slovenia is likely to remain a major structural weakness for Southeast European R&D systems for years to come.

Slavo Radosevic

9 · Southeast Europe

Slavo Radosevic

INTRODUCTION

Southeast Europe encompasses the relatively developed science systems of Greece and Slovenia, the 'semi-developed' systems of Bulgaria, Croatia, Romania and Serbia, along with science systems in real need of development – those of Albania, Bosnia and Herzegovina, Kosovo, Montenegro and the Former Yugoslav Republic of Macedonia. The Republic of Moldova shares many features with this last group of countries, although it follows a specific post-Soviet system.

Contemporary Southeast Europe is the most diverse region in Europe in terms of socio-economic development, institutional frameworks and the level of science and technology (S&T) capacity.

There is a ten-fold difference in per-capita income between the richest (Greece and Slovenia) and poorest (Moldova) countries in this region (Table 1). This is both a historical legacy and the result of the civil wars that accompanied the gradual break-up of Yugoslavia in the early 1990s. In fact, the disintegration of Yugoslavia was only complete in 2008, after popular referenda in Montenegro (May 2006) and Kosovo (February 2008) opted for independence from Serbia.

Four countries from Southeast Europe have so far acceded to the European Union (EU): Greece in 1981, Slovenia in 2004 and Bulgaria and Romania in 2007. These countries are covered in the present chapter but also appear in that on the EU (*see page* 147). The remainder either have candidate status for the EU (Croatia, Former Yugoslav Republic of Macedonia and Turkey) or uncertain prospects regarding membership (Albania, Bosnia and Herzegovina, Kosovo, Moldova, Montenegro and Serbia).

For those countries still on the outside looking in, European integration represents the only viable project for ensuring social and political coherence. For those countries that are already EU members, prosperous neighbours are the best guarantee of political stability and economic growth.

In the 1990s, all but Greece grappled with the challenges of an economic transition to post-socialism following the disintegration of Yugoslavia. This led to a deterioration of their science systems, which in some cases has been extremely severe, as described in the *UNESCO Science Report 2005*.

At the end of the first decade of the 21st century, Albania, Bulgaria, Croatia Romania and Slovenia have all fully recovered from the crisis of transition from the Soviet system to a market economy. In the remaining countries, however, income levels still compare unfavourably with income per capita during the socialist period. Nonetheless, since 2000, the economies of all of the Southeast European countries have been growing at average rates of around 3% or higher. With the onset of the global recession in 2008, growth rates in the region are likely to slow down considerably.

The key challenge for the majority of these countries is to ensure further sustainable economic growth. These are open economies; however, the majority of them are still burdened with high unemployment, weakness in the rule of law and an undeveloped financial system.

CONDITIONS FOR R&D

Disparities in the pace of restructuring

The socio-economic features of Southeast European economies strongly influence the role of science in the region and prospects for national economic growth based on domestic knowledge. Their research and development (R&D) systems face acute challenges, in particular regarding science-oriented innovation.

The pace of restructuring varies enormously. Albania, Bosnia and Herzegovina – and the Former Yugoslav Republic of Macedonia to some extent – are the most disadvantaged. They are still striving to establish functioning R&D systems and are thus primarily addressing science policy issues. At the other end of the scale, Bulgaria, Croatia and Romania are implementing very much EU-driven and EU-inspired changes. Together with Turkey, these three countries are making a visible attempt to shift the focus from conventional science policy towards innovation policy. Individual national plans, such as the 2005 Turkish *National Science and Technology Strategy*, have created new momentum which, if it continues, could provide examples of good practice for other countries in the region (*see page* 202).

In Southeast Europe, external conditions for innovation, such as institutions, market efficiency and business sophistication, have shown improvement since the early 1990s, as a result of institutional changes in these transitional economies. However, these changes have not necessarily been accompanied by a greater capability

The Rio-Antirrio, a cable-stayed bridge in Greece

Photo: Parisvas/ iStockphoto

Table 1: Key socio-economic indicators for Southeast European economies, 2008

	Annual average growth rate, 2002–2008 (%)	GDP per capita, (current international) $PPP 2008	Unemployed (% of labour force) 2008	Employment in industry (% of total employment) 2008	Gross fixed capital formation (% of GDP) 2008	Trade (% of GDP) 2008	Exports of goods and services (% of GDP) 2008	Domestic credit to private sector (% of GDP) 2008	Rule of law*, 2006	FDI net inflows (% of GDP) 2008
Albania	5.7	7 293	22.7^{-7}	13.5^{-2}	32.4	90.5	31.2	36.0	-0.70	7.6
Bosnia and Herzegovina	5.6	8 095	29.0^{-1}	–	24.4	73.6	36.8	57.8	-0.52	5.7
Croatia	4.3	17 663	8.4	30.6^{-1}	27.6	92.2	41.9	64.9	0.03	6.9
Rep. of Moldova	6.1	2 979	4.0	18.7^{-1}	34.1	132.3	40.7	36.5	-0.66	11.7
Serbia	5.2 10	544	13.6	26.2	20.4	82.1	29.7	38.4	-0.57	6.0
Montenegro	6.4	13 385	30.3^{-3}	19.2^{-3}	27.7	115.0	40.3	80.4	–	19.2
Romania	6.8	13 449	5.8	31.4	31.1	70.3	29.9	38.5	-0.17	6.9
Slovenia	4.6	27 866	4.4	34.2^{-1}	27.5^{-1}	141.6	70.2^{-1}	85.6	0.84	3.5
Bulgaria	6.1	11 792	5.7	35.5^{-1}	33.4	143.7	60.5	74.5	-0.14	18.4
Greece	4.1	29 356	7.7	16.4	19.3	55.0	23.1	93.5	0.65	1.5
FYR Macedonia	4.3	9 337	33.8	31.3^{-1}	23.9	131.1	52.6	43.8	-0.47	6.3

n = data refer to *n* years before reference year
*Rule of law measures the extent to which a population has confidence in, and abides by the rules of, society. It includes the incidence of violent and non-violent crime, the effectiveness and predictability of the judiciary and the enforceability of contracts.

Source: World Bank, Knowledge for Development, KAM database, July 2010

among firms to absorb new technology and innovate (Radosevic, 2007). Both the new EU member states and the ex-socialist countries have come to realize that policies have not succeeded so far in promoting growth in the absence of strategies that directly address S&T and training, although there are of course also major intra-regional differences in terms of technological readiness.

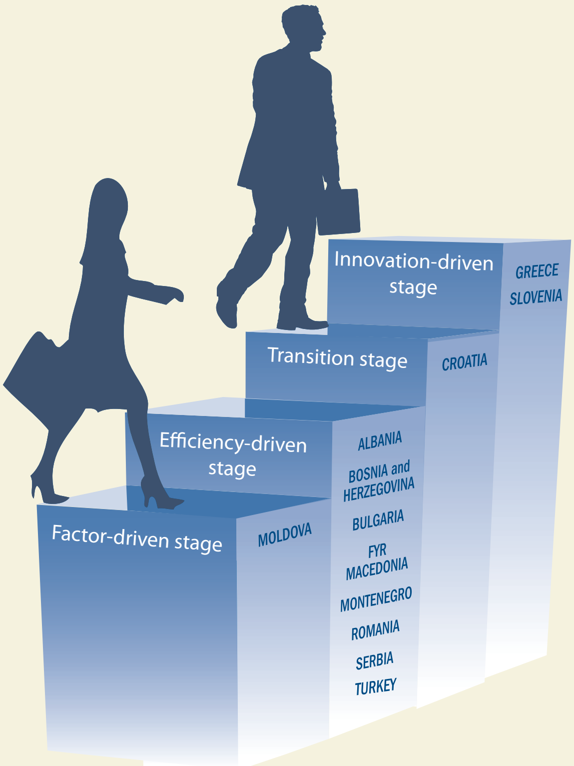
Science, technology and innovation (STI) play very different roles in economic growth in the sub-region. The *Global Competitiveness Report* (WEF, 2010) categorizes countries according to their stage of transition towards a globally competitive economy, taking into account drivers of growth that range from the availability of labour or raw materials to measures of efficiency and innovation (Figure 1). The report considers eight of the Southeast European countries to be at the 'efficiency-driven' stage and Slovenia and Greece to be at the 'innovation-driven' stage. Nestled in-between is Croatia, in transition from efficiency- to innovation-driven. Albania and Bosnia and Herzegovina were upgraded to efficiency-driven economies in 2008, whereas Moldova has remained at the factor-driven stage.

Weak demand for R&D

The R&D systems of countries in Southeast Europe cover a wide spectrum in terms of their relative size, performance and role in society and the economy. However, all but Slovenia share a common feature: domestic demand for R&D and for skilled employees is relatively weak, especially compared to the supply of R&D (Radosevic, 2007). There are several reasons for this. One is no doubt the structure of industry, which is dominated by small firms working in traditional industries that do not exploit new technologies. Lack of capacity is another factor. Serbia easily has the biggest demand–supply gap, both because of unsophisticated industries and the inability of local demand to make up for limited international co-operation. Poor demand for R&D is also the greatest weakness of the new EU Member States.

Throughout the region, R&D systems have stabilized in recent years and are gradually recovering from the recession caused by the transition to a market economy. In the new EU member states, the pace of change is much faster, as these countries are enjoying significant increases in funding of their R&D through EU structural funds (*see page* 173).

Figure 1: Drivers of growth: ranking of Southeast European economies, 2010



Note: The Global Competitiveness Index ranks countries according to three types of attribute. 'Basic requirements' encompass institutions, infrastructure, macro-economic stability, health and primary education. 'Efficiency enhancers' include higher education and training, labour efficiency, financial market sophistication, market size and technological readiness. 'Innovation and sophistication' factors include business sophistication and innovation.

Source: WEF (2010) *Global Competitiveness Report 2010/2011:* www.gcr.weforum.org

R&D INPUT

R&D expenditure

Throughout the region, the decline or, at best, stabilization of employment in R&D has been accompanied by either stagnation or a drop in the share of GDP invested in R&D. Only Slovenia and Romania have managed to inverse the trend. Serbia, meanwhile, is trying to make up lost ground (Figure 2).

Differences in gross domestic expenditure on R&D (GERD) are much greater when population size is taken into account (Figure 3). For example, Slovenian investment per capita in R&D is 2.5 times that of Greece and 21 times that of the Former Yugoslav Republic of Macedonia.

Sectoral structures of R&D funding and performance differ significantly from employment structures, largely due to the lower capital intensity of R&D in higher education when compared to the business sector (Figures 4 and 5). This explains the relatively higher share of GERD spent in the business enterprise sector, the much lower share of the higher education sector and the relatively similar position of the government sector.

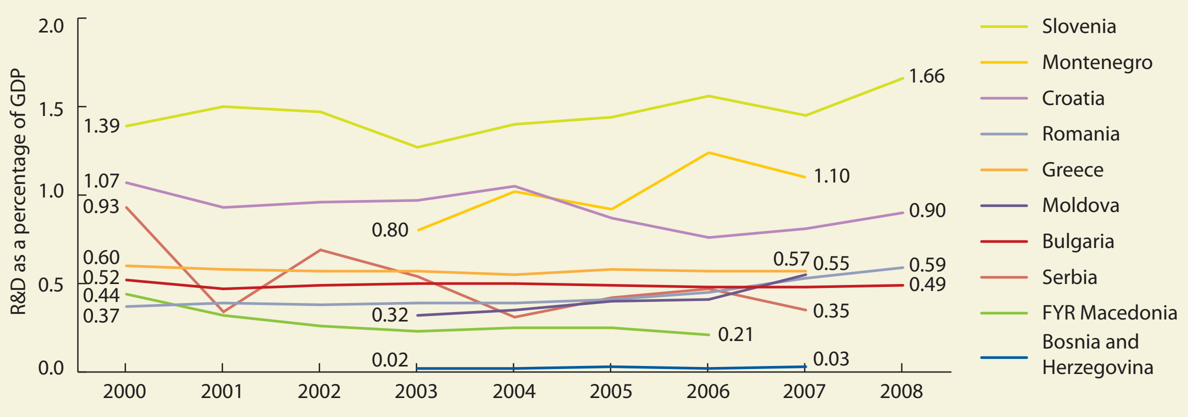
The main source of R&D funding in the sub-region is the government (Bulgaria, Croatia, Romania and Serbia) or a combination of government and foreign sources (Greece). Only in Slovenia is the business enterprise sector the dominant funder and performer of R&D, which is to be expected, given the relatively strong role of innovation and knowledge in Slovene growth. On the whole, the business sector enjoys limited support from government in most countries, as evidenced by the relative similarity of its shares in R&D funding and in performance. Only in Romania is the business sector heavily financed by government, where business accounts for 48.5% of R&D performed but only 30.4% of R&D funding. The higher education sectors in all Southeast European countries are also largely government-funded. With EU accession, the shares of foreign funding (primarily from the EU) are likely to increase in both Romania and Bulgaria.

The above structural features indicate a relatively slow transformation of R&D towards enterprise-based R&D systems. Yet, during the transition period and until recently, the trend was towards a stronger higher education sector. With continuing recovery and economic growth, we can expect the business enterprise sector to take on added importance.

Severe brain drain

As a consequence of poor demand for R&D, Albania, Bosnia and Herzegovina, Bulgaria, Moldova, Montenegro, Romania, Serbia and the Former Yugoslav Republic of Macedonia all suffer from severe brain drain. An assessment of the severity of this affliction ranks these countries at between 109th and 121st out of the 125 countries studied (WEF, 2007).

Figure 2: GERD/GDP ratio in Southeast Europe, 2000–2008 (%)

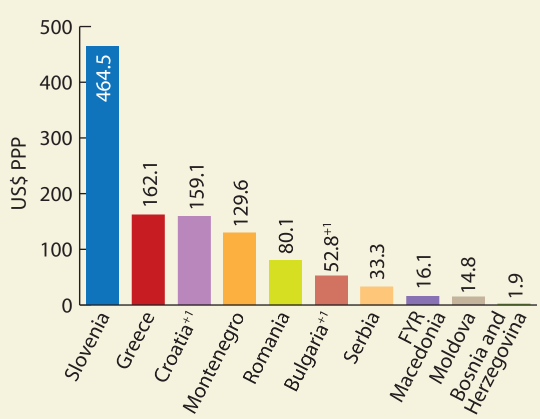


Source: UNESCO Institute for Statistics database, August 2010

Growing demand for education

In parallel, there is a growing demand for education, which is perceived as being the best way to avoid unemployment or increase one's chances of emigrating. Strong economic growth since 2000 has created more employment opportunities for the highly skilled. This has swollen the number of tertiary graduates at bachelor level in all but Bulgaria. One of the positive legacies of socialism is the high quality of mathematics and science teaching in schools, as evidenced by assessments in Croatia, Romania, Serbia and Montenegro (WEF, 2008).

Figure 3: GERD per capita in Southeast Europe, 2007



+*n* = data refer to *n* years after reference year

Source: UNESCO Institute for Statistics database, August 2010

In Romania, Serbia and the Former Yugoslav Republic of Macedonia, there has been a huge expansion in the number of undergraduates. Their number increased by between 95% and 287% over 2002–2008. There has also been a stark increase in the number of master's degrees and PhDs awarded in the region (Figure 6).

Declining or stagnant numbers of researchers in Croatia, Moldova, Romania and the Former Yugoslav Republic of Macedonia suggest a shrinking demand for R&D. Despite economic growth, the R&D systems of these countries have actually downsized, while others have remained stable or progressed (Figure 7).

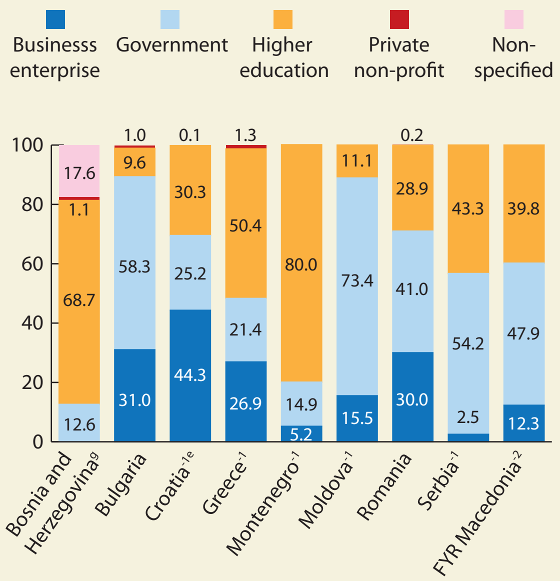
Systemic change in R&D

A decreasing demand for R&D accompanied by a growing number of tertiary graduates suggests that Southeast European economies are facing significant structural changes in terms of the demand for knowledge. Once very focused on R&D, demand for knowledge is becoming non-R&D-based.

In addition, formerly extramural-based R&D systems are experiencing difficulties in adjusting to an enterprise-based R&D system. As in other countries at a similar level of development, R&D systems in the sub-region are either dominated by the government sector or by the higher education sector (Figure 8).

Slovenia is the only country where private industry is the biggest employer. In Slovenia, this reflects the country's

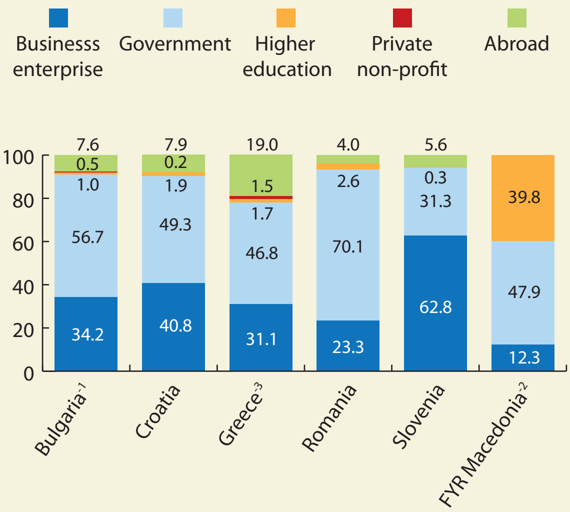
Figure 4: GERD in Southeast Europe by perfoming sector, 2008 (%)



-n = data refer to *n* years before reference year
g = underestimated or partial data e = estimation

Source: UNESCO Institute for Statistics database, August 2010

Figure 5: GERD in Southeast Europe by source of funds, 2008 (%)
Selected countries



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

Source: UNESCO Institute for Statistics database, August 2010

high level of development and the increasing role of knowledge in ensuring the competitiveness of industry. It is alos the case in Romania but this was much more a reflection of the unrestructured network of former industrial institutes that still operate under state ownership to the detriment of the development of in-house R&D.

Countries in Southeast Europe do, however, have some trends in common. Between 2001 and 2006, there was a relative rise in employment in the higher education sector in all but Slovenia and a drop in employment in the government sector in all but Romania.

The shift towards higher education is symptomatic both of the neglect of university R&D in the past and of better financial opportunities for universities, enabling them to combine R&D and teaching.

Growth in employment in the private sector has been observed in all but Croatia, Serbia and Romania but remains modest in all but Greece and Slovenia.

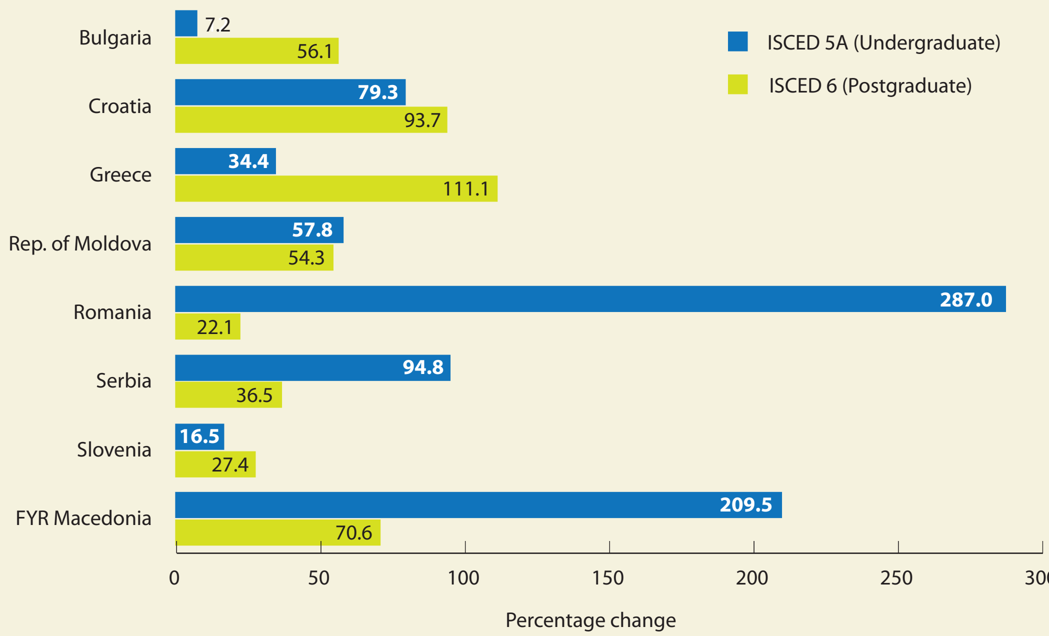
R&D OUTPUT

Publications and patents

The current performance of R&D in Southeast Europe is strongly linked to investment per capita and to the overall level of development. Trade in licenses is a useful indicator for measuring performance, in that it not only shows the degree to which countries are involved in exchanging knowledge but also relates to both the size of R&D systems and to the technological level of industry.

Slovenia, Croatia and Greece are far more involved in this type of exchange than their neighbours (Table 2). These three countries are also the biggest contributors in the region to world S&T in terms of three important indicators: the number of papers published per capita, the number of US patents obtained per capita and the amount received per capita in royalty payments and receipts. In this context, university–industry linkages are the most developed in Slovenia and Croatia. That this is not the case in Greece is largely due to the low technological level of Greece's industry.

Figure 6: Growth in numbers of tertiary graduates in Southeast Europe, 2002–2008 (%)



Note: For Greece, the period covered for undergraduates is 2002–2007, for Romania, it is 2004–2008 for graduates.

Source: UNESCO Institute for Statistics database, August 2010

Published scientific papers are not only a key output of a country's science system; they also indicate the degree to which the country is integrated in the international scientific community. In this respect, Greece stands out in the region in terms of the overall number of published scientific articles, with three to four times as many as any other country in the sub-region (Table 3). That said, the most developed science system in the sub-region is that of Slovenia, as evidenced by the number of scientific papers published per capita (Figure 9). Bulgaria, Croatia, Romania and Serbia are all intermediate countries. As for Albania, Moldova, Montenegro and the Former Yugoslav Republic of Macedonia, they all have relatively undeveloped science systems.

Science in Southeast Europe is dominated by four broad disciplines: physics, engineering/technology, chemistry and clinical medicine (Figure 10). In all but Albania, these four areas account for from 56% (Croatia) to 89% (Moldova) of all scientific publications. There was no significant evolution in the relative specialization of published scientific texts between 2002 and 2008, according to Science Citation Index data.

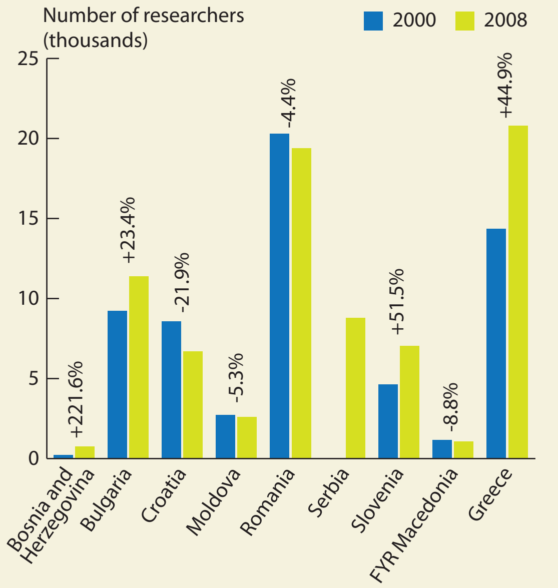
COUNTRY PROFILES

As we have seen above, the combination of weak demand for local R&D and innovation, on the one hand, and poor support systems for science and innovation, on the other, are the biggest bottlenecks to more effectively harnessing S&T to socio-economic growth in Southeast Europe.

Constraints on the demand side are further reinforced by constraints on supply, embodied by persistently strong external and internal brain drain coupled with an ageing pool of researchers. This portrait applies mainly to those countries in the Western Balkans[1] and to Moldova – the very same countries that are yet to become EU members and which face uncertain prospects for future EU membership.

Whereas the EU members from Southeast Europe share their neighbours' weakness on the demand side, they are generally in a much better position when it comes to their support systems for science and innovation (Slovenia and Greece) and the opportunities at their door for greater R&D funding and better S&T governance (Romania and Bulgaria).

Figure 7: Growth in researchers (FTE) in Southeast Europe, 2002 and 2008 (%)



Note: For Bosnia and Herzegovina and Romania, the period covered is 2003–2007, for FYR Macedonia 2002–2006 and for Greece 2001–2007.

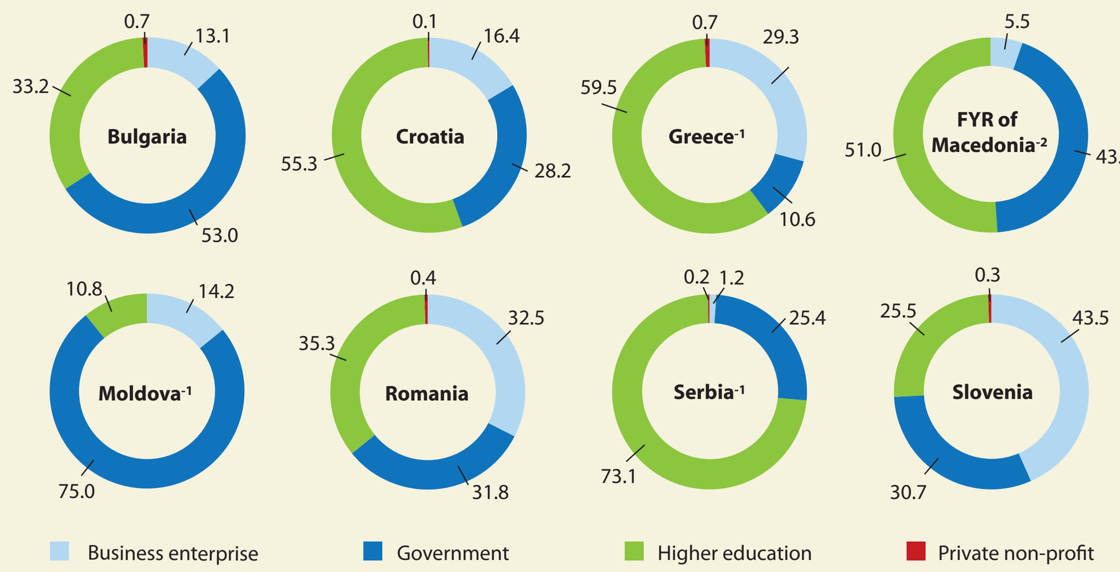
Source: UNESCO Institute for Statistics database, August 2010

A review of changes in individual countries reveals yawning differences in the degree of development and pace of restructuring of R&D systems, not to mention S&T governance (Nechifor and Radosevic, 2007). The R&D systems of Albania, Montenegro and Bosnia and Herzegovina – and to some extent the Former Yugoslav Republic of Macedonia – are the most disadvantaged. These countries are still striving to establish functioning R&D systems and are primarily addressing issues of science policy. Moldova is a specific case of a post-Soviet R&D system that has not reformed substantially. Bulgaria, Croatia and Romania have R&D systems at similar levels of development. In these three countries, there is a visible attempt to shift the focus from a narrow science policy to an innovation policy, or to integrate science into innovation policy.

As new EU members, Romania and Bulgaria have begun instigating vigorous changes that include introducing new sources of funding and internationalizing R&D. This should result in a substantial reform of their R&D systems in the medium term.

1. The Western Balkans encompass Albania, Bosnia and Herzegovina, Croatia, Former Yugoslav Republic of Macedonia, Montenegro and Serbia.

Figure 8: Researchers (FTE) in Southeast Europe by sector of employment, 2008 (%)



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

Source: UNESCO Institute for Statistics database, August 2010

Table 2: R&D output in Southeast Europe, 2006
In terms of patents, publications and royalty payments

	Total royalty payments and receipts (US$ per capita) 2006	University–company research collaboration (scale of 1–7) 2007	Patents granted by USPTO (per million population) annual average 2002–2006
Albania	2.39	1.7	0
Bulgaria	10.38	2.7	0.74
Bosnia and Herzegovina	–	2.4	0.10
Croatia	50.02	3.6	2.45
Greece 42.53		2.9	1.87
FYR Macedonia	6.64	2.9	0.10
Moldova	1.48	2.3	0.33
Romania	10.22	2.7	0.34
Serbia	–	3.1	–
Slovenia	85.62	3.8	9.40

Source: World Bank, Knowledge for Development, KAM database, http://go.worldbank.org/JGAO5XE940, March 2009

In view of its R&D capacities, Serbia should also be in this group. However, owing to its international isolation in the 1990s, accompanied by a dire economic situation, Serbia is trailing behind in terms of change, especially when it comes to gearing its science system towards innovation.

Although the structure of industry differs greatly in Slovenia and Greece, both of these countries have well-established frameworks for science and innovation governance. We shall begin with them in the following country analyses before moving on to the two other EU member states then the countries of the former Yugoslavia, before concluding with Albania and Moldova.

Slovenia

The Slovenian R&D system managed to elude a post-socialist crisis in the 1990s. Since joining the EU, Slovenia's research system has been developing well. Business sector investment in R&D is growing, even as public expenditure remains stable as a percentage of GDP. In terms of scientific output, indicators such as publishing and citation rates for scientific articles and the impact factor all show a strong progression, while the overall system continues to internationalize. In parallel, the inclusion of various measures supporting R&D and innovation in the EU's structural assistance programmes within the EU's Seventh Framework Programme for Research and Technological Development (FP7, 2007–2013) is providing the necessary stability for public investment in R&D (*see page* 172).

The government has used EU funds to implement two operational programmes. The first is Slovenia's Operational Programme for Strengthening Regional Development Potential. This focuses on improving the competitiveness of the country's enterprises and its research excellence, and promoting entrepreneurship and infrastructure for economic development, with a total investment of €558.71 million. The second is the Operational Programme for the Development of Human Resources. This programme benefits from a fund of €39.54 million to foster entrepreneurship among experts and researchers and to promote their adaptability to the world of corporate competitiveness. These two operational programmes complement the Programme of Measures and provide the basis for effective implementation of a national policy to encourage entrepreneurship and competitiveness, as well as the efficient use of resources from structural funds.

Although business R&D is developing relatively well, linkages with the public sector remain weak. In 2006, for example, only 10.1% of public R&D funds went to the business sector, a decline of approximately 20% since the turn of the century. This trend suggests that demand for business knowledge is best met by the business sector's own R&D capacities and that public research should keep to its own areas of interest (ERAWATCH, 2008).

Measures designed to stimulate private investment in R&D include a corporate income tax subsidy, various means of co-financing R&D projects, subsidized loans for R&D investment, co-financing of the services that technology parks offer the business sector, development of business incubators and mobility schemes, and support for technology centres and platforms. One policy measure to improve the quality of research is the establishment of centres of excellence. The government has supported the establishment of 10 such centres, providing a new form of co-operation between business and public research.

Greece

The Greek science system operates in an economic environment with limited demand for R&D, due to an industrial structure dominated by traditional business

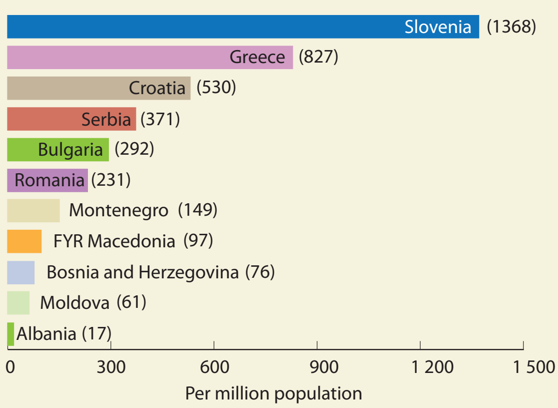
Table 3: Scientific publications in Southeast Europe, 2002 and 2008

	2002	2008	change (%)
Albania	35	52	48.6
Bosnia and Herzegovina	35	287	720.0
Bulgaria	1 528	2 227	45.7
Croatia	1 254	2 348	87.2
Greece	5 588	9 296	66.4
FYR Macedonia	104	197	89.4
Moldova	160	223	39.4
Montenegro	–	93	–
Romania	2 127	4 975	133.9
Serbia*	1 003	2 729	172.1
Slovenia	1 609	2 766	71.9

* Serbia includes Montenegro for 2002.

Source: Thomson Reuters (Scientific) Inc. Web of Science, (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

Figure 9: Scientific papers per million population in Southeast Europe, 2008



Source: Thomson Reuters (Scientific) Inc. Web of Science. (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies. Population data from Eurostat and World Bank, March 2009

activities and small and medium-sized enterprises. Even though Greece has developed an R&D-oriented innovation policy, the non-R&D-intensive structure of its industry is limiting the policy's impact on the economy and employment (PRO-Inno Trendchart, 2007).

Business R&D is not only stagnant but also negligible, despite persistent efforts to reorient firms towards R&D and other knowledge-intensive activities. Most of these efforts have been undertaken within the EU's structural assistance programme for competitiveness and entrepreneurship, and the five regional programmes covering the 13 regions of Greece. Thematic priorities include information and communication technologies (ICTs), agriculture, fisheries, food science and biotechnology.

Greece has set itself a target of devoting 1.5% of GDP to GERD by 2015. This is ambitious, given that Greece's GERD/GDP ratio has been a steady 0.6% since the turn of the century. The EU contribution to this effort amounts to €1 291 million. Nearly half of these EU funds (46.5%) are channelled into areas related to innovation: innovative investments; R&D activities and infrastructure; the provision of advanced services to firms and entrepreneurship; and strengthening linkages between R&D units and small and medium-sized enterprises. However, faced with limited local demand, R&D-intensive firms have reoriented themselves towards EU funding or foreign markets.

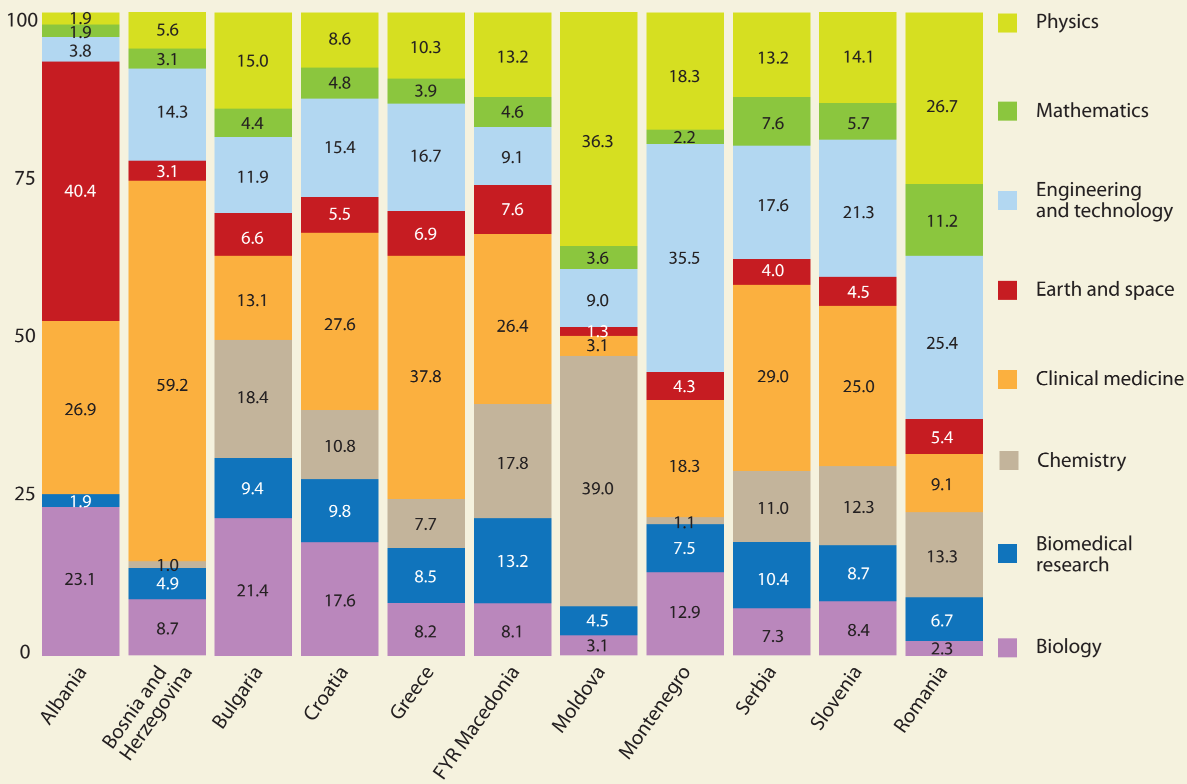
In parallel, the education system in Greece remains unreformed and slow to meet new demands, despite having expanded considerably. This is because any form of evaluation of the education system or accountability was rejected for many years. Without feedback from the labour market, teaching methods and curricula have remained based on centrally selected manuals. There is an ongoing debate about possible reforms, mainly in universities. A reform law re-regulating administrative issues has begun a very slow and controversial process of implementation.

Romania

The Romanian R&D system has emerged from its own 'transition crisis' and is now recovering, especially since Romania gained EU membership in 2007 (*see page* 172). There has been some growth in public R&D expenditure, up from 0.37% in 2000 to 0.46% in 2006, as part of the government's commitment to meeting the 3% target of the Lisbon Strategy (Box 1).

The need to converge towards EU norms and practices has strongly influenced science and innovation policy in Romania. The decision-making system has been

Figure 10: Publications in Southeast Europe by major field of science, 2008 (%)



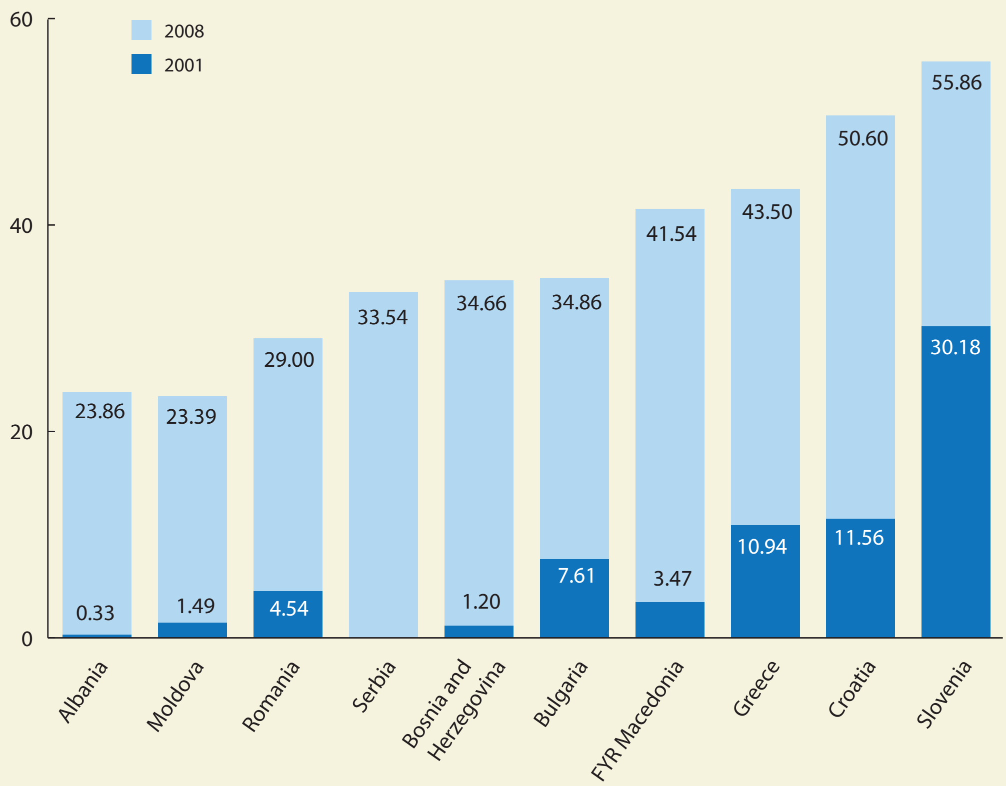
Source: Thomson Reuters (Scientific) Inc. Web of Science, (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

decentralized, funding systems have diversified and become more flexible, there has been a gradual increase in domestic competition-based funding, and the country's first *National R&D and Innovation Plan* has rewarded and assisted outstanding R&D groups.

Romania's second *National R&D and Innovation Plan* (2007–2013) contains strong provisions for investment in research, highly consistent with the priorities of the EU Seventh Framework Programme. The priorities of the *Plan* reflect the results of the first Romanian foresight exercise in S&T. As part of this exercise, a broad Delphi survey was employed in which over 3500 experts identified in the first phase of the project were consulted in two rounds. As a result of the survey, nine priority domains were identified as having substantial potential for socio-economic progress and the second plan was built around them. These nine priority domains are: ICTs, energy, environment, agriculture, food safety and security, biotechnologies, innovative materials, processes and products, space and security, and socio-economic and humanistic systems. Each of the nine domains comprises several priority themes.

Within the framework of the second plan, competitive bidding for five of the six programmes was organized in 2007 and 2008. A better utilization of resources is expected in the years to come, through support for research programmes directed more towards satisfying demand from the public and private sectors. Stricter norms have

Figure 11: Internet users per 100 population in Southeast Europe, 2001 and 2008



Source: United Nations Statistical Division, Milliennium Development Goals Indicators

also been introduced in the second plan for evaluation and quality control during a project's life-cycle.

On the downside, international co-operation in R&D remains very weak in Romania, a situation exacerbated by the paltry demand for R&D from the business sector. Infrastructure for science-oriented innovation also remains underdeveloped but it is expected that, through EU-support programmes, this situation will turn around. The benefit of improvements to the public R&D system may be limited unless business R&D expands and takes on new orientations. Accession to the EU has certainly had a positive impact on the mobility of students. In the long term, this should provide Romania with more highly skilled employees and improve the absorptive capacity of firms.

Bulgaria

The Bulgarian research system bears similarities to that of Romania. For one thing, it is emerging from a prolonged period of downsizing, restructuring and meagre investment in R&D. The country's EU accession has promoted a large spectrum of institutional changes in the governance of science and innovation.

The National Innovation Fund within the Ministry of Economy and Energy has become the primary public financial instrument for implementation of Bulgaria's National Innovation Strategy. The Ministry has also approved the creation of several Centres of Entrepreneurship within Bulgarian Technical Universities. An important step towards developing innovation in

Box 1: The Lisbon Strategy's elusive 3% target

When the European Council met in Lisbon in March 2000, the Heads of State and Government assigned to the EU the objective of becoming, by 2010, 'the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion' (Lisbon European Council, 2000). Two years later in Barcelona, they fixed a target for each country of devoting 3% of GDP to R&D by 2010. It was proposed that two-thirds of this share (2% of GDP) come from the private sector. Non-EU members are not bound by these ambitious goals.

Of the four EU members from Southeast Europe, only Slovenia stands a chance of achieving the Lisbon goals, particularly that for private-sector investment in R&D.

However, many 'older' EU members are also struggling to attain the elusive Eldorado. In 2008, just two European countries exceeded the 3% target – Sweden and Finland – and the average for the 27-member European Union was 1.8%.

Source: author

For details of the situation in the EU, see page 166.

Bulgaria is the implementation of the European PHARE project focusing on the cluster approach and establishing the cluster model.

Each individual ministry has a plan to shape and implement sectoral research policies but there is no national co-ordination body. As a result, synchronizing sectoral policies and achieving synergy is proving problematic. Another weakness of the innovation system is the lack of well-developed public–private partnerships.

The government has recently introduced incentives for private financing of R&D through the establishment of the National Innovation Fund (NIF) and National Science Fund (NSF). These funds introduce competitive bidding for up to 50% of R&D project funding.

In parallel, the state has committed to increasing public spending on research and innovation: the annual NSF budget for 2008 nearly quadrupled to roughly €32 million over the previous year. Although the share of the competitive funding provided by the NSF and NIF remains low, it still allows funds to be allocated to the best proposals. Other strong points are that the NSF projects are evaluated by international experts and that, since 2007, 30% of grants can be used for additional remuneration of any young researchers who have participated in the preparation of a project proposal.

It should be noted, however, that these two funds would need to be substantially bigger to have an impact on R&D and innovation. The government would be wise to reallocate part of the current institutional funding to these competitive funds.

Long-term research funding is highly dependent on European funding, notably via the EU structural funds (*see page* 173). EU membership is also providing Romanian researchers with greater access to knowledge. However, links are still missing between innovative Romanian enterprises and the bulk of the R&D system (Ruslanov, 2007). The country's support system for science-oriented innovation remains undeveloped.

Croatia

The Croatian R&D system is strongly oriented towards research in the public sector. This helped to preserve and maintain the national science base during the 1990s but also led to neglect of the private sector. As a result, the private sector's technological capacities are weak, generating a limited demand for local R&D. Support for science-oriented innovation is currently being developed through five technology centres and the Croatian Institute of Technology (Svarc and Becic, 2007). This dynamic will most likely be pursued, with expected accession to the EU in the next few years.

However, the scope of innovation policy is confined to infrastructural support for the commercialization of private R&D results. There is a need to broaden this framework and to foster co-operation between public science and private industry.

Serbia

Serbia made only cosmetic changes to its R&D system during the 1990s. The country's R&D system has transformed itself gradually by diversifying sources of income and activities, by closing R&D institutions and by reducing reliance on domestic R&D activities. This 'silent transition' (Kutlaca, 2007) has been accompanied by brain drain and an absence of middle-aged researchers.

Since 2003, Serbia has begun establishing a support system for science-oriented innovation through technology incubators, innovation centres and science and technology parks. The downsized business sector remains in crisis, however, pending changes in ownership and larger inflows of foreign direct investment. The opportunity for Serbia to participate in EU Framework Programmes for R&D will most likely prove beneficial for the country's R&D system.

Former Yugoslav Republic of Macedonia

The Former Yugoslav Republic of Macedonia has begun modernizing its science system and is in the process of preparing a national science policy. In 2005, it initiated this reform by introducing a new system of project evaluation. A year later, the government approved the national Programme for the Development of Scientific Research Activities for the period 2006–2010, the first official programme adopted by the government relating to developing the country's R&D capacities.

Bosnia and Herzegovina

More than a decade after the inter-ethnic war following the break-up of Yugoslavia, Bosnia and Herzegovina has not yet established its own R&D system. Current investment in R&D is estimated to be between 0.05% and 0.15% of GDP (Matic, 2007; Papon and Pejovnik, 2007). The division of political and administrative responsibilities among the three levels of government[2] makes it very difficult to define and implement country-level science policy.

For many years, the country remained isolated in terms of access to EU R&D funding and other co-operation agreements. This was partly due to its inability to operate as a single entity in international relations. This changed on 1 January 2009 when Bosnia and Herzegovina became an 'associated country' with respect to the EU Seventh Framework Programe. This new status will, at last, enable the country to access the international R&D community; it is also an important incentive to overcome internal fragmentation.

2. Inherited from the General Framework Agreement for Peace in Bosnia and Herzegovina, signed in 1995

Montenegro

Four years after gaining independence from Serbia in May 2006, Montenegro is in the process of establishing its own science system and science policy. The country's S&T system consists of the Montenegrin Academy of Sciences and Arts (founded in 1973) and the University of Montenegro (founded in 1974). The university comprises 14 faculties and one college, with 1 000 students, and incoroprates four scientific research institutes.

Albania

Public investment in R&D is less than 0.18% of GDP in Albania and there is little business R&D to speak of (Sulstarova, 2007). Brain drain strongly undermines the rejuvenation of the country's R&D system.

Albania initiated a reform in 2005 by creating a single system of scientific research, concentrated in universities. In 2007, 14 of the institutes attached to the Academy of Sciences were subsumed into universities.

Since 2008, the Albanian government has initiated a range of policy measures. In June 2009, it published a *Cross-cutting Strategy for Science, Technology and Innovation in Albania*. This identifies five 'strategic goals' for the country to 2015:

- to triple public spending on research to 0.6% of GDP;
- to increase the share of GERD from foreign sources to 40% of the total, including via the EU's Framework Programmes for Research and Technological Development;
- to create four or five Albanian centres of excellence in science;
- to double the number of researchers through 'brain gain' incentives like a Young and Returning Researchers grant scheme and the training of new researchers, including 500 PhDs: three new doctoral programmes are to be established in Albanian universities;
- to increase innovation in 100 companies through investment in local R&D, or via consortia with either academic research institutes or foreign partners.

The *Cross-cutting Strategy* is to be implemented in synergy with the *National Strategy for Development and Integration* (2007–2013) and other sectoral strategies, including Albania's *Higher Education Strategy* (2008).

Box 2: The Venice Process

Since 2001, the Venice Process has been rebuilding scientific co-operation among Southeast European countries. The goal is to encourage countries to share limited resources and to heal the scars of a decade of political and socio-economic turmoil. In parallel, the process sets out to build scientific co-operation between the sub-region and the rest of Europe, in order to prepare countries for integration into the European Research Area.

The process was officially launched at the Venice Conference of Experts on Rebuilding Scientific Co-operation in Southeastern Europe, on 24–27 March 2001. Seven months later, the recommendations adopted by the conference met with the unanimous approval of the ministers responsible for science and technology from the countries concerned, at a roundtable organized during UNESCO's General Conference. Also attending the roundtable were numerous countries from the EU and several non-governmental organizations.

The Venice Process is named after the host city of UNESCO's Regional Bureau for Science and Culture in Europe (BRESCE). Since 2002, UNESCO's Venice office has provided science policy advice and expertise to Southeast European countries, in order to raise awareness of the importance of investing in S&T for national and regional development. In addition to gathering ministers and other high-level decision-makers together on issues related to STI governance, BRESCE has contributed to the elaboration of national STI strategies in Bosnia and Herzegovina and in Albania.

Moreover, the Venice office has provided financial support and organized programmes to encourage regional networking in life sciences, environmental sciences and astronomy as a means of tackling brain drain, supporting communication services and strengthening scientific co-operation as a tool for reconciliation and dialogue.

Four new Southeast European networks

In 2003, Prof. Alexander Boksenberg of Cambridge University (UK) undertook an expert mission to the main centres of astronomy in the region on behalf of UNESCO. This resulted in a programme entitled Enhancing Astronomical Research and Observation in Southeast Europe and Ukraine, with financial support from the Italian government. Within this programme, the most important telescope in Southeast Europe was upgraded with financial support from BRESCE. Today, the Astronomical Observatory of Rozhen in Bulgaria which hosts the telescope has become a major research facility shared by researchers throughout the sub-region.

A Southeast European Astronomical Research Network has also been created with statutes drafted by its members. The network has since established a co-ordination mechanism for astronomical research, the Sub-regional European Astronomical Committee, which has a rotating presidency and secretariat. A large number of astronomical events in the region have been organized within this framework, some of which have benefited from financial support from UNESCO's Venice office.

Galvanized by this success story, the Venice office has gone on to support the creation of a Human Genetics and Biotechnology Network, which met for the first time in March 2006 at the Research Centre for Genetic Engineering and Biotechnology in Skopje (Bulgaria).

The Venice office also spear-headed the establishment, in 2007, of a sub-regional network for Risk Assessment and Mitigation, co-ordinated by the Institute of Geodynamics in Athens and a sub-regional Mathematical and Theoretical Physics Network, hosted by the Faculty of Science and Mathematics at the University of Niš in Serbia.

The GRID computing project

UNESCO's GRID project is sponsored by the Hewlett Packard company. Since 2004, it has helped to combat brain drain and facilitate networking by donating GRID computing technology to seven universities in Southeast Europe. This has enabled students to collaborate on research projects with their peers worldwide without having to leave their home institution. Seed money provided by the project has also given students the opportunity to participate in short exchanges with universities abroad.

Source: UNESCO

Also in 2009, Albania launched its first survey of R&D statistics, including business R&D and innovation, with the support of UNESCO.

Moldova

Moldova is the only post-Soviet country in Southeast Europe. Its R&D system continues to be organized around the Academy of Sciences. Investment in R&D has continued its downward spiral, dropping to 0.4% in 2004 from 0.6% in 2000. Between 2000 and 2004, employment of research scientists and engineers declined by 5%. Mass emigration accompanied by brain drain is hindering domestic innovation and entrepreneurship.

INTERNATIONAL CO-OPERATION

The violent break-up of Yugoslavia in the 1990s threw most of the Western Balkan countries into isolation for the greater part of the decade, including in terms of international scientific co-operation. The first decade of the 21st century marks a new era, one in which science systems of Western Balkan countries are being rebuilt and reconnecting to the R&D networks of the EU. The process is still painfully slow. It is being hindered not only by external factors like EU policies but, to an even greater extent, by the lack of a national consensus on the need to base economic growth on science-oriented innovation.

Since 2000, UNESCO has been leading initiatives to improve co-operation in the region, within what has come to be known as the Venice Process (Box 2). This process has since been followed by various EU initiatives such as the Southeast European ERA-NET, a horizontal network that aims to structure and expand the European Research Area to the Western Balkan countries. Strengthening the relationship between the EU and the Western Balkan countries, including Moldova, is the most effective way to overcome their isolation and give them greater access to international R&D networks.

In addition, international co-operation may further improve with the integration since 2007 of the Western Balkan countries into the EU Seventh Framework Programme for Research and Technological Development (FP7). The FP7 is now the single biggest source of foreign R&D funding for Western Balkan countries and represents a major opportunity for them to introduce the notion of excellence into evaluation criteria.

Beyond Europe, the major partner for individual countries in Southeast Europe is the USA, through bilateral co-operation. There is of course also considerable scope for intra-regional bilateral co-operation, one of the goals of the Venice Process. This bilateral co-operation within Southeast Europe should include not only bilateral projects but also fellowships, information services and joint refereeing systems.

Box 3: Measuring implementation of the *Science Agenda*

Where does Southeast Europe stand in relation to the *Science Agenda*, the document adopted by governments on 1 July 1999 at the World Conference on Science organized by UNESCO and the International Council for Science?

One of the *Science Agenda's* 90 recommendations was for countries to devote a greater share of GDP to R&D. In most of Southeast Europe, there is the political will to do just this. In the four EU member states from the region, a range of measures have been taken which point in the right direction. Among the three most recent EU members – Bulgaria, Romania and Slovenia – there is also a trend towards a diversification of funding sources for R&D.

Most countries from the region are increasing support for university–industry partnerships as a way of enhancing science-oriented innovation, another recommendation of the *Science Agenda*. However, the experiences of those countries that are ahead in this area, including Greece, indicate that this is a slow process hampered by a lack of domestic demand.

Another recommendation advocates a greater mobility of professionals between universities and industry, and between countries, as well as through research networks and inter-firm partnerships. In Southeast Europe, the level of support for professional mobility varies widely.

The biggest weakness in the region remains an insufficient focus on institutions of higher learning in the fields of engineering, technological and vocational education, not to mention lifelong learning.

Source: author

For details of the *Science Agenda*: UNESCO (1999)

CONCLUSION

The diversity of Southeast Europe is both a massive obstacle (such as in terms of competitiveness) and an asset for intra-regional integration and integration with the EU.

Countries also have points in common. Demand for R&D tends to be weaker than supply, with the notable exception of Slovenia. Even supply is hampered by continuing severe external brain drain.

In those countries with functioning R&D systems, namely Bulgaria, Croatia, Romania and Serbia, there is a need to broaden the focus of science and innovation policy and to link public R&D to the countries' industrial, agricultural and health care sectors. These countries also need to make better use of international assistance to integrate R&D into the European Research Area and to facilitate linkages between the EU and domestic systems of innovation.

There has been some limited progress in integrating the Western Balkan countries into the European Research Area. International stakeholders are aware of the need to support S&T to facilitate this integration and ensure long-term growth. However, this will necessitate huge improvements in infrastructure and a restructuring of the countries' S&T systems.

The Western Balkan countries in particular cannot afford *not* to increase investment in R&D funding, even though the benefits are sometimes only seen in the long term. The alternative would be for them to fall farther behind the rest of Europe in terms of economic development. However, this increase should be accompanied by a strong focus on funding both excellence and locally relevant research. This will require fair competition, priority-setting, transparency and international criteria of excellence.

The 'Europeanization' of the region's R&D systems via EU research networks will serve to connect the research endeavours of countries in Southeast Europe with the best the EU can offer in terms of R&D teams. We can expect a better balance between incentives (selection through project funding) and stability (the share of institutional funding). However, the bottleneck caused by little domestic demand for R&D and a weak private sector in all but Slovenia is likely to remain a major structural weakness in Southeast European R&D systems for years to come.

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The challenge now will be to boost output from S&T and to transform R&D results into innovation and viable business opportunities for the benefit of both society and the economy.

Sirin Elçi

10 · Turkey

Sirin Elçi

INTRODUCTION

Turkey is a regional power bridging East and West. In recent years, it has experienced dynamic growth and rapid recovery from a severe economic crisis in 2001. Today, the Turkish economy is among the world's 20 largest, with GDP of over US$ 500 billion.

Turkey has a young population: 64% are under 34 years of age. Population growth is the highest among countries of the Organisation for Economic Co-operation and Development (OECD), the population having climbed from 53 million in 1986 to 73 million in 2006. Turkey also possesses a larger labour force than any of the 27 countries that make up the European Union, with an active population of over 24.7 million in 2007, according to the Turkish Investment Support and Promotion Agency. The population is very urbanized, with 67% of Turks living in towns or cities, according to the United Nations Statistical Division.

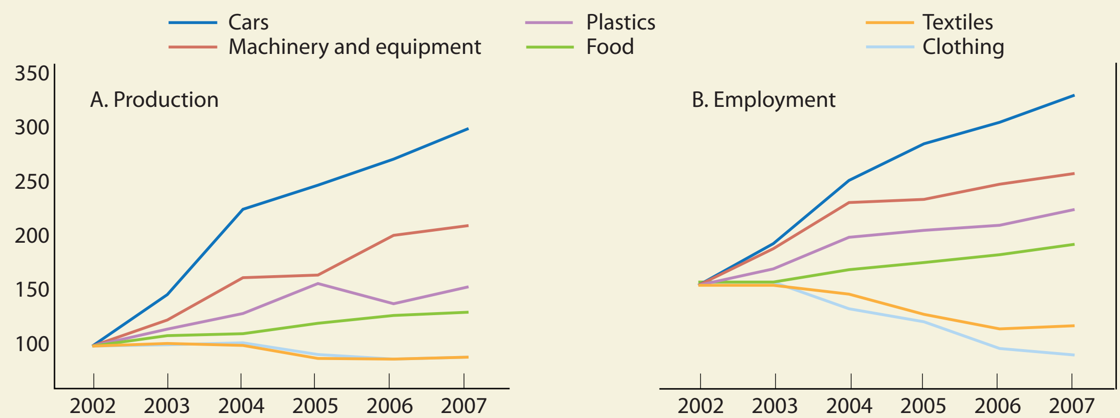
To spur recovery from the 2001 crisis, Turkey adopted structural reforms that included exchange-rate flotation, privatization, strengthening the administration of revenue, creating a better climate for investment and reforming both social security and the financial and energy sectors. These measures succeeded in regenerating growth and putting an end to chronic inflation. By 2007, GDP had grown to 5.1%, compared to -7.5% six years earlier. At 8.8% in 2007, inflation was at its lowest for almost 30 years. Although still lower than the rates of the past three decades, inflation did climb to 10.1% in 2008.

With average annual GDP growth of 4.2% between 1988 and 2007, Turkey ranked fifth among OECD economies by 2008 for this indicator. Estimated growth for 2008 is 3.4%, according to Eurostat. Improvements have also been observed in other indicators, such as in terms of labour productivity and the level of foreign direct investment (FDI).

The structural reforms have also strengthened the regulatory and supervisory role of the State in the economy by boosting the private sector's role. Since 2003, economic growth has been driven by the private sector, particularly in the automotive industry and the machinery and equipment sectors (Figure 1). Total exports doubled between 2005 and 2008, from US$65 billion to US$132 billion. Turkey's main export partners are Germany (11.2%), the UK (8.0%), Italy (7.0%), France (5.6%), Spain (4.3%) and the USA (3.9%), according to the Turkish Statistics Institute (Turkstat).

The economic upturn suddenly went into reverse in early 2009, as the impact of the global economic recession began making its presence felt. Turkish exports plummeted 35% in February alone over the same period the previous year, falling to US$6.87 billion, according to the Turkish Exporters Association. Although the

Figure 1: Economic performance of key industries in Turkey, 2002–2007
The starting point for the year 2002 is 100



Source: OECD (2008) *Economic Survey of Turkey*. Policy Brief. Accessible at: www.oecd.org/dataoecd/53/42/40988838.pdf

Satellite dishes on an Istanbul rooftop

Photo: © oneclearvision/ iStockphoto

automotive sector was also hit hard, it still managed to pocket export earnings of US$1.98 billion.

Second to Turkey's car industry is the iron and steel industry, with exports worth US$984 million. This is followed by the ready-to-wear clothing industry, with exports amounting to US$967 million. Among the early indicators of the recession, the number of new companies was down by 34.7% in February 2009 over the previous year, according to Turkstat, and unemployment was up from 9.7% in 2007 to 10.9% in 2008.

POLICY OBJECTIVES

Turkey has a long tradition of science and technology (S&T) policy-making. This dates back to the 1960s when this exercise was an integral part of development plans. The country also has a well-developed institutional framework. Since the turn of the century, Turkey has attached increasing importance to investment in science, technology and innovation (STI) for sustainable socio-economic development. The key milestones have been:

- The implementation of the *Vision 2023 Project* (2002–2004), a technology foresight study aimed at achieving the widest participation possible and greater commitment around a shared vision for the formulation of STI strategies for the next two decades.
- Full association with the Sixth Framework Programme of the European Union (EU) in 2003. Turkey provided this programme with €250 million, the largest contribution among the EU candidate countries; Turkey is expected to contribute €423.5 million to the current Seventh Framework Programme by the end of 2013.
- The launch in 2004 of the Turkish Research Area (TARAL) by the Supreme Council of Science and Technology (BTYK)[1] and identification of the main targets for science and technology (S&T).
- The approval by BTYK in 2005 of the five-year implementation plan for the *National Science and Technology Strategy (2005–2010)* and of the new priority areas of technology.

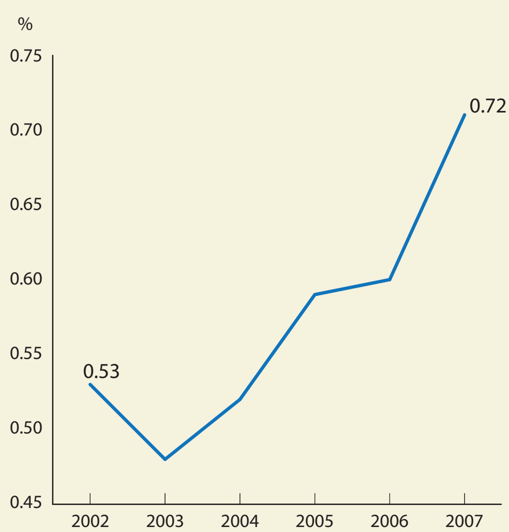
1. The Supreme Council of Science and Technology (BTYK) is the top policy co-ordination body for STI in Turkey. See also page 210.

The *Ninth Development Plan (2007–2013)*, issued in 2006, reflects Turkey's growing political commitment to S&T. The plan forms the basis for other national and regional plans and programmes and for the documents required by the EU for the accession process. It defines improving STI performance as one of the building blocks for greater competitiveness. The main policy objective of the *Medium-Term Programme (2008–2010)*, published by the State Planning Organization (SPO) of Turkey, is 'to become capable in STI and to transform this capability into economic and social value by enhancing the innovation skills of the private sector specifically' (SPO, 2007).

The basic objectives of the *National Science and Technology Strategy (2005–2010)* are to improve living standards, solve social problems, develop competitiveness and raise public awareness of S&T. This is to be achieved by stimulating demand for research and development (R&D), enhancing the quality and quantity of scientists, other professionals and technical personnel and increasing gross expenditure on R&D (GERD).

In line with these goals, two primary targets were fixed by BTYK in 2005. These targets were subsequently revised in 2008: the country's GERD/GDP ratio is to nearly quadruple from 0.53%[2] in 2002 to 2.0% by 2013, half of this share being funded by the private sector (Figure 2);

Figure 2: GERD/GDP ratio in Turkey, 2002–2007 (%)



*using new GDP series

Source: TÜBITAK 2009 (from the database of Turkstat) *secondly,* the number of full-time equivalent (FTE) research personnel is to be carried from 28 964 in 2002 to 150 000 by 2013 (Figure 3). The number of vocational and technical staff is also to be increased proportionally.

In 2005, BTYK also identified priority areas of technology for capacity-building, including the following:

- information and communication technologies (ICTs);
- biotechnology and genetic technologies;
- material technologies;
- nanotechnologies;
- design technologies;
- mechatronics;[3]
- production processes and technologies;
- energy and environmental technologies.

Thanks to a strong political commitment, public expenditure on S&T has taken off since 2005, with more than US$1.5 billion being allocated to the Scientific and Technological Research Council of Turkey (TÜBITAK) alone for R&D programmes in the period 2005–2008. This, along with other factors like economic growth, caused R&D expenditure to almost triple between 2002 and 2007 (Figure 4).

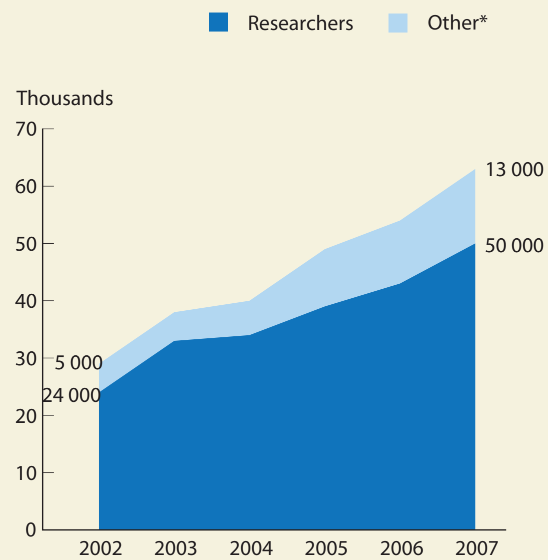
However, political commitment has been weaker when it comes to translating the technology foresight exercise, *Vision 2023*, into policy initiatives. No special effort has been made since 2005 to build capacity in the priority technology areas identified by BTYK in 2005. This is a policy challenge that the government will need to address.

It is important for Turkey to channel R&D resources strategically into priority technology fields rather than spreading them thinly across generic programmes. The priority areas identified by *Vision 2023* are fields in which Turkey recognizes the need to build critical knowledge and technological capacities for the next 20 years. The majority of the priority fields, such as nanotechnologies, ICTs and design technologies, are general-purpose technologies with numerous potential applications for productive sectors in Turkey. Thematic measures

2. In 2008, the GDP series were changed and Turkstat recalculated the GERD/GDP ratios. Using the new series, the 2002 ratio now stands at 0.53%, against 0.66% previously.

3. Mechatronic systems consist of mechanical, electronic and control components. Robots are the most common product but mechatronics can also be used to develop mind-controlled artificial limbs, (ecological) transport systems and so on.

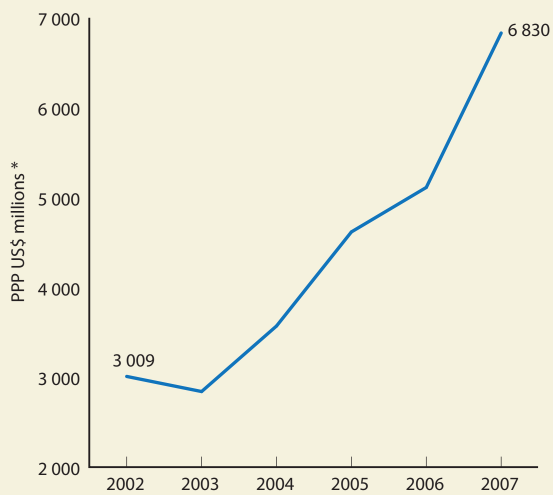
Figure 3: R&D personnel in Turkey, 2003 and 2007
Full-time equivalent



* includes administrative staff and technicians

Source: TÜBITAK 2009, from the database of Turkstat

Figure 4: GERD in Turkey, 2002–2007



* The corresponding amounts in Turkish lira for 2002 and 2007 are: 2 349 million and 6 091 million.

Source: OECD, Main Science and Technology Indicators database

– as opposed to generic ones – will be vital to boost STI in the priority areas identified for socio-economic development.

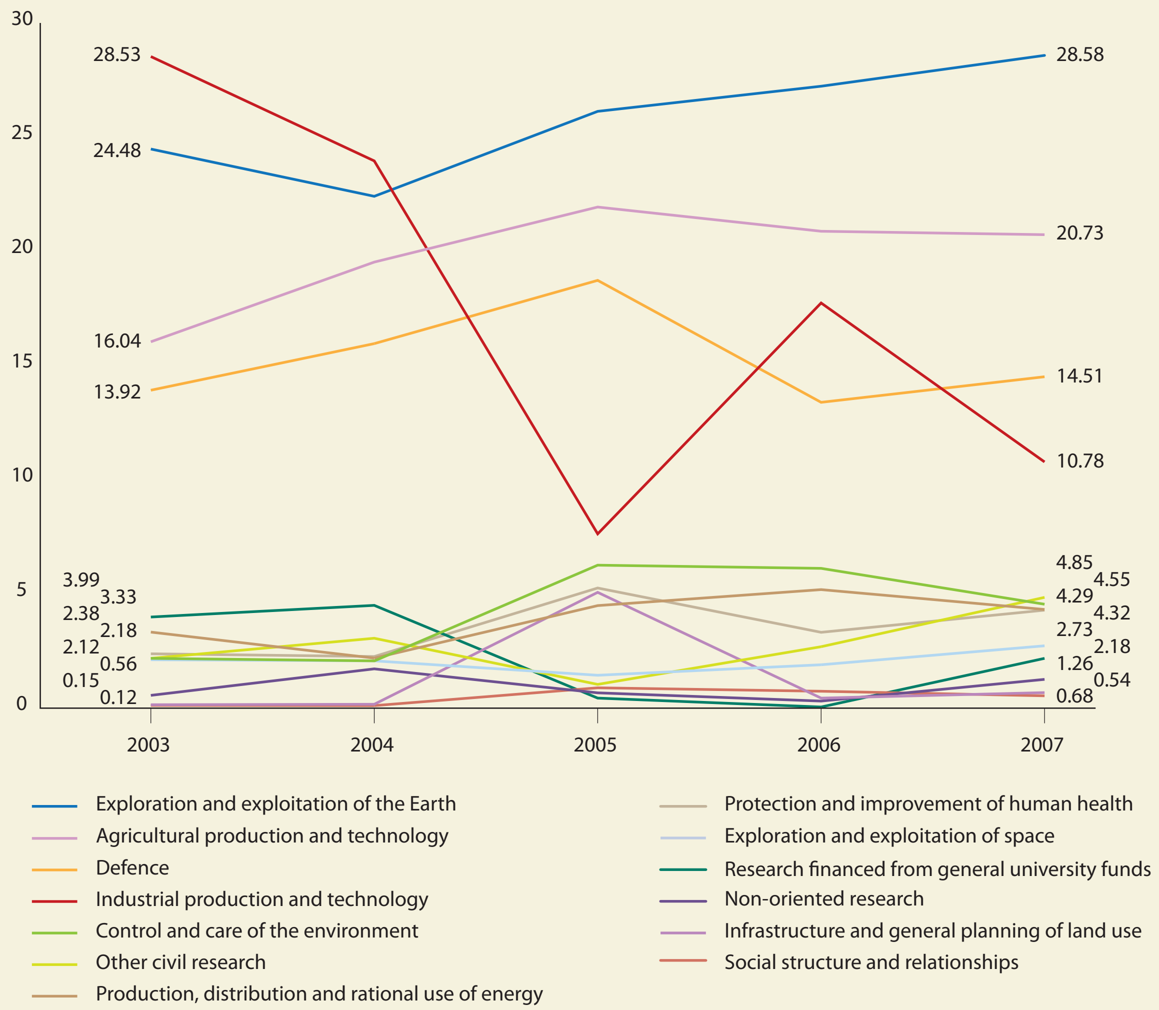
The need to invest in these priority areas is also evident from statistics on GERD in relation to Turkey's socio-economic objectives (Figure 5). For example, although energy and environmental technologies figure among the priority fields, between 2003 and 2007, government expenditure on R&D only increased from 2.2% to 4.6% for 'control and care of the environment' and from 3.3% to 4.3% for 'production, distribution and rational use of energy'.

R&D INPUT

R&D expenditure

Between 2003 and 2007, GERD more than doubled in Turkey, from US$ 2.8 billion (PPP) to US$6.8 billion (PPP). This growth rate is substantially higher than the EU-27 average (9%) and matched globally only by China. In terms of growth in R&D intensity, also known as the GERD/GDP ratio, Turkey ranks fourth in the world after China, South Africa and the Czech Republic for 2002–2007, according to TÜBITAK: R&D intensity grew by

Figure 5: Government expenditure on R&D in Turkey by socio-economic objective, 2003–2007 (%)

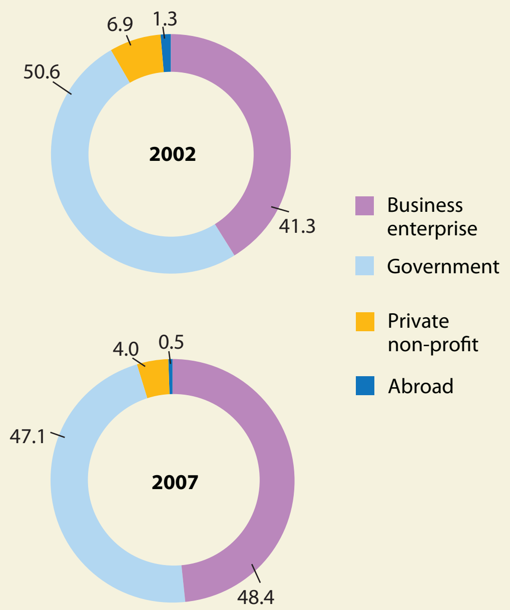


Source: Turkstat

34% in Turkey between 2002 and 2007, compared to 36% in the Czech Republic and 39% in South Africa. Turkey is no match for China, though, where R&D intensity grew by as much as 51% between 2002 and 2007. The GERD/GDP ratio in Turkey is expected to continue rising, despite the global economic recession.

Between 2004 and 2007, the share of business expenditure on R&D (BERD) in total spending climbed by nearly 60% in Turkey. The catalyst was a boost in public support for R&D in 2004, which saw BERD rise overnight to 34%. However, the share of higher education in R&D spending remains high and, even at 48%, Turkish BERD remains well below the OECD average of 69% (Figure 6).

Figure 6: GERD in Turkey by source of funds, 2002 and 2007 (%)



Source: UNESCO Institute for Statistics, June 2010

Enlarging the research pool

The government attaches great importance to boosting the numbers of R&D personnel, one of the key targets of the *National Science and Technology Strategy*, as we have seen above. At first glance, there has been a remarkable increase in both the numbers of FTE R&D personnel and FTE researchers, as seen in Figure 3. However, the main reason for the increase since 2003 is the change in the way Turkstat defines FTE R&D personnel and researchers in surveys.

In point of fact, as of 2006, the number of researchers per 1 000 members of the labour force remains low in Turkey (2.0), both by EU-27 standards (5.8) and in comparison with individual Eastern European countries like Poland (4.7) [World Bank, 2008].

In order to reach the ambitious target of 150 000 FTE research personnel by 2013, Turkey will need to devote more resources to tertiary education, swell university rolls and graduation rates and attract Turkish PhD students living abroad. Turkey devotes 1.1% of GDP to public spending on tertiary education; although this is comparable with many countries or better, it remains below the level of Scandinavian countries (World Bank, 2007). The number of Turkish PhD students who remain in the USA for five years or more is close to 60%, the fifth-largest proportion after China, India, Iran and Argentina (Box 1).

Enrollment rates in higher education are lower for Turkey than for most countries with similar or higher levels of income. Just 11% of Turks in the 25–34 year-old bracket have a tertiary degree, the lowest rate of any OECD country: the OECD average is 31%.

Furthermore, Turkey needs to increase enrollment and graduation rates among women. The gross enrollment ratio for female students in tertiary education in 2006 was 30%, compared to a regional average of 66% (UNESCO Institute for Statistics). Turkey had 5.7 new science and engineering graduates per 1 000 population in 2005, corresponding to 44% of the EU-27 average. This remains low but a positive trend is emerging: between 1995 and 2004, Turkey's average annual growth in R&D personnel was as high as Finland's and among the top three in the world, even though this was partially due to its much lower starting point (World Bank, 2008).

Building a science culture and a society open to STI calls for an education system capable of providing pupils with the requisite skills from an early age. To meet this challenge and that of developing a larger pool of researchers, the government has been implementing various measures since 2004; these range from revising primary and secondary curricula to measures designed to stimulate the international mobility of students and scientists (see for example Box 2).

Box 1: The Tale of a Turkish PhD Returnee

Dr Batu Erman was the 2008 winner of the prestigious European Marie Curie Excellence Award. He completed his PhD in the USA in 1998 before moving back to Turkey in 2004 to take up a post at Sabancı University in Istanbul. In the USA, he had been a postdoctoral fellow and research associate at the National Institutes of Health until 2004.

At 40, Dr Erman does not consider himself unique among the academics at Sabancı University: the average age is 43, over 85% received their PhD outside Turkey and over 45% have conducted postdoctoral research abroad in academia or industry. Nor does he consider Sabancı University unique in its ability to recruit a young generation of highly trained faculty members.

Dr Erman's laboratory at Sabancı University conducts basic research in immunology using techniques from molecular biology. In his laboratory, he works with some of the many 'young, enthusiastic, ambitious life scientists who are setting up shop in Turkish universities'. These young scientists choose to teach and conduct research in Turkey, not because this is a 'safe' choice but for the thrill of choosing a challenging alternative to staying in the USA after a postdoctoral fellowship.

Dr Erman is currently training six MSc students, two doctoral students and two postdoctoral scientists. He has also helped to organize an association of 15 molecular biologists from eight different universities in Istanbul, Ankara and Izmir. These scientists have all been trained at prestigious universities and institutes in the USA, Europe and Japan. All are in the same age group, all are eager to teach a new generation of life scientists and all have the 'pioneer spirit'. For Dr Erman, the members of this group are typical of the new generation of scientists who want to create a culture of conducting basic research in Turkey. He admits that this means tackling problems that may not exist in North America, Western Europe or Japan, in addition to the customary hardships associated with conducting research.

Dr Erman's Marie Curie Excellence Award was publicized in the mainstream media in Turkey as illustrating the success of a Turkish scientist. As a result, he was contacted by many non-scientists curious to know more about immunology, molecular biology and the research his team is conducting. According to Dr Erman, there may be limited job opportunities but, even so, Turkish society views a career in science as being 'cool'. He observes that there is a large pool of highly qualified, well educated, English-speaking, young researchers in the Turkish education system.

Source: Erman (2009)

R&D OUTPUT

Scientific publications on the rise

Since 2002, Turkey has been stepping up R&D output as well. The number of research publications continues to rise, from 15 403 in 2004 to 21 779 in 2007 (Figure 7). This is mainly due to the fact that a large portion of R&D is conducted at universities, which employ the majority of researchers, and to the increase in R&D funding. Turkey's ranking in journals covered by the Science Citation Index (SCI) has likewise improved, from 41st in 1990 to 19th in 2005. In the SCI, Turkey is most visible in clinical medicine, followed by engineering and technology (Figure 8).

A similar trend can be observed in patents. Patent Co-operation Treaty applications from Turkey have been growing since 2004 (Figure 9). In addition, domestic patent filings and grants rose more than four-fold from 2002 to 2007, according to the Turkish Patent Institute.

ENRICHING THE POLICY MIX

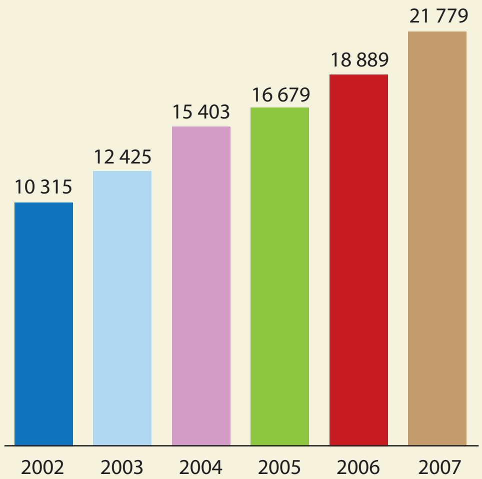
To support these positive trends, the government has been enriching the STI policy mix, particularly since late 2006. This policy mix now addresses a broad range of needs on the part of the research community and industry.

Overall, the existing policy mix focuses on five main categories: (1) raising expenditure on research and technological innovation in private enterprises, (2) intensifying co-operation on R&D projects between public or university research and private enterprises, (3) swelling the number of new innovation-intensive enterprises and their chances of survival, (4) increasing the rate of commercialization/marketing of the results of R&D conducted by public research bodies and the university sector (Elçi, 2008), and (5) developing human resources for S&T.

Generic government programmes to support R&D

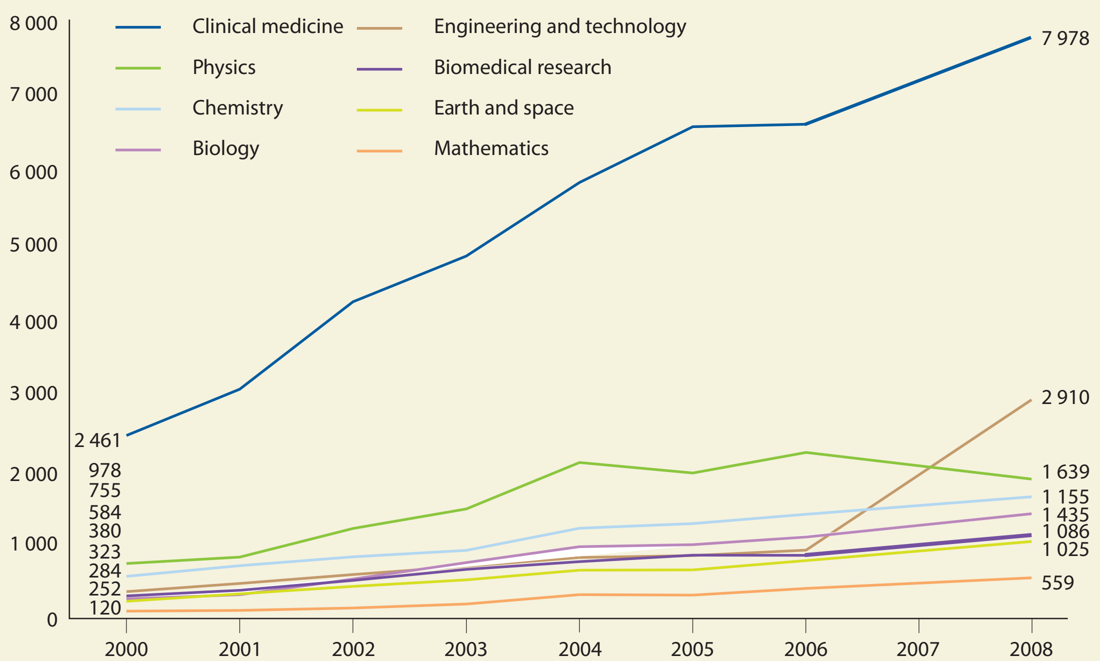
In terms of government support for public R&D, programmes tend to be generic in nature, as opposed to thematic, with no focus on specific areas for capacity-building. Typical of this approach is the Support Programme for Research Projects of Public Institutions, implemented by TÜBITAK. This programme provides R&D projects with financial support to develop new products and processes to meet the needs of public organizations. Since its inception in 2005, the programme has supported 83 projects from a total budget of €123 million. The top 10 beneficiaries of the programme are, in descending order, the Undersecretariat of National Defence, the Undersecretariat for Defence Industries, the Ministry of Agriculture and Rural Affairs, the Ministry of Energy and Natural Resources, the Ministry of Public Works and Settlement, the Social Security Institute, the Ministry of the Environment and Forestry, the Ministry of Transport, the Directorate-General of Security and the Ministry of Health.

Figure 7: Scientific publications in Turkey, 2002–2007



Source: TUBITAK 2009 from the databases of Turkstat, WIPO and Thomson Reuters

Figure 8: Scientific publications in Turkey by major field of science, 2000–2008



Source: Thomson Reuters (Scientific) Inc. Web of Science, (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

Thematic government programmes to support R&D

Defence, space and nuclear technologies are the only three fields supported through thematic programmes. The Defence Research Programme has been implemented by TÜBITAK in co-operation with the Ministry of Defence since 2005. As of December 2008, 39 projects were being funded, to the tune of about €243 million.

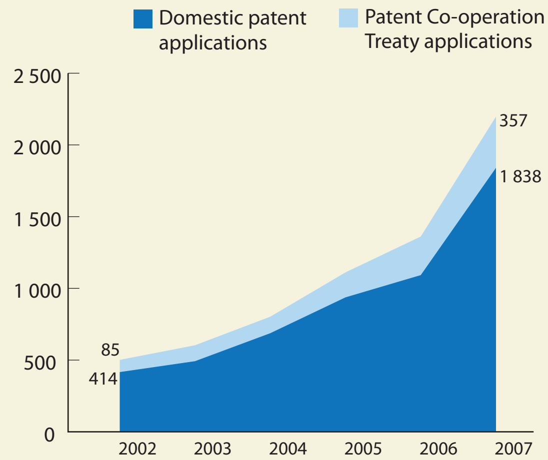
The National Space Research Programme has been carried out by TÜBITAK since 2005 with the involvement of the Turkish Armed Forces, related ministries, universities and private companies. TÜBITAK's Space Technologies Research Institute is actively involved in the implementation of projects under this programme. TÜBITAK also manages an international scholarship programme to develop human resources in the field of space technologies; in 2008, 10 students were selected from among 294 applicants to attend graduate programmes abroad. This programme is accompanied by a scheme to make pupils and their teachers more aware of space and space sciences: seminars, training courses and visits to the National Observatory are organized by TÜBITAK. A recent development under this programme is BTYK's decision to create a National Space Technologies Platform to initiate dialogue and stimulate two- and three-way collaboration among the private and public sectors and academia in this area. In parallel, Turkey is taking steps to intensify international scientific collaboration in space science and technology. The most significant development in this respect has been the closer ties forged with the European Space Agency, which has led Turkey to apply for membership.

The National Nuclear Technologies Development Research Programme is being implemented for the period 2007–2015 by the Turkish Atomic Energy Authority (TAEK), in co-operation with the Ministry of Energy and Natural Resources. The programme aims to establish a centre offering research and training in the field of nuclear technologies.

Wooing the private sector

An important impediment to a flourishing Turkish STI system is the underdeveloped venture capital and business angels market. The total fund for venture capital and private equity is estimated at around €400 million and annual investments at no more than €100 million. Only a handful of these investors prefer to invest in small and medium-sized enterprises (SMEs) and almost none have chosen to invest in start-ups at an early stage. Similarly, investments by business angels are low and the small number of business angel networks makes this an elusive option for entrepreneurs in search of finance. This insufficient funding at an early stage is an obstacle to the development of the venture capital industry, as initial funding of start-ups by business angels helps to generate more deal flow[4] for venture capital investments (Elçi, 2008).

Figure 9: Patent applications in Turkey, 2002–2007



Source: TUBITAK 2009, from the databases of Turkstat, Turkish Patent Institute and WIPO

In 2001, the government set up a Co-ordination Council for Improving the Investment Climate under the reform programme of the same name. The council acts through 12 technical committees which focus on company start-ups, employment, sectoral licenses, localities for investment, taxes and incentives, foreign trade and customs, intellectual and industrial property rights, FDI legislation, investment promotion, small and medium-sized enterprises, corporate management and R&D.

The council's R&D Technical Committee was established in January 2008. The core action plan currently being implemented by the committee members revolves around:

- developing university–industry collaboration;
- promoting R&D awareness in society;

4. 'Deal flow' refers to the rate at which investment offers are submitted to funding bodies.

Box 2: Learning about innovation in Turkey's schools

Innovation has been taught since 2006 in Turkish secondary schools as part of a compulsory course in technology and design, thanks to a private–public partnership entitled Triggering a Cultural Change for Innovation (Project Ekin). The project was implemented by the Technology Management Association (TYD) between 2005 and 2006, in co-operation with the Technopolis Group, Bilkent University, the Turkish Informatics Association, METU Technology Park and the newspaper *Referans,* and with the participation of the Board of Education of the Ministry of Education.

The project was one of the winning proposals of the World Bank's Turkey Development Marketplace Competition in the category 'Social inclusion and progress on the way to Europe'. Three schools participated in the pilot phase; two from a developed region of Turkey and one from a less developed region.

In the first of two stages, the curriculum was defined, a book was produced and the teachers were trained. In the second stage, the pupils received instruction from their teachers, in accordance with the prepared content. The pupils also experienced real-life examples of innovation and entrepreneurship by visiting several innovative companies located in science parks. After these visits, each school formed four teams to develop their own innovative ideas, establish virtual companies and prepare business plans. A group of university students trained in the subject material coached these 12 virtual companies throughout the business planning process.

The pilot project ended with an event at which the teams presented their ideas for innovation and their business plans. Participants were invited to visit the virtual companies established by the pupils and become their 'business angels' by buying virtual shares in those in which they preferred to invest. The three companies that received the most investment were presented with an award.

Source: author

- identifying barriers to the employment of foreign researchers;
- developing international R&D co-operation;
- investigating what motivates foreign multinationals to invest in R&D in a particular country;
- ameliorating the quality of data to improve Turkey's ranking in international innovation indexes.

In addition, the government has devised a number of instruments to foster private-sector R&D, ranging from grants to soft loans. Tax incentives for R&D, which have been provided for technoparks since 2001, have been broadened by the Law on the Support of Research and Development Activities, ratified in 2008. The new incentives under this law aim to boost investment in R&D and attract the R&D branches of foreign companies to the country. The law also sets out to encourage collaboration on R&D and to stimulate the creation of technology-based firms. It is implemented by the Ministry of Industry and Trade in co-operation with the Ministry of Finance.

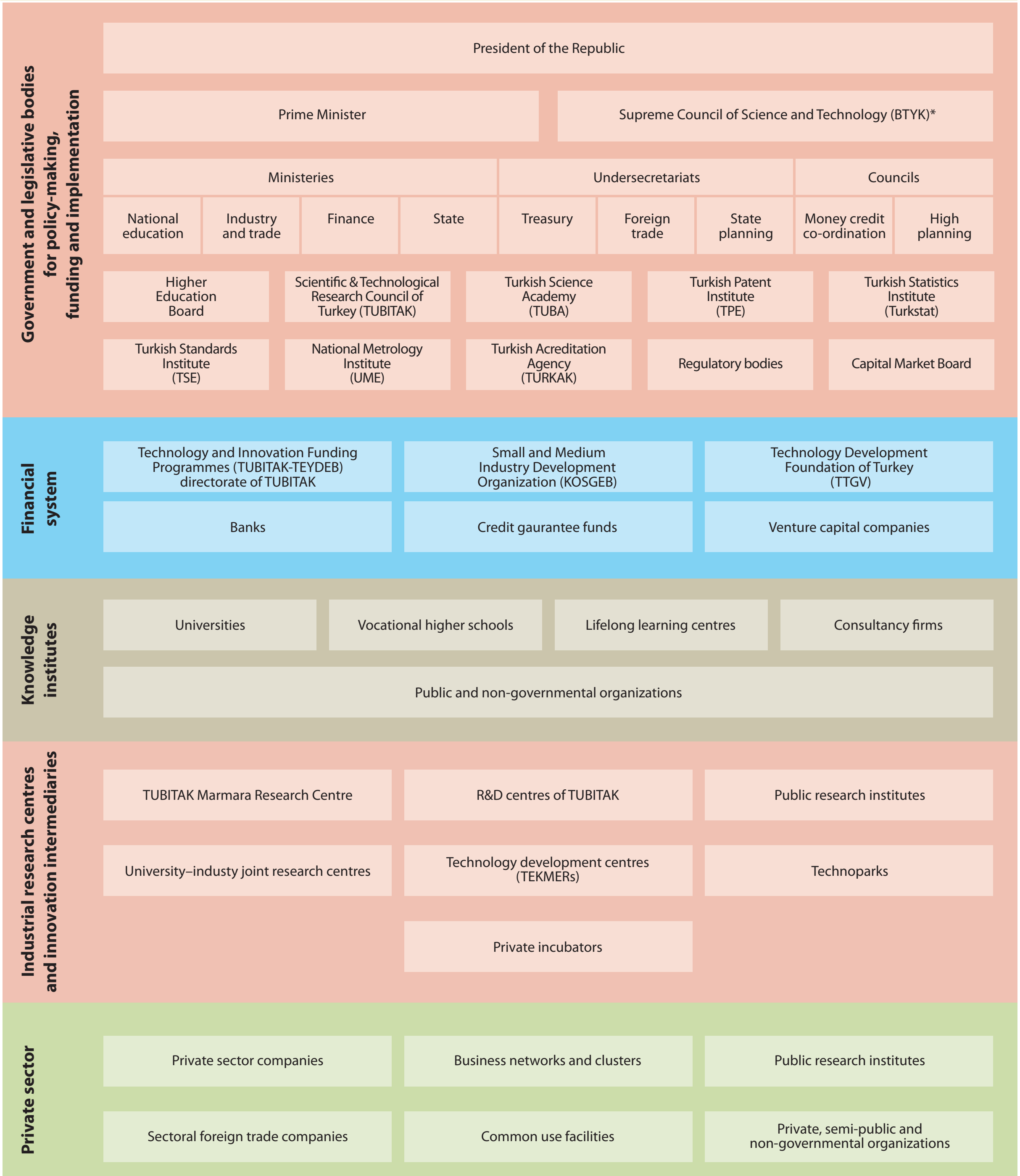
In regional S&T systems, technoparks are one of the key instruments being used by the government to increase private investment in R&D. By 2008, 31 technoparks had been approved in Turkey by the Ministry of Industry and Trade, under the Technology Development Zones Law of 2003.

Eighteen of these technoparks are currently active and house 890 companies – 32 of them foreign – which employ 9 475 people, 78% of whom are researchers. These companies are implementing 2 671 R&D projects in ICTs, electronics, defence, telecommunications, medical/biomedical research, new materials, industrial design and environmental technologies. They accounted for US$250 million of export revenue in 2008, up from US$144 million in 2006, according to the Ministry of Industry and Trade. Technoparks are provided with a broad range of incentives, including generous tax benefits, to encourage business R&D and help close the gap between the business sector and the research community.

The role of non-profit bodies in fostering STI

In parallel to the greater government commitment to S&T, both private non-profit bodies and non-governmental organizations (NGOs) have been highly effective in creating awareness of STI. Two examples are the Innovation Association and the National Innovation Initiative (Elçi, 2008). The latter is a platform comprised of leading executives from the private sector, rectors of several established universities and leaders

Figure 10: The Turkish STI system



* The Supreme Council of Science and Technology (BTYK) is the top policy co-ordination body for STI in Turkey. It is chaired by the Prime Minister and composed of the relevant ministries, high-level representatives of government bodies, universities and NGOs. TUBITAK acts as secretary to BTYK.

Source: Elci (2008) *INNO-Policy TrendChart – Policy Trends and Appraisal Report* from some of the more influential NGOs in Turkey. The initiative develops and recommends strategies to the government in the field of innovation. Moreover, since 2004, there has been a marked increase in initiatives by private non-profit bodies and NGOs to increase private investment in STI.

These bottom-up developments have also fostered a regional approach to the governance of technology and innovation: regional innovation strategies have started being designed and new models of innovation intermediaries have been established. Two examples are the relay centres (Box 3) and regional innovation centres, developed by the Turkish Industrialists and Businessmen's Association jointly with the Turkish Enterprise and Business Confederation. In parallel, the introduction of regional development agencies has broadened funding opportunities for regional organizations engaged in STI activities: private enterprises, universities and public research institutes.

International co-operation

International co-operation in STI is an important policy objective of the Turkish government. A key element of this is the integration of the Turkish Research Area (TARAL) with the European Research Area. A big step in this direction has been Turkey's involvement in the European Union's Research Framework Programmes, as well as in the Competitiveness and Innovation Framework Programme. As we have seen earlier, it is estimated that Turkey's contribution to the current Seventh Framework Programme will total €423.5 million by the end of 2013. In addition to research collaborations with the EU, Turkey has a bilateral research agreement with a large number of countries and TÜBITAK implements programmes to stimulate international R&D partnerships.

Box 3: The Aegean Innovation Relay Centre

The Aegean Innovation Relay Centre (IRC-Ege) has been selected as the best of its kind by the EU, out of 71 centres in 33 countries. It was established in April 2004 under the auspices of Ege University Science and Technology Centre (EB?LTEM), the Aegean Region Chamber of Industry (EBSO), the Izmir Ataturk Organized Industrial Zone (IAOSB) and the Small and Medium Industry Development Organization (KOSGEB) as one of two innovation relay centres in Turkey.

The IRC-Ege has been providing R&D services in 14 provinces of Western Anatolia. IRC-Ege has been pro-active in promoting its services and creating awareness of R&D and innovation among SMEs in the region. In addition to conferences, road shows, television programmes and so on, since its inception, IRC-Ege has visited 706 companies and conducted 124 technology audits, bringing to light 83 new technologies. In order to promote these new technologies, which were developed by Turkish SMEs in the region, the centre has organized and participated in 111 brokerage events Europe-wide. It has also acted as go-between by passing on 'technology requests' submitted by the regional SMEs to the members of the EU Innovation Relay Centres network. Some 2084 bilateral meetings were organized during these events between Turkish and European SMEs with the centre's assistance.

This hive of activity has led to 67 transnational technology transfers (TTT) between Turkish and European companies. Thirty of these transfers emanated from Turkish companies, with the technology transferred to companies in European countries including Bulgaria, the Czech Republic, Finland, Greece and Italy, while 37 involved transfers from European companies towards Turkish companies. In addition, eight Turkish companies have also entered into business partnerships with other European companies with the help of IRC-Ege.

The value added to the Turkish economy through these technology transfers is estimated at around €42 million. Eleven of the SMEs that made a technology transfer had not contacted any foreign companies for any reason prior to being approached by IRC-Ege. Another 15 SMEs do not employ anyone who speaks a foreign language. Two technology-based start-ups were created after inward technology transfers enabled them to begin producing new products and services for the domestic market.

Nearly 260 new jobs have been created in Western Anatolia as a result of the TTT. In addition, some SMEs have taken on extra staff to keep abreast of new technologies via the IRC network and to participate actively in activities organized by IRC-Ege.

CONCLUSION

Turkey has demonstrated remarkable progress in STI in the new Millennium. The challenge now will be to boost output from S&T and to transform R&D results into innovation and viable business opportunities for the benefit of both society and the economy. In this respect, public intervention needs to address longer-term drivers and relatively short-term direct needs of the private sector and academia.

To this end, the key recommendations that follow include further investment in developing human capital in STI; facilitating knowledge creation and diffusion and; increasing the number of innovative high-growth enterprises, which generate new jobs:

- There needs to be greater investment in education at all levels. Particular attention should be paid to expanding enrollment, raising attainment levels and improving the quality of education in tertiary institutions. Curricula need to be aligned further on the needs of the business sector. In addition, participation in life-long learning should be stimulated through postgraduate programmes, corporate training, online learning and other means;

- Since the majority of research is performed by universities, it is important to encourage the commercialization of research results and the diffusion of knowledge generated by universities. The government's efforts to encourage university–industry collaboration should be reinforced by other measures to facilitate spin-off formations, providing researchers with training and mentoring in business planning and other key topics such as intellectual property rights management and the commercialization of products and services. The government should also encourage the creation of specialized institutions for technology transfer. Moreover, support for the creation and running of STI networks and clusters is essential to foster knowledge generation and diffusion among knowledge producers and enterprises;

- It is important for Turkey to focus on priority technology areas and specific thematic fields to build capacity. This requires incentives, specifically design and address key challenges of today and tomorrow. ed measures and having government funds strategically channelled to these areas;

- To increase the number of innovative high-growth enterprises, innovation capabilities in existing firms need to be improved and more measures put in place to facilitate the creation of innovative enterprises. Existing firms need to be made aware of the vital importance of innovation and to be given incentives to develop their capabilities. It is equally important to attract investment in the form of venture capital and via business angels, in tandem with tax incentives for innovative start-ups.

These and other policy measures, combined with a lasting government commitment to stimulating STI in Turkey, will not only allow the country to close the gap with the developed nations but also ensure that it reaps the social benefits of higher productivity and economic growth.

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TÜBITAK – Scientific and Technological Research Council of Turkey: www.tubitak.gov.tr

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Turkish Statistics Institute: www.turkstat.gov.tr

World Bank Turkey: www.worldbank.org.tr

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During the course of her career, she has taken part in several projects and programmes of the European Commission. In addition, she has worked as a consultant on international and national projects with the World Bank, European Union and a variety of government departments and organizations in Turkey.

Currently, she is the national correspondent for the INNO-Policy TrendChart and ERAWATCH of the European Commission. She has also participated actively in a number of international and national associations and networks on R&D and innovation.

Major trends in recent years are the stronger orientation of R&D towards the needs of industry, a quite substantial focus on non-oriented research and the still insufficient share of government funding assigned to social and environmental issues.

Leonid Gokhberg and Tatiana Kuznetsova

11 · Russian Federation

Leonid Gokhberg and Tatiana Kuznetsova

INTRODUCTION

According to the strategic document adopted by the Russian government in 2008, *Long-Term Social and Economic Development to 2020: A Policy Framework (LTDP-2020)*, Russia had completed its transition to a market economy and the transformation of its social and political systems by the turn of the century (Government of Russian Federation, 2008).

Since 2005, economic trends in Russia have clearly fallen into two distinct periods. During the first period (2005–2007), the economy grew and quality of life gradually improved, thanks largely to high oil prices and an initially weak currency, combined with rising domestic demand, consumption and investment.

The country then experienced a severe economic downturn in the last quarter of 2008, caused by a global financial crisis and subsequent economic recession (Table 1). In an effort to combat the repercussions of this recession, the Russian government, like governments elsewhere, developed an extensive national recovery package, *The Anti-crisis Plan for the Russian Federation* (Government of Russian Federation, 2009). This package is expected to help cushion the social cost of the recession, maintain a robust financial system and support some key industrial sectors, such as motor vehicle and aircraft manufacture, metallurgy and pharmaceuticals. This will require substantial public funds; the recovery package cumulated at about US$ 88.4 billion for 2008–2010 and represented approximately 9% of Russian GDP for 2009. Experts believe, however, that the recovery package may aggravate the risk of immoderate government intervention in the economy and slow down certain institutional reforms, particularly those intended to bring about a radical modernization of the economy and reform the country's science, technology and innovation (STI) system (INSOR, 2009).

The current economic recession is making it even more difficult for Russia to respond to pressing long-term global challenges, such as demographic trends, health issues, climate change and both energy and food security. These challenges are exacerbating domestic weaknesses and hampering the growth of the Russian economy. According to the *LTDP-2020*, the gravest among these weaknesses include:

- Russia's dependence on raw materials, with economic growth and a better quality of life being ensured chiefly by export earnings from oil, gas and other raw materials;
- persistent structural imbalances in the economy and a technological gap with leading industrial nations;
- the monopolization of most local markets, which suppresses incentives to improve productivity and competitiveness;
- persistent barriers to entrepreneurship and inadequate protection of ownership rights, including intellectual property rights;

Table 1: Major socio-economic indicators in Russia, 2005–2009
Percentage change over previous years

	2005	2006	2007	2000–2007*	2008	2009
GDP	106.4	107.4	107.6	107.0	105.6	92.1
Consumer price index	110.9	109.0	112.0	113.6	114.1	111.7
Industrial production index	104.0	104.4	106.0	105.8	102.1	95.7
Capital investment	110.9	113.7	120.0	112.5	109.1	83.0
Real income of population	112.4	113.3	110.3	111.6	102.7	101.9
Real average monthly wages	112.6	113.3	115.8	115.0	109.7	108.5
Retail trade turnover	112.8	113.9	115.0	111.6	113.0	94.5
Turnover of services purchased by population	106.3	107.6	107.2	105.7	112.8	95.7
Exports 133.1		124.7	116.5	122.1	140.2	60.9
Imports 128.8		131.3	136.8	124.6	134.9	63.6

*Annual average growth rate

Source: Government of Russian Federation (2008) *Long-Term Social and Economic Development to 2020: A Policy Framework;* MED (2009) *Monitoring of Economic Development in the Russian Federation;* Rosstat (2009) *The Socio-Economic Position of Russia: 2009*, p. 7.

Constructed in 1959, the Pushchino Radio Astronomy Observatory in Russia has four fully steerable radio telescopes, a wide-band radio telescope and a nomenclature Large Phased Array.

Photo: © Dmitry Mordvintsev/ iStockphoto

- a lack of appropriate incentives and conditions for fostering a 'pragmatic coalition' between business, the government and the public;
- a low level of confidence in state authorities, combined with the insufficient effectiveness of public governance;
- glaring economic and social differences between regions; and
- a number of social issues, such as the significant inequality in income distribution and in the development of social infrastructure.

All this makes Russia's position extremely vulnerable and unsustainable in the long term and prevents a rapid transition to post-crisis recovery and growth. The President of the Russian Federation, Dmitry Medvedev, conceded this fact, in essence, when he decided to set up and head the Commission for the Modernization and Technological Development of Russia's Economy in May 2009.

More recently, in his State of the Nation address to both houses of Parliament on 12 November 2009, he said that 'We must start modernising and technologically upgrading the entire production sphere. This is an issue of our country's survival in today's world.' The President spoke of the decision to develop new medicinal and space technologies and telecommunications, as well as to 'radically increase energy efficiency.' One target he cited was for 50% of medicines commercialized in Russia to be Russian-made by 2020. The President added that government support would henceforth target those companies with explicit plans to raise efficiency and implement high-tech projects (President of the Russian Federation, 2009).

R&D INPUT

Trends in R&D expenditure

Gross domestic expenditure on research and development (GERD) in Russia almost doubled at constant prices during 1998–2008 (Figure 1). This is one of the highest growth rates for R&D investment worldwide. However, current GERD in Russia has still not climbed back to 1991 levels (it stands at 76.4%), nor even to half the level of 1990, the last year of existence of the Union of Soviet Socialist Republics (USSR).

Federal budget allocations for civil R&D grew 1.3-fold between 2005 and 2008 at constant prices, about 40% of which was allocated to supporting basic research. Also on the rise has been financial support for R&D through public procurement procedures – such as within the framework of federal targeted R&D programmes – as well as contributions to public science foundations, grants to outstanding research scholars and international co-operation in science and technology (S&T).

As a consequence, the salaries of research staff have also gone up. These are now 8.5% higher than the average for the economy as a whole and 13.5% higher than salaries in the manufacturing sector. The amount of R&D spent on each researcher in Russia (PPP US$ 40 100) nevertheless remains much lower than in other leading countries such as Germany (PPP US$ 238 000), the USA (PPP US$ 233 000) or the Republic of Korea (PPP US$173 000). Levels of expenditure in Russia are still insufficient to upgrade radically the quality of research equipment to compensate for years of neglect, even though this is a crucial factor in ensuring excellence in R&D (Box 1).

Box 1: Russia's inadequate facilities for research

For many years, Russia has neither upgraded on a grand scale nor replaced or acquired machinery, equipment and other facilities for research when the need has made itself felt. As a consequence, vital resources for research have now deteriorated or are in short supply.

One-quarter (25%) of the machinery and equipment used for R&D in Russia is more than 10 years old and 12.3% more than 20 years old. The degree of wear and tear has been calculated at 55.2%. Overall, the share of scientific equipment in the aggregate value of machinery and equipment in the Russian R&D sector is 35.5%.

Installations specifically designed for R&D are available at less than 7% of R&D organizations and less than 20% of them have their own experimental base; for the former USSR, this figure was 34%.

Source: HSE (2008*a*)

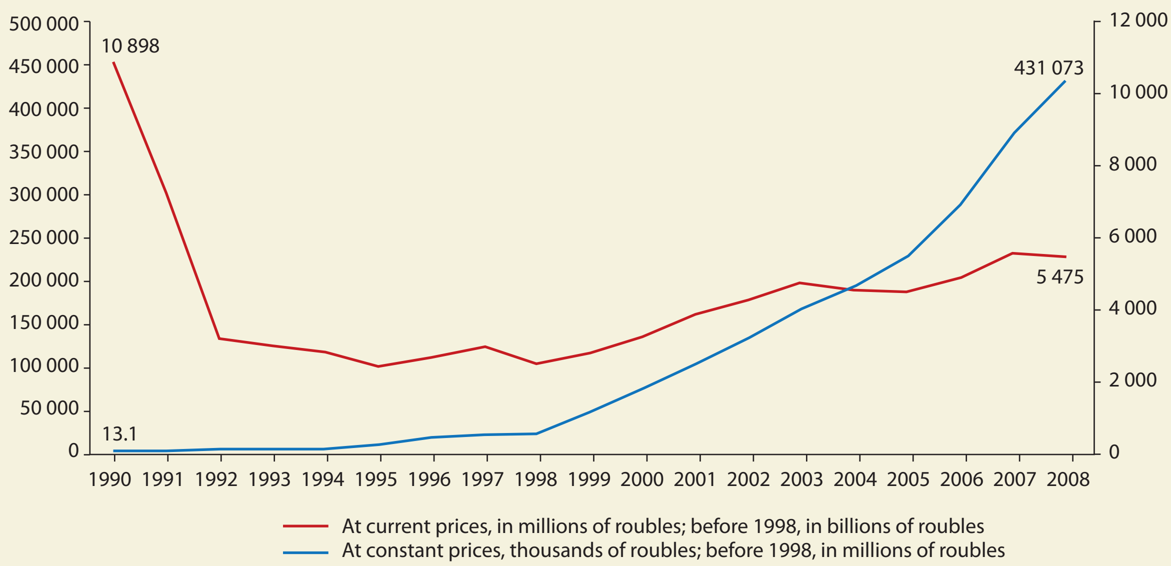
This said, in absolute terms, Russia has managed to conserve its place among the world's top ten spenders since 2000. During 2005–2008, GERD in Russia increased from PPP US$18.1 billion to PPP US$24.5 billion. This still places Russia far behind the USA (fifteen times higher), Japan (six times higher), China (four times higher), Germany (three times higher) and France (twice as high). For the purposes of comparison, Russia trailed only the USA, Japan, Germany and France in 1991 after the collapse of the Soviet Union. As for Russia's GERD/GDP ratio of 1.03% (2008), this is lower than in 2007 (1.12%) and a far cry from its level of 1.43% in 1991. Russia ranks 31st for this indicator in OECD and UNESCO publications (*Gokhberg, 2007, pp. 10–11)*.

Over the past few years, there has been little improvement in the structure of R&D funding and performance, or in the socio-economic objectives of GERD. Demand for R&D in Russia still comes mostly from the government, which remains the key source of R&D funding at around 65% of GERD. The continuing large share of the state budget dedicated to R&D is a necessity to a certain extent, reflecting the weakness of all other sources of funding. The business sector provides just 29% of GERD, a share that has even fallen slightly since 2005 (30%).

However, the roles of the government and business sectors are reversed when it comes to performing R&D. Here, it is the business sector (including both private and publicly owned companies) which performs nearly two-thirds of R&D and the government sector just 30%. Higher education institutions contribute the remaining 7%. Our analysis suggests that, unless it is accompanied by strong government incentives for private investment in R&D, growing public funding for R&D may increasingly substitute company financing rather than complementing it.

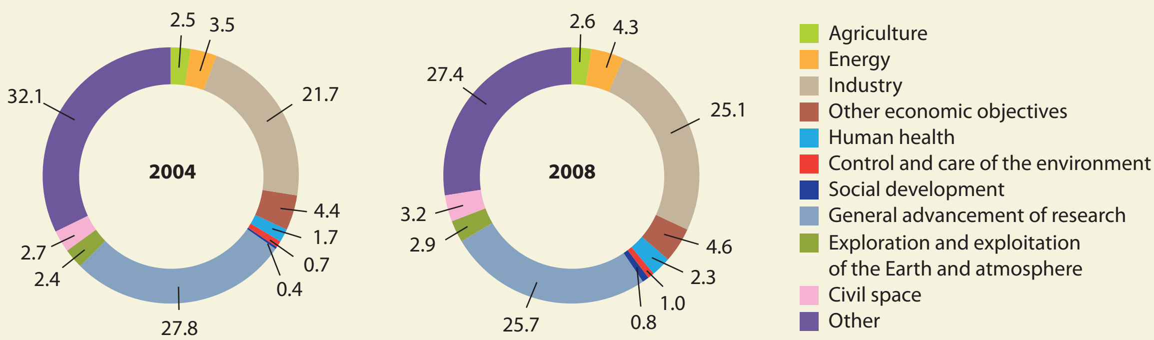
Figure 2 shows government funding of R&D by socio-economic objective. Major trends in this regard in recent years are the stronger orientation of R&D towards the needs of industry, a quite substantial focus on non-oriented research (at a stable quarter of GERD) and the still insufficient share of government funding assigned to social and environmental issues, even though these areas are no less important than others for socio-economic progress in Russia. Energy-related research, as well as that aimed at exploration and exploitation of the Earth and atmosphere and civil space applications, has recently gained a slightly greater stake in the overall financing of R&D.

Figure 1: GERD in Russia, 1990–2008



Source: HSE (2010) *Science and Technology. Innovation. Information Society;* HSE (2009b) *Science Indicators: 2009*

Figure 2: Government expenditure on R&D in Russia by socio-economic objective, 2004 and 2008 (%)



Source: HSE (2010) *Science and Technology. Innovation. Information Society;* HSE (2009*b*) *Science Indicators: 2009*

TRENDS IN HUMAN RESOURCES

An ageing research population

In 2008, there were 761 300 people engaged in R&D in Russia, including researchers, technicians and support staff. This represented 1.3% of the Russian labour force, or 0.6% of the total population. After several years of decline, this number has now more or less stabilized. The same is true for researchers, who totalled 375 800, or 49% of R&D personnel, in 2008. In terms of the absolute numbers of R&D staff, Russia is among the world leaders, coming only after the USA, Japan and China. However, the dynamics and structure of R&D personnel in Russia reveal an unhealthy imbalance. Unlike in many other countries, researchers in Russia account for less than half of R&D personnel. The remainder are mostly support and auxiliary staff (43%), rather than technicians serving the scientific process (8%). As a result, Russia ranks 10th globally in terms of the number of people engaged in R&D per 10 000 employees but 19th in terms of researchers. To compound matters, more than 70% of researchers in Russia hold no advanced scientific degree.

Between 2002 and 2008, the age structure of researchers was marked by absolute growth in the two polar groups, namely scientists under 30 years of age (up by nearly 18%) and those aged 70 years and above (up by a factor of two). Simultaneously, the ranks thinned of such creative age groups as 40–49 year-olds (down by nearly 58%) and 50–59 years (down by 13%). The bottom line is that about 40% of Russian researchers have overstepped the official retirement age of 55 years for women and 60 years for men. In 2008, researchers were 49 years old on average, compared to an average age of 40 years for those working in the national economy as a whole.

A new type of university

The network of institutions of higher education is growing steadily in Russia. By 2009, they numbered 1 134 across the country. Of these, 660 are state-owned or municipal institutions, the remainder being privately owned.

Existing legislation defines three types of higher education institution: universities with multi-profile research activity (53% of the total), academies with mono-profile research activity (25%), and institutes that conduct no research at all (22%). In addition, a fourth type was introduced in 2008–2009, the federal university. This is a large-scale institution usually resulting from the merger of smaller local universities to become a key educational centre for macroregions. So far, the government has decided to inaugurate seven such universities in Russia: in the city of Rostov-on-Don in the south of the country, in the Siberian city of Krasnoyarsk, in Arkhangelsk (the European North), in Kazan (Volga Region), in Ekaterinburg (Urals), in Yakutsk (East Siberia) and in Vladivostok (Far East); other candidate institutions are under consideration.

Box 2: Higher education popular in Russia

According to the 2002 population census, 19.0 million people aged over 15 years hold university degrees in Russia. This represents about 16.0% of the overall population in this age group, compared to 11.3% in 1989. Among those aged 20–29 years, the share is nearly the same: 16.1%.

Regular surveys of household attitudes to education show that the majority (77%) of respondents with children aged between 4 and 22 years consider higher education to be important for their children's future; 56% of households say they would be willing to invest in higher education. University degrees are valued for the crucial role they play in obtaining well-paid positions (72% of respondents), becoming highly demanded professionals (45%), achieving success and enjoying rewarding careers (41%), and securing interesting and creative jobs (22%).

Source: Petrenko *et al.* (2007)); HSE (2009*a*)

The status of a given higher education institution in terms of its allocation to one of these four categories depends on the nature of the education and research offered, as well as the comprehensiveness of educational programmes. In the present chapter, we shall use the generic term of 'university' to cover the various types of higher education institutions, in the interests of simplicity.

In 2008, 4.5% of university students were enrolled in natural sciences and 18.6% in engineering. Medicine and agriculture attracted 2.8% and 3.2% of student enrollment respectively. Socio-economic and managerial disciplines and the humanities have enjoyed sustainable demand ever since a shortage in educational supply in this sphere was revealed in the 1990s when market-oriented reforms were launched. Within a few years, the situation had righted itself to the point where concern was voiced at the excessive numbers of lawyers, economists, managers, accountants and the like being produced by universities. Today, the proportion of graduates in these fields remains unchanged: in 2008, 32.5% students in the public university sector obtained degrees in economics and management, 16.3% in humanities and 9.2% in education. Private universities are even more reluctant than the public sector to alter their policies and continue to turn out large numbers of students specializing in the humanities (32.6%) and in economics and management (58.4%).

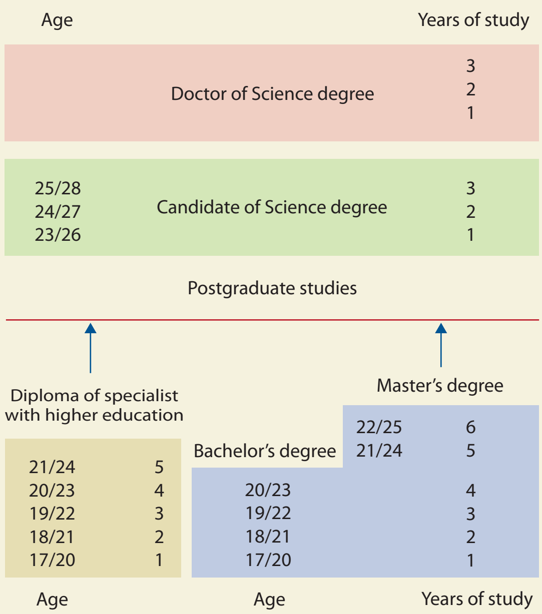
In 2008, the university enrollment rate in Russia was 529 persons per 10 000 population, up from 495 in 2005 (Box 2). Over the same period, the number of graduates per 10 000 employees shrank from 198 to 172. Despite the dynamic growth of private universities (by nearly one-third during the 2000s), over 80% of all students – both undergraduates and graduates – still pass through public universities. In view of this large proportion and the after-effects of the global economic recession, it would be difficult to say what the future prospects will be for private universities in Russia, especially considering the broad criticism they have attracted for the quality of training they offer. With stronger competition, those universities that are unable to ensure quality education will be ousted from the market. Another essential factor is the growth of student bursaries: in 2008, nearly 59% of entrants admitted to public universities were in possession of a bursary. This trend is also having an impact on the way private institutions of higher education function, since they mainly serve local markets and usually have no substantial impact on inter-regional student mobility.

Modernizing the higher education system

The Russian higher education system has undergone significant modernization in recent years. In addition to the traditional five-year specialist training programme, bachelor's and master's programmes have been introduced (Figure 3). Since Russia only joined the Bologna Convention in 2003 (*see page* 150), over 90% of graduates with five years of study behind them still receive 'specialist with higher education' diplomas; just over 1% obtain a master's degree after six years of study and 7% a bachelor's degree after four years of study.

The qualifications of lecturers have improved visibly. By early 2009, the number of Doctors of Science in public universities had climbed to 42 100, or 12.3% of all faculty staff, a proportion that includes those working part-time. More than half of lecturers held a Candidate of Science degree, equivalent to a PhD. In 2003, the proportions were a little lower: 11.3% and 46.8% respectively.

Figure 3: Higher education system in Russia for scientific disciplines, 2009



Source: HSE (2009a) *Education in the Russian Federation*

The training of professionals with top scientific qualifications includes postgraduate programmes that confer a Candidate of Science degree (equivalent to a PhD) and doctoral courses leading to the highest scientific degree in Russia, the Doctor of Science. In 2008, postgraduate S&T programmes were offered by 1 529 organizations, 718 of which were universities and the remainder research institutes. Some 39% of these organizations – 388 universities and 205 research institutes – also ran doctoral courses.

Women made up just under half (43–45%) of the 147 700 postgraduate and 4 200 doctoral students in S&T fields in 2008. Most of the postgraduates (88%) and doctoral students (92%) specializing in scientific disciplines are on the university payroll. This means that the training of highly qualified scientists in Russia, like elsewhere, is increasingly becoming a core mission of universities and a top priority for them. Among disciplines for postgraduate training, it is engineering, economics, law, medicine and pedagogy which take the lead. Engineering and economics also tend to attract the most doctoral students, although their next preferences go to pedagogy, philology, physics and mathematics.

The dynamics of postgraduate training in Russia have generally stabilized in recent years. However, this also means that success rates have not improved: the percentage of students who completed their thesis within the prescribed period dropped from 30% to 26% in 2000–2008 (and even from 23% to 15% in research institutes). The average age of researchers upgrading their qualifications has risen to 41 years for doctoral students and 26 years for postgraduate students.

The national system for training scientific personnel and providing certification still suffers from inefficiency and inflexibility. The key concerns are:

- the declining quality standards for theses;
- the poor output of postgraduate and doctoral courses, with most graduates failing to deliver their completed theses on time;
- protracted and excessive formalization of certification procedures that are sometimes accompanied by biased attitudes and lack of objective peer review;
- the insufficient transparency of activities undertaken by dissertation boards at some universities and research institutes.

These issues become even more alarming in light of the shift announced by policy-makers towards an economy where the capacity to innovate is crucial. In this context, there is a need for efficient mechanisms to renew the stock of highly qualified personnel and, in particular, to ensure their high-quality training, promotion and rotation. This also calls for conditions conducive to consolidating human resources in S&T, education and high-tech industries. One policy currently being considered is the instigation of a separate advanced degree system for practitioners, such as businessmen, civil servants and lawyers, to ensure adequate recognition of their professional achievements in a form other than advanced scientific qualifications.

MAJOR TRENDS AND KEY PROBLEMS IN R&D

Greater support required for university research

Russia's higher education sector possesses significant S&T potential and long-standing research traditions. However, universities still play a minor role in new knowledge production: in 2008, they contributed just 6.7% of GERD, a figure that has remained fairly stable for the past two decades. Other key indicators also reflect a low engagement of university staff in R&D (Figure 4). Only one out of three universities performs R&D, compared with half (52%) in 1995. As for the private universities which emerged in the 1990s, they hardly perform any research at all. University R&D laboratories have not yet become a magnet for scientists. As a result, the population of full-time researchers at universities remains relatively small but stable in most cases: 28 900, or about 7.7 % of the country's research pool.

In addition to insufficient, albeit growing government support for university research, the higher education sector faces serious problems that are to a large extent dependent on available funding mechanisms. Public universities are budget entities with legally limited rights. They receive regular funding within the framework of educational programmes primarily but only a handful are able to compete with research institutes for tender-based R&D projects.

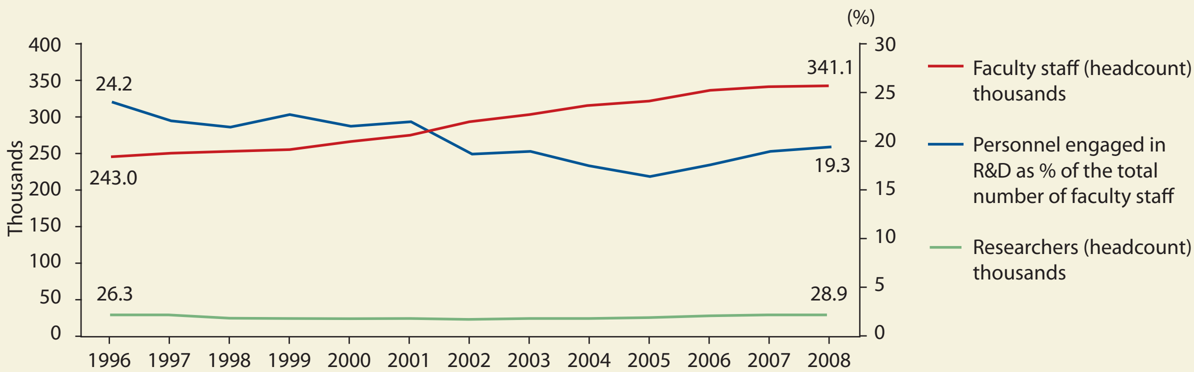
Boosting support for university research has become one of the most important strategic orientations of STI and education policies in Russia. For instance, the National Priority Project for Education (2006–2007) envisaged competitive grants for universities implementing innovative education programmes. It provided each of these centres of excellence with additional funding of approximately US$ 30 million in the form of two-year institutional grants. These grants served to promote human resource development, high-quality R&D and educational projects, and the acquisition of research equipment. There were 57 beneficiaries in 2006–2007. The main challenge today will be to ensure the sustainability of this project (Gokhberg *et al*., 2009*a*).

The National Priority Project for Education is not the only government initiative to have provided centres of excellence with support. In 2008, two Moscow-based universities, the University of Engineering and Physics and the University of Steel and Alloys, obtained the coveted label of national research university, a status that should channel subsequent incentives for R&D and educational activities their way. In 2009–2010, a follow-up programme selected another 27 national research universities in different areas of S&T.

Over the period 2009–2013, the federal programme Science and Education Personnel for an Innovative Russia (launched in 2008) is offering various incentives to attract young talent and highly skilled professionals to universities and R&D institutions. These incentives come in the form of contest-based funding for advanced research projects at science and education centres; and grants for gifted young scientists, teachers and postgraduate students, as well as for Russian scientists and teachers returning from abroad. All of these initiatives will be implemented regardless of any current financial obstacles.

In order to bring research institutes and universities closer together and remove existing legal and administrative barriers, a federal law on *Changes to Selected Laws of the Russian Federation concerning the Integration of Education and Science* was adopted in 2007. It provides a legal basis for different models of integrating scientific research with university training, such as setting up laboratories of public research institutes on university grounds and establishing specialized university departments at leading research institutes.

Figure 4: Staffing levels at Russian public universities, 1996–2008



Source: HSE (2010) *Science and Technology. Innovation. Information Society;* HSE (2009*a*) *Education in the Russian Federation;* HSE (2009*b*) *Science Indicators: 2009*

Conflicting trends in R&D

The R&D sector in Russia is still developing along conflicting lines and remains subject to conflicting trends. On the one hand, many positive changes can be observed, which are particularly important since they mark a break with a longlasting 'big crisis' period for Russian S&T. Despite all the difficulties in the past two decades born of the collapse of the USSR and the so-called shock-therapy transition to a market economy, Russia has been able to maintain its strong position in basic research and in certain priority fields of applied R&D (examples being physics, nuclear research, space, biotechnology, organic chemistry and Earth sciences) to ensure an unbroken flow of technology to industry. At the same time, the national S&T sector continues to stagnate. It has three special characteristics which still follow – to a certain extent – the Soviet model:

- The S&T sector is relatively large in relation to its productivity, centrally directed and government financed (Kuznetsova, 1992; Gokhberg *et al*., 1997). These features are ill-suited to a market economy;
- There is a striking imbalance between the country's performance in STI, on the one hand, and the growing quantity of financial resources devoted to R&D, on the other. Moreover, the lion's share of these resources mostly circulates beyond the realm of the industrial and university sectors in public research institutions. Market reforms of the national innovation system are much slower and more superficial than those in other sectors of the economy and remain incomplete. Accordingly, while only 3–4% of businesses in the Russian economy are still publicly owned, the figure for R&D-performing units is over 70% *(*Rosstat, 2008, pp. 349; HSE, 2009*b,* pp. *36–37).*
- Structural indicators demonstrate that the institutional model of Russian S&T remains obsolete and erects multiple barriers between R&D, industry and education; this is impairing the quality of the supply of S&T in Russia and weakening Russia's position in the global S&T arena. It will obviously be extremely difficult for Russia to pursue its economic development and sustain its competitive position if this model is not radically amended. However, the S&T sector will not be able to deal with the problems it faces in its development, nor implement the necessary reforms effectively, as long as it remains under the yoke of government.

Changing the organizational structure of the R&D network

Institutions executing R&D in Russia have been sensitive to demand. In 2000–2005, their number decreased by nearly 13%, whereas in 2005–2007, their number increased by 11%. It is hardly surprising that the latest financial crisis has sent numbers plunging again: the network shrank by 7% in 2007–2008, from 3 957 units to 3 666.

However, the structure of the R&D network remains much the same, given that the institutional features of Russia's R&D sector have changed little. As before, it is mostly dominated by research institutes, industrial design bureaux and technological organizations that are legally independent of universities and industrial enterprises (Figure 5). This tradition does not correspond to institutional arrangements characteristic of mature market economies, where national R&D sectors are typically led by industrial companies and universities. On the contrary, the latter still play a minor role in Russian R&D: according to official statistics, there were only 239 industrial enterprises and 503 universities engaged regularly in R&D in 2008 *(HSE, 2010)*.

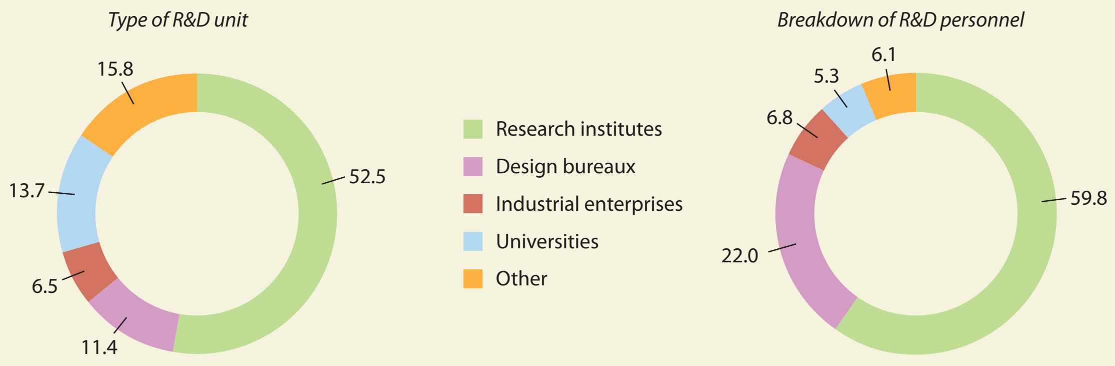
R&D OUTPUT

Trends in publications and patents

Deficiencies in Russia's S&T sector are reflected in R&D output and the impact of research applications on the economy and society. In 2008, Russian scientists published 27 300 articles in the journals indexed in the Web of Science, corresponding to 2.48% of the world total (HSE, 2010). For this indicator, Russia ranks 14th worldwide. This is a drop from 7th place in 1995 and an even greater fall from the 3rd place occupied by the former USSR in 1980.

While patenting activity in Russia is relatively intensive, with about 42 000 patent applications annually, placing Russia 6th worldwide, the share of registered licensing contracts in the country is low: 5–6% of annually registered patents. This can largely be explained by insufficient industrial demand for innovation but also by the poor competitiveness of Russian technologies, especially those destined for civilian applications. The supply of technology is unsubstantial in Russia and biased towards mostly unpatented R&D results. Annual technology exports from Russia amount to just US$ 0.8 billion; this compares with US$ 2.5 billion for Hungary, US$ 3.8 billion for Finland and US$ 85.9 billion for the USA.

Figure 5: R&D units in Russia by type and breakdown of personnel, 2008 (%)



Source: HSE (2010) *Science and Technology. Innovation. Information Society*

If we take another indicator, Russia's innovation activity expressed as a percentage of the industrial enterprises engaged in technological innovation has remained at 9–10% since 2000. The economies of the European Union (EU) perform much better for this indicator, ranging from a low of 20% in Hungary to a high of 63% in Germany. At the same time, the substantial 1.6-fold increase in expenditure on technological innovation in Russian industry between 2000 and 2008 holds some promise for domestic goods being more competitive in the future.

NEW STI POLICIES

Towards greater competitiveness and economic growth

The objectives of Russian STI policies since 2005 have been largely determined by socio-economic and political factors. As we have seen in Figure 1, the government was able to pump considerable additional resources into the S&T sector, thanks to high oil and gas prices up until the start of the global recession in the third quarter of 2008. However, Russia needs to deal with a whole set of complex challenges simultaneously, including those connected with the generation of new ideas, their commercialization and transformation into efficient technologies and, lastly, the production of competitive goods and services**.** STI policies face the dual challenge of having to stimulate both the demand and supply side of innovation markets.

In recent years, the Russian government has introduced a new cycle of strategic documents and implementation programmes, laying down the foundations and major objectives of STI policies for the medium term and long term. A most essential document, *The Strategy for S&T and Innovation in the Russian Federation until 2015* (2006), establishes crucial new approaches to promoting allied activities, as well as a system of programmes and other policy instruments that are interrelated in terms of tasks, timelines, resources and target indicators.

Another key document is the federal target-oriented programme *Research and Development in Priority Areas for S&T Development in Russia for 2007–2012* (2006). It aims to ensure accelerated development of the key segments of the national innovation system that have immediate links to priority S&T areas.

More generally, concern over how to address new global and national challenges underpins the president's report *On the Strategy for Russia's Development to 2020* (2008) and the aforementioned *LTDP-2020* with the same horizon of 2020. The report's emphasis on the need to shift towards an innovation-based scenario, dictated by the current state of the national economy, is of utmost importance. It also suggests that lessons could be learned from the experience of other nations that have succeeded in retaining or improving their global position by relying on effective institutions and instruments of innovative growth. Both documents also fix long-term objectives for S&T and socio-economic development in Russia consistent with global trends and national specificities and capabilities.

Despite their inevitable adjustment in 2009 due to the global recession, the measures outlined in *LTDP-2020* will, in the long run, make it possible to tackle the principal systemic problems facing the national S&T sector, namely an inefficient utilization of resources allocated to R&D, combined with weak industrial demand for innovation. In particular, *LTDP-2020* outlines four broad policy objectives for strengthening STI:

- promoting industrial demand for new technology and innovation;
- increasing the quality and scale of national R&D output;
- developing human capital capable of meeting the challenges and requirements of an innovative economy; and
- establishing an effective system for fixing and attaining R&D objectives and for setting and implementing long-term R&D priorities.

SETTING NEW PRIORITIES FOR R&D

Russia has an established system for identifying and implementing R&D priorities so that resources can be distributed effectively to a limited number of fields in compliance with national development objectives, internal and external challenges and limitations. The current list of S&T priorities was approved by the President of the Russian Federation on 25 May 2006. It includes eight priority areas and 34 critical technologies. This list is intended to help Russia address global issues, ensure national competitiveness and promote innovation in key areas. It is also expected to evolve over time in both size and scope (Table 2). This list was used to design the federal target-oriented programme *Research and Development in Priority Areas for S&T Development in Russia for 2007–2012*. This was in turn followed by a government resolution *Approving the Rules for Setting Up, Adjusting and Implementing S&T Priority Areas and the List of Critical Technologies of the Russian Federation* (2009).

A persistant priority: ICTs

A national S&T foresight exercise to 2025 was carried out in Russia in 2007–2008 to develop a better approach to identifying promising S&T areas and assessing their technological potential for improving the competitiveness of domestic industry. Figure 6 shows the results for the field of ICTs obtained from a Delphi survey[1] conducted within the framework of the same foresight exercise. These estimates are used in strategic documents on socio-economic development and to define government policies for STI. A new round of the foresight exercise up to 2030 was initiated by the Ministry for Education and Science in 2009.

An emerging priority: nanotechnology

Since the *Strategy for Nanoindustry Development* was published at the President's initiative in 2007, great importance has also been attached in Russia to the development and wider use of nanotechnology (President of the Russian Federation, 2007). Owing to the economic crisis Russia experienced in the first half of the 1990s in its transition to a market economy, the country joined the global nanotechnology race a little late. As a consequence, its domestic 'nanomarket' is still in the early stages. Nonetheless, the country has managed to preserve its scientific potential in this domain, along with its world-class expertise and unique scientific facilities, which include synchrotron and neutron sources and atomic force microscopy. Russia figures among the global leaders in a number of specific areas of nanotechnology, including the development of new construction materials, catalysts and catalytic membranes; the production of biochips for rapid analysis and diagnostics of dangerous infections and diseases; light-emitting diodes and advanced light sources; and new technological and diagnostic equipment using these advanced technologies. Figure 7 shows how the level of Russian nanotechnology R&D in certain areas compares with state-of-the-art nanotechnology worldwide.

In order to mobilize organizational, material, financial and intellectual resources in this priority area, earmarked government programmes are being implemented. The list includes:

- the Programme for Nanoindustry Development in Russia to 2015;
- the federal target-oriented programmes for the Development of Nanoindustry Infrastructure in Russia for 2008–2010 and for Research and Development in Priority Areas for S&T Development in Russia for 2007–2012. The latter includes the priority area 'industry of nanosystems and materials'; and
- specialized publicly funded programmes in nanotechnology conducted by state science academies and science foundations.

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1. The Delphi method uses a series of surveys to gather feedback from experts on possible developments in particular areas in order to establish a collective vision of the future.

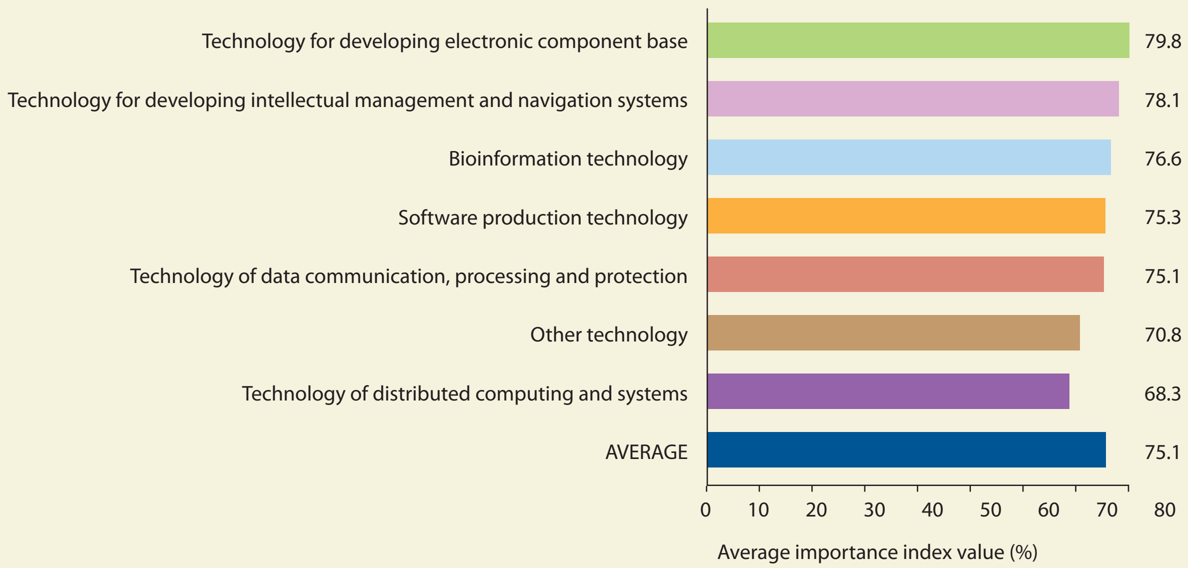
Table 2: Evolution of priority areas for R&D in Russia, 1996, 2002 and 2006

1996 *Basic research*	**2002**	**2006***
Information technologies and electronics	Information and telecommunication technologies and electronics	Information and telecommunication systems (18.1%)
New materials and chemical technologies	New materials and chemical technologies	Industry of nanosystems and materials (9.2%)
Transportation	New transportation technologies	Transportation, aviation and space systems (44.6%)
Manufacturing technologies	Manufacturing technologies	
Living systems technologies	Living systems technologies	Living systems (5.9%)
Ecology and rational utilization of nature	Ecology and rational utilization	Rational use of natural resources (8.7%)
Fuel and power engineering	Energy-saving technologies	Power engineering and energy saving (5.1%)
	Space and aviation technologies	
	Armaments, military and special equipment	Arms, defense and special technologies
		Safety from terrorism, counterterrorism activities

* In brackets is the percentage of GERD allocated to priority areas of civil-purpose S&T that is funded from the federal budget.

Source: Sokolov, A. (2006) *Identification of National S&T Priority Areas with Respect to the Promotion of Innovation and Economic Growth: the Case of Russia,* pp. 100–101; HSE (2010) *Science and Technology. Innovation. Information Society*

Figure 6: Ranking of ICT areas by importance for Russia, 2008 (%)



Source: HSE (2008*b*) *Russian S&T Delphi: 2025*

It is expected that, by 2015, all the necessary conditions will be in place for large-scale manufacturing of new nanotechnology-related products in Russia and for Russian nanotech companies to enter global markets.

In 2008–2009, the Higher School of Economics' Institute for Statistical Studies and Economics of Knowledge in Moscow developed a new statistical methodology for collecting data regularly on sales of nanotechnology-related products in Russia. This project was carried out jointly with the Russian Corporation for Nanotechnology (Rosnano) and the Federal Statistical Service (Rosstat). Sales of nanotechnology-related products in 2009 have been estimated at around 120 billion roubles (approximately US$4 billion), a figure that could grow to seven or eight times this amount by 2015.

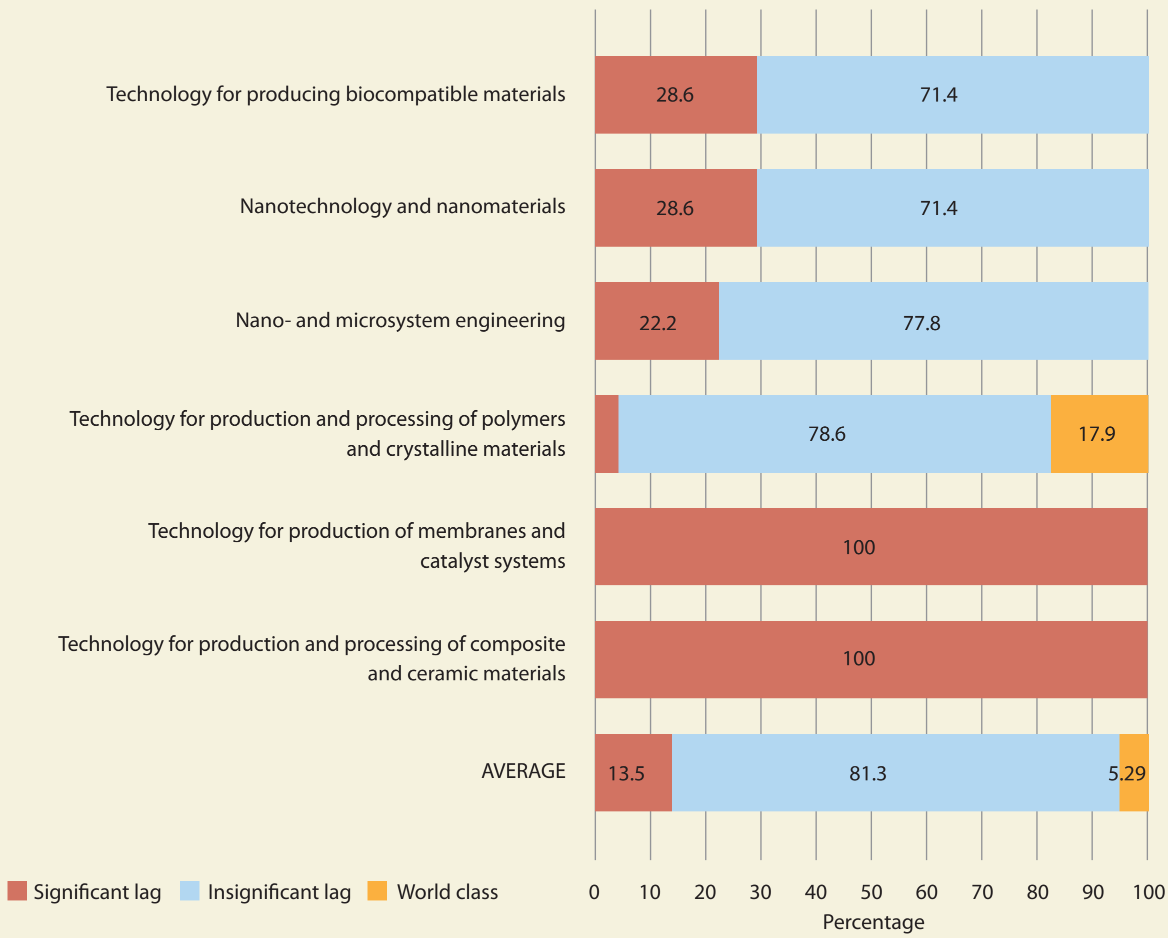
RESTRUCTURING THE R&D SECTOR

A new status for R&D institutions

The traditional dominance of the state-owned, state budget-funded institutions that was characteristic of the Soviet R&D model remains one of the key features of the Russian S&T sector (Gokhberg *et al.,* 1997). During the transition to a market economy, various types of commercial and non-profit R&D organizations were allowed to develop but government R&D organizations underwent little change. Nearly 43% of R&D institutes in Russia are still fully government-funded.

Just as national legislation imposes strict limitations on public universities, so too does it on R&D institutes.

Figure 7: Level of Russian R&D in nanosystems and materials, 2008 (%)



Source: HSE (2008b) *Russian S&T Delphi: 2025*

In many instances, this legislation contradicts academic freedom and economic reality. Government R&D institutes claim significant budgetary allocations but are not expected to provide any guarantees as to the efficient use of their budget. As a result, there is no immediate link between performance and funding. This is particularly true of state science academies (Box 3).

A new, more flexible legal model for state-owned institutions has been provided by the federal Law on Autonomous Institutions (2006). The new structures will be funded through lump-sum subsidies rather than through fixed budgetary institutional grants broken down by specific cost items, as is the case at present. This new approach is expected to provide better and more flexible opportunities for the development of research institutions and should increase their accountability when it comes to research results. Although they will remain government-owned entities, the new institutions will enjoy a certain autonomy in attracting – and spending – funds from non-governmental sources, including loans and investments.

Another important domain of organizational change in the Russian R&D landscape is the plan to establish several large-scale national research centres in order to ensure high-tech sectors obtain cutting-edge technology for the development of new products and processes. These new centres are also expected to enjoy greater autonomy than in the past. The first such research centre is the Kurchatov Institute in Moscow. It has been responsible for co-ordinating research in nanotechnology and an allied network in Russia; three R&D institutes were subordinated to the Kurchatov Institute in 2009.

Evaluation of R&D units' performance

Efficient restructuring, coupled with improvements in the way state-funded R&D institutions operate, requires comprehensive tools for performance evaluation. Such instruments are widely used in many countries where they have proven their worth. During the immediate post-Soviet period in Russia, research evaluation exercises were mostly confined to the procedures followed by government agencies and state foundations when deciding which competing R&D projects to finance; the actual output of R&D institutions was not evaluated. This situation caused R&D spending from the federal budget to spiral upwards between 1998 and 2008. Spending tripled, even as the growth rate of certain output indicators fell below zero. To reverse the trend, a government policy statement was adopted in 2008, entitled *On the System of Performance Evaluation for Civil R&D Organizations*. Its main goals are to establish procedures and criteria for regular performance assessments of government R&D organizations and to optimize their network. The policy calls for a statistical survey to be conducted every five years, combined with

Box 3: Modernizing Russia's Academies of Science

The Russian network of state academies includes the Russian Academy of Sciences and the five academies for agriculture, medicine, architecture and construction, education and arts. Together, these academies control 865 research institutes which employed a total of 137 500 R&D personnel in all occupational categories in 2008. Over two-thirds of R&D personnel are employed by the Russian Academy of Science's 468 institutes.

The most unusual feature of the academies` legal status is their 'mixed' nature, combining elements of a government institution, public association and corporation. In reality, academies act as holdings, 'owning' non-profit organizations. As government institutions, the academies are responsible for managing, controlling, creating and closing these organizations.

The most worrying issue is the mismatch between, on the one hand, the amount of public resources spent on funding research and running costs like maintenance of the academies' premises and, on the other hand, the performance of the academies in terms of R&D output.

In 2005, a programme was adopted to modernize the structure, functions and funding mechanisms of the state academies of science. The aim was to streamline the network of institutes governed by the academies. Some which did not meet quality standards were to be closed, staff numbers were to be reduced and salaries increased. Also envisaged was the reorganization of the way in which R&D was conducted to improve efficiency. This programme was supposed to be fully implemented by 2008 but had still not been completed in early 2010.

Source: authors

reviews by evaluation commissions involving major interest groups, such as government agencies, businesses, academia, the scientific community and nongovernmental organizations.

Evaluation criteria are based on the relationship between input and output. At the end of the evaluation process, every R&D organization will be assigned to one of three performance groups: the leaders, middle-runners or outsiders. Subsequent recommendations can then vary from closure for outsiders to earmarked support for leaders.

A better legal framework for IPRs and the commercialization of new technologies

In recent years, the government has made a determined effort to promote the market for intellectual assets in Russia and develop a national system for registering and controlling publicly funded research projects. It has also created a single legal and organizational tool addressing intellectual property rights (IPRs) generated at the expense of the federal budget. The idea is to involve them in the economic turnover more widely and effectively than before.

In 2005, the government adopted two resolutions to improve the efficiency of intellectual property protection and promote lawful business transactions, co-ordinate the activities of partner agencies and strike a balance between the interests of all stakeholders. These are entitled *On the Procedure for Disposing of Rights to the Results of S&T Activity* and *On Government Registration of the Results of Civil-Purpose R&D.*

Subsequently, the government focused on developing and enforcing legislation to regulate the commercialization of technologies and protect related rights. In 2006, the Parliament adopted a new Part IV of the *Civil Code* which was designed to regulate intellectual activities in Russia. Two years later, the Law on the Transfer of Rights to Integrated Technology was adopted. This law aims for a multiple use of IPRs due to greater patenting and licensing activities. IPRs created at the expense of the federal budget will be transferred to market actors on the basis of open competition. This will allow public R&D organizations and universities to sell technologies developed under government-funded contracts to companies which, in exchange, will be obliged to commercialize these technologies. Subsequently, most publicly financed IPRs will not remain in state possession out of the reach of industrial demand but rather will enter into market transactions.

The ultimate objective of these and other laws and regulations is to improve the economic, legal and organizational framework for the commercialization of technologies to generate income from this activity and make the national R&D sector more competitive. Another important objective is to harmonize national legislation with the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), in order for Russia to meet the requirements for joining the World Trade Organisation.

Promoting public–private partnerships

Faced with the low demand for innovation and an insufficient influx of private investment into high-tech industries, the government decided to set up the Russian Venture Company (RVC) in 2006. This move was complemented by the founding of sector-specific state corporations, such as Rosnano (nanotechnologies), Rosatom (nuclear energy) and Rosteknologii (Russian Technologies) in 2007 and 2008.

The role of the RVC is to promote the investment of venture capital and other forms of financial support for S&T countrywide. Resources for its capitalization are allocated from the Investment Fund of the Russian Federation. The RVC then invests in regional and sectoral venture companies. The financial role of the sector-specific state corporations is to ensure that resources are concentrated in areas of national interest. As a rule, these corporations are established by special federal laws that determine their legislative framework, goals and organizational principles. For example, Rosnano is specifically dealing with the growing challenges posed by the rapid development of new nanotechnologies. Its key objectives include the commercialization of nanotechnology, investment in nanotechnology-related new businesses and infrastructure and the development of professional training in this field (Gokhberg *et al.*, 2009*a*; HSE/IWEIR, 2008).

Tax incentives for strengthening R&D and innovation

After much debate, several new regulations for reducing the tax burden on R&D and innovation were adopted in 2007, followed by tax breaks established by the latest changes to the *Tax Code* taking effect in 2008. The most important novelties include new rules for calculating value-added tax (VAT), a tax on profits, and an overall simplification of the taxation system. For example, profits generated by selling or licensing IPRs are now exempt from VAT. A list of tax-exempt services that support the development of new or improved products was also approved. Regarding the taxing of profits, the list of R&D-sponsoring foundations whose goal-oriented funding does not have to be included in the calculation of the taxation base at R&D organizations has been lengthened. In addition, more favourable accelerated depreciation conditions have been introduced for R&D fixed assets.

These innovation–friendly taxation instruments will help to create a more favourable climate for innovation. In order to encourage business investment strategies to promote R&D and innovation further, a new round of tax legislation initiatives was launched recently. For example, in 2009, the government introduced tax benefits for entities investing in R&D and priority S&T areas, such as bio- and nanotechnology, nuclear energy and new types of transport system. The next round of favourable tax novelties will take effect in 2010, with a particular emphasis on easing conditions for compulsory social security payments for employees of companies whose main economic activities are ICT development, engineering and R&D; and tax breaks for profits generated by medical and educational services. It is planned to simplify the procedure for customs registration of imports of high-tech equipment and materials, as well as to introduce financial guarantees for exports of high-tech products.

Improved infrastructure for innovation

Infrastructure for technology commercialization and transfer makes up an important part of Russia's national innovation system. This infrastructure includes 66 technology transfer centres, 84 technoparks, 174 innovation and technology centres, and 81 business incubators. In most cases, these are associated with research institutes or universities (HSE, 2008*b*).

Government schemes to strengthen infrastructure promoting innovation have primarily been concentrated in three areas:

Technoparks

There are dozens of technoparks in Russia, although technopark policies are fraught with problems due to multiple 'white spots' in the legislation that dramatically weaken the capabilities of universities and R&D institutions to commercialize new technologies. On account of their legal status, state universities and government R&D institutions have limited rights when it comes to creating or directly supporting innovative small and medium-sized enterprises; in particular, they are not allowed to provide any funding or facilities for start-ups[2]. That is why Russian technoparks either do not function autonomously but rather as part of a 'host organization', or do not engage in innovation at all, merely leasing the premises and facilities to others.

To make better use of technoparks, the government is considering the following options: providing technoparks with federal land on a competitive basis, both for purchase and long-term leasing; direct investment in technopark infrastructure by government agencies and publicly sponsored venture companies; and sharing costs between federal and regional authorities.

Special economic zones

These were introduced in Russia in 2005 in order to provide a favourable regime for innovative entrepreneurship in certain areas of S&T. Particular locations were identified specifically to encourage the development of new high-tech businesses. Special economic zones can be found in Saint Petersburg, Dubna, Zelenograd, Tomsk and elsewhere.

Science cities

The concept of science cities follows the Soviet-era tradition of urban settlements specialized in S&T. At one time, about 70 municipalities were ranked as science cities, 29 of which were located in the Moscow region. During the 1990s, their heavy reliance on S&T activities resulted in economic and social hardship. In a new approach, the government is determining priorities for each city and a state programme for S&T development, with specific forms of federal support. Science city funding, along with assistance with logistics and maintenance, is provided by the federal budget, by the budgets of regional and local authorities, and by other funding sources. Once science city status for 25 years is confirmed by the President of the Russian Federation, this decision serves as a catalyst for the allocation of additional federal funding on a competitive basis for the implementation of innovation projects. In addition, more efficient mechanisms for transferring federal funds to local innovation-related initiatives are to be introduced in 2010–2011 through amendments to existing legislation.

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2. A special law to eliminate these barriers was adopted in 2009 and further legislative initiatives in this direction are in the pipeline.

INTERNATIONAL CO-OPERATION IN S&T

In order to facilitate its integration in the global S&T arena and assume a greater role, Russia has been stepping up its efforts to develop international co-operation. A crucial aspect of this co-operation are the ties with the EU, international organizations and regional economic associations.

The *Agreement on Co-operation in Science and Technology between the European Community and the Government of the Russian Federation* was adopted in 1999. Although this formally expired in 2007, both sides have agreed to prolong its validity until a new accord can be signed. A road map for setting up the EU–Russia Common Space of Education and Science has been developed jointly with the European Commission on the basis of the principles of equality and partnership, taking into account the mutual interests of both parties. At the same time, the EU and Russia are strengthening the co-ordination of their priorities for S&T and innovation in areas that include new materials, nanotechnology, non-nuclear energy production, ICTs and biotechnology in fields such as food and health. These efforts have already yielded a growing number of joint initiatives, including co-ordinated calls, for project proposals. Thus, for the EU's Sixth Framework Programme for Research and Technological Development (2002–2006), Russia ranked first among participating third parties, both in terms of the number of projects implemented with European partners and the amount of funding obtained from the EU (European Commission, 2009). Moreover, bilateral discussions regarding Russia's association with the EU Framework Programme started in 2008–2009.

Strategic importance is also attached to contacts with the European Organization for Nuclear Research (CERN), the Organisation for Economic Co-operation and Development (OECD) and other international bodies. Apart from the obvious benefits associated with access to modern multilateral programmes and facilities, participation in international projects allows Russian companies to secure large-scale orders. Other projects make it possible for Russia to adapt and adopt efficient instruments for promoting S&T and innovation. These instruments include various forms of public–private partnership, technology foresight exercises, cross-country co-operation and technology transfer, and support for small and medium-sized enterprises.

In addition, Russia continues to participate in most of the international projects and alliances involving space research, including the International Space Station in low orbit above the Earth[3] and the 'Sea Launch'.[4] These partnerships are supported by the Russian Space Agency, which considers them an essential element for implementing the national space programme. Russia is also an active participant in the International Committee on Space Research (COSPAR) and the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS).

Within the framework of international S&T co-operation, many joint laboratories, research, education and innovation alliances and partnerships have been established. Examples include joint laboratories organized with the participation of Russian research centres and universities together with the Dutch Organisation for Applied Research (TNO), CNRS (France), Industrial Technology Research Institute (Chinese Taipei), partner organizations from the Republic of Korea, etc., in chemistry, biology, nanotechnology and other S&T fields. In addition, legal and organizational tools for co-operation at both intergovernmental and interdepartmental levels have been improved. It is even more promising that a growing volume of commercial contracts and agreements are being concluded in the S&T sector with other countries and that an increasing number of joint ventures are being set up in Russia. Thus, the joint–stock enterprise Alcatel-Lucent RT established by the respective French company and state corporation Russian Technologies is starting to invest in 2010 in the development, manufacturing and marketing of telecommunications equipment for the Russian market and those of the countries of the Commonwealth of Independent States[5]. Rosnano and its Italian partner company Galileo Vacuum Systems is launching a new company to produce Radio Frequency Identification (RFID) labels at manufacturing units located

3. The assembly of the International Space Station is expected to be completed by 2011. The project involves the American National Aeronautics and Space Administration (NASA), Canadian Space Agency (CSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA) and Russian Federal Space Agency (RKA).

4. Sea Launch is a unique, mobile platform from which spacecraft can be launched and rockets fired at sea from an optimum position on the Earth's surface. It involves a consortium of four companies from Norway, Russia, Ukraine and the USA.

5. The CIS consists of nine former Soviet republics. See Annex I for the list of CIS countries.

in Russia, Italy and Serbia. The Russian side will contribute 49% of the requisite investment and the company will be a proprietor of any technologies that are developed. Meanwhile, the jointly owned US–Russian company IsomedAlpha has begun production of high-tech medical equipment like computer tomographs.

These international partnerships are making it possible to increase exports of high-tech products and services in certain areas. For example, in 2005–2007, exports of Russian ICT products doubled and those of electronic equipment, aircraft and spaceships grew by 40–50% (HSE/IWEIR, 2008; HSE, 2009*c*, p.65).

CONCLUSION

As 2010 gets under way, Russia, like other nations, is in the throes of a highly complex global economic recession. Owing to its national peculiarities, the country not only enjoys certain advantages – primarily, its huge resource potential and substantial financial reserves – but also faces great challenges in its efforts to recover from the economic recession. The need to innovate in response to the crisis is obvious and is confirmed by the fact that most industrial nations are implementing economic recovery packages. These programmes normally focus on improving macro-economic parameters and on ensuring national competitiveness in the post-crisis period. To this end, the recovery packages of these countries envisage measures for supporting promising areas of S&T, as well as indirect incentives for innovating companies.

The Russian government today favours the same approach. Anti-crisis measures that are clearly innovation-oriented, along with other initiatives, are placing considerable demands on the R&D sector. This requires prompt intervention to move institutional reforms forward in order to overcome the lack of co-ordination at the departmental level, lower persisting administrative barriers between science, education and industry, and increase the efficiency of R&D organizations. This should lead ultimately to the concentration of resources in the centres of excellence created in leading research institutes and universities. These centres of excellence should be able to ensure the delivery of cutting-edge achievements in basic science, as well as applied results and technology that can meet growing demand from the national economy. This should be accompanied by additional policy measures to provide greater opportunities for public research bodies and universities to participate in innovation, facilitate academic mobility and radically modernize the professional training of scientists and engineers.

At the end of the day – recession or not – Russia will have no choice but to improve substantially the efficiency of its national S&T sector and innovation policies. All the necessary transformation processes have undoubtedly been set in motion but they call for a stronger focus on the part of all stakeholders; direct and indirect systemic support from the government; forward-looking innovation-based company strategies; and for monitoring of both the steps taken and their impact.

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The [countries of Central Asia] should take advantage of the vast potential for international scientific co-operation offered by their close political, historical and cultural ties. It would be mutually beneficial for their scientific communities to join forces to improve environmental and food security in the region, conserve and use natural resources sustainably and stabilize national economies

Ashiraf Mukhammadiev

12 · Central Asia

Ashiraf Mukhammadiev

INTRODUCTION

Central Asia covers a vast territory consisting of deserts, steppes and mountains. Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan are all primarily agrarian economies: about 70% of the total surface area (418 million hectares) is classified as agricultural land. In theory, 15 % of agricultural land is irrigated but the true figure is closer to 3%. The contribution of the agriculture sector to the national economy varies from 31% in Kyrgyzstan to just 6% in Kazakhstan (Figure 1).

The region has one of the most varied plant collections in the world: fruit, nuts, grains and beans but also wild relatives and ancestors of food crops which are of regional and global importance. The intensification of grain crop production and overgrazing are threatening the region, however, with the loss of local varieties and wild relatives of cultivated plants. The fact that all five countries have ratified or otherwise endorsed several international agreements[1] over the past 15 years related to environmental protection and the conservation of genetic resources offers governments a policy framework for tackling problems of global importance, such as climate change, desertification and loss of biological diversity.

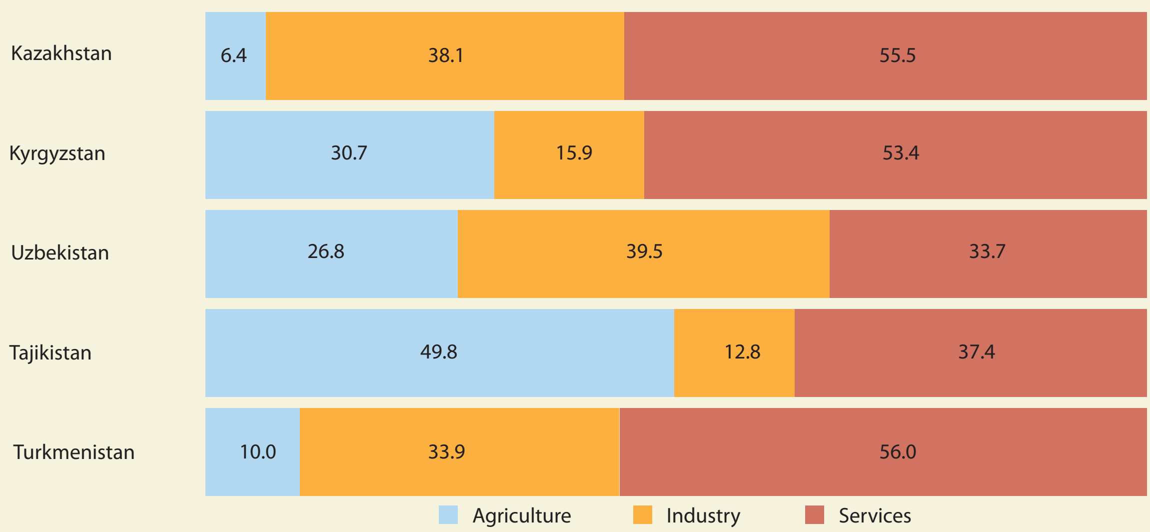
Central Asia has so far escaped largely unscathed from the global economic recession. Unlike many post-Soviet countries which are experiencing a sharp recession, including giants Russia and Ukraine, the economies of the five Central Asian countries studied here are holding their own, even if it is too early for this to be reflected in the data (Table 1).

All but Turkmenistan belong to the Commonwealth of Independent States (CIS), a loose association of nine former Soviet republics[2]. The Eurasian Economic Community (EAEC) is increasingly appearing as a more unifying body, especially as several countries have withdrawn from the CIS in recent years, including Georgia in 2008. The EAEC originated from a customs agreement between Belarus, the Russian Federation and Kazakhstan in 1996 and was joined by Tajikistan four years later. In 2010, the EAEC was working towards establishing a common energy market and exploring ways to use water more efficiently in Central Asia. More than a purely economic association, the EAEC offers potential for the development of co-operation in science and technology (S&T) in the region.

1. Including the UN Convention on Biological Diversity, UN Framework Convention on Climate Change and UN Convention to Combat Desertification.

2. See Annex I for the list of CIS countries.

Figure 1: Composition of GDP in Central Asia by economic sector, 2009 (%)



Note: In each case, the percentage share is an estimate.

Source : https://www.cia.gov/library/publications/the-world-factbook/

The Big Solar Furnace in Uzbekistan hosts a laser powered by the 12-storey high concave mirror seen here. It translates solar energy into laser radiation

Photo: © UNESCO/ Alexandr Osipov

Table 1: Socio-economic indicators for Central Asia, 2002 and 2008 or most recent year available
Other countries are given for comparison

	GDP (PPP US$ millions)		GDP per capita (PPP$ US$)		High-tech exports in manufactured exports (%)		Adult literacy (%)	Knowledge Index (ranking out of 145 countries)		Knowledge Economy Index (ranking out of 145 countries)	
	2002	2008	2002	2008	2002	2007	2008	1995	2005–2006	1995	2005–2006
Kazakhstan	92 446	177 354	6 222	11 315	4.9	23.2	99.7**	55[x]	70	76[x]	72
Kyrgyzstan	7 165	11 549	1 435	2 188	5.7	2.4	99.3**	81[x]	89	90[x]	84
Tajikistan	6 859	13 027	1 087	1 906	–	–	99.7**	75[x]	105	97[x]	106
Turkmenistan	3 441	33 389	2 903	6 641	–	–	99.5**	–	–	–	–
Uzbekistan	40 202	72 547	1 591	2 656	–	–	99.2**	64[x]	94[x]	89[x]	104[x]
Armenia	8 071	18 678	2 637	6 070	1.9	2.0	99.5**	57[x]	65[x]	66[x]	56[x]
Azerbaijan	22 459	76 072	2 748	8 765	8.9	3.9	99.5[-1]	63[x]	91	80[x]	97[x]
Belarus	58 959	118 695	5 940	12 261	4.2	2.7	99.7**	41	52	56	73
Georgia	11 268	21 370	2 442	4 896	45.8	7.1	99.7**	50[x]	71	61[x]	69
Republic of Moldova	6 361	10 628	1 606	2 925	3.9	5.1	97.3**	6 568	74	71	–
Mongolia	4 838	9 388	1 976	3 566	0.5	7.5	98.3**	102[x]	81[x]	98[x]	78[x]
Ukraine	192 531	336 355	3 994	7 271	4.8	3.6	99.7**	43[x]	46	52[x]	51

-*n* = data refer to *n* years before the reference year
* national estimate
** UNESCO Institute for Statistics estimate
x = incomplete data

Source: for population: United Nations Department of Economic and Social Affairs (2008) *World Population Prospects: the 2008 Revision*; for GDP, high-tech exports, KI and KEI: World Bank, *World Development Indicators*, April 2010; for adult literacy: UNESCO Institute for Statistics, April 2010

R&D INPUT

R&D expenditure remains low

R&D funding has remained low over the past decade in all five republics and throughout Central Asia. No country in the region devoted more than 0.25% of GDP to gross domestic expenditure on R&D (GERD) in 2007 (Table 2).

In the five countries under study, R&D is conducted by 836 organizations in total (Table 3). On average, 21.5% of GERD is invested by universities and other institutions of higher learning. Government laboratories account for much of the remainder (62.6%). The role of the private sector varies considerably from one country to another. In Kazakhstan, business contributes 45% of GERD, compared to just 2% in Tajikistan (Figure 2). Data on R&D is unfortunately unavailable for Turkmenistan.

The 'Soviet generation' is nearing retirement

The five countries under study can boast of good institutional infrastructure, a solid legislative base and qualified experts inherited from the Soviet era, assets that provide a solid foundation for the development of S&T. Two-thirds of R&D is conducted by government institutes (64.5%) [Figure 3].

It is Uzbekistan which counts the greatest number of researchers per million population (Table 4). At 954, this ratio is close to the world average of 1 081 and is higher than the average for CIS countries in Asia as a whole (526) [*see page* 8].

The low numbers of research personnel should be a policy concern for many Central Asian countries, all the more so in light of the ageing R&D personnel. In Kazakhstan, 13% of Doctors of Science are more than 60 years old, compared to 11% in Tajikistan and Uzbekistan. The proportion is even higher in Tajikistan for

Table 2: Investment trends in Central Asia, 2002 and 2008
Other countries are given for comparison

	Total expenditure on health (% of GDP)		Public expenditure on education (% of GDP)		Expenditure on tertiary education (% of total expenditure on education)		GERD/GDP ratio (%)		GERD per capita (US PPP$)	
	2002	2006	2002	2008	2002	2008	2002	2007	2002	2007
Kazakhstan	3.6	3.7 3.0		2.8^{-1}	13.1	13.9^{-1}	0.26	0.21	15.8	22.9
Kyrgyzstan	5.4	6.4	4.4	6.6^{-1}	19.6	15.9^{-1}	0.20	0.25	2.8	4.9
Tajikistan	4.5	5.0	2.8	3.5	12.1	14.2	0.07	0.06	0.8	1.1
Turkmenistan	4.0	4.8	–	–	–	–	–	–	–	–
Uzbekistan	5.6	4.7	–	–	–	–	–	–	–	–
Armenia	5.6	4.7	2.1	3.0^{-1}	–	–	0.25	0.21	6.7	11.8
Azerbaijan	4.7	3.4	3.2	1.9	5.8	7.9	0.30	0.18	8.6	13.9
Belarus	6.6	6.4	6.2^{-2}	5.2^{-1}	–	20.2^{-1}	0.62	0.97	36.9	105.3
Georgia	8.7	8.4	2.2	2.9	–	11.6	0.19	0.18^{-2}	4.5	6.2
Republic of Moldova	6.4	7.8	7.9	5.1^{-1}	15.5	18.4^{-4}	0.32^{+1}	0.55	6.2*	14.8*
Mongolia	6.0	5.1	5.5	8.2	–	18.6	0.28	0.23	5.5	7.4
Ukraine	6.6	7.0	5.4	5.3^{-1}	34.0	28.8^{-1}	1.00	0.87	40.0	60.1

-n/+n = data refer to *n* years before or after reference year
* national estimate

Source: for education and GERD: UNESCO Institute for Statistics, April 2010; for health: World Health Organization (2009) *World Health Statistics 2009*

holders of a Candidate of Science[3] degree: 20% (Table 5). The problem will become more acute when the 'Soviet generation' retires in 2012–2015. It should thus be attracting greater attention in government policy circles.

Moreover, among the up and coming generation, the proportion of students studying for a Candidate of Science degree is much lower than the proportion of those studying for a Doctor of Science degree, a situation reversed in the case of researchers. This suggests that the number of scientists with a high level of specialization will decline in coming years.

To make matters worse, rare are those who successfully defend their thesis. On average, just 8% of candidates obtain their Candidate of Science degree in Kazakhstan, 22% in Uzbekistan and 15% in Tajikistan. The main reason for student's low success rate lies in the inadequate government funding for postdoctoral research. Furthermore, the subject of student theses, which tend to be confined to basic research, rarely corresponds to government priorities. A third explanation can be found in the falling prestige of researchers in a society where the market now wields considerable influence.

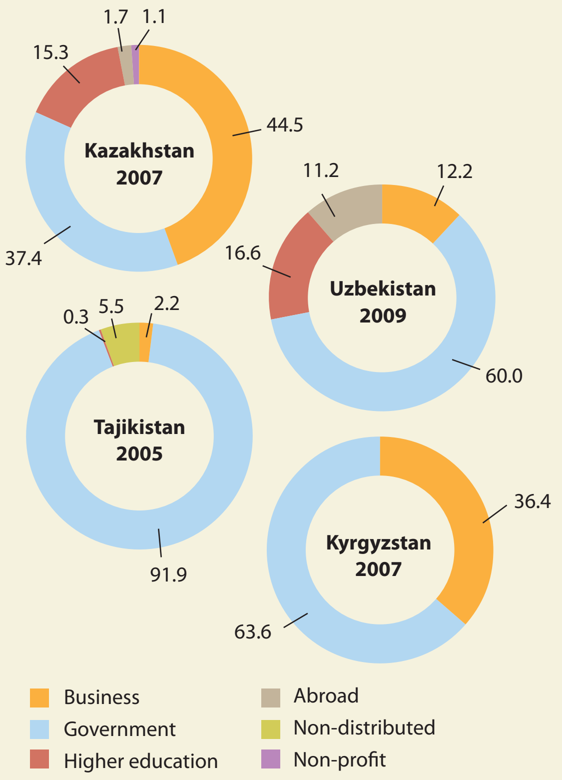
Table 3. R&D institutions in Central Asia, 2009

		Institutions of higher education		Research institutes, design bureaux, etc.	
	Total	Number	%	Number	%
Kazakhstan	438	167	38.2	271	61.8
Kyrgyzstan	64	31	48.4	33	51.6
Tajikistan	65	12	18.5	53	81.5
Turkmenistan	45	16	35.5	29	64.5
Uzbekistan	224	71	31.7	153	68.3
Total	836	297	35.5	539	64.5

Source: national data

3. The Central Asian republics still use the Soviet system of higher education. See Figure 3 on page 220.

Figure 2: GERD by source of funds in Central Asia, 2009 or most recent year available (%)
Selected countries



Source: UNESCO Institute for Statistics; for Uzbekistan: reporting data of the Committee for the Co-ordination of the Development of Science and Technology, Tashkent, 2009

COUNTRY PROFILES

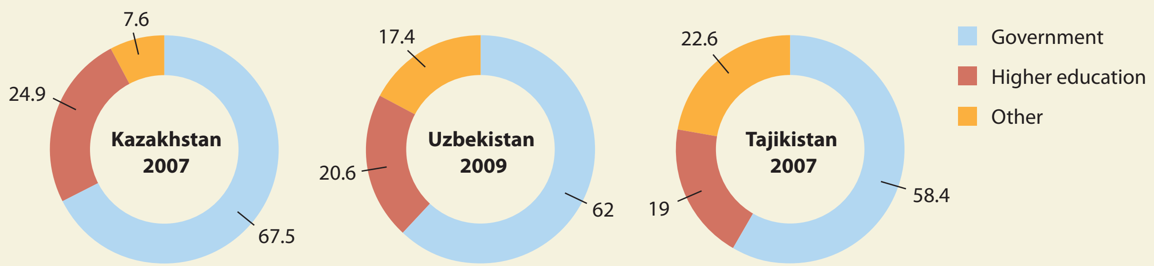
Kazakhstan

Kazakhstan has a relatively good capacity for R&D, as evidenced by the pool of qualified personnel and the 1 169 patents accorded in 2009. Kazakh scientists contributed 0.02% of articles to international journals in 2008, or one article per nine scientists, a figure close to the global average. It is evident that, with greater government support, Kazakh R&D could make a substantial contribution to both GDP and world science.

At present, Kazakhstan devotes just 0.21% of GDP to GERD, a figure comparable to the R&D effort of other Central Asian countries but well below the global average of 1.7% (*see page* 2). A GERD/GDP ratio of 2% has been proposed as the safety threshold for economic growth. With investment levels being too low to cover the cost of R&D in Kazakhstan, scientists are at a disadvantage. The government has fixed a number of targets for remedying the situation within a strategic programme for an Intellectual Nation – 2020 which is discussed overleaf.

Industry contributes more than one-third of GDP (Figure 1). The main branches are mining, non-ferrous and ferrous metallurgy, mechanical engineering, oil refining and petrochemistry, as well as the production of building materials. According to the national statistics agency, in 2008, half (51%) of R&D funding was provided by the government, 29% by customers of R&D services, 18% came from the institute's own funds and 1.7% from foreign sources. One state enterprise that provides customer R&D

Figure 3: Distribution of research institutions in Central Asia, 2009 or most recent year available (%)
Selected countries



Source: Paroda (2004) *Problem-solving for the sustainable development of agriculture in Central Asia*; Suleimenov *et al.* (2008) *Status and trends in development of scientific and technical capacity in the Republic of Kazakhstan*; Najmudinov (2009) *The Scientific and Technical Capacity of the Republic of Tajikistan in 2007*; Mukhammadiev (2008) *Coordination of the Development of Science and Technology in the Republic of Uzbekistan*

Table 4: R&D personnel in Central Asia, 2009 or most recent year available

Selected countries

					Holders of a Doctor or Candidate of Science degree				Postgraduate and postdoctoral students			
	Population (millions)	Researchers per million population	Total research personnel (including technicians)	Total researchers	Doctors of Science	% of researchers	Candidates of Science	% of researchers	Doctor of Science candidates	Doctor of Science graduates (success rate %)	Candidate of Science students	Candidate of Science graduates (success rate %)
Kazakhstan (2007)	17.1	674	11 524	4 224	1 166	27.6	3 058	72.4	2 200	8.0	508	21.0
Kyrgyzstan (2007)	5.1	490	2 500	851	251	29.5	600	70.5	–	–	–	–
Tajikistan (2007)	6.9	814	5 617	2 686	596	22.2	2 090	77.8	864	15.4	43	22.5
Uzbekistan (2009)	27.4	954	26 145	11 952	2 721	22.8	9 231	67.3	2 540	22.0	260	25.3

Source: Najmudinov (2009) *The Scientific and Technical Capacity of the Republic of Tajikistan in 2007*; Suleimenov *et al.* (2008) *The Dynamics of the Scientific and Technical Capacity of the Republic of Kazakhstan in 2000-2007*; Suleimenov (2009) Scientific development in the Republic of Kazakhstan; Statistical Office (2009) *Science, Technology and Innovation Indicators for the Republic of Uzbekistan*

Table 5: Age pyramid for Central Asian researchers, 2009 or most recent year available

Selected countries

	Kazakhstan (2007)		Tajikistan (2007)		Uzbekistan (2009)	
		%		%		%
Doctors of Science	1 166	27.6	586	22.2	2 721	22.7
younger than 40 years	24	0.6	1	0.04	63	0.5
40–59 years	580	13.7	289	10.7	1 309	10.9
60 years +	562	13.3	306	11.4	1 349	11.3
Candidates of Science	3 058	72.4	2 090	77.8	9 231	77.2
younger than 40 years	793	18.8	445	16.6	1 800	15.2
40–59 years	1 628	38.5	1 119	41.6	5 026	42.0
60 years +	637	15.1	526	19.6	2 405	20.0
Total	4 224	100	2 686	100	11 952	100

Source: Najmudinov (2009) *The Scientific and Technical Capacity of the Republic of Tajikistan in 2007*; Suleimenov *et al.* (2008) *The Dynamics of the Scientific and Technical Capacity of the Republic of Kazakhstan in 2000–2007*; Statistical Office (2009) *Science, Technology and Innovation Indicators for the Republic of Uzbekistan*

services is the Engineering and Technology Transfer Centre. It conducted a feasibility study for the establishment of an industrial zone in Kostanay in 2007 for the Ministry of Trade and Industry, for instance, and a market study on using laser beam technologies to weld trunk pipelines for the Joint Stock Company (JSC) Park of Nuclear Technologies in 2008.

In Kazakhstan, the use of technologies for information-sharing on S&T tends to be more sophisticated than in other Central Asian countries. In recognition of this fact, Kazakhstan was nominated Vice-Chair of the Interstate Co-ordination Council for the S&T information of the CIS countries in 2010 and will chair the council in 2011.

Kazakhstan's national Centre for Scientific and Technical Information functions under the parent organization mentioned earlier, JSC, which is also the parent organization for a number of research institutes. The centre has developed modern services, such as reference indexing and rating systems for organizations and scientists. It has also extended existing services like the analysis and commercialization of research results, in addition to developing international co-operation. The aim of the portal is to make it easier for the scientific community to access scientific, technical and educational information by making it available via Internet. The Internet has become one of the most popular media for the exchange of information (Figure 4). In 2004, the centre also developed a web portal in English, Russian and Kazakh called *All about Science in Kazakhstan*.

An intellectual nation by 2020

Kazakhstan has not been impervious to the global economic recession, a sign of the country's integration in the global economy. Like other countries, it has revised its S&T policy in the wake of the recession. During a meeting with students from the Balashik Intellectual School in Astana in 2009, President Nazarbaev unveiled a programme for the coming decade entitled Intellectual Nation – 2020. It has three main thrusts:

- There are currently 'intellectual schools' known as Balashik in the cities of Astana and Semipalatinsk. By 2011, it is planned to open similar schools in every part of the country. The objective is to spot talented children, identify their specific gift then begin targeted training to nurture it. The curriculum of these schools will emphasize exact and natural sciences and the development of critical and creative thinking. Together with a new international university in Astana, these Balashik are the main elements of a new approach designed to bring the national education system up to international standards.

- On the premise that science should be the basis of an innovative economy, there will be a drive to push up government and private-sector funding of R&D. In the past five years, funding for science has almost quadrupled. In 2009, it amounted to 18.5 billion tenge, or US$ 123 million. GERD per capita came to US$ 23, by far the highest ratio in Central Asia (Table 2). The government programme plans to multiply investment in R&D tenfold to 2.5% of GDP by 2015. A second goal is to achieve parity of 45–50% for government and private-sector funding of R&D by 2012. Foreign sources will account for the remainder.

- The third thrust is the development of a national innovation system. Innovation is always a meeting of ideas and business. Such an encounter results in tangible growth in goods manufacturing and a sharp increase in profits and competitiveness. Following the adoption of a Law on State Support for Innovative Activity in March 2006, the president instructed the government to stimulate innovation through such measures as the creation of a complex system of technology and knowledge transfer; an innovation monitoring system and the development of infrastructure to foster innovation, including the construction of an Information Technology Park in Almaty and the creation of regional technoparks and industrial zones.

  The Intellectual Nation – 2020 programme sets out four priority areas for R&D:

- *Biotechnologies and biochemistry*: with a focus on improving food safety and strengthening the human immune system;

- *Ecoenergy*: in the form of renewable energy sources, 'green power', solar energy, superconductors and the capture and storage of light with low energy consumption;

- *Ecology*: the development of technologies to reduce greenhouse gas emissions and of a water treatment system permitting rapid recognition of various biosubstances, to be coupled with the introduction of biodecomposed plastics and the identification of bacteria capable of destroying sources of environmental pollution;

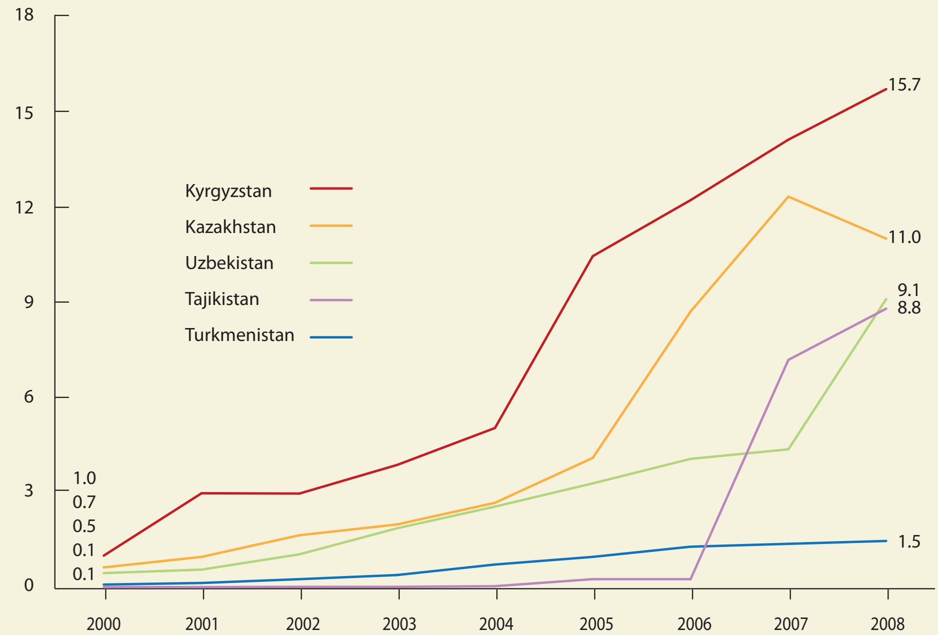
- *Anti-ageing*: research into extending life expectancy and rejuvenation.

Technoparks to foster innovation

The focus of R&D has changed little over the past decade. The modest share of research devoted to experimental development (25%) means that high-tech products developed in Kazakhstan do not always get as far as the marketplace (Figure 4). As was noted during an international conference on Science and Time Challenges in Almaty in November 2008, scientific personnel basically focus little on the innovation component of scientific endeavour, as they tend not to have adapted yet to the market economy.

Moreover, there are no professional training programmes for the management of innovation activity, nor any monitoring of available and potential consumers. To compound matters, there is a lack of staff qualified to orient the economy towards innovation. There is also a penury of university

Figure 4: Internet users per 100 population in Central Asia, 2000-2008



Source: United Nations Statistical Division, Millennium Development Goals Indicators

teachers with knowledge of how to use modern technologies in project management or any familiarity with the principles and techniques of training specialists in fields related to innovation. Kazakhstan does, however, train a fairly large pool of economists, as economics (12.6%) is the second-most popular specialization for Doctor of Science candidates after medicine (17.1 %), just ahead of law (12.4 %).

If Central Asia is to embrace the knowledge economy, it will need to develop infrastructure to foster innovation. The most effective model for integrating science, education and production processes establishes linkages between the research team and the consumer of the finished product or, in other words, between the scientific idea and its practical application. Infrastructure for innovation typically consists of a network of business incubators and technoparks. In Kazakhstan, there are already several technoparks in existence: in Karaganda (UniScienTech Technopark), Uralsk (Algorithm Technopark) and Almaty (Alatau ITCity National technopark, Almaty Regional Technopark and KazNTU Technopark at the Kazakh National Technical University, named after Academician K. I. Satpaev). The majority of these technoparks are still start-ups. Their activity tends to be confined to the development of small businesses in various fields.

Kyrgyzstan

Kyrgyzstan has escaped largely unscathed from the global recession. Professor Jumakadyr Akeneev, President of the Kirghiz Investment Fund, has observed that Kyrgyzstan recorded economic growth of 3% in 2009, at a time when the economy of many countries – Kazakhstan, Russia and Ukraine included – was stagnating.

Over the past five years, Kyrgyzstan has enjoyed considerable economic growth, with GDP peaking at US$ 5 billion in 2009. This prowess needs to be relativised, however: prior to independence in 1991, Kyrgyzstan generated GDP of US$ 13 billion.

In 2010, Kyrgyzstan plans to increase repayments on the foreign debt in excess of US$2 billion accumulated under the republic's first President Askar Akaev (1991–2005), the possibilities for restructuring the country's debt having been almost exhausted. Under such a scenario, the prospects for Kyrgyzstan's economic and scientific development appear more sombre than in either Kazakhstan or Uzbekistan. Moreover, at the time of writing in late April 2010, President Kurmanbek Bakiyev had just been forced to resign and the country was in the hands of a transition government led by former foreign minister Roza Otunbayeva. The political situation in Kyrgyzstan was thus somewhat uncertain.

The republic does have some S&T capacity, even if the number of researchers per million population is relatively low (Table 4). The government has also introduced a programme entitled 21st Century Personnel to improve the quality of education.

Building a system for information exchange

In November 2005, former President Bakiyev published a Decree on the Optimization of the Structure of State Bodies of Kyrgyzstan. This decree abolished Kyrgyzpatent, the centre for S&T information, and transferred its functions to the Department of Science, Innovation and Scientific and Technical Information under the Ministry of Education and Science. The objectives of this department are to:

- participate in the formulation and implementation of state policy and government programmes in the sphere of scientific, technical and economic information;
- gather, process, store, analyse and distribute S&T information;
- participate in the creation and development of a national system of scientific, technical and economic information-gathering of national importance, which will then be stored in a database of the Ministry of Education and Science;
- gather S&T information using domestic and foreign sources;
- provide interested state bodies, organizations and individuals with reference works and analytical information related to S&T;
- organize and co-ordinate international co-operation and the exchange of S&T information with other countries within the bounds of legal agreements.

The key to accelerating S&T progress in Kyrgyzstan will be the creation of a national system capable of supplying information to the actors of economic development and scientific progress. It is the Ministry of Education and Science which is responsible for elaborating state policy in the field of S&T information. The ministry is one of the bodies implementing the state Programme for the Development of Education and a Scientific and Technical Information System in Kyrgyzstan for 2004–2010. Within this role, the ministry develops co-operation and the exchange of S&T information with branch research institutes, institutions of higher education, academic institutes and other ministries and agencies.

The Ministry of Education and Science has concluded a number of international agreements and contracts for the exchange of S&T information. It also participates in bilateral co-operation with scientific institutes abroad, such as with the JSC Centre for Scientific and Technical Information in Kazakhstan, mentioned earlier, UkrInTel in Ukraine and the All-Russian Institute of Scientific and Technical Information under the Russian Academy of Sciences. This is a step in the right direction but both the Department of Science, Innovation and Scientific and Technical Information and the Ministry of Education and Science will need to expand their international partnerships to include a greater number of international centres responsible for S&T information in Central Asia. Of note is that Kyrgyzstan is a member of the CIS Interstate Co-ordination Council for Scientific and Technical Information.

Thanks to a scientific project for the Organization and Co-ordination of International Co-operation and the Exchange of Scientific and Technical Information, a 'unique window' is being developed which will allow researchers to use information and communication technologies (ICTs) in various branches of science and innovation.

Adapting the economy to market needs

The Ministry of Education and Science is confronted with a second urgent challenge: that of preserving the country's S&T capacity and adapting it to market needs. In 2009, the ministry involved students in a project to create databases for the storage of degree theses. The ministry is also reforming the competitive funding of research programmes to ensure that the bidding process encourages projects that favour socio-economic development.

The government needs to do more to foster innovation. It should stimulate the influx of foreign and private capital for innovation by proposing such policies as participation funding, state guarantees, project insurance, tax incentives for the private sector and the creation of patent and innovation funds. The adoption of measures to foster innovation is of strategic importance not only for Kyrgyzstan but also for other Central Asian countries.

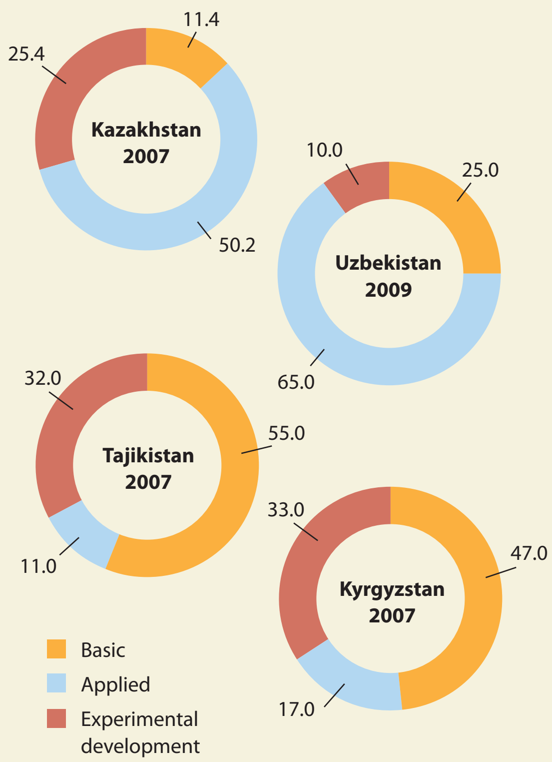
Tajikistan
In Tajikistan, the higher education sector employs more than half of the country's researchers (3 883 out of 5 617), followed by the Academy of Sciences (706), the Ministry of Public Health (380) and the Tajik Academy of Agricultural Sciences (352). Women make up 13% of Doctors of Science and 29% of Candidates of Science. The number of Candidates of Science among those younger than 35 years leapt from 173 to 445 between 2005 and 2007, even though overall numbers of researchers will decline in Tajikistan in the coming years, as the older generation approaches retirement. Although the spurt in the number of young Candidates of Science is an encouraging sign, it is not the only indicator of the level of efficiency of the country's research network.

The level of investment in R&D is another indicator. If we examine the state of scientific equipment and facilities, such as experimental stations or botanical gardens, it emerges that, of the 67 organizations carrying out R&D in Tajikistan, just 16 concentrate most of the budget for scientific equipment and machinery. Generally speaking, material and technical support for science is sorely inadequate and most scientific equipment is obsolete. Those scientific organizations that do receive new equipment owe their good fortune primarily to grants from international bodies. Tajikistan devotes just 0.06% of GDP to R&D, the weakest effort in all of Central Asia. Yet, incredibly, the level of R&D funding was 16 times higher in 2007 than in 2000.

The government considers basic research a priority for R&D funding. Basic research accounted for half of GERD in 2007 and experimental development for one-third (Figure 5). The government has adopted a number of laws to protect intellectual property in recent years. In February 2004, two laws were passed On Invention and On Industrial Samples respectively. These were followed in December 2006 by a Law on Rights Protection for the Topology of Integrated Microcircuits then, in March 2007, by a Law on trademarks and Service Marks and a second Law on Geographical Indicators.

Much of the R&D conducted by Tajik scientists finds practical applications in the major branches of the national economy, such as agriculture, construction, metallurgy, the chemical industry, water-power engineering, computer facilities, geology and public health services. As a result, Tajik scientists have succeeded in recent years in developing new materials, industrial objects and medicines, in furthering risk prevention for earthquake hazards and in improving dam construction to increase agricultural productivity.

Figure 5: R&D in Central Asia by type of research, 2007 (%)
Selected countries



Source: national data

In the analytical compendium of the National Patent Information Centre, which is the structural division of the Ministry of Economic Development and Trade, there are unfortunately no data available on the articles published by Tajik scientists in reviewed international journals. Bearing in mind that many Tajik scientists are not proficient in English, the data available in Thomson Reuters' Science Citation Index give only some indication of the productivity of Tajik scientists (*see Annex II, Tables 5 and 6*).

Conscious of the need to prepare the next generation of R&D personnel to take over from their ageing peers, President Rakhmon declared 2010 the Year of Education and Technical Knowledge. The government plans to double the value of scholarships for talented students from state schools and universities. Moreover, at the president's initiative, it is planned to open a presidential lycée in 2011 for 1 000 pupils.

Developing international S&T co-operation

In many respects, the scientific future of Tajikistan will depend on how fast it can build the necessary infrastructure to take its rightful place in world science. The government has effectively recognized this fact in the strategy for S&T adopted for 2007–2015. In the strategy, science appears as a national priority and is described as being vital for progress and a better quality of life. The strategy outlines an ambitious programme for developing scientific co-operation with other countries, including fellow members of the CIS, as well as with international organizations, via intergovernmental agreements and partnerships to be concluded by the Academy of Sciences, research institutes and universities.

There are good prospects for expanding multilateral scientific co-operation via such bodies as the International Association of Academies of Sciences, the Association of Academies of Sciences of Central Asian Countries, the Academy of Sciences for the Developing World (TWAS) and the standing Committee on Scientific and Technological Cooperation of the Organization of the Islamic Conference.

Lately, the opportunities for professional training or joint research projects with scientists abroad have grown considerably for Tajik scientists. Nevertheless, the level of international scientific co-operation remains modest: in 2010, just 15 research projects were funded by international grants and there were only nine joint projects.

Turkmenistan

About 86% of Turkmenistan's territory is covered by the Karakum desert. Only in the southwest are there low mountains known as the Kopet Dag. Turkmenistan shares the Amu Darya River with Uzbekistan and can count on the Karakum Canal for freshwater; the canal stretches more than 1000 km from the upper course of the Amu Darya River to Ashkhabad, the capital.

Despite being largely desert, Turkmenistan is not without natural resources. It possesses about one-third of the world's reserves of natural gas: up to 24 billion m^3. It is also blessed with considerable oil reserves of 7–12 billion tons and has substantial deposits of potassium and the world's largest reserves of natural salt deposits.

The potential for solar and wind energy is inexhaustible. 'In Turkmenistan, solar panels generate 1682–1890 kW/hour per m^2 every year', observed Professor Luis Lemkov Zetterling in June 2009. The Director of the Scientific Institute for Environment and Technologies of the Independent Unviersity of Barcelona in Spain was speaking at an international conference in Ashkhabad on The Scientific Basis for the Introduction of new Technologies during the Epoch of New Revival. Professor Lemkov Zetterling (2009) observed that Turkmenistan enjoyed 2 768–3 081 hours of sunlight each year and affirmed that 'all electric power developed at present can be produced by means of solar batteries'.

A new epoch for science in Turkmenistan

After the disintegration of the Soviet Union, Turkmen science encountered great difficulties under the presidency of Saparmurad Niyazov. By the year 2000, more than 250 000 Russian-speaking Turkmen had left the country. Among them were many well-known researchers and other skilled experts. The Academy of Sciences of Turkmenistan was closed down and many research institutes ceased to exist.

With the election of President Gurbanguly Berdymuhamedov in February 2007, science in the republic has revived again. At a meeting of cabinet ministers on 12 June 2009, the President stated that 'today, during this epoch of new revival, we shall raise science to a level worthy of the intrinsic scientific value and wisdom of our ancestors'. He also said that science should aim to solve key problems facing the country and society and become the foundation for national well-being. Innovation, he said, should be the prerequisite for Turkmenistan's successful integration in the world of ideas and high technologies. The same day, he declared 12 June National Science Day and issued a decree reinstating the Academy of Sciences (Nazakov, 2009*a*).

The academy consists of 11 research institutes, including six new open institutes. It is responsible for co-ordinating and organizing science in Turkmenistan. It is also entrusted with the vital task of translating the president's decree into reality: the development of a system for managing science capable of accompanying the modernization of the Turkmen economy. Highly skilled managers will be a prerequisite for the creation of infrastructure for science and innovation.

As of January 2010, the country counted 29 research institutes and 16 institutions of higher education. The president has determined the following priority areas for R&D in the coming years:

- 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;
- 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 agriculture sector;
- medicine and pharmaceuticals;
- natural sciences;
- humanities, including the study of the country's history, culture and folklore.

Uzbekistan

Science in Uzbekistan has a long history, particularly in astronomy, mathematics, medicine and philosophy. Uzbekistan is home to Ulugh Beg, for example, the only astronomer ever to rule a mighty state. It was Ulugh Beg who built the enormous observatory in Samarkand in 1420. Even today, the country has the third-biggest pool of researchers among CIS countries after the Russian Federation and Ukraine: 26 000. Just under one in ten researchers (2 421) work for the Academy of Sciences.

In August 2006, President Islam Karimov issued a decree On Measures for Improving Co-ordination and Management for the Development of Science and Technologies. The purpose of this decree is to strengthen the role of science in the country's socio-economic development, to use progress in S&T to liberalize the economy and to improve the quality of research and technological innovation by creating a favourable environment. One key measure has been the establishment of a Committee for the Co-ordination of the Development of Science and Technology which answers directly to the Cabinet of Ministers. The committee's main objectives are to:

- select priority areas for R&D, taking into account the political and socio-economic role of R&D and the achievements of modern science;

- co-ordinate the activities of research institutes and agencies, design bureaux and institutions of higher education falling under the umbrella of ministries and agencies, and the activities of the Academy of Sciences in priority areas of R&D;

- ensure that R&D objectives are achieved and elaborate S&T programmes;

- oversee effective monitoring of the implementation of S&T programmes and projects;

- develop international co-operation in S&T of mutual benefit.

On the basis of proposals by the Cabinet of Ministers of the Republic of Karakalpakstan[4] and other regions, by ministries, agencies, economic bodies and the Academy of Sciences, the Committee for the Co-ordination of the Development of Science and Technology has selected seven priority areas for R&D:

- Study of the legal, economic and social bases of development of the democratic state and civil society, and deepening of economic reforms;

- Study of moral and historical processes and problems related to the spiritual and cultural development of society and curricular reform based on historical, national and universal values;

- Development of high technologies and methods for prospecting and conducting mining operations and deep-processing of mineral raw materials and secondary resources;

- More rational use and conservation of land, water resources and biological diversity, and the creation of agrotechnologies for crops and animals based on the rational use of genetic resources and biotechnologies;

- Development of high technologies and modern methods in medicine, an improved system of public health care and greater environmental security;

4. An autonomous region of Uzbekistan

- Development of high technologies to produce a new generation of cars, equipment and materials, engineering tools and information technology to drive the knowledge economy;
- Study of problems related to the creation of an information society, development of technologies for the transfer, processing and protection of information and the creation of software for design and management.

Once the seven priority areas for R&D had been established, scientific institutions and universities were invited to develop 17 broad research programmes for the period 2008–2018. In parallel, the committee consulted the Academy of Sciences and ministries and agencies responsible for economic development on which system of competitive bidding to adopt for the selection of research proposals submitted by scientific institutions and universities in areas corresponding to the seven national priorities for R&D. A first round of the selection process took place in 2007 for projects in basic research and a second round in 2008 for projects in applied research and experimental development. Eight basic research programmes consisting of 417 projects were adopted for implementation during 2007–2011. A further 17 programmes consisting of 591 projects in applied research are being implemented during 2009–2011. Eight programmes consisting of 172 projects in experimental development were implemented in 2009 and 2010.

As the national budget for research is very low – just 0.20% of GDP in 2010, according to estimates – government funding of selected projects is complemented by foreign and private investment representing of 25–30% of GERD.

Box 1: The Big Solar Furnace

In 2007, the most powerful solar laser in the world began operating in the Tian-Shan mountains about 50 km from Uzbekistan's capital, Tashkent. Capable of cutting through metal as if it were paper, the laser is powered by a concave mirror as tall as a 12-storey building that is the world's largest thickener of solar beams: it can focus up to 1 million watts of solar energy (*see photo, page* 234). Facing the giant concave mirror are 62 other mirrors that refract solar beams, rotating during the day to follow the Sun's path across the sky then sending the solar beams they capt to the primary mirror. The heat generated can melt any known material: in the heart of the 'furnace', the temperature climbs to 3000°C. A specially developed computer programme prevents the furnace from overheating.

This unique optical–mechanical complex is known as the Big Solar Furnace. Constructed in 1991, it is operated by the Institute of Materials Science at the Uzbek Academy of Sciences, with the participation of the Institute of Nuclear Physics. The project has succeeded in its objective of transforming solar energy – a clean and inexhaustible source of energy – into laser radiation.

Solar lasers can be applied to a wide spectrum of fields. The Institute of Materials Science has an industrial line for ceramics. Using the solar furnace, materials are developed which present unique physical and chemical properties, such as limited thermal expansion, high durability and heat-resistance in extreme environments, such as during a fire. Multipurpose ceramics include high-temperature heaters, fire-resistant materials, transformers, gas burners and radiators for medicine. Other products include thread drivers for the textile industry and insulators for the electrical power industry. Ceramic pontoons are also produced for the oil and gas industry.

When you consider that lasers are more efficient than cable lines, it is only a small step to imagine them being used one day for satellite communications in space – and perhaps even to send signals to distant planets.

Arguably the most exciting potential for the solar laser lies in the development of solar power stations orbiting Earth, where the Sun's radiation is about twice as powerful as on our planet. Such an experiment would be extremely costly, however, not to mention premature; the technology for a solar power plant is still being tested at the Big Solar Furnace. The Uzbek team is co-operating with Japanese scientists on this project and hopes to identify partners in other countries.

Source: Institute of Materials Science; Yakhyaev (2007)

For details: jabbar@uzsci.net; www.mat-sci.fan.uz

The quota for funding allocated to each research programme is fixed by the committee together with the Ministry of Finance. The state budget is assigned by the Ministry of Finance directly to the 'customers' responsible for each R&D programme or project. These customers may be the Academy of Sciences, Ministry of Higher Education and Secondary Specialized Education, Ministry of Public Health, Ministry of Agriculture and Water Resources, Ministry of Public Education or other ministries, leading research centres and other agencies and organizations.

It is the committee which monitors implementation of R&D programmes and projects. In 2006–2008, it reported that R&D programmes and projects had led to the obtention of 166 patents. Over this period, among articles published in international journals, approximately the same number concerned basic research as applied research. Uzbek scientists contributed 0.19% of scientific articles worldwide, compared to 0.02% for Kazakhstan.

Developing innovation infrastructure

Throughout the republic, regional centres are being created to foster technology transfer and innovation. Meanwhile, the Ministry of Education has developed a curriculum for the Training of Qualified Administrative Staff and Specialists in Venture Funds and Company Rules (2008).

In July 2008, the President published a Decree on Additional Measures for Stimulating the Introduction of Innovation Projects and Technologies in Production. In parallel, innovation fairs were held in Tashkent in April 2008, April 2009 and March 2010. Each fair produced a catalogue of ideas, technologies and projects related to innovation. These catalogues may be consulted on the committee's website. The innovation fairs produced 1200 contracts with state enterprises for the development of innovative products and processes. Fourteen state enterprises have since started production of high-tech products in the medical field, ICTs and the transformation of local raw materials. Moreover, the market model adopted by the government includes support for intellectual property protection. This has given scientists the chance to increase the volume of research results they translate into products and processes from 8–10 % to 27–30% without the need for additional government capital investment. It should be noted, however, that, although the innovation fairs have stimulated R&D, the regional innovation centres remain at an embryonic stage of development and still face many hurdles.

CONCLUSION

In economically developed countries like France, Germany, the UK and USA, the R&D infrastructure pools the efforts of a wide spectrum of actors: the state, large industrial companies and small private companies specializing in innovation, the higher education sector and non-profit organizations. This experience should be analysed by Central Asian countries interested in developing their own infrastructure.

We have seen that, of the five Central Asian republics, it is Kazakhstan and Uzbekistan which have the most developed science systems. The woefully inadequate funding levels for R&D is a problem common to all Central Asian countries, however. All five need to make a determined effort to attract non-governmental sources of funding, especially from small and medium-sized businesses and in the form of venture capital and foreign direct investment. A second necessity is for countries to make greater use of electronic means to enable stakeholders to share STI information.

Central Asian countries share a variety of other problems, namely:

- the lack of an effective system of interaction between actors of innovation;
- an inadequate supply of R&D personnel;
- insufficient innovation on the part of scientific organizations and industrial enterprises;
- an inadequate legal basis for the development of innovation;
- a lack of large international research projects oriented towards solving regional problems such as environmental degradation, the inadequate conservation of plant genetic resources and food and environmental insecurity.

The five countries under study should take advantage of the vast potential for international scientific co-operation offered by their close political, historical and cultural ties. It would be mutually advantageous for the scientific communities of these countries to join forces to improve environmental and food security in the region, conserve and use natural resources sustainably and stabilize national economies. This said, joint research programmes will only be effective if they are backed by funding levels sufficiently high to allow the region to realize its potential and raise the population's standard of living.

Box 2: A blue dye to the rescue of the Aral Sea Basin

Both Kazakhstan and Uzbekistan border the Aral Sea. The Uzbek part of the Aral Sea shrank by 80% between 2006 and 2009, according to satellite imagery provided by the European Space Agency. The water situation in Uzbekistan has become critical. Intensive irrigation and drainage of lands for agriculture over the past 40 years have turned what was once the fourth-largest lake in the world into a salty, toxic desert where little will grow. Even today, farmers still depend upon cotton for their livelihood, even though this thirsty crop is ill-adapted to the region's ecosystem.

Indigofera tinctoria is a natural blue dye. Although the plant has never before been grown in Central Asia, it possesses properties that make it a likely candidate for rehabilitating the region's salt-ridden soils. In 2006, a team led by UNESCO Science Advisor Professor Abdukodir Ergashev devised a series of experiments within UNESCO's UzIndigo project to determine how indigo would react to saline, low-yield soils. The trials were conducted on the experimental farm of Urgench State University and led to the development of a new cultivar of indigo especially adapted to the harsh local conditions, Feruz-1. The new cultivar is able to grow in exceedingly saline soils thanks to the combination of highly developed bacteria in the plant's roots.

In 2008, additional field experiments were carried out in collaboration with an association of farmers in Bagat District to identify the effect of various dosages of fertilizer on the size of indigo plants. Although the indigo plant fixes nitrogen in the soil, it was discovered that the plant would grow considerably taller if mineral fertilizers were added.

In 2009 and 2010, UNESCO's Tashkent office ran a series of training workshops for farmers on growing indigo. The workshops also attracted teachers and scientists eager to learn about the biotechnology of natural dyes and how to improve soil ecology. UNESCO used this opportunity to provide farmers with seeds of Feruz-1 to enable them to conduct field tests on their own properties. The main obstacle to widespread cultivation of *I. tinctoria* is the absence of seeds in Uzbekistan. One option would be to establish the country's first farm specialized in seed production then to share this technology with Uzbek farmers.

From the outset, it was decided to target both the local and international markets for indigo dye from the region. The European Bank for Reconstruction and Development helped to identify reliable markets in Europe, where it transpired that 1 kg of indigo dye could fetch up to €240.

By 2010, natural indigo was well on the way to being produced commercially in the Aral Sea Basin. Farmers were also being encouraged to develop other alternative cash crops to cotton, such as medicinal plants, vegetables and fruit. The project is also promoting water-saving technologies of benefit not only to agriculture but also to the domestic and industrial sectors.

Source: Osipov (2010)

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National Innovation Fund (Kazakhstan): www.nif.kz

Ashiraf Mukhammadiev was born in Uzbekistan in 1946. An agricultural engineer, he obtained his Doctor of Science degree in 1993 from the Tashkent State Agrarian University. From 1970 to 1991, he was Head Researcher at the Central Asian Institute of Mechanization and Electrification then Director of the Scientific Research Laboratory at the Institute of Engineers of Irrigation and Agricultural Mechanization in the Tashkent region.

From 1993 to 1996, Dr Mukhammadiev served as Director of the Small Scientific Production Enterprise (ISKRA) in Tajikistan before being appointed Head of the Specialized Construction Bureau in Tashkent. In 1996, he was nominated Deputy Director of Management at the State Committee of Science and Technology of Uzbekistan, where he combined the roles of Head of the Scientific Research Laboratory, Head of the Specialized Construction Bureau and Professor at Tashkent State Agrarian University. From 2002 to 2006, he was Head of Department at the Uzbek Centre for Science and Technology under the Cabinet of Ministers. Since 2006, he has been Head of Department for the Uzbek Committee of Co-ordination and the Development of Science and Technology.

Dr Mukhammadiev has 50 inventions to his name and is the author of more than 250 published scientific works.

Basic education is not sufficient to create wealth, to address concerns of food, water and energy security, to provide better health services and better infrastructure. For that, science is required.

Adnan Badran and Moneef Zou'bi

13 · Arab States

Adnan Badran and Moneef R. Zou'bi

INTRODUCTION

The Arab world stretches from the Indian Ocean in the East to the Atlantic Ocean in the West. Twenty Arab countries occupy the southern and eastern shores of the Mediterranean and border the Red Sea.

It is an area of historical importance, as it is the birthplace of the world's three Abrahamic religions. For centuries, the region was a hub of groundbreaking science. It is of contemporary strategic importance owing to its location and a wealth of subterranean natural resources, essentially in the form of oil and natural gas – 32% of the world's known natural gas reserves are to be found in the region – as well as phosphate: Morocco alone possesses more than half of the world's reserves.

The region encompasses remarkable cultural similarities as well as highly distinct political and economic systems with a heterogeneous social fabric. Its peoples share a commonality of language, history and religion but their societies are at variance in terms of natural wealth, governance, currency, traditions and socio-economic systems.

The period since the *UNESCO Science Report 2005* appeared has been one of mixed fortunes for Arab countries. The region has witnessed continuing political upheaval and military conflict in the Gaza Strip and the West Bank, Iraq, Lebanon and Sudan. The oil-exporting Arab states of Kuwait, the Libyan Arab Jamahiriya, Qatar, Saudi Arabia and the United Arab Emirates have enjoyed a short-lived downpour of revenue resulting from the hike in international oil prices to a peak of more than US$ 140 a barrel in July 2008. Conversely, oil-importing countries such as Jordan, Tunisia and Morocco have faced fiscal difficulties due to their mounting national energy bills, a situation compounded by the associated rise in the cost of imported food commodities.

The subsequent plummet in oil prices, which fell to about US$ 40 by the end of 2008 before recovering slightly in 2009, has brought this exceptional situation to an end. It has also highlighted the volatility of oil prices and the need for Arab oil-exporting countries to diversify their economies in future.

Notwithstanding these difficulties, the same period also witnessed renewed interest on the part of many Arab countries in reinvigorating science and technology (S&T) and higher education, with the launch of a number of top-down initiatives to support education and research. Some of these will be highlighted in the present chapter. A handful of countries have also approved plans to allocate more resources to research and development (R&D), among them Egypt, Tunisia and Qatar.

The current global economic recession may not affect Arab states in the immediate term, as the banking sector in the majority of Arab states is highly regulated and only loosely linked to international money markets. However, the economic fallout will ultimately be felt by all, negatively affecting foreign direct investment flowing into Arab countries and real estate markets. This will cause a slowdown in economic growth and a rise in unemployment in the region. Arab countries reliant on exporting goods and services to the USA and European Union (EU) and those that normally receive aid from these quarters may suffer. Even before the economic recession emerged in the last quarter of 2008, unemployment in the Arab world was higher than in any other part of the world, at around 12%. Young job-seekers constitute over 40% of the region's unemployed (UNESCWA, 2007).

Despite the international economic uncertainty, Arab states will have no choice but to stimulate science, technology and innovation (STI), together with the education sector, if only to overcome some lingering problems like food, water and energy insecurity. Arab countries can also learn from the remarkable socio-economic progress of countries such as Brazil, China, India, Malaysia and Mexico, due in part to S&T.

THE SOCIO-ECONOMIC SITUATION

Demography and economics

Arabs are young. Over 30% of the population of Arab countries is less than 15 years of age (UNESCWA, 2007). This is a double-edged sword for Arab decision-makers. Young populations can stimulate growth and create dynamic societies, particularly if they are well-trained and well-educated. However, the inability of Arab governments to provide the young with schooling or a university education or to expand the productive capacity to create a repository of jobs may well result in social upheaval (UN/LAS, 2007). The World Bank estimates that the region will have to create over 100 million jobs by 2020 to employ the young men and women joining the

Professor Lihadh Al-Gazali examining a young patient in the United Arab Emirates

Photo: Michelle Pelletier/l'Oréal

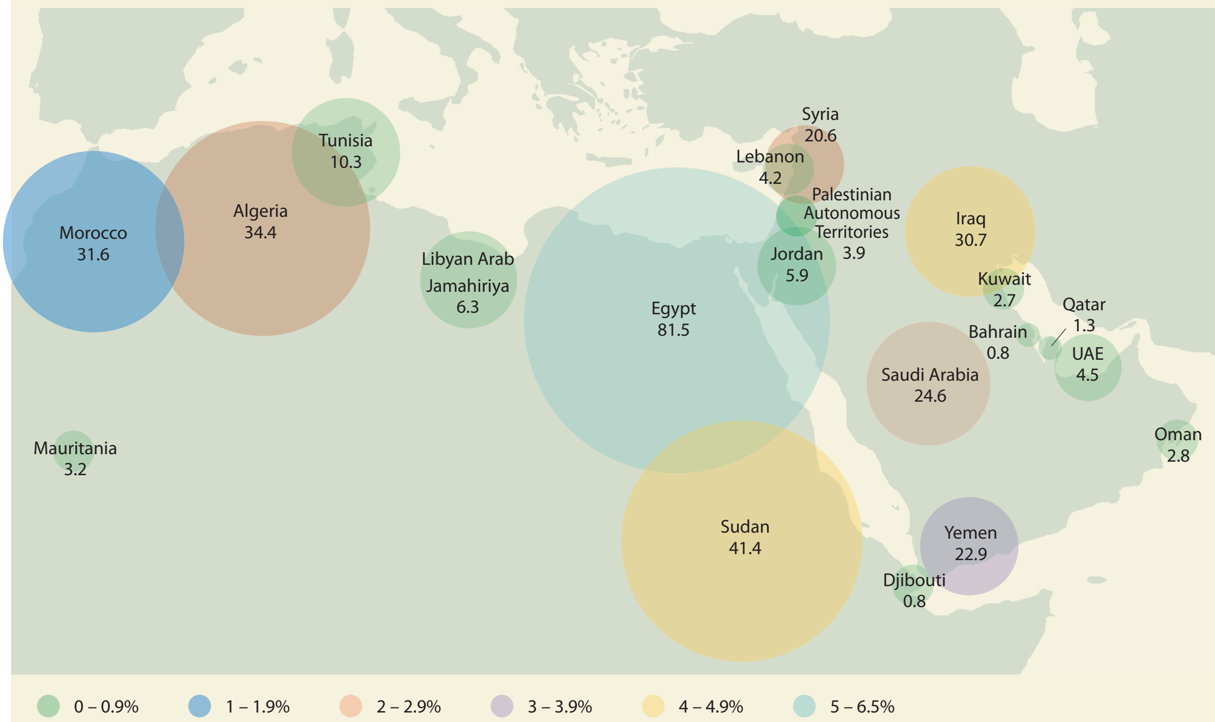
employment market. Whereas the problem of unemployment may prove to be insurmountable in some of the poorer Arab countries like Yemen, it will be manageable for those which count among the richest in the world: Qatar, Kuwait and the United Arab Emirates.

Countries of the Arab region may be grouped into three categories in terms of per capita income. The first category is characterized by almost total economic dependence on oil: the Gulf States of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates, with GDP per capita income being highest in Qatar (PPP US$ 65 182 in 2007) and lowest in Oman (PPP US$ 22 695). Some 37 million people belong to this group of countries, representing around 11% of the Arab population (Figure 1). The STI and higher education systems in these countries are new but developing rapidly thanks to sizeable investments by their heads of state and governments.

The second group encompasses Algeria, Egypt, Iraq, Jordan, Lebanon, the Libyan Arab Jamahiriya, Morocco, the Palestinian Autonomous Territories, Syria and Tunisia. Here, GDP per capita is highest in the Libyan Arab Jamahiriya at US$ 7 773 and lowest in Egypt at US$ 1 505. Although the countries in this category have modest oil reserves – with the notable exception of Iraq and the Libyan Arab Jamahiriya – they boast relatively mature higher education infrastructure. This includes some of the oldest universities in the Arab world, including Cairo University, the American University of Beirut, Ezzitouna University in Tunisia and the University of Al-Karaouine in Morocco. The population of this group amounts to around 219 million, constituting 70% of the population in the Arab world.

There is a distinct dichotomy between these two groups, as countries belonging to the former have the material and financial resources to carry out R&D but lack the solid S&T and higher education systems to generate knowledge. In the second group of countries, the situation is reversed. Egypt, for example, is not wealthy but is nevertheless considered a regional leader in terms of S&T human resources and scientific publications.

Figure 1: Population growth in the Arab region, 2002–2008
Population in millions in 2008 and growth since 2002 (%)



Source: data from World Bank, World Development Indicators, June 2010

The third group of countries is characterized by limited or underdeveloped natural resources and an equally meagre supply of trained human resources. Countries in this category also possess some of the lowest GDP per capita in the world, which classifies them as least developed countries (LDCs). They are Comoros, Djibouti, Mauritania, Sudan and Yemen. This group of countries represents around 19% of the total population of the Arab world. The proportion of those living below the national poverty line rose by almost 10% in the Arab LDCs between 1990–1995 and 2000–2004, from 37% to 47% (UN/LAS, 2007). The problems faced by Arab LDCs have been compounded by internal political strife over the past 20 years.

As Figure 2 demonstrates, the level of human development varies widely across the Arab world. Seven countries – Bahrain, Kuwait, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia and the United Arab Emirates – have achieved high human development. GDP per capita has risen steeply in all seven in recent years.

Between 2002 and 2007, the Arab region enjoyed average economic growth of around 4% per annum. The bulk of this growth was due to the hike in oil prices, although other factors also contributed, such as economic diversification, international free trade agreements and the rapid development of the financial sector and other services sectors, especially in the Gulf.

A key impediment to the region's economic development has been the lingering political conflicts in Iraq, Lebanon, the Palestinian Autonomous Territories and Sudan. These conflicts have erupted into violence since the turn of the century. Acts of terrorism in Algeria, Egypt, Jordan and Saudi Arabia have exacerbated the situation, causing many Arab countries to divert resources towards security, military and defence budgets at the expense of resources earmarked for development. Figure 3 shows military expenditure in Arab countries as a percentage of GDP, the highest ratio in the world, even if it has declined in relative terms. Much of this spending goes on the purchase of expensive armaments from industrialized countries. The world's top seven military spenders per capita all come from the Middle East: Iraq, Israel, Jordan, Oman, Qatar, Saudi Arabia and Yemen (CIA, 2009).

This phenomenon calls for serious review. Surely, the introduction of security arrangements by the countries of the region and the resolution of political problems would pave the way for a drop in defence spending, thereby freeing up resources for development.

Governance

Governance in the majority of Arab countries is in a state of turmoil. Arab regimes are torn between upholding national security – as they perceive it – and maintaining social order on the one hand, and generally adopting good governance practices, on the other; these practices include promoting democracy and the 'rule of law', promulgating accountability and combating corruption.

Notwithstanding the security issue, Arab governments can help knowledge and knowledge-based industries to flourish by creating an environment conducive to enlightening young minds, nurturing creativity and scientific enquiry and generally encouraging people to work harder. By allowing citizens to enjoy the basic freedoms of expression and association, in other words, by allowing citizens to participate in their own governance, governments would contribute to mitigating the brain drain of scientists and intellectuals.

By applying laws fairly and equally, governments support businesses and attract investment to their societies. Without good governance, achieving a knowledge society that simultaneously advances human development, innovation and economic growth will be difficult, if not impossible.

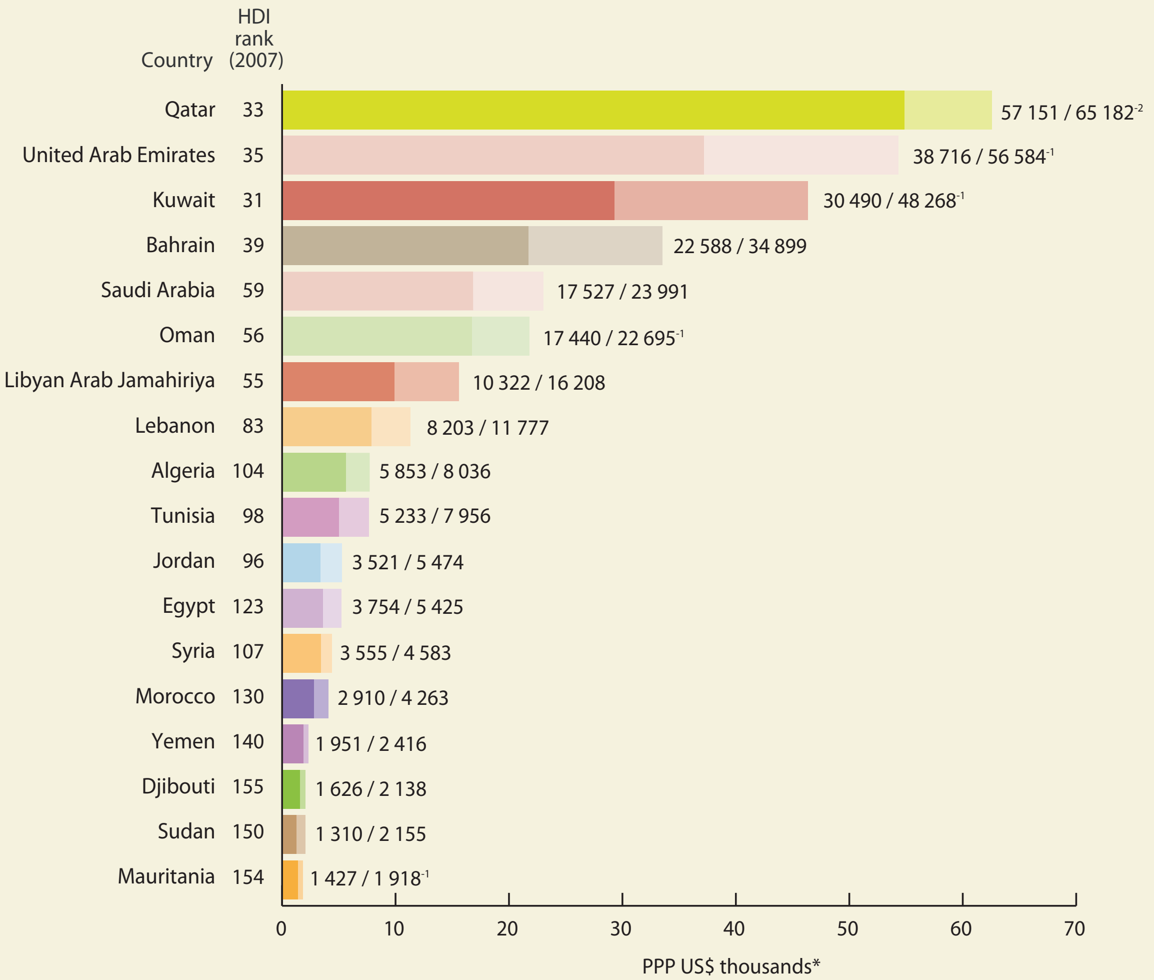
Universities, in particular, can only produce quality higher education and R&D that responds better to national socio-economic needs if freedom, democracy and tolerance are allowed to prosper within their walls.

For the purposes of the present report, two governance indicators will be examined to gauge where Arab countries stand: the rule of law and voice and accountability.

Rule of law

The 'rule of law' has been described as a yardstick as important as the Millennium Development Goals (*see Annex II*) and as being the key to achieving all of these goals. Strengthening the rule of law lays the foundations for safer societies that are able to offer their citizens security, justice and development. The *Arab Human Development Report* (UNDP, 2003) called for a 'fair and predictable rule of law'.

Figure 2: GDP per capita in the Arab region, 2002 and 2008



-*n* = data refer to *n* years before reference year
*in current international purchasing power parity dollars

Source: UNDP (2009) *Human Development Report*; World Bank, World Development Indicators, June 2010

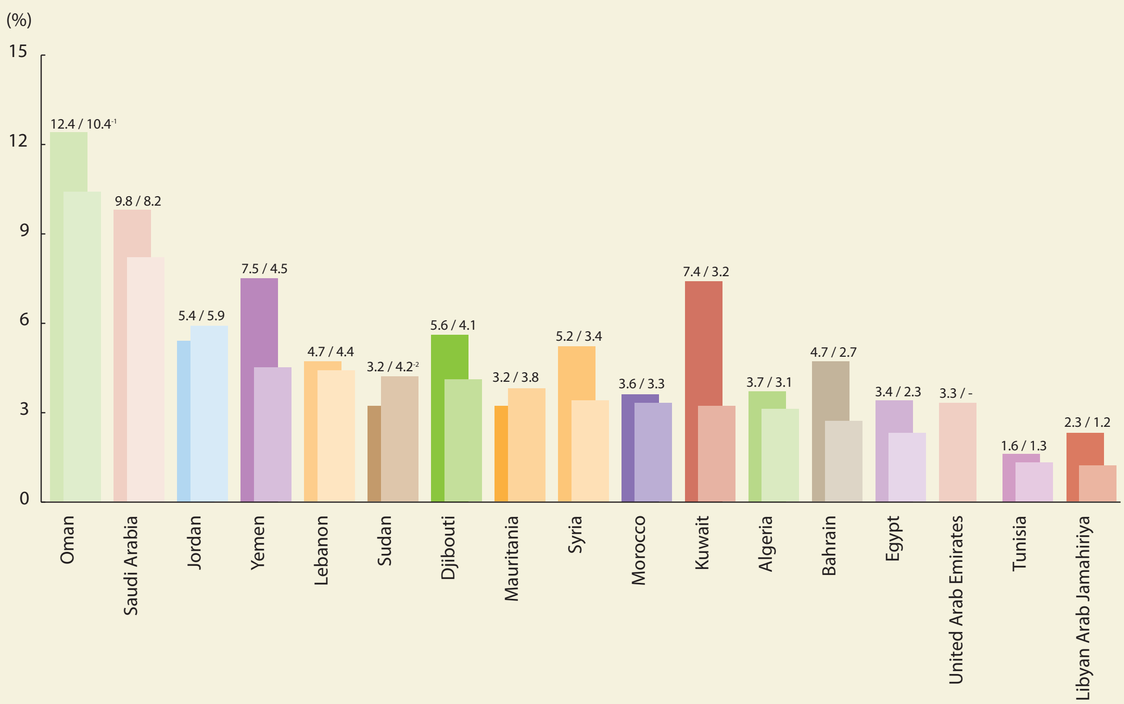
Recent research has shown that the performance of Arab countries is a mixed bag. Kaufmann *et al.* (2008) measured the 'rule of law' in 1998 and 2007 as the outcome of governance in Arab countries. Even if the standard error estimate is taken into account, Qatar emerges from their survey as the only Arab country to rank above the 75th percentile on a global scale in 2007. Four Arab countries rank around the 65th percentile: Oman, Kuwait, United Arab Emirates and Bahrain. These are followed by Jordan, Tunisia and Saudi Arabia around the 60th percentile. A further two Arab countries rank around the 50th percentile mark: Egypt and Morocco. The remaining countries rank below the 40th percentile, with Iraq recording the lowest score. Noteworthy is that the rule of law has actually receded since 1998 in Iraq, Lebanon, Morocco, Saudi Arabia, Syria and in the West Bank and Gaza.

Voice and accountability

An 'independent knowledge sphere', in which knowledge can be produced and shared without political interference, must be an objective of all Arab governments in their quest to achieve sustainable development. The foundation of this knowledge sphere lies in providing and sustaining an environment conducive to creativity and R&D

Figure 3: Military expenditure in selected Arab countries, 2002 and 2008

As a percentage of GDP



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

Source: World Bank, World Develpment Indicators, June 2010

entrepreneurship, where freedom of opinion, speech and assembly prevail to stimulate STI.

Although the Cold War of the 20th century and other recent history have shown that progress in S&T is possible under totalitarian regimes, any progress has rarely benefited the population under such regimes. Cutting-edge innovation is more likely to thrive – and endure – in open societies. Most importantly, gains in knowledge production in such societies are more likely to permeate society as a whole.

Here again, the region's showing for the 'voice and accountability' indicator over the past decade has been disappointing. According to the study by Kaufmann *et al.* (2008), the top five Arab countries for this indicator are Lebanon, Kuwait, Morocco, Qatar and Jordan. However, even for these countries, the scores are low by international standards, as all five rank between the 35th and 30th percentiles. A further four countries have shown a marked improvement: Bahrain, Algeria, Djibouti and Iraq. Overall, 12 out of 18 Arab countries and territories registered a decline in 'voice and accountability' between 1998 and 2007, including four of the top five countries for this indicator: Egypt, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Morocco, Oman, Syria, Tunisia, United Arab Emirates, the West Bank and Gaza and Yemen.

THE S&T LANDSCAPE

Innovation not yet part of S&T parlance

Interest in S&T was kindled in the majority of Arab countries after the Second World War, when most gained independence. Universities and research centres were founded principally by central governments from the 1960s onwards. National S&T policies would come much later. Jordan, for example, founded its main national university, the University of Jordan, in 1962 and its main industrial research centre, the Royal Scientific Society, in 1970, yet adopted a National Science and Technology

Policy only in 1995. Saudi Arabia adopted its own national policy for S&T as recently as 2003 (Al-Athel, 2003).

Today, many Arab countries still possess no national policies or strategies for S&T. However, they are in the process of taking this important first step. Where S&T policies do exist, they are either too ambitious or ambiguous. All Arab countries nevertheless have sectoral policies, such as those for agriculture, water resources and the environment.

Innovation is not yet part of S&T parlance in the region. This may be attributed to the weak linkages overall between private and public R&D, as evidenced by the low output of patents. In 2003, Tunisia carried out an innovation survey as a first step towards remedying this situation. The United Arab Emirates is the highest-ranking Arab country in terms of its capacity for innovation. It comes 27nd out of the 133 economies covered by the Global Competitiveness Index 2009/2010, followed by Saudi Arabia (32nd), Qatar (36th), Tunisia (38th), Oman (55th) and Jordan (59th) [WEF, 2009].

Among recent developments, a European Union–Egypt Innovation Fund has been established at the Egyptian Ministry of Scientific Research as part of a joint research, development and innovation programme. Set up in 2008, the fund will support projects for applied research on a competitive basis, with special emphasis on innovation (Mohamed, 2008).

The establishment of science parks in Bahrain, Morocco, Qatar, Saudi Arabia, Tunisia and the United Arab Emirates represents a move towards partnerships in innovation between private and public R&D. In 2009, Jordan was in the process of launching El-Hassan Science Park as part of a major science project in Amman and Egypt was setting up its own Mubarak Science Park.

Politics and policies

But why should any Arab country have an S&T policy in the first place? What would the objective be of such a policy? In answer to these questions, we can cite two examples from beyond the Arab world: Malaysia and the USA. Malaysia is often cited by Arab decision-makers as a developing country that has achieved economic success thanks, in part, to the contribution of S&T. As for the USA, this world leader in science is developing bilateral scientific relations with a number of Arab countries, including Algeria and the Libyan Arab Jamahiriya.

The former prime minister of Malaysia, Dr Mahathir Muhammad, declared back in 1992 that the basic objective of Malaysian S&T policy was to help Malaysia become fully developed by the year 2020. Three decades earlier, in 1961, John Fitzgerald Kennedy had said in a presidential address that the objective of the US space programme within US S&T policy was to put a man on the Moon before the end of the decade. This became a reality on 20 July 1969, nearly six years after the president's death.

At the United Nations' World Summit on Sustainable Development in 2002, former Secretary-General Kofi Annan outlined five key priority areas for sustainable development. Known collectively by the acronym of WEHAB, these areas are water, energy, health, agriculture and biodiversity. For Arab countries, key targets will need to be met in all five priority areas. Other priorities they need to address include wealth creation and the Arab region's contribution to world civilization.

National S&T capacity is required to address the priorities symbolized by WEHAB. The authorities can also draw upon this capacity in an emergency, such as in the event of a natural disaster or pandemic along the lines of the Severe Acute Respiratory Syndrome pandemic scare in late 2002 and the advent of avian influenza (bird flu) in 2003 and the H1N1 influenza virus in early 2009. In Egypt, the emergence on the global scene of H1N1, misnamed 'swine flu', caused mass confusion and the culling of all 250 000 of Egypt's pigs, even though the virus did not originate from pigs but rather was transmitted from one human being to another. These drastic measures will have no impact on the spread of the H1N1 virus in Egypt. Rather, they are a knee-jerk reaction to the wide criticism levelled at the authorities after they were slow to respond to the bird flu epidemic – thought to have resulted in the disease becoming endemic in the country – coupled with fears of the bird flu virus mutating in Egypt's pigs to form a new and more dangerous influenza virus (El-Awady, 2009). It is regrettable that the media missed a golden opportunity here to inform the public dispassionately of the facts and thereby avoid widespread panic.

Towards an Arab plan for S&T

During the Arab Summit of March 2010, the Heads of State adopted a resolution mandating the General Secretariat of the League of Arab States to develop an S&T strategy for the entire Arab region, in co-ordination with specialized Arab and international bodies. This strategy is due to be submitted to the upcoming Arab summit in 2011 for adoption. It is expected to address the important issue of facilitating the mobility of scientists within the region and to enhance collaborative research with the sizeable community of expatriate Arab scientists.

Both the strategy and the subsequent *Arab Science and Technology Plan of Action* (ASTPA) will be drawn up by a panel of experts from the region with the institutional support of the Arab League Educational, Cultural and Scientific Organization (ALECSO), the Union of Arab Scientific Research Councils and UNESCO, among others.

ASTPA will envisage both national and pan-Arab initiatives in about 14 priority areas, including water, food, agriculture and energy. It is also expected to recommend the launch of an online Arab S&T observatory to monitor the S&T scene in Arab states and highlight any shortcomings in implementation. One of the keys to implementing measures at the country level will lie in first identifying some of the national challenges that Arab countries face.

One example from the Arab world is Kuwait, which for some time was a leading regional hub for S&T until the Second Gulf War of 1990–1991. In 2008, Kuwait adopted a plan to reform its S&T sector by facing up to a number of challenges that hindered development. According to the journal *Alrai* (2008), these include:

- the absence of an S&T governance mechanism at state level;
- low gross domestic expenditure on R&D (GERD);
- a lack of co-operation between scientific organizations and productive sectors;
- a low technology component, leading to few manufactured exports and a limited number of high-tech exports;
- a poor capacity to innovate according to society's needs;
- a lack of databases providing information on S&T;
- challenges facing organizations involved in science.

The above challenges are as true for Kuwait as for other Arab states. To address them, political support for S&T at the highest level is required, coupled with affirmative government action, an upgrade of existing STI infrastructure and an increase in GERD.

Needless to say, for any country's S&T policy to be implemented successfully with public backing, it is critical for its objectives to be clearly stated. These must also be understood by the executive branch of government. For instance, is the objective for a given Arab country to mould society into a fully industrialized, export-oriented economy? In the agriculture sector, is the objective to achieve food security? It would clearly be beneficial if reasonable targets were set at the outset, as this would provide the implementing agencies with a benchmark for measuring progress. Through regular appraisals, they could then make any necessary adjustments to improve the rate of implementation.

R&D governance

Research has shown that the bulk of S&T research in the Arab world is carried out within the higher education system, even in Egypt where this represents 65% of R&D (IDSC, 2007). Table 1 shows that, in eight Arab countries, it is the ministries of higher education and scientific research that are responsible for R&D. In another five countries, councils and government academies assume this role. This function falls to universities and research centres in four Arab countries, to ministries of education in three and to the ministry of planning in one (Saleh, 2008).

Only seven Arab countries or territories out of 22 have a national academy of sciences or play host to a supranational academy (Table 2). This is an astounding fact, as academies of sciences, being strong advocates of science and impartial advisory bodies, have been at the vanguard of scientific endeavour in advanced countries such as the USA, UK and France for centuries. They are also part of the landscape in economically emerging economies such as Brazil, China, India, Malaysia and Mexico (see also Box 1).

The organization of science at the institutional level is crucial for the effectiveness of R&D. In Arab countries, the indifference shown by decision-makers to S&T is a major contributor to the current vegetative state of S&T. Furthermore, the kaleidoscope of institutional models renders it quite difficult for Arab states to move forward collectively. If meaningful regional collaboration in S&T is to develop beyond individual scientists working together on small research projects and publishing joint research work, some uniformity needs to be established among the institutions responsible for science in the Arab region.

Table 1: Government bodies responsible for R&D policies and co-ordination in the Arab world, 2006

Algeria	Ministry of Higher Education and Scientific Research
Bahrain	Bahrain Centre for Studies and Research
Egypt	Ministry of State for Scientific Research
Iraq	Ministry of Higher Education and Scientific Research
Jordan	Ministry of Higher Education and Scientific Research Higher Council for Science and Technology
Kuwait	Kuwait Foundation for the Advancement of Sciences Kuwait Institute for Scientific Research Kuwait University/ Research Center
Lebanon	National Council for Scientific Research
Libyan Arab Jamahiriya	Higher Education and Research Secretary General Planning Council National Authority for Scientific Research
Mauritania	Ministry of National Education
Morocco	Hassan II Academy of Sciences and Technologies Ministry of National Education, Higher Education, Staff-Training and Scientific Research Permanent Interministirial Commission of Scientific Research and Technological Development National Centre for Scientific and Technical Research Co-ordination Council of Higher Education Institutions outside Universities
Oman	Research Council
Palestinian Autonomous Territories	Ministry of Higher Education R&D Unit at Ministry of Planning
Qatar	Secretariat General, Council of Ministers
Saudi Arabia	King Abdul Aziz City for Science and Technology
Somalia	Ministry of Agriculture Ministry of Education
Sudan	Ministry of Education and Scientific Research
Syria	Higher Council for Sciences Ministry of Higher Education
Tunisia	Ministry of Higher Education, Research and Technology
United Arab Emirates	University of United Arab Emirates Ministry of Agriculture
Yemen	Ministry of Higher Education and Scientific Research

Source: Saleh (2008) *S&T Indicators in the Arab States*

Table 2: Arab countries hosting a national or supranational academy of science, 2009

		Founded
Egypt	Academy of Scientific Research and Technology	1948
	Egyptian Academy of Sciences	1944
Iraq	Iraq Academy of Sciences	1944
Jordan	Islamic World Academy of Sciences	1986
Lebanon	Arab Academy of Sciences	2002
Morocco	Hassan II Academy of Sciences and Technology	2006
Palestinian Autonomous Territories	Palestine Academy of Sciences and Technology	1997
Sudan	Sudan National Academy of Science	2006

Source: Compiled by A. Badran, and M.R. Zou'bi from personal contacts and interviews

R&D INPUT

Trends in R&D expenditure

GERD as a percentage of GDP has been consistently low in the majority of Arab countries for over four decades (Figure 4). It is much lower than the world average. It varies from 0.1 to 1.0% of GDP, whereas advanced countries spend over 2.5% of GDP on R&D.

Countries such as Egypt, Qatar and Tunisia have set themselves ambitious targets for GERD. In November 2006, Qatar announced that it was lifting GERD to 2.8% of GDP over five years (Shobakky, 2007). Since then, Qatar has launched a number of initiatives in S&T and education and is approaching this figure for GERD, according to Weingarten (2009). The figure for Egypt remained stable at 0.23% of GDP in 2007, although there are plans to raise it to 1% of GDP over the next five years. Meanwhile, Tunisia's spending on R&D has been climbing steadily since 2000. In 2005, it was the leading Arab country in terms of its R&D effort, which stood at slightly more than 1% of GDP. The government's objective is to reach a GERD/GDP ratio of 1.25% by 2009, of which 19% would be funded by the business sector (Arvanitis and Mhenni, 2007).

In 2005, Jordan introduced a law whereby 1% of the net profit of public shareholding companies was transferred to a special R&D fund to finance research. Another law has since been introduced that compels public and private universities to allocate 5% of their budgets annually to R&D. Together with the funding made available by the Middle

Box 1: The Islamic World Academy of Sciences

Launched in 1986, the IAS was the brainchild of a handful of scientists who persuaded the Organisation of the Islamic Conference (OIC) to establish the academy to serve the S&T community in OIC countries and others in the developing world. It was created in Amman (Jordan) as an independent non-political, non-governmental organization.

The IAS combines three different functions. *Firstly*, it is a learned society that promotes the values of modern science. The IAS identifies and honours high achievement and disseminates the latest scientific achievements internationally through meetings and publications.

A *second* function of the IAS that is yet to be fully realized is that of acting as a funding agency to support outstanding scientists in undertaking imaginative and far-reaching research.

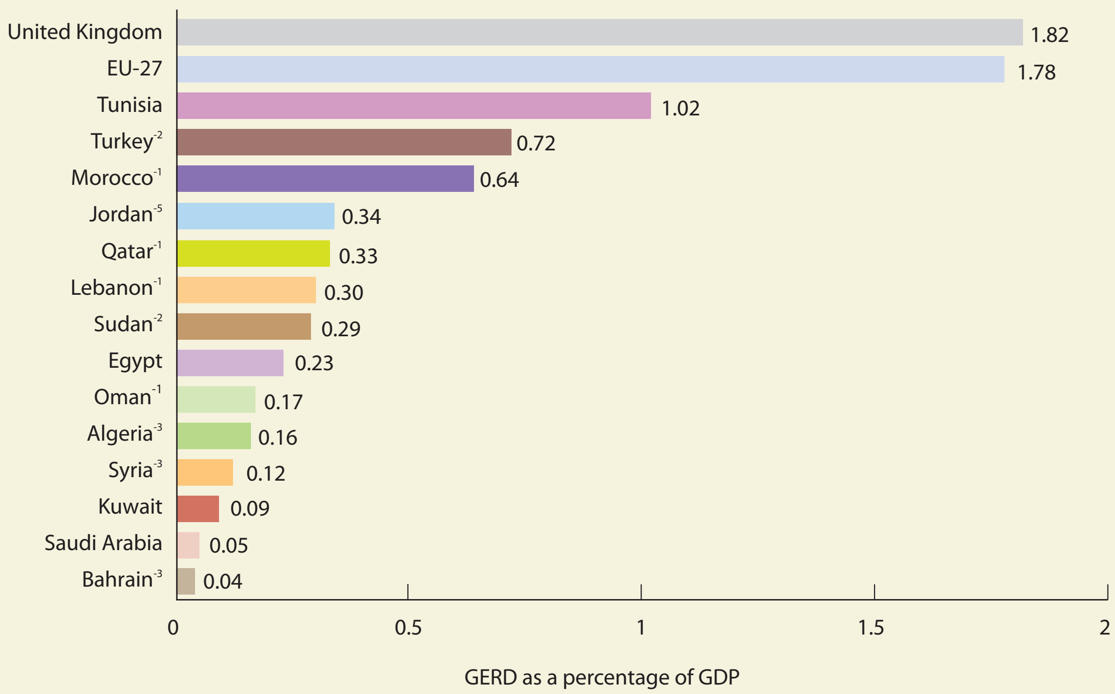
Thirdly, the IAS leads the scientific community of the OIC in its relations with governments, scientific societies and academies of sciences worldwide.

The IAS receives seed funding from Jordan and raises its budget for activities from the OIC and other international bodies, including UN agencies.

For details: www.ias-worldwide.org

Figure 4: GERD/GDP ratio for Arab countries, 2007 or latest year available (%)

Other countries and regions are given for comparison



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

Note: For Tunisia, Turkey and Sudan, the data are an estimation; for Egypt, Kuwait, Algeria and Saudi Arabia, the data are either underestimated or partial; for Mauritania, Qatar, Lebanon and Oman, the data are for gross national expenditure on R&D as a percentage of GDP.

Source: for Egypt: UNESCO Institute for Statistics database, July 2010; for Mauritania, Lebanon, Oman and Mauritania: Saleh (2008) *S&T indicators in the Arab States;* for Bahrain and Syria: Waast *et al.* (2008) *Draft Regional Report on Arab Countries: Study of National Research Systems*

Box 2: The Mohammed bin Rashid Al Maktoum Foundation

In 2007, Mohammed bin Rashid, the ruler of Dubai and Prime Minister of the United Arab Emirates, launched a foundation to help build 'a knowledge-based society' in the region. With an initial endowment of $10 billion, the foundation will invest in knowledge creation and in translating knowledge into goods and services, as well as in human development. It will focus on developing and nurturing a generation of future leaders and on elevating research, knowledge creation and higher education infrastructure to international standards. It will also stimulate entrepreneurship and innovation and pay special attention to culture, heritage and cross-cultural understanding in the region.

The foundation's programmes include publishing an annual *Arab Knowledge Report* issued in co-operation with the United Nations Development Programme, a scholarship programme and a grants programme to support Arab authors wishing to publish books in Arabic.

Future projects will include teacher training programmes, online education for women and initiatives for translating acclaimed scholarly and scientific works into, and from, Arabic.

Source: authors
For details: www.mbrfoundation.ae

East Science Fund, these measures will considerably raise Jordan's GERD, starting from 2008.

In 2008, Kuwait endorsed a five-year plan to reform the country's S&T sector, partly by increasing the budget from 0.2% of GDP in 2008 to 1% of GDP in 2014 (Alrai, 2008).

Turning now to the Arab private sector, by all accounts, spending here is minimal. Out of 131 countries studied, Tunisia ranked 36th in terms of private companies' expenditure on R&D. Qatar and the United Arab Emirates both ranked 42nd, Jordan 96th, Egypt 99th, Syria 108th and Bahrain 119th (Waast, 2008).

Two promising new initiatives have been launched recently in the United Arab Emirates and Jordan which will make more funds available in future for scientific activities. The first is the Mohammed bin Rashid Al Maktoum Foundation (Box 2) and the second, the Middle East Science Fund (Box 3). Both initiatives offer grant programmes for regional research projects in priority areas for Arab countries.

Researchers in the Arab world

Arab countries have not produced a critical mass of full-time equivalent (FTE) researchers in the majority of disciplines. Moreover, links between universities and research centres remain weak. This leads to little or no co-ordination at the national level between research communities. Also, even when fresh graduates are ready to become engaged in research, there is often no capacity within the R&D system to absorb them, or even any willingness on the part of senior researchers to mentor young minds.

To make matters worse, unemployment within the R&D community is high, especially among women researchers, who constitute around 35% of the total researcher community in Arab countries, according to estimates by the UNESCO Institute for Statistics (UIS).

Estimating R&D personnel is a difficult task, as counting only individuals whose primary function is to perform R&D would result in underestimating the national effort. On the other hand, to do a headcount of everyone spending some time on R&D would lead to an overestimate. The number of individuals engaged in R&D must, therefore, be expressed in full-time equivalents of the time spent on R&D, both in the government and private sectors.

The survey carried out in 2006 by UNESCO, ALECSO and the Arab Academy of Sciences covered both the numbers of FTE researchers and support staff in Arab states (Saleh, 2008). The figures for FTE researchers only are presented in Figure 5. It can be concluded from this study that the numbers of FTE researchers in the majority of Arab countries are small in comparison to a country like Argentina, for example, with its 980 FTE researchers per million population in 2007, or Spain (2 784), or Finland (7 382), according to the UIS.

Only a handful of Arab researchers have been internationally recognized. The annual L'Oréal–UNESCO Awards for Women in Science bestow US$ 100 000 each on five women, one from each continent. Of the 13 recipients of this award for the Africa and Arab States region between 1998 and 2010, five came from Arab countries: Egyptian immunologist Rashika El Ridi (2010) and Egyptian physicist Karimat El-Sayed (2004), Tunisian physicists Zohra Ben Lakhdar (2005) and Habiba Bouhamed Chaabouni (2007), and Lihadh Al-Gazali from the United Arab Emirates, who won the prize in 2008 for her work on genetic disorders (*see photo, page* 250).

More surprising is the fact that only one of the world's top 100 highly cited scientists comes from the Arab world: Professor Boudjema Samraoui, a biologist at the University of Annaba in Algeria (ISI, 2009).

The only Nobel laureate in a scientific discipline to come from the Arab world is Egyptian-born Ahmed Zewail, who received the distinction for chemistry in 1999 while working at the California Institute of Technology in the USA.

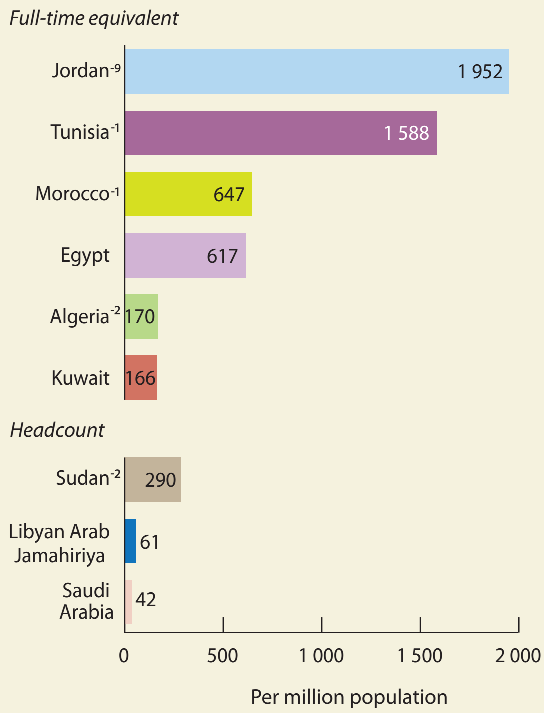
R&D PRIORITIES

Arab countries speak almost in unison when it comes to their designated S&T priorities: water and energy. The traditional sector of agriculture also features in the S&T policies of some Arab countries. The relatively new fields of information and communication technologies (ICTs), nanotechnology and biotechnology are also viewed as priority research areas (Arab League, 2008).

Water security

With the exception of Sudan and Iraq, all Arab countries are water-poor, meaning that water is unavailable in sufficient quantities for household use, industry or agriculture. In agriculture, modern water-saving technologies have been adopted in many Arab countries and some regional initiatives have been launched.

Figure 5: Researchers per million population in the Arab world, 2007
Selected countries



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

Note: For Tunisia, the data are overestimated; for Egypt, Morocco, Algeria, Kuwait, Libyan Arab Jamahiriya and Saudi Arabia, the data are underestimated or partial.

Source: UNESCO Institute for Statistics database, July 2010; for Mauritania, Oman, Qatar and Yemen: Saleh (2008) *S&T indicators in the Arab States*

Box 3: The Middle East Science Fund

The Middle East Science Fund was launched in Jordan in 2009 to support regional research projects and promote scientific co-operation and development. It supports regional scientific activities in the areas of medicine, physics, chemistry and economics. The fund also promotes scientific endeavour in vital areas that include energy and renewable energy sources, water management, the environment and technology.

The initial capitalization of the Middle East Science Fund is US$10 million with a seed contribution donated by King Abdullah II Ibn Al Hussein.

An International Advisory Council of Nobel Laureates advises the Middle East Science Fund on policy and reviews eligible proposals. They also advise on scientific projects deserving of funding and on policy matters related to scientific research in the Middle East.

Source: authors
For details: www.mesfund.org

One such initiative is the International Centre for Biosaline Agriculture, based in Dubai (Box 4).

The shortage of water for agriculture has led some Arab states to lease large plots of arable land in countries like Sudan to grow food. These countries include Saudi Arabia and Kuwait. Foreign direct investment in Sudan's agriculture sector in the form of land leasing amounted to US$279 million in 2007. The Sudanese government aims to secure US$1 billion in from Arab and Asian investment groups in 2009–2010. This amount has already been designated for 17 lead projects, covering a land area of 880 000 ha in northern Sudan (*Sudan Tribune*, 2008).

The United Nations Environment Programme (UNEP) is increasingly sceptical about the wisdom of such investments, however, and has pointed to failures of previous mechanized farming schemes to observe fallow periods, improve land use and respect prior tenure relations (UNEP, 2007). Although such projects seem to be commercially viable from the investor viewpoint, depending on the scale and types of crop grown, they cannot be a real alternative to attempting to achieve national, or at least regional, food security.

Energy security

Energy insecurity is another strategic quandary that many Arab countries face. In their quest to diversify energy sources, many Arab states have embarked on R&D programmes to develop alternative energy sources, such as solar and wind energies.

Jordan embarked on a solar energy research programme in 1972. Jordan's National Agenda, a government policy adopted in 2005, stipulated that the projected share of solar energy in the country's total energy mix should rise to 3% by 2015, by which time 80% of households ought to be using solar energy water collectors (Badran, 2006). This is an achievable target for Jordan which would reduce the national energy bill of imported oil by about the same percentage. Furthermore, it is an environment-friendly technology that is relatively cheap to install and maintain.

Morocco is also increasing investment in renewable energies. The country aims to raise the share of renewable energy sources from 4% of the total to 12% by 2012. A unit within the National Centre for Scientific and Technological Research is devoted to the Renewable Energy Economy and Technologies and the Moroccan National Electricity Office has put together a US$3.2 billion renewable energy investment plan for 2009–2014. The plan provides for the development of local wind energy technologies and farms, solar energy demonstration projects and greater investment in R&D. Within the plan, a 'knowledge campus' is to be designed to strengthen research and training in clean technology. An industrial park for clean energy is also under construction in Oujda near Morocco's border with Algeria. At a cost of US$219 million, the park is expected to open its doors in 2010. It will be supporting private investment and companies specializing in renewable energy (Sawahel, 2008*a*).

Box 4: The International Centre for Biosaline Agriculture

The International Centre for Biosaline Agriculture (ICBA) is a centre for applied R&D based in Dubai in the United Arab Emirates. The centre was established in 1999 with strong support from the Islamic Development Bank and the Government of the United Arab Emirates. It is developing and promoting the use of sustainable agricultural systems that use saline water to grow crops.

The centre initially focused on forage production systems and ornamental plants in countries of the Gulf Co-operation Council and other parts of the Islamic world. The technologies developed by ICBA are, however, of global value and importance. Wherever farmers face the problem of saline soils or irrigating with salty water, ICBA can help.

ICBA also endeavours to demonstrate the value of saline water resources for the production of environmentally and economically useful plants. It plans to transfer its research results to national research services and communities in the Islamic world and elsewhere.

ICBA will help water-scarce countries improve the productivity, social equity and environmental sustainability of water use through an integrated water resource systems approach, with special emphasis on saline water and water of marginal quality.

Source: authors
For details: www.biosaline.org

Box 5: The Regional Centre for Renewable Energy and Energy Efficiency

The Regional Centre for Renewable Energy and Energy Efficiency (RCREEE) came into existence in Cairo in June 2008. It acts as a platform for regional exchanges on policy issues and technological questions. In addition, RCREEE encourages the participation of the private sector in order to promote the growth of regional industry.

RCREEE has ten founding members: Algeria, Egypt, Jordan, Lebanon, Libyan Arab Jamahiriya, Morocco, Palestinian Autonomous Territories, Syria, Tunisia and Yemen. Egypt is serving as host country for the centre.

During the launch phase, RCREEE is being sponsored by Egypt through the Ministry of Electricity and Energy. The European Union, German Agency for Technical Co-operation and Danish International Development Agency are its development partners. These three development partners have pledged to provide financial and technical assistance to RCREEE worth an aggregate value of 15 million € over the initial five years from 2008 to 2012. In the future, RCREEE will be funded through contributions from the member states and income generated from research and consultancy work.

Source: authors
For details: www.rcreee.org

Jordan and Morocco are two of the ten founding members of a think tank set up in 2008, the Regional Centre for Renewable Energy and Energy Efficiency (Box 5).

Nanotechnology

Plans are underway to boost nanotechnology R&D in Egypt and Saudi Arabia. In Egypt, a North African Nanotechnology Research Centre was set up in 2009. Located at the 'Smart Village' near Cairo, this is a joint initiative of IBM and the Egyptian government for research in such nanotechnology-related fields as: Thin Film Silicon Photovoltaics; Spin-On Carbon-Based Electrodes for Thin Film; Photovoltaics; and Energy Recovery from Concentrated Photovoltaic for Desalination.

In Saudi Arabia, the national R&D organization is the King Abdulaziz City for Science and Technology (KACST) based in Riyadh. In February 2008, KACST and IBM agreed to establish the Nanotechnology Centre of Excellence at KACST. The centre will conduct research into nanomaterials for solar energy and nanomembranes for water desalination, combined with investigating new methods for recycling plastics (Sawahel, 2008*b*).

R&D OUTPUT

Patents and publications

From the foregoing, we can see that the R&D landscape in the Arab region is changing. However, it will take some time before the results of current initiatives start to emerge. Furthermore, the success of such initiatives will depend largely on sustained national interest and support, hard work and regional co-operation. Another key factor will be whether or not researchers and research institutions have the capacity to pool the know-how that each has acquired so that this can be reinvested to develop related new technologies and products that are economically viable.

Notwithstanding the fact that the number of published journal articles is but one measure of the research interest of a country, research carried out by Thomson Reuters and cited by Naim and Rahman (2009) reveals a certain heterogeneity in research strengths in the region. The research strength of Egypt, Morocco and Algeria lies in chemistry, whereas it is clinical medicine for Jordan, Kuwait, Lebanon, Oman, Saudi Arabia, Tunisia and the United Arab Emirates. Syria's strength lies in plant and animal science, whereas Qatar makes its mark in engineering.

Given the meagre resources allocated to R&D in Arab countries, it is imperative that an attempt be made to synchronize research strengths, R&D initiatives and national S&T priorities. Each country will have to optimize resources carefully between investment in basic sciences – the backbone of S&T capacity – and investment in demand-driven research that can address national S&T priorities and/or increase national wealth. One major interdisciplinary project that can stimulate regional co-operation in S&T and thereby drive output is the SESAME project being launched in Jordan (Box 6).

Arab countries produce fewer books and fewer S&T articles than many other regions of the world. According to the Mohammed bin Rashid Al Maktoum Foundation, 20 Arab countries produce 6 000 books per year, compared to 102 000 in North America (Lord, 2008).

According to Thomson Reuters Inc., the total number of scientific research articles originating from Arab countries stood at 13 574 in 2008, up from 7 446 in 2000. In terms of articles per million population, it is Kuwait which ranks first, followed by Tunisia (Figure 6). For this indicator, the average for Arab countries is only 41, compared to a world average of 147. Over the 2002–2008 period, all but Mauritania showed an increase in the number of authored scientific articles (Figure 7). With 2 026 published articles, Tunisia came close to quadrupling its output. Egypt, however, continues to lead the region for this indicator.

From 2000 to 2008, there was a steady increase in the number of Arab scientists collaborating with the diaspora. This is evident from the number of scientific publications in international collaboration. The notable exception is Morocco. Of the 3 963 publications published by Egyptian scientists in 2008, one-third (1 057) were co-authored by scientists outside Egypt (Figure 8).

As for patents, Figure 9 shows that their number increased in most Arab countries from 2004 to 2008. However, Arab countries still lag a long way behind in comparison with relatively small countries such as Chile (19 patents in 2008) and Finland (894 in 2008). The Republic of Korea, which back in the 1960s was on a par with Egypt in terms of S&T output, acquired an astonishing 84 110 patents in 2008, compared to a total of just 71 patents for the entire Arab region.

Box 6: The SESAME story

It was Pakistani Nobel Laureate Abdus Salam who first recognized the need for an international synchrotron light source in the Middle East more than 25 years ago. An opportunity arose when it was announced that the Bessy I synchrotron source in Berlin, Germany, was about to be decommissioned. The Chair of the Middle East Scientific Co-operation Group, Sergio Fubini, and Herwig Schopper, former Director-General of the European Organization for Nuclear Research (CERN), invited the German government to donate the Bessy I components to a project for an international synchrotron light source in the Middle East (the future SESAME). The government agreed.

At a meeting convened by UNESCO in 1999, countries from the region set up an Interim Council for SESAME under the chairmanship of Herwig Schopper. In 2002, UNESCO's Executive Board approved the request to place the SESAME centre under UNESCO's auspices.

Construction of the centre was completed in Allan, Jordan, in 2008. Once fully operational in 2014 with three initial beamlines, SESAME will offer the Middle East a world-class laboratory for basic research and numerous applications in biology, medical sciences, material sciences, physics, chemistry and archaeology.

Synchrotron radiation is produced by an electron beam accelerated in a ring at almost the speed of light. The refurbished microtron (Bessy I) installed at SESAME successfully produced an electron beam on 14 July 2009. The booster synchrotron (also from Bessy I) was being upgraded and installed in 2010. To meet the users' demands, a completely new 2.5 GeV storage ring with a circumference of 133 m has been designed by the SESAME staff and will be built by 2014.

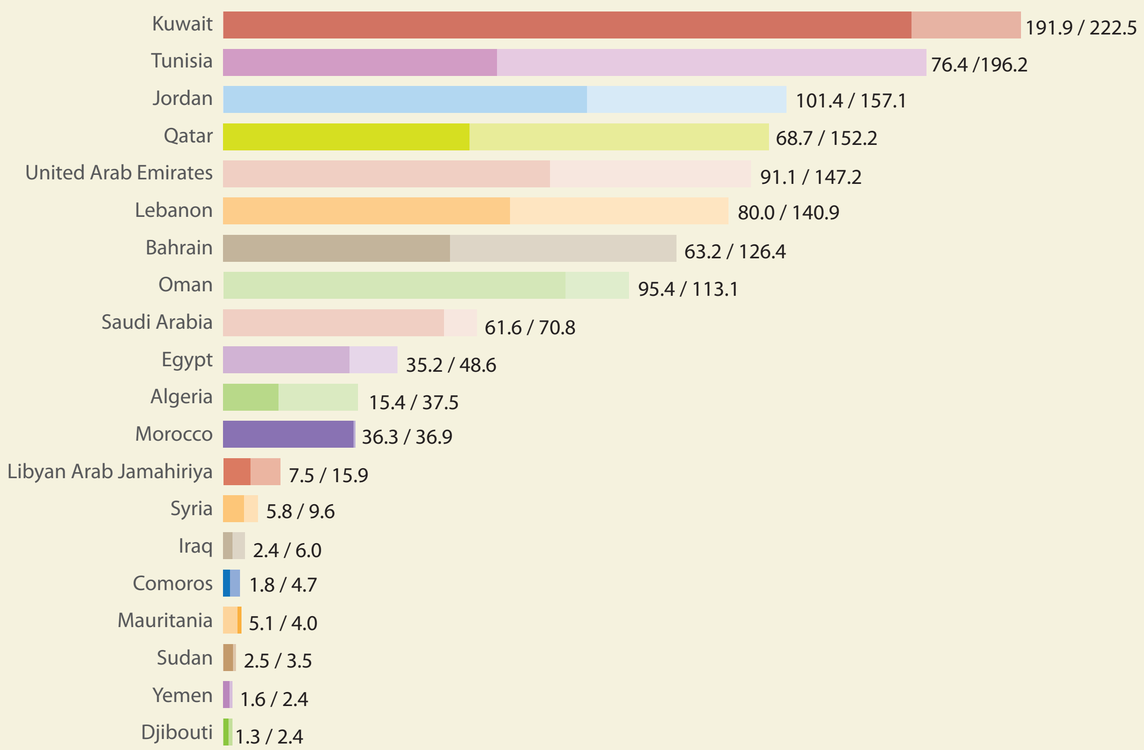
By 2010, more than 400 scientists and engineers had participated in 17 workshops and schools in the Middle East and elsewhere on applications in biology, materials science and other fields, as well as on accelerated technology. Approximately 65 of these men and women have spent periods of up to two years working at synchrotron radiation facilities in Europe, the USA, Asia and Latin America. The majority of these facilities are situated in observer countries, some of which have been donating beamline components. The 12 observer countries include France, Japan, Kuwait, the UK and USA.

SESAME will enable scientists to work together across countries and cultures within the same research facility. UNESCO calls it a model project for other regions, as it has brought together people from nine countries and territories who do not all see eye to eye politically. In 2009, the members of SESAME were Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey.

Source: UNESCO

For details: www.sesame.org.jo

Figure 6: Scientific publications per million population in the Arab world, 2002 and 2008



Source: Thomson Reuters (Scientific) Inc. Web of Science. Science Citation Index Expanded, compiled for UNESCO by the Canadian Observatoire des sciences et des technologies; for population data: World Bank, World Development Indicators, June 2010

TOWARDS THE KNOWLEDGE ECONOMY

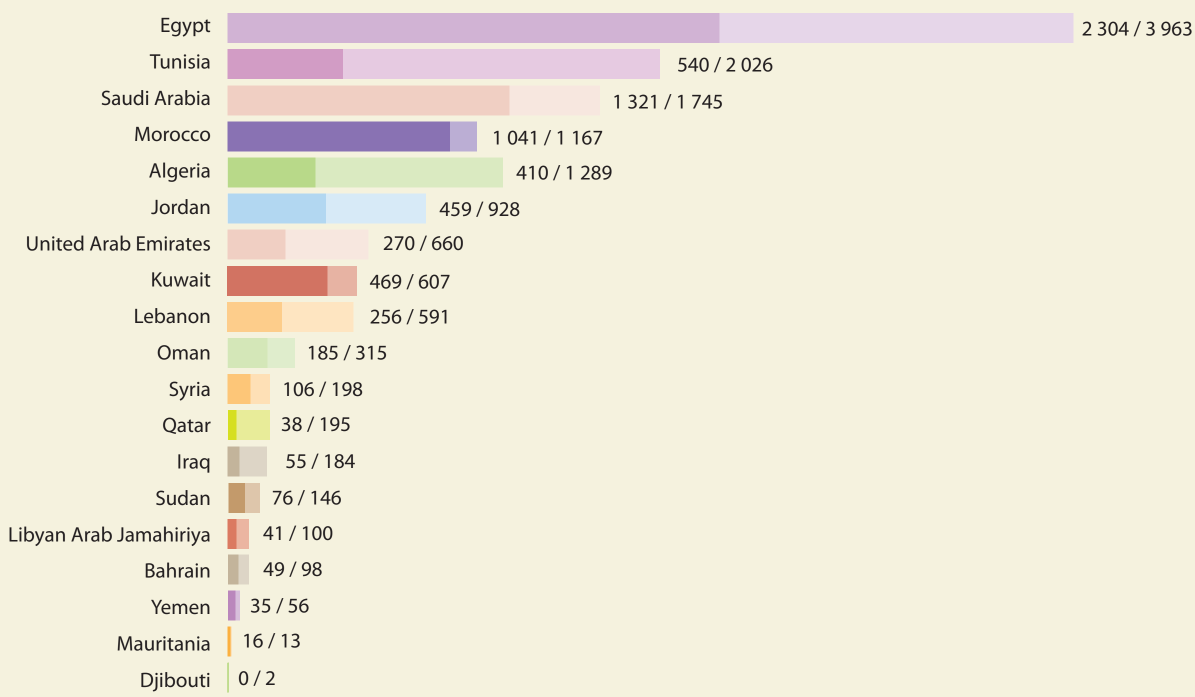
ICTs

The development of ICTs and their primary manifestation, the Internet, has offered societies – and the STI communities within – a new means of knowledge accumulation, assimilation and production, a new means of teaching, learning and communicating. ICTs have undoubtedly helped research communities to access a greater volume of information than before at a faster pace, to undertake more complex research, achieve better results and communicate with much more ease. Even if R&D in informatics and computer science can be a complex and expensive business, it necessitates relatively basic tools. Writing complex software, for instance, does not require elaborate laboratory equipment.

The majority of Arab states have successfully ridden the IT wave, as the figures for Internet penetration in Table 3 demonstrate. This is due to the fact that ICTs are pervasive and general-purpose technologies. Even before the current global economic recession, telecommunications the world over were undergoing a transformation towards advanced Next Generation Networks and converged services. This is revolutionizing the roles of telephone companies, Internet service providers and media and content delivery companies (GAID, 2009).

The leading Arab country in terms of Internet use is the United Arab Emirates, which has a penetration rate of almost 50%. Saudi Arabia and Morocco have both overcome their late start in introducing Internet access and have caught up with other countries in the region, with Internet penetration rates of 22% and 21% respectively. Syria, Algeria and to a lesser extent Iraq seem to be trying to catch up, although language in the case of the former two countries may represent a barrier, as the second spoken language in both is French rather than English.

Figure 7: Scientific articles published in the Arab world, 2000 and 2008



Source: Thomson Reuters (Scientific) Inc. Web of Science, Science Citation Index Expanded, compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

The ICT sector in Jordan planned to reduce Internet access tariffs in 2009, in order to raise the Internet penetration rate to around 24% by the end of the same year.

One regional organization that was 'born digital', however, is the Bibliotheca Alexandrina (Box 7).

High-tech exports

High-tech exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments and electrical machinery. Some Arab countries have a relatively advanced pharmaceutical industry that can contribute to high-tech exports.

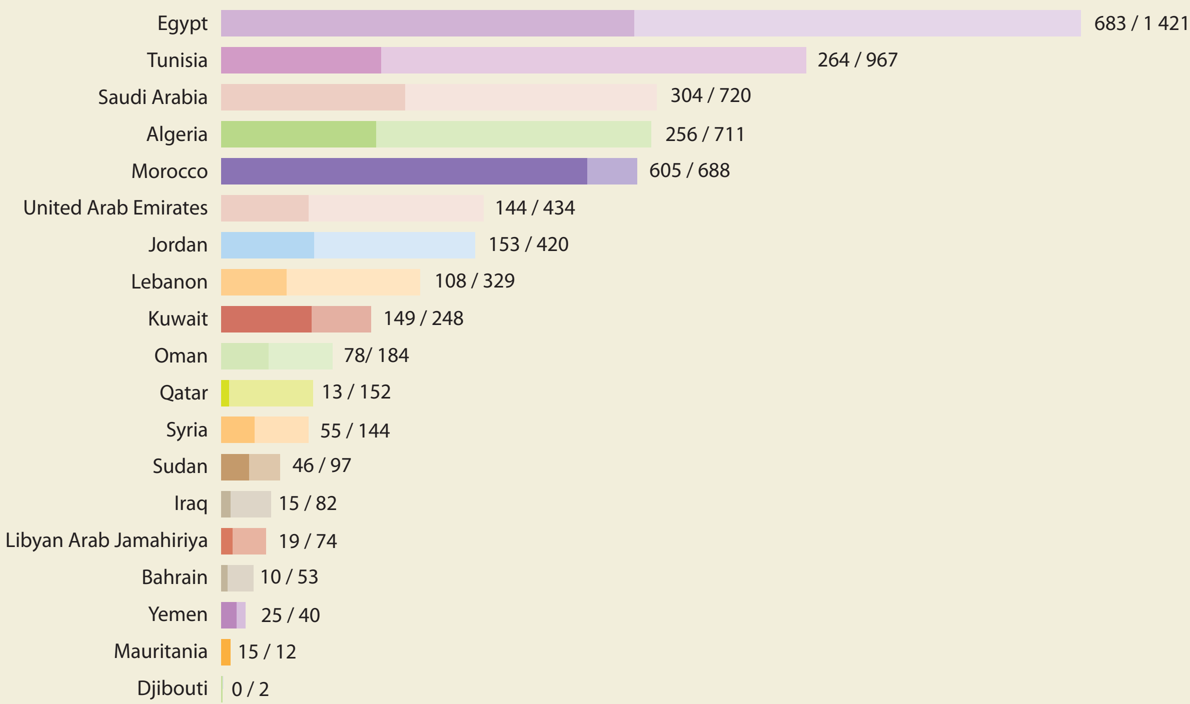
High technology contributes to rapid growth and is a major source of wealth generation. It contrasts with the resource-based industries that dominated the 20th century. High-tech exports are a function of a country's level of inward foreign direct investment, consumer demand at home and technological infrastructure.

Seyom (2005) has shown that the state of a nation's technological infrastructure is dependent on two variables: GERD per capita and the number of scientists and engineers engaged in R&D. He has concluded that good technological infrastructure has a positive, significant influence on high-tech exports.

Figure 10 shows the share of high-tech exports as a percentage of total exports for selected Arab countries. With high-tech exports constituting around 10% of all national exports, Morocco is the leading Arab country for this indicator. However, the high-tech exports of a country like Malaysia constitute as much as 55% of total exports. This is due in part to the country's developing technological infrastructure but also to the multitude of multinational companies that have set up manufacturing hubs in Malaysia, unlike in the majority of Arab countries.

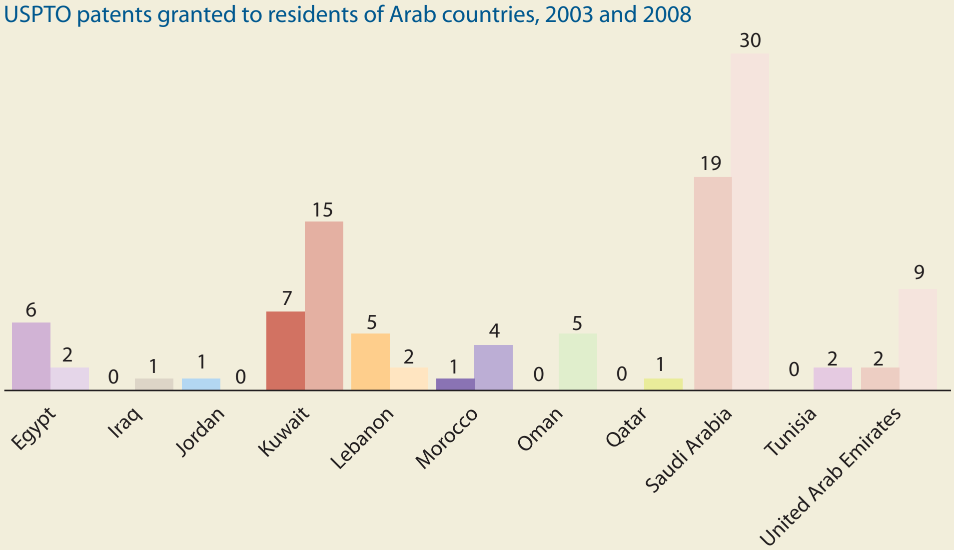
Figure 11 shows the Knowledge Economy Index (KEI) for the majority of Arab countries. Among non-oil economies, Jordan achieves the highest score for this

Figure 8: Scientific co-publications in the Arab world, 2000 and 2008



Source: Thomson Reuters (Scientific) Inc. Web of Science, Science Citation Index Expanded, compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

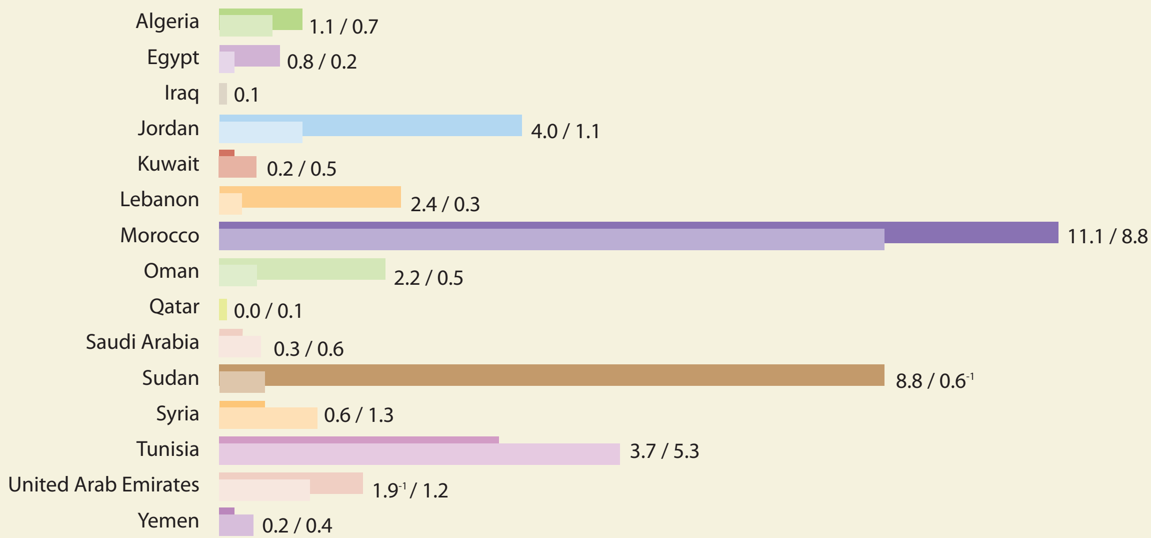
Figure 9: USPTO patents granted to residents of Arab countries, 2003 and 2008



Note: The country of origin is determined by the residence of the first-named inventor. No patents were granted to residents of Algeria, Bahrain, Libyan Arab Jamahiriya, Mauritania, Sudan and Yemen in 2003 and 2008.

Source: United States Patents and Trademark Office

Figure 10: Share of Arab high-tech exports in total manufactured exports, 2002 and 2007 (%)



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

Note: The relatively high share of high-tech exports for Sudan in 2002 can be explained by the fact that overall export figures for Sudan are very low, so a single large order in a given year may represent a large share of the total.

Source: World Bank, World Development Indicators, June 2010

index, closely followed by Oman and Lebanon. Morocco, on the other hand, has some way to go for the education and innovation parameters used to calculate the KEI, even though it boasts a high rate of Internet penetration.

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Higher education: forming the S&T labour force

In the Arab world, the number of students in higher education has increased considerably, from 5.4 million in 2000 to 7.3 million in 2008. In 2000, there were 1 907 students for 100 000 inhabitants. By 2008, this number had increased to 2185, according to the UIS.

These increases have not been uniform across Arab countries. This is due not only to the lack of financial resources in some countries but also to factors related to policies, social values and so on. The issue of equal access to higher education, on the other hand, can be attributed to wealth divides between communities within societies, geographical areas and social categories, as well as to disparities in gender and age.

In 20 Arab countries, there are over 300 public and private universities (Saleh, 2008). This corresponds to one university per million population. This is less than the world average, as there are around 10 000 universities worldwide for a global population of about 6.7 billion.

How do Arab universities compare with others?

The majority of universities in Arab countries are new. The older ones have not been able to keep up and have seen their standing fall by international yardsticks.

Rankings of universities, although controversial, have become increasingly popular. Two publications have attracted wide attention from policy-makers, scientific communities and the media since they began publishing their own rankings: the journal of *Shanghai Jiao Tong University* in China (*SJTU*, since 2003) and the *Times Higher Education Supplement* in the UK (*THES*, since 2004). In 2007, Cairo University was the only Arab university to rank among *SJTU*'s top 500 universities in the world. No Arab university has ever appeared in the *THES* ranking.

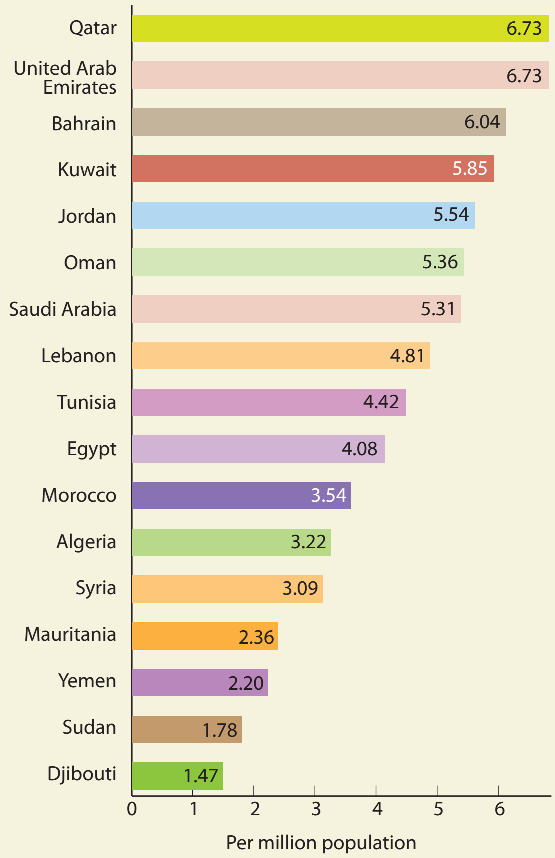
Research by the statistical agency of the OIC placed only nine Arab universities in the top 50 of the OIC member countries (Table 4). Arab universities do not seem to compare favourably with their OIC counterparts in Iran, Malaysia or Turkey, in particular (SESRTCIC, 2007).

Table 3: Internet penetration in the Arab region, 2002 and 2009

Country/ territory	Internet users per 100 population		Growth 2002–2009
	2002	2009	(%)
United Arab Emirates	28.3	82.2	272
Bahrain	18.1	82.0	429
Oman	6.9	43.5	624
Saudi Arabia	6.4	38.1	600
Kuwait	10.3	36.9	340
Tunisia	5.3	34.1	592
Morocco	2.4	32.2	1 371
Qatar	10.2	28.3	470
Jordan	6.0	27.6	466
Lebanon	10.3	23.7	150
Egypt	2.7	20.0	739
Syria	2.1	18.0	978
Algeria	1.6	13.5	840
Sudan	0.4	9.9	2 525
Palestinian Autonomous Territories	3.1	8.3	239
Libyan Arab Jamahiriya	2.2	5.5	183
Comoros	0.6	3.6	659
Djibouti	0.5	3.0	600
Mauritania	0.4	2.3	650
Yemen	0.5	1.8	320
Iraq	0.1	1.1	1 200
World	10.7	26.8	140

Source: International Telecommunications Union, World Telecommunications/ICT Indicators, July 2010

Figure 11: Knowledge Economy Index for selected Arab countries, 2008



Note: Data are weighted by population ranges from a low of 0 to a high of 10.

Source: World Bank http://info.worldbank.org/etools/kam2/KAM_page5.asp

Box 7: The Bibliotheca Alexandrina

Inaugurated in 2002, the Bibliotheca Alexandrina in Egypt seeks to recapture the legacy of the original Alexandria library which burnt down 2000 years ago, by disseminating knowledge and becoming a forum for dialogue, learning and understanding between cultures and peoples.

The Bibliotheca Alexandrina has capitalized on opportunities presented by ICTs. Library patrons can access 21 core databases and 19 584 scholarly electronic journals, e-book databases and other Internet resources. The library has emerged as a leader in the digitization of Arabic manuscripts, maps, books and pictures. It is also an active participant in global campaigns to make knowledge universally accessible.

The Bibliotheca Alexandrina reaches out to the general public, especially the young. The library includes special collections for youth, as well as cultural performances and programmes designed for young audiences.

Source: authors
For details: www.bibalex.org

We can deduce from the afore-mentioned studies that higher education across the Arab region is in need of serious reform. In the majority of countries, higher education is succeeding only in producing bureaucrats with little innovative capacity to meet the needs of the private sector. There is a dire mismatch between the skills companies are seeking and what most universities in the region are producing. The result is millions of young people with high expectations and no hope of fulfilling their dreams.

Investment trends in higher education

Various governance models for higher education exist in Arab countries. In the majority, a Ministry of Higher Education is in charge of management, planning, policies and strategies. In some countries, such a ministry is also responsible for scientific research. Despite such an elaborate set-up, it is almost impossible to estimate, for example, how much Arab countries invest in higher education.

Research published by the Economic Research Forum (Kanaan *et al.,* 2009) reveals that government expenditure on higher education amounted to 1.4% of GDP on average for the countries of the Organisation for Economic Co-operation and Development (OECD) in 2007. This compares with 1.7% in Tunisia, 1.5% in Saudi Arabia, 1.3% in Egypt, 1.2% in Yemen and Egypt, 0.8% in Jordan and 0.5% in Syria. Jordan spends no less than 4.3% of GDP on higher education but most of this comes from the private sector (Kanaan *et al.,* 2009).

Tunisia's public spending on higher education constituted around 25% of total public expenditure on education in 2007 (Abdessalem, 2009). Egypt made a similar commitment in 2004 (28%) but investment was lower in Jordan (18%) and Morocco (15%) for the same year.

Table 5 compares average annual expenditure on education in Arab states for 2001 and 2006. For many Arab countries, there has been little change, even though government expenditure on education has shown a marked increase in Oman, the United Arab Emirates and, to a lesser extent, in Morocco.

The stampede towards higher education

The percentage of young men and women enrolled in higher education in Arab countries is increasing overall. In Lebanon and the Palestinian Autonomous Territories, about 50% of the age cohort is on the student rolls. In Algeria, Jordan, Lebanon, Oman, the Palestinian Autonomous Territories, Qatar, Saudi Arabia, Tunisia and the United Arab Emirates, more women than men opt for higher education.

If we compare the figures in Table 6, we find that the total number of students enrolled in tertiary education has increased significantly in Algeria, Jordan, Lebanon, Oman, the Palestinian Autonomous Territories, Saudi Arabia and Tunisia. The situation in Qatar has deteriorated.

Arab countries fare well in terms of student gender balance in higher education. At the bachelor degree level however, the percentage of female students enrolled in social sciences and humanities is around 10% higher than for S&T disciplines (Table 7). It is interesting to note that, although there were no female PhD students in S&T streams in Bahrain, Oman or Jordan in 2006, women accounted for more than 41% of PhD students in S&T streams in Algeria, 38% in Egypt, 31% in Morocco and a sizeable 29% in Saudi Arabia.

More than 125 000 university faculty members in Arab countries are MSc and PhD holders, 30% of them women. Some researchers have put this figure at over 170 000 (Waast *et al.,* 2008) but this could be due to the inclusion of faculty teaching at more than one university, meaning they would be counted more than once.

Table 4: Arab universities in top 50 for Islamic countries
Composite index for number of citations 2001–2006

University	Country	Ranking
American University in Beirut	Lebanon	8
United Arab Emirates	United Arab Emirates	9
Suez Canal University	Egypt	10
Kuwait University	Kuwait	11
Cairo University	Egypt	25
King Fahd University of Petrol and Minerals	Saudi Arabia	34
Tanta University	Egypt	43
Jordan University of Science and Technology	Jordan	44
Sultan Qaboos University	Oman	50

Source: SESRTCIC (2007) *Academic Rankings of Universities in the OIC Countries: a Preliminary Report*: www.sesrtcic.org/files/article/232.pdf

Table 5: Public expenditure on education in the Arab world, 2002 and 2008
Selected countries

Country	Public expenditure on education			
	as % of GDP		as % of total government expenditure	
	2002	2008	2002	2008
Algeria	–	4.3	–	20.3
Bahrain	–	2.9	–	11.7
Djibouti	8.4	–	–	–
Egypt	–	3.8	–	11.9
Kuwait	6.6	–	14.8	–
Lebanon	2.6	2.0	12.3	8.1
Mauritania	3.5	4.4	–	15.6
Morocco	5.8	5.7	26.4	25.7
Oman	4.3	–	22.6	–
Saudi Arabia	7.7	5.7	26.9	19.3
Tunisia	6.4	–	16.5	–
United Arab Emirates	2.0	0.9	23.5	27.2
Yemen	–	5.2	–	16.0

Note: For Mauritania, the 2008 data are an estimate by the UNESCO Institute for Statistics; for the UAE, the 2002 data are a national estimate.

Source: UNESCO Institute for Statistics database, July 2010

Despite a sizeable teaching community, in the majority of Arab countries, the student/teacher ratio falls short of the OECD average of 14 students per faculty member or even the world average of 16 students. Statistics dating from 2004 reveal that, in Egypt for example, the ratio was 1:30 and 1:27 in Jordan. Only in Lebanon does the ratio surpass the OECD and world ratios by an impressive margin, at 1:8 (Waast *et al.,* 2008).

Three regional initiatives exemplify recent top-down initiatives in higher education: Qatar's Education City; the Masdar Institute in Abu Dhabi, and the King Abdullah University of Sciences and Technology in Saudi Arabia (Boxes 8, 9 and 10). These initiatives are likely to staunch brain drain in Arab countries like Algeria and Egypt which have been hit by an exodus of talent.

Figures released by the National Science Foundation in 2000 reveal that there are thousands of Arab scientists and engineers living in the USA: 12 500 Egyptians, 11 500 Lebanese, 5 000 Syrians, 4 000 Jordanians and 2 500 Palestinians. Scientists from Morocco and Tunisia tend to head for Europe (Waast *et al.,* 2008).

The causes of low academic standards in higher education

A number of features in the Arab region contribute to low academic standards. Some are outlined below.

- Although extensive and well-established, the higher education system in the Arab region has not maintained the distinction it once had. Despite being confronted with globalization and the ascendance of private education, new knowledge and knowledge delivery modes, it remains essentially supply-driven rather than demand-driven.

- Arab universities are under pressure to fulfil many complementary yet conflicting roles: knowledge transmission (teaching), knowledge generation (research) and knowledge preservation and diffusion. University governance in the majority of Arab countries remains unsteady, unable to assume one or more of these roles successfully. This is further complicated by governments exerting undue influence over universities, mainly out of political considerations.

- The archaic hierarchical system of promotion and incentives at universities remains a major hurdle. As knowledge transmitters, universities in Arab countries must aim to form highly productive work-ready professionals, not bureaucrats, with the appropriate skills to address economic needs and opportunities, as well as those of the economy's component industries and sectors. This requires student admission policies and faculty recruitment policies that are essentially merit-based and transparent.

- Arab universities and research centres have been unable to develop a smart R&D environment over the past four decades. There is a certain improvisation in the way R&D is rewarded. As clear long-term research policies are generally lacking, researchers are never certain that they will obtain requisite funding. Often educated and trained in the West, faculty could implement the best research practices they picked up during their studies. Instead, they are frequently forced to take on heavy teaching loads to supplement their income, leaving little time for scientific research. Even sabbatical leave is rarely used for research. As knowledge generators, universities are the

Table 6: Tertiary student enrollment in the Arab region, 2002 and 2008
As a percentage of the age cohort

Country	2002 Male (%)	2002 Female (%)	2002 Total student enrollment (%)	2008 Male (%)	2008 Female (%)	2008 Total student enrollment (%)
Algeria	–	–	17.8	25.3	36.4	30.7
Djibouti	1.1	0.9	1.0	–	–	–
Egypt	–	–	–	–	–	28.5
Iraq	16.0	8.7	12.4	–	–	–
Jordan	29.5	30.6	30.0	38.5	42.9	40.7
Kuwait	15.1	29.2	21.8	–	–	–
Lebanon	38.9	42.8	40.9	48.0	57.1	52.5
Libyan Arab Jamahiriya	51.8	56.7	54.2	–	–	–
Mauritania	4.6	1.3	3.0	–	–	–
Morocco	11.7	8.9	10.3	13.0	11.6	12.3
Oman	15.9	12.4	14.3	27.2	32.0	29.5
Palestinian Autonomous Territories	30.4	29.7	30.0	42.5	52.2	47.2
Qatar	7.6	31.1	16.8	5.1	31.1	11.0
Saudi Arabia	17.3	28.0	22.3	22.6	37.4	29.9
Tunisia	21.0	25.7	23.3	27.2	40.5	33.7
United Arab Emirates	12.9	36.9	22.8	17.4	35.7	25.2

Note: For Algeria, Iraq, Morocco, Oman, Saudi Arabia and the United Arab Emirates, the data for 2002 are an estimate by the UNESCO Institute for Statistics.

Source: UNESCO Institute for Statistics database, July 2010

Arab world's engine room for discovery and invention; the principal creators and disseminators of new knowledge. Research is considered the most salient example of a country's intellectual resources, economic strength and global competitiveness. Universities should be producers of research, not investors. They currently spend too much time looking for funding for research projects.

- The present system is eating away at precious resources from teaching programmes, in order to maintain research performance. Heavy teaching loads may be relieved by a long-term faculty development programme, the introduction of innovative university management practices and by facilitating further the movement of faculty between countries.

- Bilateral and trilateral exchanges of faculty and joint research projects are rare among Arab universities compared to the co-operation programmes concluded with parties beyond the Arab world. Arab countries should each attempt to have at least one model university that excels in one role: teaching, research or knowledge diffusion. This will make networking between Arab universities of similar outlook easier.

- An Arab Bologna Process is required to create an Arab Higher Education Area along the lines of the European model (*see page* 150). There is a need for Arab ministries and other bodies responsible for higher education to co-operate in areas such as the recognition of diplomas and the exchange of information and expertise in higher education. An Arab Bologna Process could make Arab higher education more comparable, more competitive and more attractive.

CONCLUSION

Arab countries have been aware of the importance of STI for socio-economic development for at least four decades. Many Arab countries have had a core STI system for as long. However, little has changed in terms of the impact of science and the scientific enterprise on achieving socio-economic development, or generating new knowledge.

The challenges facing Arab countries in S&T is enormous. However, they can be overcome with vision, commitment and hard work. The huge strides made by countries that two or three decades ago were at the same level of development as Arab states, including Brazil, China, India, Ireland, Mexico and the Republic of Korea, show that it is possible.

Table 7: Postgraduate students at Arab universities, 2006

Country	Science and technology						Total social sciences and humanities plus science and technology						Total headcount
	MSc			PhD			MSc			PhD			
	M	F	Total	M	F	Total	M	F	Total	M	F	Total	
Algeria	8 104	7 204	15 308	4 503	3 186	7 689	13 176	12 006	25 181	7 689	4 917	12 606	37 787
Bahrain	30	53	83	1	0	1	273	278	551	1	0	1	552
Egypt	28 811	21 476	50 287	9 080	5 529	14 609	41 204	37 528	78 732	14 590	9 221	23 811	102 543
Jordan	434	345	779	30	0	30	881	697	1 578	36	0	36	1 614
Morocco	4 005	2 112	6 117	3 591	2 111	6 702	8 201	4 416	12 617	8 565	4 078	10 849	23 466
Oman	172	91	263	1	0	1	353	212	565	1	0	1	566
Saudi Arabia^{-1}	2 249	1 154	3 403	239	99	338	5 251	3 884	9 136	1 189	1 011	2 200	11 336
Tunisia	3 415	3 439	6 854	–	–	–	7 146	11 438	18 584	–	–	–	
Yemen	341	155	496	–	–	–	1 444	546	1 990	–	–	–	

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

Note: Data cover both national and foreign-born students. Science and technology include natural sciences, engineering and technology, medicine, health sciences and agricultural sciences.

Source:Saleh (2008) S&T indicators in the Arab States

Box 8: Education City, Qatar

The Qatar Foundation founded Education City in 2001 as a hub for capacity-building and character development. At the heart of Education City are six international universities. In 2007 and 2008, these established branches with the campuses of prestigious institutions in the USA: Carnegie Mellon University, Georgetown University's School of Foreign Service, Virginia Commonwealth University, Weill Medical College of Cornell University and the Texas Agricultural and Mechanical University (Texas A&M).

A significant percentage of the Qatari students enrolled in these branch campuses are girls seeking to pursue higher education close to home. For instance, 75 of the 120 Qatari students at the Carnegie Mellon satellite campus are female. On Georgetown's satellite campus, 68 of the 107 students are female. Education City includes an Academic Bridge Programme which prepares students for study in world-class universities.

For details: www.qf.org.qa

Box 9: The Masdar Institute of Science and Technology

Abu Dhabi in the United Arab Emirates launched the Masdar Initiative in 2006 as a global co-operative scientific platform to address pressing issues, such as energy security, climate change and the development of human expertise in sustainability science. Masdar aims to position Abu Dhabi as a world-class R&D hub for new energy technologies and to drive the commercialization and adoption of these and other technologies in sustainable energy, carbon management and water conservation.

Developed in co-operation with the Massachusetts Institute of Technology (MIT), the Masdar Institute of Science and Technology emulates MIT's high standards and offers Master's and PhD programmes focused on the science and engineering of advanced energy and sustainable technologies. MIT is working with Masdar to establish a sustainable, home-grown academic and scientific research institute. The Masdar Institute aspires to become a centre of high-calibre renewable energy and sustainability research capable of attracting leading scientists from around the world.

For details: www.masdaruae.com

Box 10: King Abdullah University of Science and Technology

King Abdullah University of Science and Technology (KAUST) has been built in Saudi Arabia as an international, graduate-level research university dedicated to inspiring a new age of scientific achievement in Saudi Arabia, the region and the world. It is supported by a multi-billion dollar endowment that is governed by an independent, self-perpetuating Board of Trustees. KAUST is merit-based and open to men and women from around the world.

KAUST's core campus is located on more than 36 000 km^2 on the Red Sea 80 km north of Saudi Arabia's second-largest city, Jeddah.

Since it opened in September 2009, AUST has pursued a research agenda in four strategic areas: energy and the environment; biosciences and bioengineering; materials science and engineering; and applied mathematics and computational science.

Source: authors
For details: www.kaust.edu.sa

Although Arab decision-makers have been increasing expenditure on education, there is still little political patronage of science and the scientific endeavour, despite a legacy of creativity and innovation. Lack of expenditure on R&D is a major cause of the poor output of the Arab STI system but it is not the only quandary. The lack of a science culture in turn leads to a lack of appreciation for science. So why do Arab decision-makers seem more concerned with education than STI? Can it be that education is viewed as a necessity, whereas STI is considered a luxury? Basic education empowers citizens to read, comprehend basic mathematics and make a living. However, basic education is not sufficient to create wealth, to address concerns of food, water and energy security, to provide better health services and better infrastructure. For that, science is required.

The major contemporary problems Arab countries face which require scientific or technological solutions are well known. Despite this, the purpose of scientific research remains unclear. Research undertaken by the higher education sector, although important, often serves purely academic purposes.

Appreciation for S&T is also an almost alien concept in the mindset of the Arab private sector, which has always been strong in trading goods and services rather than manufacturing. Even in instances where funding has been no object, the private sector has been unable to produce a critical mass of knowledge workers to utilize these resources to meet national objectives, add to the national and global pool of knowledge or produce patents leading to products and services.

Another factor stalling change in Arab countries has historically been the top-down approach to governance. This places political leaders in a position where they have to assume the role of championing science for the scientific enterprise to blossom.

Arab countries today are nation states, a particularly European invention that became obsolete with the signing of the Treaty of Rome in 1959. Since then, European countries have set about harmonizing their economic and scientific policies.

It is true that, in the Arab world, there are regional umbrella organizations that do the job of the European Union. There is the Arab League, which has been in existence for over six decades. Its primary concern has been to deal with political problems, however, causing issues in S&T and higher education to be neglected by this body. There is also the Organisation of the Islamic Conference. This umbrella organization embracing both Arab and non-Arab Islamic countries has made some bold attempts to address S&T issues. However, due to a chronic shortage of funds, it too has been unable to implement its programmes fully.

Oil wealth has been a double-edged sword. On the one hand, it has helped Arab countries to consolidate their infrastructure, invest in service industries and promote trade. On the down side, 'easy money' has meant that STI-based development and industries took a back seat until very recently. The slump in oil prices since 2008 has given oil states a glimpse into the future when they will no longer be able to count on oil for their major source of income.

High-tech exports form Arab countries are negligible. The acquisition and application of technology is a function of an enabling environment, yet this environment is almost non-existent in many parts of the Arab world. For instance, although expenditure on defence in Arab countries is among the highest in the world, there is no home-grown defence industry.

There is very little linkage between universities and industry when it comes to research output and thus little wealth generation via the commercialization of R&D. In the majority of Arab states, intellectual property regimes are very weak, providing little protection for the output of scientists. A patent culture being almost non-existent, researchers often come up against a blank wall when attempting to commercialize or otherwise develop their research output.

A number of Arab countries have a sizeable S&T potential. This potential is often dispersed and championed by individuals rather than institutions. S&T output has been growing unsteadily over the past three decades. Today, exploiting this output still relies on a handful of dedicated knowledge workers based at a few universities and research centres in the Arab world.

Some countries have begun to streamline R&D into basic research, applied research and technological development. They have also started assimilating market parlance, not only when it comes to producing papers and patents but also prototypes and products. There are also those which are attempting to leapfrog the development cycle by importing ready-made models of research centres and universities; this may yield success but only at the local level unless an inter-regional component is added.

Last but not least, the stability and security of Arab countries cannot simply be a function of military expenditure and expenditure devoted to upholding law and order. Long-term security and prosperity for all countries in the region can only be achieved by assuring the triple helix of food, water and energy security, combined with sustainable and equitable socio-economic development in tolerant societies where accountability and rule of law prevail. S&T can achieve some of these goals, if not all.

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Adnan Badran is a former Prime Minister of Jordan (2005) and former Minister of Agriculture and of Education. He joined UNESCO in 1990 as Assistant Director-General for Natural Sciences before serving as Deputy Director-General of UNESCO from 1996 to 1998.

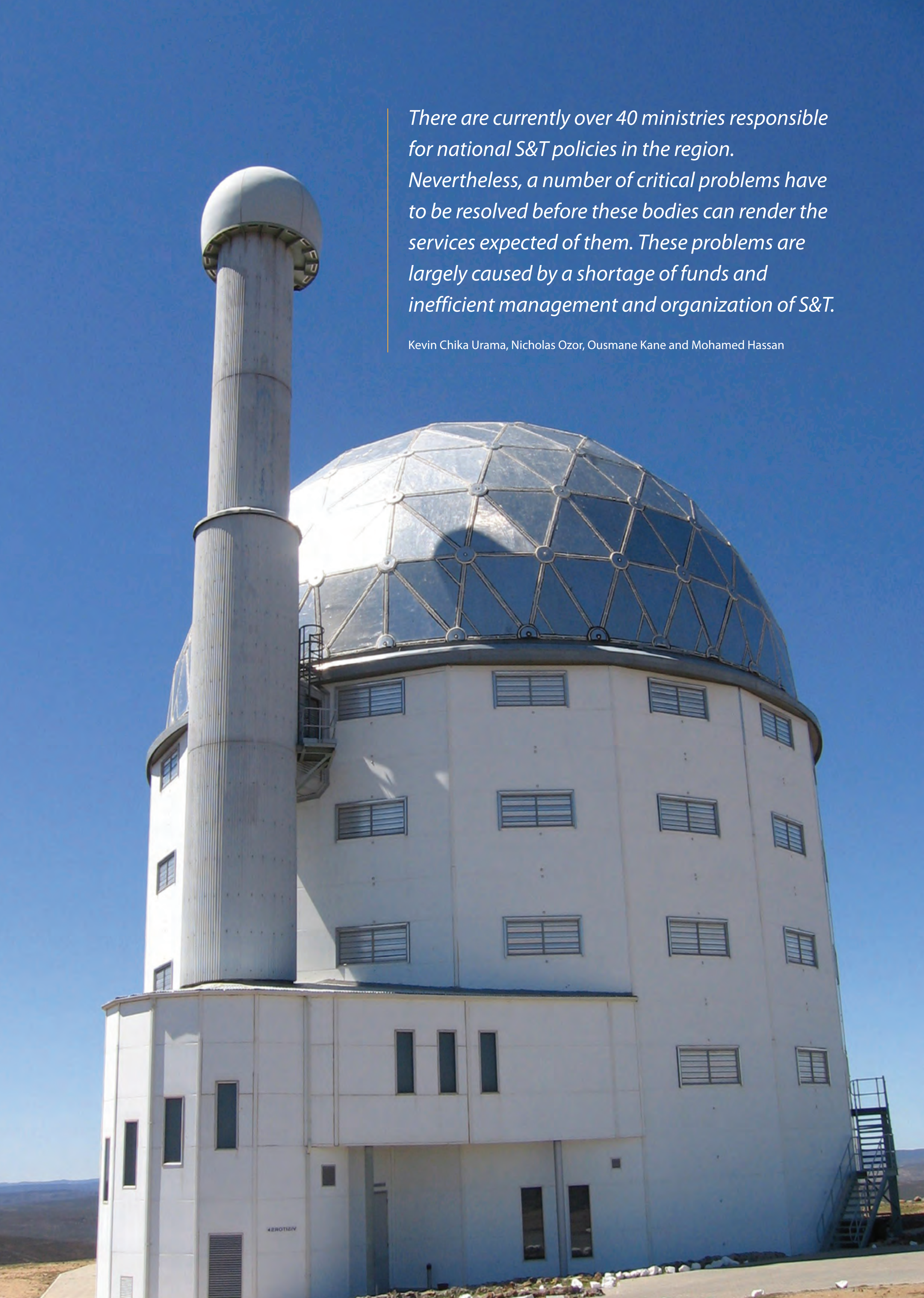
Born in Jerash, Jordan, in 1935, Dr Badran received his PhD from Michigan State University in 1963. After conducting basic research in plant physiology in the USA, he became a Professor of Biology at the University of Jordan. He was later appointed Dean of the Faculty of Sciences at the same university then founding President of Yarmouk University and of Jordan University of Science and Technology, where he served from 1976 to 1986.

Currently, he is President of Petra University, Senator and Chair of the Senate Committee on Science, Education and Culture, and President of the National Centre of Human Rights of Jordan. He is a Fellow of the Academy of Sciences for the Developing World (TWAS) and of the Islamic World Academy of Sciences and President of the Arab Academy of Sciences.

Moneef R. Zou'bi has been a researcher for 20 years. Born in Amman, Jordan, in 1963, he studied for his undergraduate and postgraduate degrees in Civil Engineering at Brighton and Loughborough Universities in the United Kingdom between 1980 and 1987. He then worked with a number of consulting firms in the United Kingdom.

In 1990, he joined the Islamic World Academy of Sciences (IAS), embarking on a career in international collaboration involving 50 countries. As Director-General of the IAS since 1998, he has worked to promote the academy's role in bridging divides in S&T development and even political divides between countries.

Over the course of his career, he has published over 45 papers on issues related to S&T policy and has edited or co-edited 10 books on higher education, the environment and water resources. He has also been involved in various studies implemented by the Islamic Development Bank and the General Secretariat of the Organisation of the Islamic Conference.



There are currently over 40 ministries responsible for national S&T policies in the region. Nevertheless, a number of critical problems have to be resolved before these bodies can render the services expected of them. These problems are largely caused by a shortage of funds and inefficient management and organization of S&T.

Kevin Chika Urama, Nicholas Ozor, Ousmane Kane and Mohamed Hassan

14 · Sub-Saharan Africa

Kevin Chika Urama, Nicholas Ozor, Ousmane Kane and Mohamed Hassan

INTRODUCTION

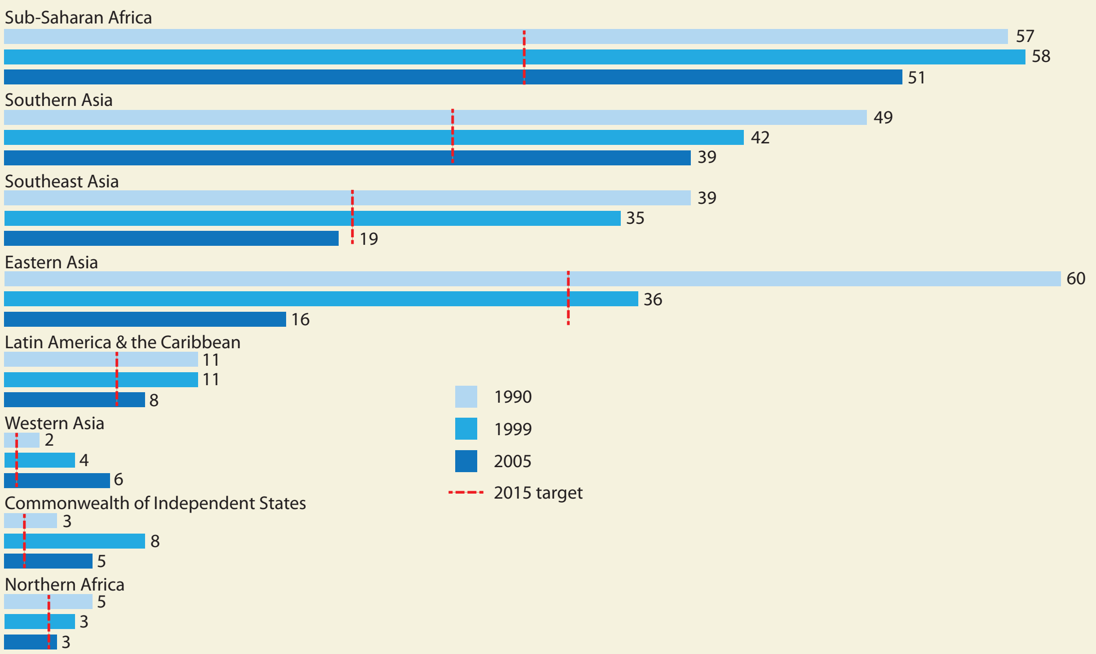
The Millennium Declaration set 2015 as the target date for achieving the eight Millennium Development Goals. These goals established quantitative benchmarks for halving extreme poverty in all its forms (*see Annex II*). As the date approaches, the world finds itself mired in an unprecedented economic recession. In sub-Saharan Africa and Southern Asia, both the number of poor and the poverty rate increased in some of the least-growth economies in 2009, a factor exacerbated by the growing burden of catastrophes caused by climate change and natural disasters. Current projections suggest that overall poverty rates in the developing world fell in 2009 but at a much slower pace than before the downturn (UNDESA, 2009). For some countries, this may mean the difference between reaching, or not, their poverty reduction target.

Replete with natural resources, intellectual capital, indigenous knowledge and culture, Africa is nevertheless at a comparative disadvantage when it comes to overall development because of its low investment in science and technology (S&T). This results in poor infrastructure development, a small pool of researchers and minimal scientific output. The situation is exacerbated by population growth, conflicts, poor governance and political instability, food insecurity, poverty and disease, among other factors.

The continent has made several bold attempts to turn around its development fortunes through treaties that include the Monrovia Strategy (1979), the Lagos Plan of Action (1980), the Abuja Treaty (1991) establishing the African Economic Community and, most recently, the adoption of *Africa's Science and Technology Consolidated Plan of Action* (CPA) by the African Union[1] in January 2007. Despite these efforts, Africa remains the poorest and most economically marginalized continent in the world (Figure 1). The continent has often adopted a short-term view of human development, persisting in a reliance on

1. Although the African Union embraces the entire continent, we shall be focusing in the present chapter on countries south of the Sahara, since the Maghreb is covered in Chapter 13.

Figure 1: Poverty levels in sub-Saharan Africa, 1990, 1999 and 2005 (%)



Note: Proportion of people living on less than US$ 1.25 a day

Source: UNDESA (2009) *The Millennium Development Goals Report*

The Southern African Large Telescope was inaugurated in 2005. It is the largest in the southern hemisphere

Photo: Wikipedia Commons

Table 1: Investment in sub-Saharan Africa, 2008 or most recent year available
Selected countries

	Military expenditure (% of GDP)	Total expenditiure on health (% of GDP)	Public expenditiure on education (% of GDP)	Expenditure on tertiary education (% of total expenditure on education)	GERD (% of GDP)	GERD (in PPP$ thousands)	GERD (per capita PPP$)
Angola	2.9	2.7	2.6^{-2}	8.7^{-2}	–	–	–
Benin	1.0	5.3	3.6^{-1}	20.2^{-1}	–	–	–
Botswana	3.5	7.2	8.1^{-1}	27.5^{-1}	0.5^{-2}	111 714^{-2}	60.7^{-2}
Burkina Faso	1.8	6.4	4.6^{-1}	15.2^{-1}	0.1^{a}	18 392^{a}	1.2
Burundi	3.8	3.0	7.2	21.2	–	–	–
Cameroon	1.5	5.2	2.9	9.0	–	–	–
Cape Verde	0.5	5.6	5.7	11.3	–	–	–
Central African Rep.	1.6	3.9	1.3^{-1}	21.3^{-1}	–	–	–
Chad	1.0	3.6	1.9^{-3}	18.7^{-3}	–	–	–
Comoros	–	3.2	7.6**	14.6**	–	–	–
Congo	1.3	2.1	1.8^{-3}	25.9^{-3**}	0.1^{-1*}	–	–
Côte d'Ivoire	1.5	3.8	4.6	25.1^{-8**}	–	–	–
Dem. Rep. of Congo	0.0	4.3	–	–	0.5$^{-2, v}$	75 217$^{-2, v}$	1.3$^{-2, v}$
Equatorial Guinea	–	1.5	0.6$^{-5,**}$	31.4^{-6}	–	–	–
Eritrea	23.6^{-5}	4.5	2.0^{-2}	19.4^{-2}	–	–	–
Ethiopia	1.5	4.9	5.5^{-1}	39.0^{-1}	0.2^{a}	106 753^{a}	1.4^{a}
Gabon	1.1^{-1}	3.7	–	–	–	–	–
Gambia	0.7^{-1}	4.3	2.0$^{-4,**}$	12.2$^{-4,**}$	–	–	–
Ghana	0.7	6.2	5.4^{-3}	20.8^{-3}	–	–	–
Guinea	2.0^{-4}	5.7	1.7	34.4	–	–	–
Guinea-Bissau	4.0^{-3}	6.2	–	–	–	–	–
Kenya	1.7	4.6	7.0^{-2}	15.4^{-2}	–	–	–
Lesotho	2.6	6.7	12.4	36.4	0.1$^{-3, a}$	1 563$^{-3, a}$	0.8$^{-3, a}$
Liberia	0.5^{-1}	5.6	2.7	_	–	–	–
Madagascar	1.1	3.2	2.9	15.4	0.1^{a}	25 753^{a}	1.4^{a}
Malawi	1.2^{-1}	12.3	4.2^{-5}	_	–	–	–
Mali	2.0	6.0	3.8	16.1	–	–	–
Mauritius	0.2^{-1}	4.3	3.4^{+1}	11.0^{+1}	0.4$^{-2, v}$	47 014$^{-2, v}$	37.5$^{-2, v}$
Mozambique	0.9	4.7	5.0^{-2}	12.1^{-2}	0.5^{-1}	83 105^{-1}	3.9^{-1}
Namibia	3.1	4.9	6.5	9.9	–	–	–
Niger	0.0^{-3}	4.0	3.7	9.4	–	–	–
Nigeria	0.0	4.1	–	–	–	–	–
Rwanda	1.5	10.4	4.1	25.4	–	–	_
Senegal	1.6	5.4	5.1**	24.5**	0.1$^{-2, a, *}$	16 252$^{-2, a, *}$	1.4$^{-2, a, *}$
Seychelles	1.0	6.8	5.0^{-2}	17.9^{-2}	0.3^{-2}	4 519^{-2}	54.5^{-2}
Sierra Leone	2.3	3.5	3.8$^{-3,**}$	_	–	–	–
South Africa	1.4	8.6	5.4^{+1}	12.5^{+1}	0.9^{-1}	4 100 875^{-1}	84.3^{-1}
Swaziland	2.1^{-1}	5.9	7.9	21.3^{-2}	–	–	–
Togo	2.0	5.5	3.7^{-1}	21.4^{-1}	–	–	_
Uganda	2.3^{-1}	7.2	3.3^{+1}	13.3^{+1}	0.4	128 012	4.2
United Rep. of Tanzania	0.9	5.5	6.8	–	–	–	–
Zambia	1.8	5.2	1.4	25.8^{-3}	0.0$^{-2, a}$	3 840$^{-2, a}$	0.3$^{-2, a}$
Zimbabwe	3.8^{-3}	8.4	4.6^{-8**}	16.6^{-8**}	–	–	–

-n/+n = data refer to *n* years before or after reference year
* national estimate; ** UNESCO Institute for Statistics estimation; a = partial data; v = overestimated or based on overestimated data

Source: for expenditure on education and GERD: UNESCO Institute for Statistics; for military expenditure: World Bank, World Development Indicators, June 2010; for health expenditure: WHO (2009) *World Health Statistics* reliance on external financial support, which often targets short-term goals. As a result, the continent has failed to invest in science, technology and innovation (STI) as drivers of economic growth and long-term sustainable development (Mugabe and Ambali, 2006). This is evident in Africa's low public expenditure on research and development (GERD) [Table 1]. Countries will need to design and implement policies, as well as create institutional arrangements, which promote the development and application of S&T to solving specific problems related to each of the Millennium Goals.

The need for change was acknowledged by the Malawi President Bingu wa Mutharika in January 2007, at the African Union summit in Addis Ababa, Ethiopia. He affirmed that building S&T capacity was the only sure way to break the long-standing cycle of extreme poverty that has gripped the African continent for decades. 'We have depended on donor countries for scientific development for so long,' he noted. 'It is time we committed more resources in our national budget to advance S&T.'

In the past decade, a number of African countries have been progressively enhancing their S&T capacity as a strategy for extricating themselves from the grips of poverty, hunger and disease, and as a means of achieving industrial development and social transformation. Attempts have been made by many African governments to develop national STI policies for their respective countries. In 2008 alone, 14 countries formally requested UNESCO's assistance with science policy reviews: Benin, Botswana, Burundi, Central African Republic, Côte d'Ivoire, Democratic Republic of Congo, Madagascar, Malawi, Morocco, Senegal, Swaziland, Togo, Zimbabwe and Zambia.

African countries have begun to recognize that, without investment in S&T, the continent will stay on the periphery of the global knowledge economy. A number of countries are taking steps to establish a national innovation system in an approach generally borrowed from the Organisation for Economic Cooperation and Development (OECD). These efforts are most visible in South Africa, where GERD as a percentage of GDP grew from 0.73% in 2001 to 0.94 in 2006, according to the UNESCO Institute for Statistics.

However, as we shall see in the pages that follow, sub-Saharan Africa still has a long way to go to reach the eldorado of the knowledge economy, not only in terms of innovation but also as regards the other three pillars of the knowledge economy: a sound economy and institutional regime; an educated, creative population capable of utilizing knowledge effectively; and a dynamic information infrastructure. Although GDP per capita rose in most African countries between 2002 and 2008, it remains low by world standards, with the notable exception of Angola and Equatorial Guinea where a surge in oil exploitation in recent years has led to a meteoric rise in national income. Oil production and related activities contribute about 85% of GDP in Angola and fuelled growth averaging more than 15% per year from 2004 to 2007, even if GDP contracted in 2009 (-0.6%) as a result of the drop in oil prices and the global recession. In Equatorial Guinea, the discovery of large oil reserves caused GDP to bound by approximately 22% in 2007 and 12% the following year before falling oil prices plunged the economy into a negative growth of about 1.8% in 2009 (CIA, 2010). This example highlights the need for oil-rich African countries to diversity their economies in order to improve their resilience to fluctuating global oil markets, a policy adopted by Nigeria in recent years (*see page* 309).

In many African countries, subsistence agriculture occupies most of the population, even though it contributes a much smaller share to GDP. Subsistence farming still predominates in Angola, Burundi, Burkina Faso and Equatorial Guinea, for instance. Moreover, in all African countries south of the Sahara, enormous hurdles remain in achieving more equitable access to both education and information and communication technologies (ICTs).

AN INVENTORY OF STI CAPABILITIES IN AFRICA

Persistently low investment in STI

As we have seen in Table 1, R&D attracts less public investment in sub-Saharan Africa than the military, health or education sectors. Only South Africa is approaching the target of a 1% GERD/GDP ratio, the level recommended by UNESCO and, more recently, by the African Union summit in January 2007. Even more worrisome is that many countries either have no record of the share of GDP they devote to R&D or simply allocate no funds at all to R&D. This is most saddening for a continent desirous to develop STI. All African countries would do well to take a leaf out of South Africa's book.

An underexploited pool of human resources

Rising school rolls

At 62%, sub-Saharan Africa holds the unenviable world record for the lowest adult literacy rate, followed closely by South and West Asia, at 64%. Despite this low rate, many countries have achieved steep rises in adult literacy rates over the past decade, including some with the farthest way to go; Burkina Faso and Chad, for example, doubled and almost tripled their literacy rates respectively between 1999 and 2007. Public expenditure on education in sub-Saharan Africa rose from 3.5% of GNP in 1999 to 4.5% in 2007, placing it on a par with the mean for developing countries but still behind the mean for developed countries (5.3%). Public expenditure on education as a percentage of total government expenditure was actually higher in sub-Saharan Africa in 2007 (17.5%) than the mean for the developed world (12.4%) [UNESCO, 2010*a*].

The picture is brightest for primary education, where the sub-continent registered strong progress between 1999 and 2007. During a period in which the size of its school-age population increased by 20 million, sub-Saharan Africa reduced its out-of-school population by almost 13 million, or 28%. The strength of the region's progress can be gauged by a comparison with the 1990s: had the region progressed at the same pace as in the 1990s, 18 million more children would be out of school today. Nevertheless, one-quarter of sub-Saharan Africa's primary school-age children were still out of school in 2007 and the region accounted for nearly 45% of the world's entire out-of-school population. Progress in the region has been uneven. Some countries with large out-of-school populations in 1999 have made great strides, including Ethiopia, Kenya, Mozambique, Tanzania and Zambia. Countries making only limited progress include Liberia, Malawi and Nigeria (UNESCO, 2010*a*).

Despite commitment to international treaties and declarations by most countries south of the Sahara, access to secondary and tertiary education in sub-Saharan Africa remains limited to a minority, with one-quarter of countries showing gross enrollment rates of no more than 26% for secondary education and just under 4% for university enrollment in 2008. Holding many countries back is the substantial gender gap, with schooling often remaining the privilege of boys. Gender disparities in primary education increase with the level of education, as can be seen in the drop in the percentage of girls between the secondary and tertiary levels of education (Table 2). Empirical studies find a distinct correlation between university enrollment rates and growth in national income in many countries (Moyer, 2007, cited in Urama, 2009). Analyses show that attaining full primary education for all, which has been the main focus of government policies in many African countries, may be necessary but is not sufficient in itself to drive development in most countries. For example, Togo and Madagascar have attained over 90% primary school enrollment rates but this has not translated into higher national income (Urama, 2009). University enrollment rates in sub-Saharan Africa are among the lowest in the world. Overall, the contribution of higher education in Africa to gross national income is very low (Moyer, 2007; Botman *et al.,* 2009).

A more in-depth analysis provided by Moyer (2007, cited in Urama, 2009) suggests that the relative cost of higher education per student as a proportion of gross national income is higher in Africa that in the developed countries. This situation leaves African higher education in a dilemma, as African governments are the primary source of funding. Therefore, if higher education does not significantly contribute to growth in national income, it is most likely that governments will prioritize other development challenges such as poverty alleviation, climate change adaptation, water insecurity, peace and so on (Urama, 2009). However, it should be noted that investment in higher education has a long-term impact on national development.

Challenges for higher education

Africa entered the Millennium with severe education challenges at every level, as underlined in the African Union's *Plan of Action for the Second Decade of Education for Africa* (2006–2015). To cope with these challenges, conferences of ministers of education have reiterated the need to broaden access to education, improve quality and relevance, and ensure equity. Specific challenges for African higher education systems include:

- poorly equipped laboratories and overcrowded lecture rooms;
- a need to adapt the higher education system to the bachelor's–master's–doctorate triumvate, which is the norm around the world;

Table 2: Education in sub-Saharan Africa, 2008
Selected countries

Country	Secondary education: Gross enrollment ratio	Secondary education: Female students (%)	Tertiary education: Gross enrollment ratio (%)	Tertiary education: Female students (%)	Tertiary education: Enrollment in S&E fields % of total	Tertiary education: Female students in S&E fields as a % of total enrollment in S&E fields	Adult literacy rate (%)**
Angola	17.3$^{**,-6}$	45.7$^{**,-6}$	2.8^{-2}	39.9$^{*,-6}$	18.3^{-6}	–	69.6
Benin	36.3$^{**,-3}$	35.4$^{**,-3}$	5.8^{-2}	19.8$^{**,-7}$	–	–	40.8
Botswana	80.2^{-2}	51.1-2	7.6^{-2}	53.2^{-2}	–	–	83.3
Burkina Faso	19.8^{+1}	41.9^{+1}	3.4^{+1}	32.1^{+1}	15.3^{+1}	12.9^{+1}	28.7^{-1}
Burundi	17.9**	41.4**	2.7^{+1}	30.5$^{**,-2}$	9.6^{-6}	13.1^{-6}	65.9
Cameroon	37.3	44.1	9.0^{+1}	43.9^{+1}	21.8^{+1}	–	75.9
Cape Verde	67.7^{-4}	52.2^{-4}	11.9	55.5	16.2	30.8	84.1
Central African Rep.	13.6^{+1}	36.2^{+1}	2.5^{+1}	30.5^{+1}	12.3^{+1}	–	54.6
Chad	19.0^{-1}	30.8^{-1}	1.9	12.7	–	–	32.7
Comoros	45.8$^{**,-3}$	42.5$^{**,-3}$	2.7$^{**,-4}$	43.2$^{**,-4}$	10.7^{-5}	27.3^{-5}	73.6
Congo	43.1$^{**,-4}$	46.0$^{**,-4}$	3.9$^{**,-5}$	15.8$^{**,-5}$	11.1^{-6}	15.5^{-6}	–
Côte d'Ivoire	26.3$^{**,-6}$	35.6$^{**,-6}$	8.4^{-1}	33.3^{-1}	23.9^{-1}	16.2^{-1}	54.6
Dem. Rep. of Congo	34.8*	35.5*	5.0	25.9$^{*,-1}$	–	–	66.6
Equatorial Guinea	26.2$^{**,-6}$	36.4$^{**,-6}$	3.3^{-8}	30.3^{-8}	–	–	93.0
Eritrea	30.5**	41.5**	2.0^{+1}	24.5^{+1}	37.0^{+1}	19.7^{+1}	65.3
Ethiopia	33.4	41.9	3.6	23.8	14.4	18.9	35.9
Gabon	53.1$^{**,-6}$	46.3$^{**,-8}$	7.1^{-9}	35.7^{-9}	–	–	87.0
Ghana	55.2	45.9	6.2^{-1}	34.2^{-1}	–	–	65.8
Guinea	35.8	36.2	9.2	24.4	28.7	19.6	38.0
Guinea-Bissau	35.9^{-2}	35.4^{-8}	2.9^{-2}	15.6$^{**,-7}$	–	–	51.0
Kenya	58.3	47.6	4.1^{+1}	41.2^{+1}	29.1^{-7}	18.3^{-7}	86.5
Lesotho	39.9$^{**,-1}$	56.8$^{**,-1}$	3.6^{-2}	55.2^{-2}	23.9^{-3}	53.7^{-3}	89.5
Liberia	31.6	42.9	17.4^{-8}	42.8^{-8}	11.2^{-8}	41.7^{-8}	58.1
Madagascar	30.1	48.6	3.4	47.2	18.9	26.7	70.7
Malawi	29.4	45.6	0.5^{-1}	33.6^{-1}	32.7^{-9}	–	72.8
Mali	38.3^{+1}	39.0^{+1}	5.5^{+1}	28.9^{+1}	9.9^{+1}	13.3^{+1}	26.2^{-2}
Mauritius	87.2**,$^{+1}$	49.8$^{**,+1}$	25.9**	53.3**	–	–	87.5
Mozambique	20.6	42.8	1.5^{-3}	33.1^{-3}	23.8^{-3}	16.1^{-3}	54.0
Namibia	65.8	53.8	8.9	56.8	12.4	43.2	88.2
Niger	11.6^{+1}	37.9^{+1}	1.4^{+1}	29.0^{+1}	10.1	10.2	–
Nigeria	30.5^{-1}	43.0^{-1}	10.1^{-3}	40.7^{-3}	–	–	60.1
Rwanda	21.9	47.8	4.0	39.0$^{**,-3}$	–	–	70.3
Sao Tome and Principe	51.3^{+1}	52.2^{+1}	4.1^{+1}	47.6^{+1}	–	–	88.3
Senegal	30.6	44.3	8.0*	35.3*	–	–	41.9^{-2}
Sierra Leone	34.6^{-1}	41.0^{-1}	2.0$^{**,-6}$	28.8$^{**,-6}$	7.7^{-7}	27.1^{-7}	39.8
Somalia	7.7$^{**,-1}$	31.5$^{**,-1}$	–	–	–	–	–
South Africa	95.1$^{**,-1}$	51.0$^{**,-1}$	–	–	–	–	89.0
Swaziland	53.3^{-1}	47.1^{-1}	4.4^{-2}	49.8^{-2}	8.8^{-2}	26.7^{-2}	86.5
Togo	41.3^{-1}	34.6$^{**,-1}$	5.3^{-1}	–	–	–	64.9
Uganda	25.3	45.7	3.7	44.3	10.5-^{4}	20.5^{-4}	74.6
United Rep. Tanzania	6.1$^{**,-9}$	44.8$^{**,-9}$	1.5^{-1}	32.3^{-1}	24.2^{**-3}	19.2^{**-3}	72.6
Zambia	45.6	45.2	2.4$^{**,-8}$	31.6$^{**,-8}$	–	–	70.7
Zimbabwe	41.0^{-2}	48.1^{-2}	3.8$^{**,-5}$	38.8$^{**,-5}$	–	–	91.4

-n: data refer to *n* years before reference year * National estimate **UNESCO Institute for Statistics estimation

.

Source: UNESCO Institute for Statistics

Table 3: Researchers in sub-Saharan Africa, 2007 or most recent year available
Selected countries

Country	Total number of researchers (FTE)	Share of women researchers (%)	Researchers per million inhabitants (FTE)	Technicians per million inhabitants (FTE)	Researchers by sector (FTE)			
					Business enterprises	Government	Higher education	Private non-profit
Benin	1 000*	–	119*	–	–	–	–	–
Botswana[-2,h]	1 732*	30.8	942	222	159*	692*	859*	22*
Burkina Faso[a,h]	187	13.4	13	27	–	165[b]	1[b]	15[b]
Cameroon[-2,a,h]	462	19.0	26	–	–	462	–	–
Cape Verde[-5]	60	52.3	132	33	–	–	–	–
Central African Rep.[a,h]	41	41.5	10	–	–	–	41	–
Congo, Rep.[-5,a]	102	12.8[F]	34	37	–	–	–	–
Côte d'Ivoire[-2,a]	1 269	16.5	66	–	–	29	1 240	–
Dem. Rep. of Congo[-2,h]	10 411	–	176	26	–	877	9 534	–
Ethiopia[a]	1 615	7.4	21	12	–	1 361	254	–
Gabon[-1,a,h]	150	24.7	107	30	–	150	–	–
Gambia[-2,a,h]	46	8.7	30	18	–	–	–	–
Guinea[-7,a,h]	2 117	5.8	253	92	–	1 096	1 021	–
Lesotho[-3,a]	20	55.7	10	11	–	11	9	–
Madagascar[a]	937	35.2	50	15	–	262	675	–
Mali[-1,a]	513	12.1	42	13	–	227	286	–
Mozambique[-1,a,h]	337	33.5	16	35	–	337	–	–
Niger[-2,a]	101	–	8	10	–	–	–	–
Nigeria[-2,a,h]	28 533	17.0	203	77	–	1 051	27 482	–
Senegal[a]	3 277*	9.9*	276*	–	–	418*	2 859*	–
Seychelles[-2,a]	13	35.7	157	640	–	8	–	5
South Africa[-1]	18 574	39.7	382	130	6 111	2 768	9 491	204
Togo	216	12.0	34	17	–	26	190	–
Uganda[h]	891	41.0	29	18	71	473	321	26
Zambia[-2,a]	792	27.4	67	106	4	565	146	77

* national estimate; a = partial data; b = the sum of the breakdown does not add up to the total; h = for these countries, data are only available for headcount; F = full-time equivalent (FTE) instead of headcount

Source: UNESCO Institute for Statistics

- the fact that women are not only much less represented than men in tertiary education but are also often confined to so-called 'feminine' fields, such as the social sciences, humanities, services and health-related courses, which do not boost their chances of equal job opportunities with men. What men and women choose to study is a key issue in the debate about gender equality;
- an inadequation and fragmentation of curricula and research programmes;
- the lack of a 'culture' of evaluation for teachers, researchers and programmes;
- a lack of co-operation and partnerships with other institutions at national, sub-regional, regional and international levels ;
- excessive bureaucracy in management procedures, together with frequent strikes by students, teachers, researchers or administrative staff, among others, which considerably hamper the stability and performance of institutions;
- a lack of linkages between academic research and innovation, hampering socio-economic progress.

A small pool of researchers

Table 3 shows that Nigeria counted the greatest number of researchers in Africa in 2005. However, when the number of researchers is assessed per million inhabitants, Nigeria slips to fifth place behind Botswana, South Africa, Senegal and Guinea. The percentage of women researchers across the continent remains low, as does the number of scientists and technicians per million inhabitants. Also worrisome is the dearth of researchers employed in the business and private non-profit sectors.

Low scientific productivity in all but a handful of countries

South Africa dominates scientific publishing

Sub-Saharan Africa produced just 11 142 scientific articles in 2008. Its share of the world's output has risen, however, since 2002 from 0.9% to 1.1% (*see page* 10). Within the sub-continent, South Africa produced almost half (46.4%) of the total, followed by Nigeria (11.4%) and Kenya (6.6%) [Figure 2]. In other words, these three countries alone produce two-thirds of the sub-continent's scientific articles, a reflection of their relatively sophisticated level of R&D.

Most African countries were unable to produce 100 publications in the natural sciences in 2008. According to Bernardes *et al*. (2003), these figures are well below the theoretical threshold that would trigger a virtuous interaction between S&T. This threshold was in the neighbourhood of 150 papers per million population in 1998 and has since risen. Of some comfort is the consistent, if modest, progression across the region in the number of scientific papers recorded in Thomson Reuters, Science Citation Index. Moreover, the language barrier may be hampering the visibility of scientific research from French- and Portuguese-speaking African countries in international databases, even though many other factors also come into play. See, for example, the case of Mali (*see page* 307).

African scientists publish mostly in the fields of clinical medicine, biology and biomedical research, followed by Earth and space science (Figure 3). In Kenya, the life sciences represented as much as 93% of scientific articles in 2008, compared to just 4% for Earth and space sciences. In Nigeria, 84% of published articles concerned the life sciences, compared to 6% for engineering and technology and 5% for Earth and space sciences. South Africa, on the other hand, has a more diversified research system. Although two-thirds of South African publications relate to the life sciences, the remainder of articles are fairly evenly spread among the other major fields of science, including chemistry, mathematics and physics.

Utility patents dominate intellectual property earnings

Table 4 shows the number of patents awarded to African inventors by the United States Patents and Trademark Office (USPTO) during 2005–2009. The continent produced 706 patents during this period, compared to 633 in 2000–2004 (Pouris and Pouris, 2009). It is interesting to note that, if the continent produces 2.0% of the world's knowledge, as manifested in research publications, it produces less than 0.1% of the world's inventions. Between 2005 and 2009, South Africa produced two-thirds of the continent's utility patents (65%) but 87% of USPTO patents, a share comparable to that for 2000–2004 (88% of the total).

NATIONAL STRATEGIES FOR DEVELOPING TECHNOLOGICAL RESPONSIBILITY IN AFRICA

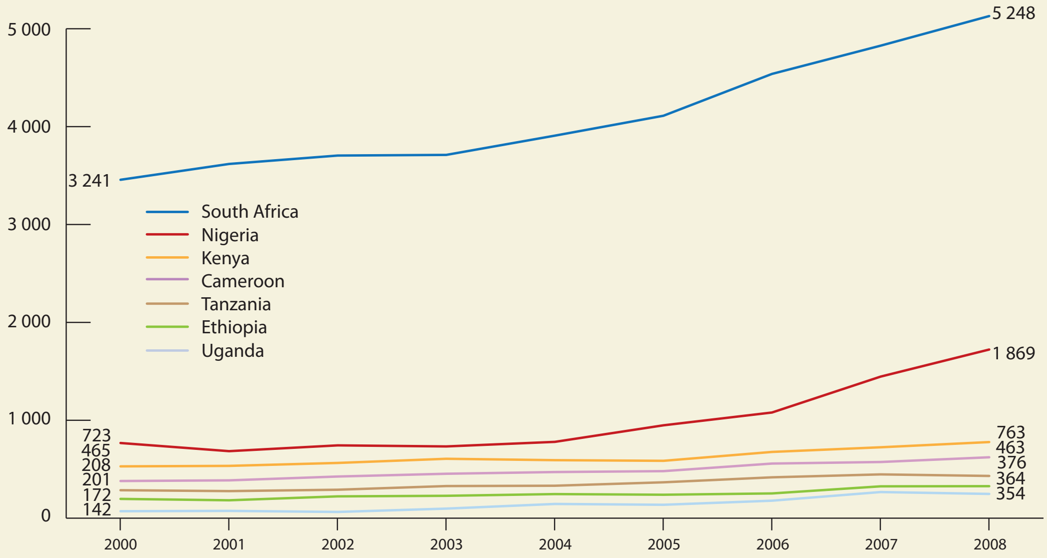
Strengthening STI development in Africa will require a shift from the business-as-usual approach to a more proactive and engaging culture of technological responsibility. An abundance of natural resources and low-cost labour do not necessarily constitute in themselves decisive comparative advantages for the continent, as the parameters of international competitiveness are increasingly S&T- based. African countries must improve their competitiveness not by relying on low labour costs but rather by improving their technical capacity. According to UNECA (2005) – the source of inspiration for many of the recommendations that follow –what Africa needs is nothing less than leadership and democratization. If we are going to mobilize S&T for sustainable development, all key stakeholders must be involved in both policy formulation and implementation. This is the way to avoid academic and elitist policies and to define and strengthen the role of public institutions, international partners, universities, non-governmental organizations (NGOs), women's organizations, civil society and the private sector. This is also the way to ensure that policies are tailored primarily to meet the specific needs of end-users and clients.

Improving governance

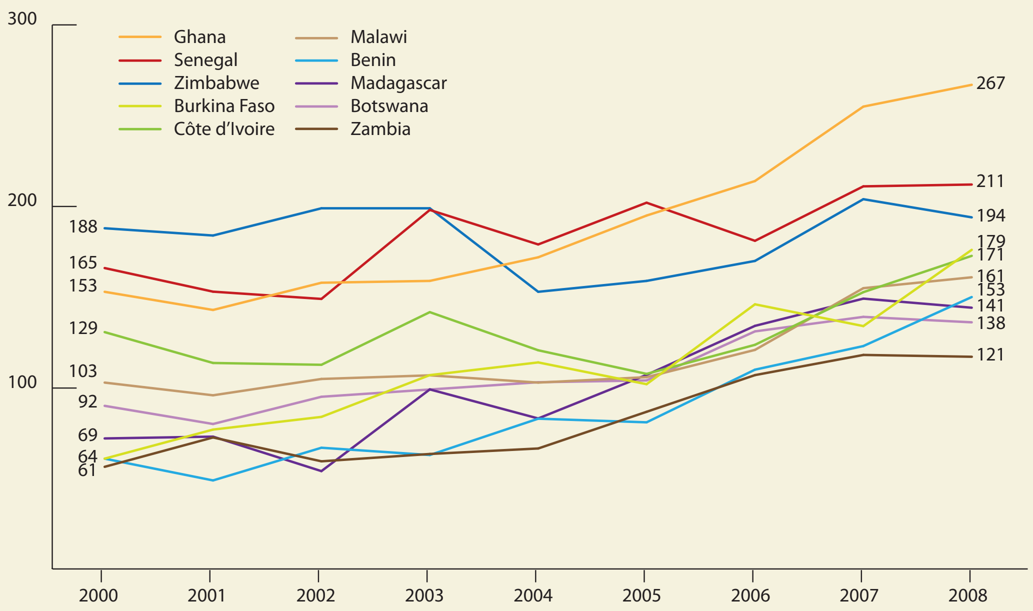
Today, in many African countries, there is a lack of stable political leadership capable of providing a clear vision and objectives for STI. The frequency of cabinet reshuffles in many countries results in instability among top officials in the ministries responsible for S&T, in turn leading to shifting priorities and disturbances in programme execution. This results in weak strategies for innovation and technology transfer, which in turn foster inadequate higher education and research systems with little innovative or inventive potential. This critical

Figure 2: Scientific publications in sub-Saharan Africa, 2000–2008
For those countries that produced more than 100 publications in 2008

Top 7 countries in terms of productivity



Next 10 most prolific countries



Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

phenomenon requires a clear understanding by the head of state and/or prime minister of the need for a strong, transparent STI policy owned by all stakeholders and fully articulated with the national socio-economic development plan. In this regard, the idea of presidential fora put forward by the late Professor Thomas Odhiambo is worthy of consideration.

Institutions responsible for policy-making and development are weak in many African countries, particularly the smaller ones. Countries such as Angola, Chad, the Democratic Republic of Congo, Djibouti, Eritrea, Gabon, Gambia, Mauritania, Liberia, Sierra Leone and Swaziland, among others, could benefit from programmes that build institutional capacity in S&T policy formulation and implementation. STI policy and operational institutions created in the 1960s and 1970s with the aid of the United Nations Economic Commission for Africa (UNECA) need to be reviewed in light of the new challenges posed by globalization and technological innovation.

Current macro-economic policies and programmes also tend to allocate too many resources to large public enterprises concentrated mostly in urban areas, thereby discriminating against small and medium-sized enterprises. Even where policies designed to realize development goals are in place, experience shows that most African governments find it difficult to implement them for reasons that include lack of finance, lack of transparency, inadequate human resources and an undue politicization of issues. In a vicious circle, low investment in education and R&D in both the public and private sectors has led to a penury of qualified personnel, eroding the quality of science and engineering education at all levels. Worse still, the infrastructure for R&D has been neglected and is decaying. Universities and research institutions are thus hard-pressed to acquire state-of-the-art facilities to conduct basic research, forcing them to depend on foreign institutions.

To strengthen Africa's technological regime will require strong political leadership and a better integration of cross-cutting STI policies with overall development policies, including economic, financial, budgetary, fiscal, labour, agricultural, industrial and micro-enterprise development. This has far-reaching consequences for policy-making, as it implies that S&T should move from the periphery to the centre of the development policy processes and pervade all relevant policy areas, impacting on the development and utilization of S&T. Success in this realignment and 'recentering' requires strong political commitment vis-à-vis S&T and the full engagement of the S&T community. This recentering may be facilitated by the setting-up or strengthening of parliamentary committees on S&T. Such committees are already in existence in a number of African countries, including Kenya, Nigeria, South Africa and Uganda. The African Ministerial Conference on Science and Technology (AMCOST) has also set up its own parliamentary committee. Recentering S&T may also be facilitated by the appointment of high-profile, credible and respected S&T advisors to the president, as in Nigeria, for example (*see page* 309). The creation of interdepartmental S&T fora comprising focal points from various ministries and government institutions dealing with S&T issues may also be useful in 'demonopolizing' S&T responsibilities and in bringing S&T issues to the heart of the development policy process.

Ensuring reliable data and indicators

Also hampering the elaboration of effective STI policies in Africa is the lack of up-to-date, reliable data and indicators on the current status of S&T, mostly due to the absence of trained experts and organizational difficulties. African institutions, ministries and organizations have not yet adopted a culture of record-keeping and data banks. This is a serious issue of concern which our governments and institutions need to address urgently as a key deliverable in the process of realizing their development goals.
One of the objectives of *Africa's Science and Technology Consolidated Plan of Action* is to remedy this situation (*see page* 297).

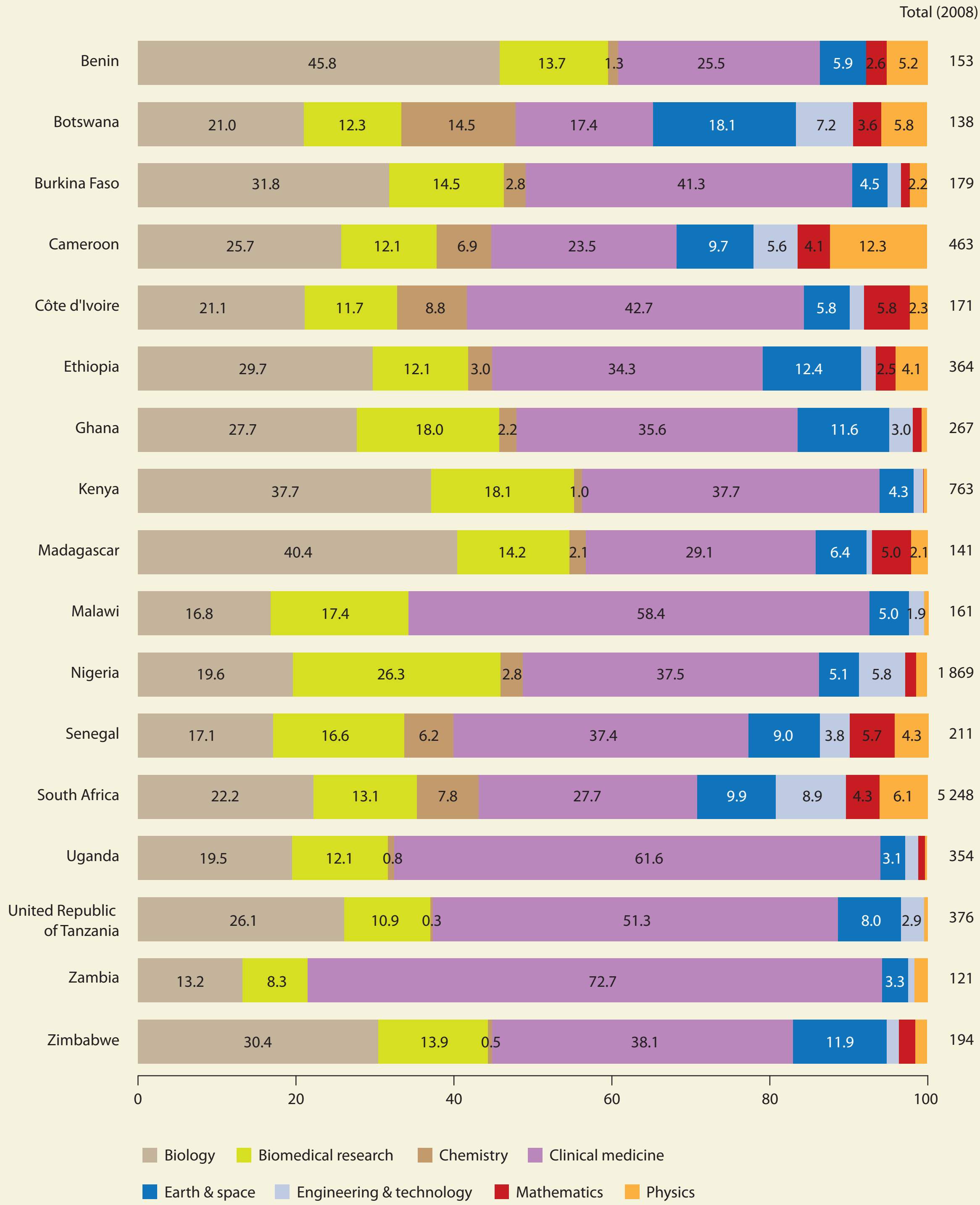
African economies also need to adopt new indicators to evaluate skills and competencies acquired in traditional sectors and assess their ability to promote linkages between actors in the adoption and absorption of new technologies.

Grouping STI programmes into a single national system

To ensure the successful implementation of STI programmes and activities in different countries of Africa, there is a need for proper co-ordination and integration of programmes and activities in the innovation system into all national socio-economic planning issues. Presently, co-ordination of STI programmes and activities seems to fall within the purview of the sole ministries of science and technology. While it is proposed that these ministries continue to serve as the main scientific advisory

Figure 3: Publications in sub-Saharan Africa by major field of science, 2008 (%)

For those countries which produced more than 100 publications in 2008



Source: Thomson Reuters (Scientific) Inc. Web of Science, (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

Table 4: Patents awarded to African inventors by USPTO, 2005–2009

	2005				2006				2007				2008				2009				Total			
	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue
Sub-Saharan Africa:																								
Benin									1												1			
Burkina Faso																	1				1			
Cameroon									1								1				2			
Chad													1								1			
Ethiopia									1												1			
Gabon									1												1			
Ghana									1												1			
Kenya	9	1			3				1				4				7				24	1		
Mauritius														1								1		
Namibia									1												1			
Seychelles					2									1							3			
South Africa	87	16	5		109	13	5		82	30	3		91	32	1		93	39	6	1	462	130	20	1
Zimbabwe	1				1				1								4				7			
Arab states in Africa:																								
Algeria					1																1			
Egypt	7				4				12				2				3				28			
Morocco	1				3				1				4				1	2			10	2		
Tunisia	1				2								2								5			

Note: The country of origin is determined by the residence of the first-named inventor. Utility patents are for new inventions.

Source: data from United States Patents and Trademark Office

committee for successful implementation of STI policy, there is an urgent need to begin weaving all STI programmes and activities into a single national system. This will bring together existing capabilities and help to avoid wastage of resources and duplication of effort, while encouraging interaction and linkages.

Improving infrastructure and capacity to develop innovative solutions

Africa's sustainable development will depend more and more on its capacity to find innovative solutions to its particular problems, including in the area of food production, and its capacity to produce and market competitive, innovative products and services. In this regard, policies need to be put in place to develop national innovation systems by filling existing gaps and strengthening interaction between critical elements of the system. Entrepreneurial capacities should be reinforced, inter-firm partnerships should be encouraged and linkages between the public and private sectors strengthened. This new technological regime calls for special attention to be paid to such key areas as agriculture, industry, energy and water. In these areas, the generation of new knowledge, the development of new technologies and the promotion of innovation are crucial to achieving food security, diversifying manufactured products, reducing poverty and protecting the environment and the natural resources base.

In this regard, UNECA and UNESCO both support the commitment by the New Partnership for Africa's Development (NEPAD) to create sub-regional centres and networks of excellence for higher education and research, with a view to promoting S&T in niche areas of high priority for sustainable development.

Nor should African countries underestimate the potential of South–South co-operation for developing these niche areas. Brazil, China, Egypt, India and Mexico have all developed world-class research institutions in recent years and are increasingly involved in South–South co-operation. One recent example concerns the development of biofuels in Sudan in co-operation with Brazil and Egypt (Box 1).

Box 1: South–South co-operation on biofuels: the case of Sudan

In June 2009, Sudan inaugurated its first biofuel plant. In the next two years, the plant is expected to produce 200 million litres of ethanol from sugarcane. The plant was built in co-operation with the Brazilian company Dedini, drawing on the long-standing experience of Brazil in the area of biofuels.

Another major project for the development of biofuels in Sudan is being carried out in collaboration with Egypt. At a cost of US$ 150 million, it is producing second-generation biofuels from non-edible crops, including agricultural waste such as rice straw, crop stalks and leaves. This is proving to be a good strategy, as it has a positive impact on both the environment and food security. By diverting agricultural waste towards the production of ethanol, the waste does not need to be burned, thereby reducing pollution. The use of agricultural waste also avoids sacrificing food supplies to energy production.

Source: authors

Strengthening the relationship between academia, government and industry

In most African countries, there is very little interaction between universities and industry, and very few universities in the region conduct research and training programmes pertinent to industrial needs. This shortcoming is coupled with a mismatch between R&D activities and national strategies and goals for industrial development. As a result, local industries lack access to research findings from public research institutions, particularly small and medium-sized enterprises. It is common knowledge that the biggest obstacle to the development of technological enterprises in sub-Saharan Africa is not the lack of resources but their isolation. Current S&T policies emphasize R&D input, forgetting that innovation does not spring from an aggregation of different forms of technological infrastructure but rather from the quality of the organization and the circulation of available resources.

The Africa Commission Report (2009) concluded that African universities were insufficiently geared to meeting the needs of industry. The report maintained that graduates often struggled to find employment, while many small businesses lacked staff with the education and skills needed to drive innovation. Essentially, the relationship between the demands of the private sector and what universities teach is too weak. The isolation of researchers and R&D institutions is cited by many African scholars as being one reason for the weak performance in building technological capabilities. The lack of linkages between the needs of enterprises, communities and R&D institutions is a real problem for the development of innovation. Despite the concentration of R&D in some fields like agriculture and medicine, community services remain a peripheral appendage to the university system in most African countries.

To bridge the gap between scientists, technologists and industrialists, African governments should encourage and support the establishment of interdisciplinary research and training centres within universities in those areas of S&T most relevant to the development of local industry. In particular, greater importance should be given to the development of strong linkages between engineering institutions, small-scale industries and the agriculture sector with the principal aim of producing simple, modern tools and equipment required by farmers to increase their productivity and efficiency (Box 2).

Small research and training units should also be formed and strengthened in areas of cutting-edge technologies relevant to industry, such as lasers, fibre optics, composite materials, pharmaceuticals, fine chemicals and biotechnology. These centres should operate as a joint venture between universities and industry and should be run by a common board involving high-level indigenous industrialists and academics. Furthermore, to strengthen the linkages between research institutions and industry, qualified staff and postgraduate students in these institutions should be encouraged to undertake specific development projects in industry.

Protecting Africa's intellectual and biodiversity capital

Harnessing S&T for sustainable development requires the protection of intellectual capital and access to technology, which are governed by a number of complex international agreements. These include the Convention on Biodiversity (1992), which, in Article 8, recognizes explicitly the importance of traditional knowledge and creates a framework for ensuring that local people share in the benefits arising from the appropriation and use of such knowledge and the biological resources of their environment. Plant breeder's rights and farmer's rights are equally recognized in the Convention. These resources are of great importance for Africa's sustainable development and they must receive adequate attention. Plant varieties, which are protected by the International Convention for the Protection of New Varieties of Plants (UPOV) and the International Undertaking on Plant Genetic Resources (IUPGR), constitute unique instruments through which Africa can strengthen its capacity in S&T (UNECA, 2005). In this regard, the decision by the focal points of Ministers of the African Agency of Biotechnology to dissolve this institution in April 2008 is most unfortunate.

The Model Law adopted by the African Union in 2000 for the Protection of the Rights of Local Communities, Farmers and Breeders and for the Regulation of Access to Biological Resources[2] established a framework for national laws to regulate access to genetic resources. Although the Model Law has been severely criticized for putting African countries on the defensive and for being too complex and cumbersome for countries at an early stage of development, it can be a useful resource for repositioning Africa in STI development and for protecting the indigenous knowledge, technological know-how and biological resources of African countries. This is an important policy area for the African Union to explore, in collaboration with other partners, such as the World Intellectual Property Organization, African Regional Intellectual Property Organization[3] and the *Organisation africaine de la propriété intellectuelle.*[4]

Of note is that the African heads of state formally adopted the Pan-African Intellectual Property Organization in January 2007 at the African Union summit in Addis Ababa, Ethiopia. It will serve as a co-ordinating body rather than as an office for the registration of intellectual property. At the time of writing, the Pan-African Intellectual Property Organization had not yet materialised, although it was on the agenda of the AMCOST meeting in Cairo in March 2010.

An urgent need for ICT development

One factor contributing to the isolation of African scientists is the communication barrier caused by the lack of infrastructure in telecommunications and the limited access to ICTs. ICTs are now also one of the most important assets for enterprises wishing to compete in world markets and, therefore, one of the main drivers of inclusion in the 'global village'. ICTs provide the main medium for the transfer of information and knowledge. Most technologically advanced countries are making massive investments in these technologies. Public infrastructure can no longer be conceived only in the traditional terms of roads, railways, power, ports and airports. The availability of fast, affordable and reliable connections to the Internet and development of mobile telephones are some of the new technological infrastructure that African countries need to put in place in order to become competitive and remain so. Investment in these technologies is crucial to give companies a global reach and enable them to conduct efficient business transactions.

2. See: www.grain.org/brl_files/oau-model-law-en.pdf

3. ARIPO is an intergovernmental organization founded in 1976 which counts 16 member states from English-speaking sub-Saharan countries.

4. OAPI has grouped 16 French-, Portuguese and Spanish-speaking sub-Saharan countries since 1977.

Box 2: Songhai: an agricultural centre of excellence

Songhai is an experimental farm founded in Porto Novo in Benin in 1985 by Dominican father Dr Godfrey Nzamujo. The aim of this NGO is to develop sustainable, integrated agriculture to raise the population's standard of living. In addition to practicing animal husbandry, crop-growing and aquaculture, the farm conducts agricultural research and experiments with renewable energies. Songhai also dispenses training and provides the local population with services to make their lives easier. For instance, it manufactures and maintains agricultural machines that are well adapted to local conditions and less costly than imported models. The farm sells its own produce on site to earn revenue and provide the local population with fresh produce.

After Nigerian officials visited the experimental farm, a centre modelled on Songhai was created in Amukpè in the Delta State of Nigeria in 2002.

In 2008, Songhai was declared a regional centre of excellence by the United Nations and, the following year, by the Economic Community of West African States. With the support of the United Nations, a Regional Project for the Development of Agricultural Entrepreneurship was launched in Africa in 2008.

Source: www.songhai.org

Box 3: Science, ICTS and space, an EU–Africa partnership

The European Union–African Union summit in Lisbon in December 2007 launched an EU–Africa partnership in eight different areas. One of these partnerships concerns Science, the Information Society and Space. A number of lighthouse projects are being implemented within this partnership in line with priorities identified by *Africa's Science and Technology Consolidated Plan of Action* (*see page* 297) and by the *African Regional Action Plan for the Knowledge Economy*, adopted at the World Summit on the Information Society in Tunisia in 2005.

Under the science component of the partnership, African research grants are being provided worth €15 million and a Water and Food Security and Better Health in Africa project has been earmarked for €63 million in funding. The African Union Commission has also contributed €1 million for the first year of the Popularization of Science and Technology and Promotion of Public Participation project. The first African Women Scientists award was held on Africa Day on 9 September 2009.

Concerning ICTs, the AfricaConnect project will seek to integrate the African research community at both regional and international levels by improving bandwidth. Meanwhile, the African Internet Exchange System (AXIS) will support the growth of a continental African Internet infrastructure. A third project concerns the African Virtual Campus. With funding from the European Commission, AfDB, Spain and Japan, UNESCO is establishing virtual campuses at universities in 15 West African countries. A 10 000 km-long submarine fibre-optic multipoint cable system is also under construction. Last but not least, a project led by the World Health Organization is lending support to telemedicine in Africa.

As concerns the exploration of inner space, Global Monitoring for Environment and Security (GMES) is a European initiative for the establishment of a European capacity for Earth observation. The GMES and Africa project was launched by the *Maputo Declaration,* signed on 15 October 2006. The initiative aims to develop infrastructure for a more coherent exploitation of Earth observation data, technologies and services in support of the environmental policies put in place in Africa. An *Action Plan* is due to be submitted to the next European–Union–African Union Summit in 2010. It is being prepared by the GMES and Africa Coordination Group, composed of seven members from Europe and seven from Africa. Among the proposed projects, one known as Kopernicus-Africa will focus on the use of remote-sensing satellites for African Global Monitoring for Environmental and Security. A second project will build capacity within the African Union Commission to use the geospatial sciences for a range of applications that include natural resources management, food security and crisis management.

Source: www.africa-eu-partnership.org/documents/documents_en.htm

GMES is an EU Joint Technology Initiative, see page 163

A number of countries have adopted ICT policies in recent years, including Nigeria, South Africa and Uganda. However, Internet connectivity remains extremely low (Figure 4). In Nigeria, just 6.8% of the population had access to Internet in 2007. Nevertheless, this represented a leap from 0.3% in 2002. Progress has been slower in South Africa, where connectivity grew from 6.7% to 8.2% over the same period. Progress has also been slow in Uganda, where just 0.4% of the population had access in 2002 and 2.5% four years later.

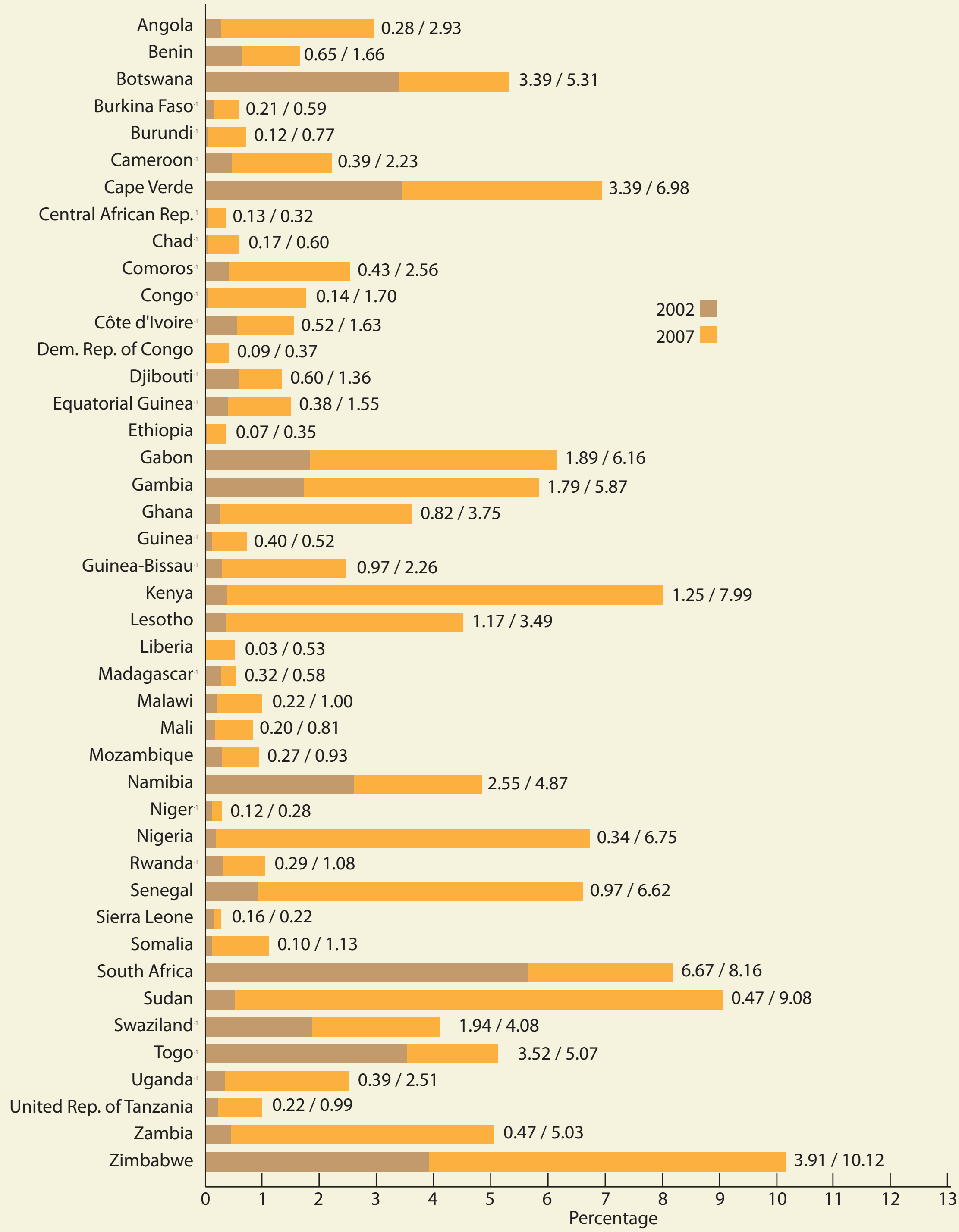
The launch of the Nigerian satellite NigComSat-1 in 2007 should offer Africa better telecommunications in future. There is also a host of international initiatives to help Africa develop its information infrastructure. Among these, perhaps one of the most ambitious is the EU-Africa Partnership (Box 3).

The brain drain syndrome

The continent's growing sustainability problem will never be solved by outside experts, despite their good intentions. How then can sub-Saharan Africa nurture and sustain the home-grown scientific talents it needs for problem-solving scientific research? Indubitably, the most worrying phenomenon for Africa is brain drain, both internal and external.

A statement on *Brain Drain in Africa* submitted by the Network of African Science Academies (Box 4) to the G8+5 Summit in July 2009 indicates that at least one-third of African scientists and technologists live and work in developed countries. Key factors encouraging brain drain include the paltry funding of education, poor incentives for research and innovation, political and

Figure 4: Internet access per 100 population in sub-Saharan Africa, 2002 and 2007
Selected countries



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

Source: United Nations Statistical Division, Millennium Development Goals Indicators religious crises, a lack of adequate regulations to protect intellectual property and, most importantly, a poor reward system for researchers, teachers and technologists working in research institutions and universities. These are the factors that have pushed native scientists to migrate to the comfortable zones of the developed world. The overriding issue should not be how to lure African expatriates back home but rather how to transform brain drain into brain gain by improving conditions at home.

Uganda figures in the top ten among developing countries for the rate of loss of university-educated citizens: 36% (ATPS, 2007). Medical doctors and researchers are leading this exodus. Uganda's national report on the economy for financial year 2008, released in July 2009, shows that remittances from Ugandans working overseas jumped from US$ 546 million in 2007/2008 to US$ 748 million a year later. Poor pay – even by East African standards – is inciting many Ugandan professionals to leave the country in search of greener pastures. Uganda's health and education sectors have been badly hit as a result. In presenting the national budget for 2010/2011 in June 2010, President Yoweri Kaguta Museveni announced a 30% hike in scientists' salaries, with a budget of 18 billion Ugandan shillings (US$ 8 million) [Nordling 2010*c*].

Uganda also faces internal brain drain. A tracer study carried out in Uganda by UNCHE (2006) targeted 1 000 graduates fresh out of university to determine how long it would take them to find gainful employment. The public sector took on only 32% of graduates, the great majority (53%) finding employment in the private sector. Among degree-holders, graduates in veterinary medicine and social sciences waited longest – more than

Box 4: The Network of African Science Academies

The Network of African Science Academies was established in December 2001. It strives to accelerate the pace at which its member academies implement best practices, in order to equip them to advise their governments on STI policy reform. Currently, the consortium has 15 national members, plus the African Academy of Sciences.

Founded in Nairobi in 1986, the African Academy of Sciences has a dual mission to honour African achievers in S&T and mobilize the African S&T community to promote science-led development in Africa. Fellows of the African Academy of Science work together in a transdisciplinary manner to tackle many of Africa's developmental problems. Through the African Academy of Sciences, they conduct R&D and disseminate the results, organize training and undertake public advocacy.

Table: The 15 national African science academies

Year of creation	
2009	Academy of Science of Mozambique
2008	Sudanese National Academy of Science
2007	Mauritius Academy of Science and Technology
2006	Hassan II Academy of Science and Technology, Morocco
2006	Tanzania Academy of Sciences
2005	Zimbabwe Academy of Sciences
2001	Academy of Science of South Africa
2000	Uganda National Academy of Sciences
1999	National Academy of Science and Technology of Senegal
1990	Cameroon Academy of Sciences
1983	Kenya National Academy of Sciences
1977	Nigerian Academy of Sciences
1959	Ghana Academy of Arts and Sciences
1948	Academy of Scientific Research and Technology, Egypt
1902	National Academy of Arts, Letters and Sciences, Madagascar

Source: authors

For details: www.nasac.org

nine months – for a job proposal. The labour market was observed to have an inadequate supply of medical doctors, engineers, information technology specialists and science teachers but was saturated with arts graduates, social workers and those with backgrounds in finance and accounting. An analysis of jobs advertised in the most widely circulated newspapers in Uganda for the period 2002–2004 found a low percentage of science-based opportunities, the majority of jobs advertised being in the service sector.

Uganda is not the only country to have taken energetic steps recently to improve its reward system. In early 2009, the Government of Cameroon used the writing-off of part of its debt to create a permanent fund of 4.2 billion Central African francs (CFA, almost US$ 9.5 million) to boost the salaries of university lecturers and researchers. Senior lecturers saw their monthly salary triple overnight to US$1 600. Within a year, the number of academics receiving the supplementary allowance had swollen from 1 800 to more than 2 500, suggesting that the scheme was already luring scientists back home. One spin-off of the scheme has been a rise in the number of scientific articles produced by state universities (Mvondo, 2010).

In November 2007, Zambia announced the reintroduction of allowances for academic staff at state universities to make salaries more competitive with those of researchers in other African countries. Other incentives to curb brain drain presented by the Ministry of Education include higher grants for academic research, home loans for academic staff and a first in Zambia: funding for the journals published by the University of Zambia and Copperbelt University (Ngandwe, 2007). In 2008, Zambia received a US$ 30 million loan from the African Development Bank (AfDB) to support teaching and research at the University of Zambia and to provide postgraduate fellowships to some 300 students majoring in science and engineering. At the African Union Summit in 2007, President Levy Patrick Mwanawasa proclaimed that building capacity in 'science and technology is the only means to develop the country.'

Another example is Botswana. One of the strongest economies in Africa, Botswana was spending millions of dollars each year to support approximately 7 000 Botswanans studying at universities abroad. In order to staunch the haemorrhage of students leaving the country, Parliament approved plans for the Botswana International University of Science and Technology in January 2006. Construction of the university began in April 2009 on a 250-hectare site in the city of Palapye, 270 km north of Gaborone. A public–private partnership, the university will focus on engineering, mining, geology and basic sciences. Due to open in 2011, it will initially house laboratories and residences for 250 students. A research park is planned for a later stage (Makoni and Scott, 2009).

Borrowing a model from football

If inadequate ICT infrastructure and poor scientific networks and exchanges are a barrier to the circulation of expertise within the continent – not to mention the language barrier between French-, English- and Portuguese-speaking Africans – African scientists and engineers also face a physical barrier, the sheer difficulty in travelling freely around the continent. The question of African countries easing immigration regulations and procedures in order to facilitate the mobility of international experts, and African expatriates in particular, has figured repeatedly on the agenda of African Union summits without ever being resolved.

A workshop organized by the African Technology Policy Studies Network in Nairobi, Kenya, in March 2010 came up with a novel idea for turning brain drain into temporary brain gain. It suggested that African governments should borrow the model of the International Federation of Association Football (FIFA) for African researchers and scientists working abroad. The FIFA model entitles foreign football clubs to release their players to play for their home countries during major events like the African Nations Cup. The 'fifarization' of African scientists and researchers working abroad would entitle them by law to return to their home countries if the occasion presented itself and to request permission to participate occasionally in charting the way forward for their country's development in STI. Once their mission was accomplished, they would return to their home base. In this way, a team of medical professionals working in the USA and Europe, for instance, could travel to their home country in Africa once in a while to share their knowledge and skills. This idea has been enthusiastically received in various STI fora in Africa.

A similar approach to tackling brain drain in Africa has been proposed by the Network of African Science Academies. In their statement submitted to the G8+5 Summit in July 2009, the academies recognize the opportunities offered by the African diaspora and call for new policies to harness their knowledge and expertise to driving scientific and economic progress in Africa, as Nigeria has been doing (*see page* 311). This approach turns the phenomenon long perceived as a one-way flow out of Africa into a two-way interaction through joint projects between Africa's emigrant researchers and home-based scientific communities. Developed countries are asked to contribute by helping to improve Africa's S&T infrastructure, fostering North–South scientific co-operation and by promoting policies that allow scientists greater mobility acrossborders.

The statement proposes five measures for tackling brain drain:

- Investing in the rebuilding of universities and research centres in Africa to enable African scientists to engage in world-class research without having to emigrate;
- Extending financial support to young African scientists to pursue postgraduate and postdoctoral training at universities in Africa and in developing countries elsewhere;
- Launching regional and international centres of excellence in Africa in areas of study of critical importance to Africa's development, especially with regard to the Millenium Goals. These centres should promote international collaboration in solving global problems relevant to Africa;
- Broadening efforts to encourage Africa's diaspora to participate in initiatives to address critical science-based issues on the continent and to engage African scientists in joint projects. To this end, policies may be devised to encourage short-term visits and collaborative projects involving Africa's scientific diaspora and scientists who have remained in their home countries; expanding North–South scientific exchange; and developing a database of highly qualified Africans in the diaspora.
- Honouring the commitment made by G8+5 countries at the 2005 G8 Summit, based on the recommendations of the Commission for Africa's publication, *Our Common Interest*, which called on its members to provide US$ 5 billion to help rebuild universities and US$ 3 billion to help establish centres of scientific excellence in Africa.

Socializing science

Last but not least, there is a need to domesticate S&T in Africa. All key stakeholders must be involved through national dialogue in the policy formulation and implementation process, so as to transcend policies that tend to be too narrowly focused on a handful of isolated, ill-equipped and underpaid researchers and academicians. This will contribute to moving away from elitist policies and to defining and strengthening the respective role of public institutions, international partners, universities, NGOs, women's organizations, civil society and the private sector (UNECA, 2005). It will also ensure that policies are tailored primarily to meeting the specific needs of end-users and clients. In this regard, the fight against illiteracy should aim to give girls and boys the same chances of being empowered through S&T.

Various means should be employed to promote science popularization and to ensure that information on S&T reaches all the relevant stakeholders, via such media as science centres and museums, radio programmes for farmers, media-training for scientists, public libraries with a focus on S&T, booklets and other printed materials, school science days, inter-school science competitions, public lectures, science fairs, academies and associations, adult education, demonstration centres, national merit awards in science, science quizzes, science newsletters, exhibitions, science clubs, science festivals, etc.

Kenya's National Council for Science and Technology is working with the African Technology Policy Studies Network on a project entitled Science, Ethics and Technological Responsibility in Developing and Emerging Countries (SETDEV) in the context of the European Union's Seventh Framework Programme for Research and Technological Development. The broad objective of this project is to help an emerging economy (India) and a developing country (Kenya) to elaborate their own perspective on the socialization of research. The National Council for Science and Technology is involved in the development of a *Handbook on the Socialization of Science and Technological Research in Kenya*, the findings of which may feed into the implementation plans for the country's *Kenya Vision 2030* (*see page* 306).

A REGIONAL STRATEGY FOR DEVELOPING STI IN AFRICA

Africa's Science and Technology Consolidated Plan of Action

We have seen from the previous section that wide disparities remain in the level of investment in R&D and scientific productivity between South Africa and the rest of sub-Saharan Africa, with only a handful of countries producing a meaningful volume of publications. However, there are also wide disparities in economic terms, with a large share of the African population being excluded from STI dividends. Inequalities in income distribution have destroyed internal demand for manufactured goods, in turn inhibiting the learning process of enterprises. These factors have also had huge repercussions for the brain drain of scientists and other qualified personnel.

One of the most ambitious strategies in recent years for strengthening STI in Africa has been the adoption of *Africa's Science and Technology Consolidated Plan of Action* for 2008–2013 (CPA). The fact that countries are at different stages of developing a national STI policy makes it all the more difficult to establish a common policy for Africa. It has been suggested in many fora that one way to give such a process a kick is to attempt a regional STI policy that will eventually key into the continent-wide action plan. The CPA is a framework for channelling investment into S&T in Africa. It was adopted in 2005 by the continent's science ministers with buy-in from development aid agencies and is overseen by AMCOST. Apart from providing a list of projects, the CPA outlines flagship R&D programmes in four areas: biosciences; water; materials science and manufacturing; and ICTs. Italso co-ordinates science aid and has put a stop to the tradition of donors cherry-picking projects to suit their own agenda (Nordling, 2010*a*).

In January 2007, heads of state and government invited UNESCO to work closely with the African Union and NEPAD secretariat to implement the CPA, in the *Declaration* adopted at the African Union summit in Addis Ababa. Later the same year, UNESCO adopted its own African Science, Technology and Innovation Policy Initiative for 2008–2013 to accompany this process. This initiative involves an assessment of the status of S&T policy formulation in Africa, the provision of technical advice and support for national STI policy reviews, the development of common African STI indicators, the creation of an African STI observatory and the launch of a pilot science park in Africa.

Five years after the CPA's adoption, several donor agencies are disappointed with progress, with some even going so far as to declare it dead (Nordling, 2010*a*). Development experts also say that fewer national-level policy-makers support the CPA than when the plan was first agreed upon. It has been noted that the CPA's proposed mechanism for channelling donor funding, the African Science and Innovation Facility, has not materialized. That notwithstanding, 'the CPA is still the framework for S&T activities on the continent,' observes Aggrey Ambali, advisor on S&T within NEPAD (Nordling, 2010*a*). Considerable progress has effectively been made on several individual programmes within the CPA, particularly in biosciences and water research. In addition, the CPA will have met another of its goals when one of its key elements, the African Science and Technology Indicators Initiative (ASTII), delivers its first set of pan-African R&D statistics in June 2010. Having taken over the reins of AMCOST in March 2010, Egypt should now champion a reintroduction of the original expectations in the CPA.

It has been suggested that three things are needed to revive the CPA: *firstly,* its implementation needs to refocus on results and co-ordination; *secondly,* it needs the African Union and NEPAD to show leadership; and *thirdly,* it needs a political and financial buy-in from African countries.

Another impediment to regional integration is the lack of dialogue, collaboration, co-ordination and harmonization among various initiatives designed to promote S&T across the continent. These initiatives include the African Science Academy Development Initiative (Box 5), UNESCO's African Science, Technology and Innovation Policy Initiative, the Knowledge Management Africa project (Box 6) and NEPAD's Science and Technology programme.

Also hampering regional co-operation and integration is the prevalence of micro-nationalism, which causes rivalry. Each country is keen to house every institution within its own borders rather than creating centres of excellence on the basis of the comparative advantages of each. There are existing international centres in Africa on which new centres could be modelled. The International Centre of

Box 5: The African Science Academy Development Initiative

The African Science Academy Development Initiative (ASADI) is a 10-year endeavour to empower African science academies to act as efficient partners in the policy-development process. Launched in 2004 with funding from the Bill and Melinda Gates Foundation, the initiative is managed by the US National Academies of Science, through the Board on African Science Academy Development at the Institute of Medicine in Washington DC.

ASADI works with African academies of science to develop and implement mechanisms for providing independent, apolitical and evidence-based advice to their national governments. ASADI supports capacity-building at the science academies of Nigeria, South Africa and Uganda. Partnering with these academies via a grants system helps to develop infrastructure, personnel, the relationship between each academy and its national government, as well as rigorous procedures for the provision of policy advice. The grant also provides some support to the academies of Cameroon, Ghana, Kenya, Senegal and to the regional African Academy of Sciences, in particular for strategic planning. It is expected that the initiative will be extended to academies in other African countries.

ASADI has already promoted strong collaboration among African academies, research institutes, universities and other S&T institutions. It is also fostering co-operation between the African academies and the Royal Society of Canada, Royal Society of the United Kingdom and the Royal Netherlands Academy of Science.

In addition to capacity-building, the initiative strives to inform African government policy-making and public discourse on issues related to the amelioration of human health and all development sectors. In this way, it aims to foster a deeper appreciation on the part of African governments of the benefits of decision-making based on evidence and analysis.

Every year, the ASADI Board organizes an international conference on a specific issue of great importance to Africa. This event brings together US and African representatives of science academies, policy-makers and experts on the specific topic under discussion. These meetings place special emphasis on what academies in Africa can do to make an impact on policy pertinent to the relevant issue. In previous years, the conferences have focused on food security, water, health and on achieving the Millennium Development Goals.

Source: authors

Box 6: Knowledge Management Africa

Knowledge Management Africa (KMA) is an African initiative launched by the Development Bank of Southern Africa in February 2005. On the premise that knowledge should be the engine that drives appropriate development solutions for Africa, KMA sets out to improve governance and service delivery in Africa through the creation, sharing, dissemination and utilization of knowledge.

KMA facilitates research by mobilizing resources and by linking basic and applied research on the continent and beyond. It encourages co-operation between universities, research institutes and other specialized institutions, in order to create a pool of African expertise on specific challenges for development.

Every two years, KMA hosts an international conference to create an environment conducive to the creation and sharing of African knowledge among policy-makers, sector professionals, researchers, knowledge management experts, government and civil society leaders, officials from international institutions, business leaders and so on.

The themes of the first three conferences were: Knowledge to Address Africa's Development challenges (Johannesburg, 2005); Knowledge to Remobilize Africa (Nairobi, 2007); and Knowledge to Reposition Africa in the Global Economy (Dakar, 2009). At the latter, it was decided to create the Knowledge Management Africa Foundation to ensure the sustainability and consolidation of the initiative.

The KMA secretariat is located in Midran, South Africa, but there are plans to conduct programmes through sub-regional chapters.

Source: authors

For details: www.kmafrica.com

Insect Physiology and Ecology and the International Institute for Tropical Agriculture, for example, both enjoy stable funding and outstanding scientific leadership and have, over the years, earned international recognition.[5]

African STI Indicators Initiative

In September 2005, AMCOST established an inter-governmental committee comprised of relevant national authorities to develop, adopt and use common indicators to survey Africa's development in S&T. This system of indicators will constitute the mainstay for production of the *African Innovation Outlook*, which will report on developments in STI at the national, regional and continental levels. The indicators can also be used to monitor global technological trends, conduct foresight exercises and determine specific areas for investment. An example is the target of a GERD/GDP ratio of 1% for African countries.

The intergovernmental committee was given the following mandate:

- Consider and agree upon common definitions, indicators and methods for conducting STI surveys. It will also determine the means of integrating STI indicators into the African Peer Review Mechanism[6];
- Identify and designate competent national authorities for the gathering and analysis of STI indicators;
- Design and adopt a work plan for preparing the *African Innovation Outlook*;
- Promote the sharing of experiences and information on national STI surveys;
- Develop, publish and widely disseminate an *African STI Indicators Manual*;
- Consider and agree on the means of establishing and running an STI observatory;
- Participate in international committees and/or processes on STI indicators. This will involve establishing formal ties with the OECD and other regional platforms and programmes for STI indicators;
- Review national surveys and propose common policies for promoting STI.

The committee has been assisted by an expert working group established by NEPAD. In 2010, this working group was preparing a document proposing indicators and guidelines for the conduct of surveys. This document should form the basis for initiating an intergovernmental process to enable African countries to agree upon definitions and methods and, where none exist, to develop these.

Since 2008, sub-regional training seminars and workshops on STI policy-relevant indicators have been co-organized by UNESCO and the African Union for English- and French-speaking Africa. The organizers are also advising on the design of questionnaires, manuals and documentation for national collection of STI data.

Towards an African STI observatory

For indicators to be used effectively, they must be embedded in the policy process. This requires interaction between key stakeholders, including policy-makers and statisticians. This process of interaction allows each group to do what it does best, policy analysis and development on the one hand, survey and questionnaire development on the other. These are quite different skills but they must be brought together if the resources available for indicator production are to be used effectively and efficiently. In both cases, there may be a need for capacity-building, which could be addressed by an African Observatory of Science, Technology and Innovation. In 2010, UNESCO and the African Union were engaged in discussions on the road map for transforming the African STI Initiative into a permanent observatory in Equatorial Guinea, which had volunteered to host the observatory and pledged US$ 3.6 million (Nordling, 2010*b*). As part of the process, UNESCO was preparing a feasibility study for the African Union in 2010. However, South Africa is also a contender for the observatory. In the time that it has been hosting the African STI Indicators Initiative in Midrand, it has gathered R&D and innovation data from 19 African countries. The interim observatory is due to deliver its first set of data in June 2010.

5. In June 2010, the International Centre of Insect Physiology and Ecology developed a collar for cattle which repels tsetse flies. The collar exudes the synthetic equivalent of the odour of animals that tsetse flies avoid. The flies transmit trypanosomiasis, a disease which kills up to three million cattle each year. The European Union has signed a US$ 1.8 million deal with the centre to trial the collars with Maasai pastoralists in East Africa over the next three years (Adhiambo, 2010).

6. This voluntary mechanism was introduced by the African Union in 2005 to help countries improve their governance. Countries develop a self-assessment report and programme of action, which is then submitted to the secretariat in South Africa and later publicly released by the country review team. Countries' progress in implementing their programme of action is reviewed in subsequent years.

The observatory will have a mandate for collecting, storing and disseminating data from the African Union's 53 member states on everything from R&D expenditure to the number of PhD students. It will ensure that STI indicators and methodologies for information-gathering and validation are standardized across the continent. The African equivalent of co-ordinating bodies like Eurostat or the OECD Directorate for Science, Technology and Industry, it will manage expert committees from African countries and oversee the collection of national statistics, in addition to producing manuals and the *African Innovation Outlook*. The observatory will also build capacity through the provision of training, sample survey instruments and case study templates, as well as practical advice on the development of country profiles, indicator reports and the use of indicators in evidence-based policy.

COUNTRY PROFILES

In the following section, we take a closer look at the strategies adopted by 14 African countries in recent years to take up the challenges discussed above. The following list is by no means exhaustive and is merely intended to illustrate some of the approaches being adopted by African countries and the persistent obstacles they face.

Benin

After the change of political regime in Benin in April 2006, the new government redefined strategic orientations for a national development policy that would fully recognize the central role of R&D in the development process. The aim is to improve higher education and the scientific research system within a National Policy for Scientific and Technological Research that takes into consideration the results of a national consultation – or *Etats généraux* – on R&D in 2004. The Benin Minister for Higher Education and Scientific Research has consequently requested UNESCO's support within its African Science, Technology and Innovation Policy Initiative.

Fully aware of the need for credible, accurate data and indicators to underpin any policy, the National Directorate for Scientific and Technical Research (DNRST) launched a study in 2006 to create databases on research conducted in the country. The DNRST also initiated the creation of the Benin Agency for the Enhancement of Research (ABVaR) and a National Fund for Scientific and Technical Research (FNRST), together with the adoption of an ethical code for R&D.

Like many other African countries, Benin devotes very little to R&D, although official figures are not available. The bulk of financial resources allocated to universities and R&D institutions goes to salaries and grants for students, leaving little for research. In addition to budgetary constraints and organizational problems, R&D in Benin faces a third challenge: the strain on existing facilities resulting from the drastic increase in the number of university students. The student body totalled about 60 000 in the 2006 academic year but the number of students is expected to rise to 160 000 by 2015 (Gaillard, 2008).

Burkina Faso

In Burkina Faso, the Ministry of Secondary and Higher Education and Scientific Research (MESSRS) is responsible for S&T policy, with the National Centre for Scientific and Technological Research (CNRST) acting as the ministry's operational arm. The CNRST participates in the elaboration and implementation of the national S&T policy and co-ordinates and assesses research programmes. It also supervises the creation and management of public research institutes, promotes research results and oversees the training and promotion of researchers.

Since the agriculture sector employs more than 90% of the active population and contributes more than 38% of GDP, the bulk of resources for R&D goes to agriculture (Figure 5). Burkina Faso has 11 agricultural research bodies. Of these, the Institute for Environment and Agricultural Research (INERA) employs around 60% of the country's researchers and absorbs about the same share of the research budget for agriculture. Burkina Faso has the highest level of education in Africa in the agriculture sector, with almost half of researchers holding a PhD (Stads and Boro, 2004).

In 2006, Parliament passed an important Law on the Security Regime for Biotechnology in Burkina Faso, followed by a decree in 2007 defining the mission and responsibilities of the relevant agencies, including the Directorate for Studies and Planning (DEP) for the collection, processing and diffusion of statistics, among them those on scientific research. However, the DEP lacked a specific tool for collecting and processing S&T data. To remedy this, a Memorandum of Understanding was signed between MESSRS and the UNESCO Institute for Statistics in 2007 to establish a new scientific information system by 2009.

Cameroon

At the time of independence in 1960, Cameroon inherited an appreciable research infrastructure established during colonial times but only a small pool of trained Cameroonian researchers. The research structure remained essentially agricultural with a focus on plant breeding and crop protection. Gradually, attention turned from subsistence crops towards cash crops for export, such as coffee, cocoa, cotton, rubber and banana. The first institute created by the new state was the *Ecole nationale supérieure d'agronomie*. In 1974, the new Council for Higher Education, Science and Technology was entrusted with the dual tasks of funding R&D and advising the government on policy issues related to higher education and R&D. Thanks to oil revenues and a genuine political will to train scientific elites, Cameroon was among the first African countries to invest consequent amounts in research, with funding levels rising from 1 billion CFA in 1976/1977 to almost 10 billion CFA a decade later. Unfortunately, during this euphoric period, research was carried out within programmes included in the country's five-year development plans, under which each researcher was simply asked to execute programmes defined beforehand by the institute in question. Under such conditions, many researchers participated in programmes without actually publishing anything.

Today, the Ministry of Higher Education, Scientific Research and Innovation (MINRESI) is charged with formulating research policy and programmes in Cameroon. Its main attributions are to initiate, co-ordinate and assess scientific research, as well as to promote science popularization and innovation through the utilization of research results, in permanent relation with all national economic sectors, others ministries and interested organizations. The ministry operates the state research institutes, which include the Institute of Agronomic Research for Development (IRAD), the Geological and Mineral Research Institute (IRGM), the Institute for Medical Research and Medicinal Plant Studies (IMPM), the National Institute for Mapping (INC) and the Centre for Energy Research (NERCE) supported by the International Atomic Energy Agency. Other institutions are attached to various ministries or are of an international character with offices in Cameroon. The latter include the French Institute of Research for Development (IRD), the Centre for International Cooperation in Agronomic Research for Development (CIRAD) and the International Institute for Tropical Agriculture. Moreover, MINRESI launched a Mission for the Promotion of Local Materials (MIPROMALO) in the 1990s, combining technology transfer, R&D and the promotion of entrepreneurship (Box 7).

The country's seven state-owned universities and four private universities provide the national platform for education and research. There is a strong demand for tertiary education, with university enrollment in S&T fields having increased from 90 000 in 2000 to 150 000 in 2010. However, the government's agenda of achieving education for all might be compromised unless proactive measures are taken urgently to align education expenditure on the growing demand for higher education. Nor can private universities make up the difference, as the high fees they charge keep student rolls low.

Cameroon has several specialized journals: the *Journal of the Cameroon Academy of Sciences,* the *Journal of Health and Disease,* the *Journal of Applied Social Sciences,*

Box 7: Technology transfer in Cameroon

In the 1990s, the Government of Cameroon set up the *Mission de promotion des matériaux locaux* (MIPROMALO) to promote the use of local building materials and thereby reduce the country's trade deficit.

A key mission of this public body, which answers to the Ministry of Higher Education, Scientific Research and Innovation but is financially independent, is to set up technology transfer centres in 10 regions across the country.

MIPROMALO consists of three main programmes: eco-construction and development (solar panels, etc); business creation and development and gender empowerment; and education and new technologies. MIPROMALO facilitates the industrialization of production of local materials in Cameroon and develops public–private partnerships. It provides the following services:

- Research and development;
- Engineering services;
- Technical assistance;
- Training;
- Laboratory analysis of materials;
- Production materials rental;
- Business incubators.

Source: http://mipromalo.com

Biodiagnostics and Therapy, and a quarterly newsletter published by the organization responsible for the surveillance of endemic diseases in Central Africa (OCEAC), the *Bulletin de l'OCEAC*. The OCEAC secretariat is located in Yaoundé and supported by the World Health Organization. Scientists would be able to access the content of these journals more easily if they were registered in standard bibliometric indexes.

One issue of concern is the low output of Cameroonian scientists. In early 2009, the government showed its willingness to strengthen university research by creating a special fund to triple the salaries of academics from US$ 550 to US$ 1 850 per month and modernize research facilities. This measure has been designed to increase the productivity of researchers and staunch brain drain.

The development of R&D has become one of the government's priorities, with an annual budget of 3 billion CFA and an average budgetary growth rate of approximately 1%. To promote excellence in scientific research and innovation, MINRESI launched a national biennial event in October 2007 tagged *Journées d'excellence de la recherche scientifique et de l'innovation du Cameroun* (Days of Excellence in Scientific Research and Innovation in Cameroon), while working in parallel on a directory of isolated or independent researchers and a scientific *Research Sectoral Strategy Plan*. Major barriers to the development of STI persist, however. These include:

- the lack of a national STI policy;
- a policy vacuum on distance learning;
- poor, expensive communication infrastructure;
- institutional inertia towards innovation that fuels a misuse of funds;
- a scarce, expensive energy supply reliant on fossil fuels and hydropower that would benefit from heavy investment in R&D to develop renewable sources of energy such as biomass, wind and solar energy.

Central African Republic

Statistics on scientists, researchers, engineers and their programmes are fragmentary in the Central African Republic, mostly due to latent political instability and repeated crises. Only the University of Bangui produces a statistical yearbook and then only with long delays, in spite of support from the UNESCO Institute for Statistics. What is certain is that the country lacks a critical mass of researchers and that the research pool is concentrated at the University of Bangui and the Pasteur Institute situated in the capital. The small size of the country's research body precludes the constitution of any associations of scientists or engineers.

Founded in 1970, the University of Bangui is the country's only university. The small pool of researchers is mostly involved in teaching rather than in research, as the budget for research is negligible. Although a High Council for Research was established in 1987, it is not operational.

To improve the situation, the government issued a Decree on the Organization and Functioning of the Ministry of Education, Literacy, Higher Education and Research in June 2005. This was followed in May 2006 by a special Decree on the Creation and Organization of the Researchers' Profession. In December of the same year, the ministry was again the subject of a decree modifying its statutes. The Decree on the Organization and Functioning of the Ministry of Education, Literacy, Higher Education and Research also fixed the minister's duties. In 2010, the ministry was implementing an important project funded by the French cooperation agency in support of higher education. Known as SUPC@, this project includes a number of R&D components.

In response to the government's request, UNESCO is currently providing support for the adoption of a national STI policy under its African Science, Technology and Innovation Policy Initiative. To that end, a consultant visited the country in July 2008 and July 2009. Moreover, a national forum was organized in March 2010 to ensure shared ownership of the new policy by all relevant stakeholder groups in the elaboration of a national STI policy: the research community, public and private entrepreneurs, civil society, funding agencies and so on.

Republic of Congo

Like Angola, Equatorial Guinea and Nigeria, among others, the Republic of Congo's industrial sector is largely dependent on oil. Oil has supplanted forestry as the mainstay of the economy, providing a major share of government revenues and exports. The country was seriously handicapped by two civil wars in the 1990s and, more recently, by the fall in global oil prices in 2008. As a result, it is currently experiencing a severe economic crisis that is jeopardizing the country's R&D programmes.

Although agriculture contributes only about 6% of GDP and 1% of exports, it is vital for the national economy, as it employs 40% of the workforce (Figure 5). This makes agricultural R&D a national priority. However, although the total number of agricultural researchers in Congo has gradually increased in recent years, expenditure on agricultural R&D has fallen by more than half over the same period. The country's 11 agricultural research centres, which fall under the Directorate-General for Scientific and Technological Research, account for about two-thirds of expenditure on agricultural R&D. The large number of these relatively small agricultural research agencies, however, coupled with their overlapping mandates, weakens the co-ordination and efficacy of agricultural research in Congo.

In 2004, the Congolese government requested UNESCO's assistance in strengthening national capacities in S&T to revitalize the science system after all the lost years of the Congolese civil war. UNESCO has since accompanied this ongoing effort to reform the country's science system step by step, with financial support from the Government of Japan. In the project's first stage, a *General Report* was prepared in 2004 to assess the state of S&T in Congo, in close collaboration with national stakeholders from the public and private sectors. The *General Report* (UNESCO, 2010*b*) found that:

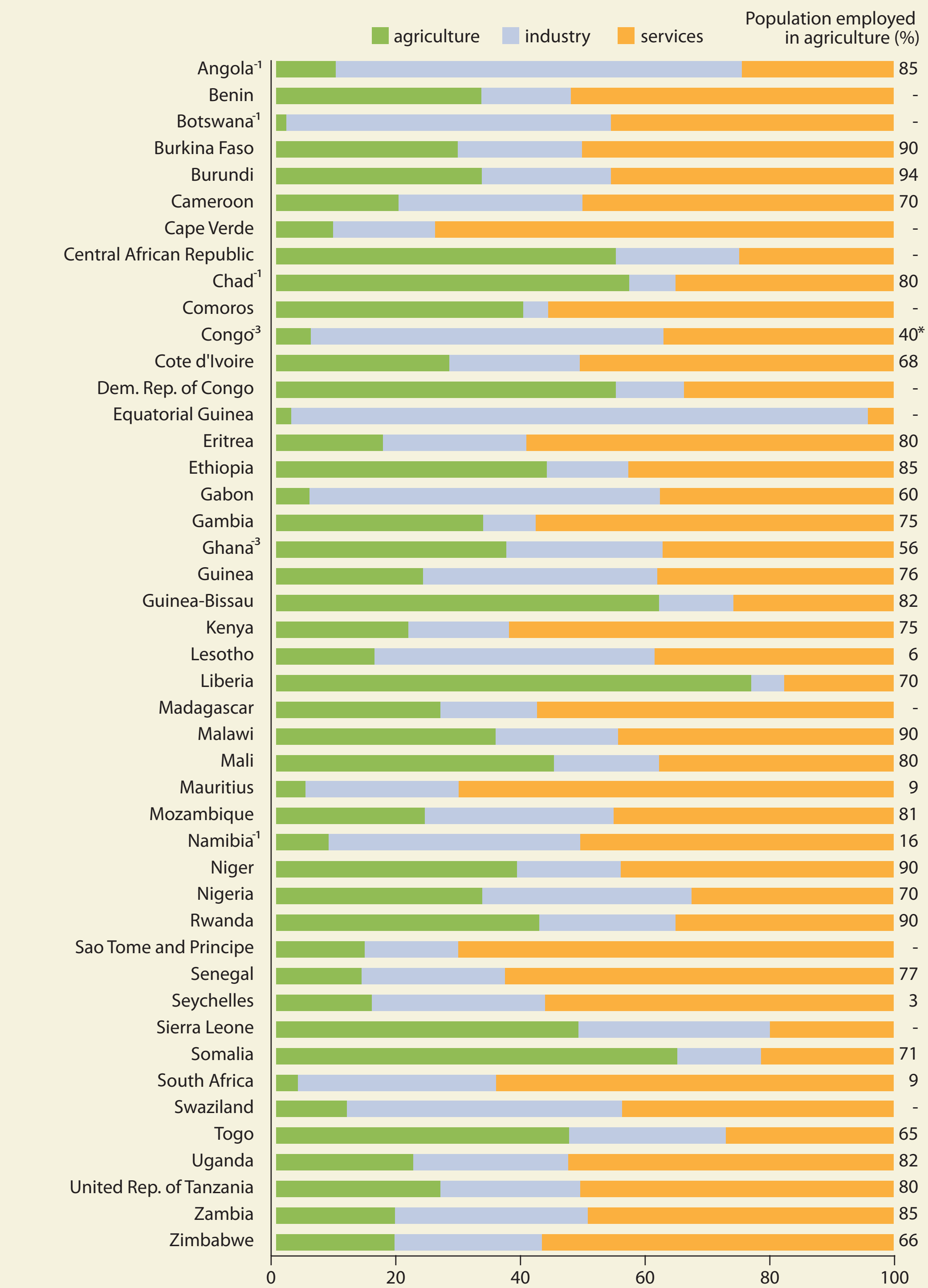
- the science governance system was dysfunctional. Some governance structures existed only in theory and, at 0.13% of GDP, public research funding was well below the stated target of 1%;
- research institutes, universities and industry remained isolated from one another and the entire system suffered from a lack of networking and intersectoral co-operation;
- the scientific community had no common representative structure, such as an academy or professional associations;
- research institutions suffered from a severe shortage of facilities, equipment, logistics and administrative and technical personnel;
- public research was placed under the auspices of the Ministry of Scientific Research and Technological Innovation but remained isolated from other sectors, such as agriculture or industry;
- since the end of the civil war, Congolese scientists had enjoyed little interaction and only rare exchanges with foreign scientists, including limited involvement in regional and international co-operation;
- the capacity of science policy-makers and managers was very low.

Once feedback had been received from officials on the diagnosis made in the *General Report*, a series of recommendations were made on the formulation, organization and implementation of an S&T policy. These were then the object of extensive consultations before being forwarded to the government in early 2006. The 'diagnosis' was validated and enriched by nearly 60 Congolese officials from various stakeholder groups at a National Policy Forum for Scientific Research and Technological Innovation organized in Brazzaville in May 2007. A series of seminars and training sessions on such themes as the governance of S&T and innovation policies followed in Brazzaville (UNESCO, 2010*b*).

Since 2005, the project has resulted in (UNESCO, 2010*b*):

- the creation of a full-fledged ministry responsible for scientific research and technological innovation in January 2005 to deal with an area that had previously come under the responsibility of the Ministry for Higher Education;
- the establishment of a Directorate for Technological Innovation within the new ministry;
- the development of specific statutes for research workers which were in the final stages of adoption in 2010, under consideration by the Supreme Court;
- a reform of the research infrastructure which was still under way in 2010, in order to group the large number of research units within three major institutes, those for agricultural sciences, health sciences and exact and life sciences;
- reconstruction of several research facilities and the allocation of greater resources to strategic areas, such as the National Agency for the Enhancement of Research (*Agence nationale de valorisation de la recherche*);

Figure 5: Composition of GDP in sub-Saharan Africa by economic sector, 2009 (%)



-n: data refer to *n* years before reference year
*provided by authors

Source: estimates from CIA (2010) *World Factbook*

- the establishment of a postgraduate school at the Marien Ngouabi University, supported by the university's Centre for Information Technology (*Campus numérique de l'Université Marien Ngouabi*);

- the elaboration and approval in April 2009 of a science policy document and an action plan for research and innovation covering 2010–2013. The action plan reiterates the 1% target for the GERD/GDP ratio. Specific research priorities have been defined, such as human and animal health; food security; and environment and biodiversity. These are in keeping with the major objectives of the country's development policy;

- the inclusion of a chapter on S&T in President Denis Sassou-Nguesso's Vision document for Congolese society, covering 2009–2016, entitled *Le Chemin d'Avenir*.

The first project phase wound up in 2010. For the second phase, UNESCO is suggesting to the Congolese government that it undertake the following projects:

- review of research institutions;
- the development of an STI financing system;
- the strengthening of human resources in science policy;
- the launch of a sub-regional parliamentary forum on the role of STI in socio-economic development;
- the setting-up of university teaching and research programmes on STI ;
- a study on how to develop science and innovation in the private sector;
- promotion of innovation and technological entre-preneurship, taking into account the informal sector;
- the establishment of an intellectual property protection system;
- a review of participation in regional and international scientific activities.

UNESCO has also recommended that the budgeting process be adjusted to allow for a multi-year budgetary programming cycle with a long-term vision, accompanied by greater flexibility in the use of funds. It proposes that the Directorate General for Scientific and Technological Research fulfil the essential role of co-ordination and supervision, in close partnership with the Ministry of Finance. UNESCO is also urging the scientific community to organize itself into fully representative bodies, such as one or more academies or associations. The scientific community is currently too fragmented to play the role of partner in a permanent process of interaction with the state authorities and civil society (UNESCO, 2010*b*).

Côte d'Ivoire

Côte d'Ivoire was a paragon of stability and economic growth in West Africa from the time of independence in 1960 until 2002 when a severe political crisis degenerated into civil war. This situation practically partitioned the country and completely jeopardized economic growth, paralysing scientific progress in the process. As a result, Côte d'Ivoire produced 129 publications in 2000 but only 111 in 2002. By 2008, productivity had recovered to 171 but the growth rate was well below that of Uganda, a country with comparable output in 2000. International collaboration was less affected. Côte d'Ivoire's scientists co-authored 363 articles in 2000 and 448 in 2002, a number that had risen to 789 by 2008.

One consequence of the political crisis has been the extreme difficulty in collecting and processing statistical data, since the second *National Strategy Document for Statistics Development* (2001–2005) was never adopted by the government and its successor for 2007–2010 was still being finalized in 2010.

Cote d'Ivoire is the world's largest producer and exporter of cocoa beans and a key exporter of coffee and palm oil. Despite government attempts to diversify the economy to reduce its vulnerability to international prices and climatic conditions, the country remains heavily dependent on agriculture (CIA, 2010). The National Centre for Agronomic Research (CNRA) employs two-thirds of the country's researchers and absorbs three-quarters of R&D expenditure.

CNRA has benefited from significant funding from the World Bank within two successive National Agricultural Services Support Projects for 1994–1997 and 1998–2010. CNRA has also attracted funding from the African Development Bank, United Nations Development Programme and the co-operation agencies of France and Belgium. It has established bilateral co-operation with the private sector via contracts with the African Sugar Company (SUCAF), the Ivorian Company for Textile Development (CIDT) and the Ivorian Cotton Company (ICCI), among others.

Democratic Republic of Congo (Kinshasa)

Endowed with rich agricultural soils, dense forests, abundant water and large reserves of minerals, this large country with enormous potential was devastated by almost uninterrupted civil war, rebellions and armed conflict between the time of independence in 1960 and the government signing of peace agreements with various rebel groups in March 2009. As a result of this prolonged political instability, the country's economy is in ruins: GDP amounted to just PPP US$ 20 billion in 2008. Scientific productivity is negligible, with just 30 publications registered in Thomson Reuters' Science Citation Index in 2008, although the language barrier may explain, in part, this poor performance.

The Democratic Republic of Congo has a small research infrastructure. Of the country's 25 public research centres and institutes, 18 fall under the Ministry of Scientific and Technological Research and seven under other ministries. There are also 19 institutions of tertiary education and 13 research centres and institutes in the higher education sector. The main private R&D institutions are the Luozi Pharmaceutical Research Centre (CRPL), Pan-African Research Development Institute (IRDA), African Centre for Industrial Research (CARI) and the Congolese Centre for Strategic Studies and Research specializing in international relations.

In May 2005, the country organized the *Etats généraux* for scientific research. This national forum brought together different stakeholder groups to draft a strategic plan for S&T and gave orientations for the future, including for the periodic assessment of the research system.

In 2008, the Democratic Republic of Congo requested UNESCO's assistance in developing a national S&T policy. This process is being conducted by the Ministry of Scientific and Technological Research, together with the National Scientific Council (CSN).

Gabon

Gabon is among the richest countries in Africa, thanks mainly to exports of petroleum, manganese, uranium and wood. Some 85% of the country is covered by dense forest. With its natural resources deteriorating, however, more importance is now being given to agriculture, although Gabon's agricultural R&D capacity remains one of the weakest on the continent. Three agricultural research institutes account for more than three-quarters of the country's total R&D staff and expenditure.

The Ministry of Higher Education, Research and Technological Innovation is entrusted with the mission of planning, promoting and assessing R&D programmes, as well as capacity-building. The ministry has signed an agreement with the French Cooperation Mission to develop a Research Directory Scheme in Gabon. This could boost scientific production, which is globally very low: in 2008, Gabonese scientists authored just 76 of the papers recorded in the Science Citation Index.

Besides the National Council for Higher Education and Scientific Research (CONAREST) and the three national universities – Omar Bongo University, the Science and Technology University of Masuku and the University of Health Sciences – Gabon's main research institutions are the National Centre for Scientific and Technological Research (CENAREST), the Centre for Specialized University Research (CERESU), the International Medical Research Centre of Franceville (CIRMF) and the Schweitzer Foundation Medical Research Laboratory.

Research programmes are mostly conducted within teams participating in international or sub-regional collaborative networks, such as with Europe (28.6%), North America (8.6%), the Economic and Monetary Community of Central Africa (17.1 %) and the Economic Community of West African States (12.4 %). In 2007, just 57 scientific articles resulted from international collaboration in S&T. However, 22% of researchers have never published within international networks and, more worrisome still, 14% of researchers have never published at all in the course of their career.

Kenya

Kenya is the regional hub for trade and finance in East Africa. Kenya's economy suffered in early 2008, after post-election violence affected tourism and investor confidence. This situation, coupled with the drop in exports and remittances as a result of the global recession, has caused annual GDP growth to slip from 7% in 2007 to barely 2% in 2008 and 2009 (CIA, 2010).

Against this backdrop, the Kenyan president decided to establish a new science ministry in 2008 by merging the Ministry of Science and Technology with the Department of Higher Education. The resultant Ministry of Higher Education, Science and Technology plans to strengthen the linkages between higher education and research. The Kenyan Parliament has since approved a national policy for biotechnology devised by the ministry (Box 8).

The government announced a *Kenya Vision 2030* in June 2008. This document calls for a series of five-year plans for the country's economic development. The first plan covers 2008–2012 and identifies six key sectors for investment with 20 flagship projects. These sectors are: tourism, agriculture, manufacturing, trade, information technology and financial services.

Concerned at the impact of climate change on the environment, the government allocated US$ 721 million to conservation in 2010 and announced plans to establish a regional carbon emissions trading scheme. The government is hopeful that such a scheme will attract funding to Kenya and add regional carbon trading hub to Kenya's established role as a regional hub for trade and finance. Most of the US$ 721 million allocated to conservation – a rise of more than 50% over the previous year's budget – will go to the environment, water and sanitation sectors (Mboya, 2010).

Mali

A landlocked country, Mali has suffered droughts, rebellions, coups and a brief border war with Burkina Faso in recent years. Endowed with a democratically elected civilian government since 1992, Mali still faces sporadic fighting with nomadic Tuareg tribes in the north. The country is saddled with a chronic foreign trade deficit and an economy largely dependent on cotton production. The low level of resources allocated to STI has spawned a small pool of ageing researchers who often lack motivation.

Since 2000, the national budget has allocated an annual grant of approximately €1 200 000 (*circa* US$ 1.8 million) to studies and research. In addition, a special budget for investment of 600 million CFA (about US$ 1.2 million) was allocated each year from 2005 to 2007 for the rehabilitation and equipping of laboratories in universities and secondary schools.

As elsewhere in Africa, agricultural research predominates in Mali. It is thus hardly surprising that it is one of the priorities of Mali's *Strategic Plan* for 2010–2019. Mali differs from many other African countries, however, in that it has adopted a policy of centralizing research. There is one main agricultural R&D agency, the Rural Economy Institute, which groups roughly 85% of the country's agricultural researchers and expenditure.

In addition to government contributions, the Rural Economy Institute is largely dependent on funding from the National Agricultural Research Project and the Support Programme for Agricultural Services and Associations of Producers (PASAOP), drawn predominantly from World Bank loans and funding from the Netherlands through the Rural Economy Institute Support Project (PAPIER). PASAOP ended in December 2009 but has been replaced by another programme supporting agricultural productivity in Mali (PAPAM).

Private-sector involvement in funding agricultural research on cotton, rice and other crops is limited to the Malian Company for Textile Development and the Niger Office. However, research institutions generate some income of their own through the commercialization of research products or services.

Despite a research environment lacking in everything from infrastructure and equipment to a well-trained, motivated young labour force, Malian research has managed to innovate, in particular in the agriculture and health sectors. Scientists have developed new varieties of maize, millet, rice and cowpea that are drought- and pest-resistant, as well as new techniques to increase yields. They have also developed traditional medicines and vaccines.

Scientific authorship remains low, however. Just 88 scientific articles from Mali were recorded in the Science Citation Index in 2008, although this was up from 30 in 2000. There was a similar level of productivity in international collaboration in 2008, with Malian scientists co-authoring 86 articles.

Today, there is a perceptible political will to support STI. The government has set up 18 national research institutes co-ordinated by the National Centre for Scientific and Technological Research (CNRST). Established in March 2004 under the Ministry of Higher Education and Scientific Research, CNRST manages the budget line for Studies and Research. This budget line leapt from 9 million CFA in 2000 to 60 million CFA in 2009.

In Mali, agricultural research is co-ordinated by the National Committee for Agricultural Research (CNRA). Health research, on the other hand, is the purview of the National Institute for Public Health Research (INRSP).

The University of Bamako was founded in January 2006 to take over from the University of Mali. It counts five faculties and two institutes. Other institutions employed in R&D and training are the: Central Veterinary Laboratory;

Box 8: Africa invests in biotech

Just three months after discovering Cuba's drug manufacturing capacity during a visit to the country, so the story goes, former South African President Thabo Mbeki announced South Africa's first National Biotechnology Strategy in 2001. Several regional and one national biotechnology innovation centres followed, the role of which was to recruit venture capitalists and distribute federal funds to start-ups. In just a few years, South Africa's biotech strategy has doubled the number of biotech companies to more than 80 and created more than 1 000 research jobs. Biotech products in development nearly doubled from 900 in 2003 to more than 1 500 in 2007 and the industry reported over US$ 100 million in revenue in 2006.

This novel approach has become the hallmark of biotech R&D in Africa. Rather than relying on big pharmaceutical companies for investment, a growing number of African governments are funding biotech themselves via support for start-ups, partnerships with foundations and United Nations agencies, and R&D collaborations between universities and private laboratories. The Wellcome Trust's African Institutions initiative is investing US$ 50 million in training researchers in neglected tropical diseases and in sponsoring collaboration between 50 scientific institutions in 18 African countries and private companies.

The World Health Organization is also pouring US$ 30 million annually into research and bringing biotech products to the market within the African Network for Drugs and Diagnosis Innovation that it has helped to establish.

In 2004, the Kenyan government decided to invest US$ 12 million to build a 'biosafety greenhouse' to allow containment of genetically modified (GM) crops, in a project funded jointly by the government and the Swiss Syngenta Foundation. Kenya thereby became the second sub-Saharan country after South Africa to be equipped to conduct GM experiments that conform to international biosafety standards. The greenhouse has been built within the Insect-Resistant Maize for Africa project. The greenhouse was developed jointly by the Kenya Agricultural Research Institute and the International Center for Maize and Wheat Research (CIMMYT), which also trained scientists to manage the facility at its centre in Mexico.

In 2007, the Kenya Wildlife Service concluded a five-year biotech research partnership with the Danish company Novozymes to use enzymes with potential industrial applications in biofuels and medicine, in particular. In return for authorizing Novozymes to exploit rich microbial biodiversity commercially within areas under its control, the Kenya Wildlife Service is collaborating with Novozymes in enzyme R&D and patenting.

Novozymes is also assisting with transfer technology to Kenya and is training Kenyan students to turn plants, animals, insects and micro-organisms into marketable goods. The company has agreed to build a special laboratory at the Kenya Wildlife Service headquarters in Nairobi. Kenya passed a biosafety bill in 2009.

Burkino Faso passed its own biosafety bill in 2006. Two years later, Uganda's Cabinet approved the country's first national biotechnology and biosafety policy. Uganda is currently using a US$30 million loan from the World Bank to improve the cassava plant.

Nigeria established a National Biotechnology Development Agency (NABDA) in 2001 as an institutional framework for implementing the National Biotechnology Policy. At a roundtable organized by NABDA in April 2008 on the introduction of GM crops into Nigeria, participants 'noted the undue delay in the processing of the Nigerian biosafety bill' and urged 'the [relevant ministers] to fast-track the process to obtain National Assembly approval without further delay.' NABDA has designated six zonal biotechnology centres of excellence for the conduct of R&D corresponding to specific biotechnology problems within each zone. The biosafety bill was finally passed in 2009.

Source: Bagley (2010); Chege (2004); Zablon (2007) ; Odhiambo (2007)

See: www.nabda.gov.ng

Rural Economy Institute mentioned above; Traditional Medicine Research Centre (CRMT); National Agency for Telemedicine and Medical Computing (ANTIM) and; Rural Polytechnic Institute/ Institute for Training and Applied Research of Katibougou (IPR/IFRA).

The Ministry of Industry holds a National Invention and Innovation Exhibition every two years, through the National Directorate for industry (DNI) and the Malian Centre for Industrial Property (CEMAPI).

A wide range of laws and decrees have been adopted in recent years to improve the legal framework for S&T. Of note are those establishing a Statute for Researchers (2000) and new institutions, or fixing the functioning modalities of existing institutions. One product of this legislative onslaught is the National Agency for Information and Communication Technologies (AGETIC) dating from January 2005. One of the first tasks for AGETIC was to conduct a study, in June 2005, for the establishment of a National Policy on Information and Communication Technologies, with support from UNECA, the European Commission and the United Nations Development Programme.

In 2010, Mali was in the process of formulating a national STI policy with a strong focus on innovation, with UNECA support.

Nigeria

With the return to democracy in 1999 after 15 years of military rule, the role of STI in driving development started to feature prominently in Nigeria's economic reform agenda. In 2001, President Obasanjo appointed an International Honorary Presidential Advisory Council on Science and Technology to advise him on:

- effective ways of developing S&T for the benefit of Nigerians, by enhancing capacities in such critical areas as biotechnologies, ICTs, space science and technology, energy, nanotechnology and mathematics;
- effective ways of promoting S&T as an instrument for co-operation and integration in Africa;
- effective capacity-building programmes for implementation by the Federal Ministry of Science and Technology, including recourse to the expertise of Nigerians in the diaspora, and partnerships with international bodies.

The Council met twice a year for nearly seven years and made several important recommendations in the areas described above.

Under the presidency of Olusegan Obasanjo (1999–2007), the National Economic Empowerment and Development Strategy (NEEDS) was adopted to provide a framework for poverty reduction and wealth creation over the period 2003–2007. It identified STI as a cross-cutting issue, the promotion of which was vital to achieving economic objectives. This was followed by a *Seven-point Agenda* and *Nigeria Vision 20: 2020*, which represents the country's current economic development policy platform. The *Nigeria Vision 20: 2020* embraces areas identified by 12 committees set up by the Federal Ministry of Science and Technology at the turn of the century. It spans:

- biotechnology;
- nanotechnology;
- institutional linkages;
- capacity-building;
- renewable energy;
- venture capital;
- space research;
- industry-targeted research by small and medium-sized enterprises;
- knowledge-intensive new and advanced materials;
- STI information management;
- information and communication technologies;
- intellectual property rights;
- traditional medicine and indigenous knowledge.

The target of the *Nigeria Vision 20: 2020* is for Nigeria to join the 20 most powerful economies in the world by 2020. This target is based on the assumption that the country will achieve a consistent 12.5% growth rate in GDP per capita over the next decade. There are nine strategic targets:

- Carry out a technology foresight programme by the end of 2010;
- Invest a percentage of GDP in R&D that is comparable to the percentage invested by the 20 leading developed economies of the world;
- Establish three technology information centres and three R&D laboratories to foster the development of small and medium-sized enterprises;
- Increase the number of scientists, engineers and technicians and provide them with incentives to remain in Nigeria;

- Support programmes designed by professional S&T bodies to build STI capacity;
- Develop an STI information management system for the acquisition, storage and dissemination of research results;
- Attain progressively 30% of local technology content by 2013, 50% by 2016 and 75% by 2020;
- Develop new and advanced materials as an alternative to the use of petroleum products;
- Establish a National Science Foundation.

In October 2004, UNESCO set up an International Advisory Board for the reform of the Nigerian science system, at the government's request. One aim of the reform process was to diversity Nigeria's economy, which had become extremely dependent on fluctuating global oil prices. The board recommended (UNESCO, 2006):

- establishing a US$ 5 billion Endowment Fund in Nigeria which would be supplemented by donors;

- creating a National Science Foundation. This would be an independent funding body for competitive research and projects and programmes in innovation. Its main functions would be the provision of grants to research bodies, universities, enterprises and individuals on a competitive basis; the equipping and capitalization of research groups; and the establishment of research universities;

- creating technology-based 'good business' zones in each state where, for instance, businesses could obtain a license within 30 days and benefit from reduced capital costs;

- providing six Nigerian universities with targeted funding and technical assistance to enable them to rank among the 200 top universities in the world by 2020.

These four recommendations have since been approved by the government. Moreover, the proposal to create the National Science Foundation has been incorporated in the Economic Transformation Blue Print for the *Nigeria Vision 20:20,* as we have seen. In 2010, the government approved a special intervention fund of US$210 million over three years to develop centres of excellence at six universities, as well as US$ 66 million for upgrading selected polytechnics and colleges of education. Nigeria has 104 approved universities, 27 of which are federal, 36 state and 41 private universities.

Box 9: African Institutes of Science and Technology

The African University of Science and Technology in Abuja (AUST), Nigeria, was established in 2007 by the Nelson Mandela Institution, a charity incorporated in the USA, as the first in a Pan-African Network of Institutes of Science and Technology and centres of excellence across the continent.

AUST started its first academic year in June 2008. Two years later, the university was offering five MSc degree programmes in pure and applied mathematics; computer science; applied physics; materials science and; petroleum engineering. The university intends to develop its own PhD programme in the coming years and to establish strong partnerships with overseas universities to allow PhD students to do part of their research abroad.

The AUST in Arusha, Tanzania, has six start-up postgraduate programmes. These are in materials science and engineering; biosciences and bioengineering; mathematics and computational science and engineering; water and environment engineering; energy science and engineering (both renewable and non-renewable energy); and humanities and business studies. The latter includes management and entrepreneurship; innovation management and competitiveness; and law and IPRs.

Each AUST intends to become a world-class research-oriented institution. In Abuja, the AUST has developed extensive links with the African scientific diaspora and partnerships with the African Institute of Mathematical Sciences in Capetown (South Africa), with the Indian Institute of Technology Bombay (India) and with an AUST affiliate centre, the International Institute for Water and Environmental Engineering in Ouagadougou (Burkina Faso). The AUST in Abuja is also expected to collaborate with the Nigerians in the Diaspora Commission established by Parliament in 2010 to identify Nigerian specialists living abroad and encourage their participation in Nigerian policy and project formulation. Sponsors of the AUST in Abuja include UNESCO's Abdus Salam International Centre for Theoretical Physics, the African Development Bank Group and the Nigerian National Petroleum Corporation.

Source: authors; see http://aust.edu.ng/; www.nm-aist.ac.tz/index.htm

In 2010, Parliament approved the establishment of the Nigerians in the Diaspora Commission, the aim of which is to identify Nigerian specialists living abroad and encourage their participation in Nigerian policy and project formulation. The African University of Science and Technology in Abuja is expected to collaborate with the Commission on implementing this project (Box 9).

Priorities for industrial development in Nigeria

Nigeria has about 66 R&D institutes covering various sectors of the economy. R&D in many of these institutes has produced a host of nationally patented inventions but the vast majority remain on the shelf rather than being turned into innovative products and processes. In line with the government's NEEDS strategy and ensuing reforms, the federal government approved funding for the development of the Abuja Technology Village in 2007 and established a project team. This project draws on similar initiatives worldwide which cluster local and multinational companies, as well as residential areas. These include Silicon Valley in the USA, Dubai Internet City, the International Technology Park in India and Cyberjaya in Malaysia. The main clusters of the Abuja Technology Village are: minerals technology, biotechnology, energy technology and ICTs.

The National Biotechnology Development Agency was established in 2001 as an institutional framework for implementing the National Biotechnology Policy adopted the same year. The agency has a mandate to co-ordinate, promote and regulate all biotechnology activities in the country with a view to making available this cutting-edge technology for the promotion of a healthy environment, ensuring national food security and providing affordable health care delivery and poverty alleviation. Its development has been hampered, however, by the delay in the adoption of a biosafety act to provide a framework for the introduction and development of GM crops in Nigeria. This act was finally adopted in 2009 (Box 8).

The state of information technology (IT) in Nigeria left much to be desired at the turn of the century. Technology and industrial policy regimes had been marked by the indiscriminate importation of technology in which transfer agreements contained unfair clauses. These clauses included monopoly pricing; restrictive business practices; export restrictions; high royalty rates; tie-in clauses with equipment, raw materials, components and so on; a lack of training and management programmes; and poor opportunities for local R&D.

The elaboration of Nigeria's National Information Technology Policy in 2001 sought to reduce Nigeria's dependence on imported technology and promote the country's global integration to facilitate economic development. The policy went through a consultative process that brought together the country's major IT stakeholders[8]. Nigeria created a National Information Technology Development Agency in 2001 specifically to implement the IT policy. Six years later, Internet access had jumped from just 0.3% in 2002 to 6.8%. One area that merits investment in Nigeria is software development.

In July 2006, the federal government launched the Computer for All Nigerians Initiative (CANI). This public–private collaboration is sponsored by the Federal Ministry of Science and Technology, Microsoft and Intel. The computers are made with Intel processors and are assembled locally by International Business Machines, Hewlett Packard and four Nigerian companies: Omatek, Zinox, Brian and Beta Computers. The scheme makes desktop computers and laptops available to employers at a 30% discount off the market price. It also offers affordable 24-month bank loans for the purchase of personal computers (PCs). The loans are guaranteed by the employer, with instalments being deducted directly from the employee's salary. Employers are being encouraged to subsidize the package by about 20% to reduce the cost of a PC to half the market price.

In 2003, Nigeria became the third country after South Africa and Egypt to have a presence in space, after the launch of a low-orbit remote-sensing micro-satellite, NigeriaSat-1, with the assistance of the Russian Federation. NigeriaSat-1 monitors the environment and provides information for infrastructure development. This prowess enabled Nigeria to join the Disaster Monitoring Constellation grouping Algeria, China, the UK and Viet Nam. NigComSat-1 followed in 2007, in collaboration with the China Great Wall Industry Corporation, to offer Africa better telecommunications.

In April 2010, the Nigerian Oil and Gas Industry Content Development Act (Local Content Act) received presidential assent. Now in force, the new law seeks to

8. These included the Computer Association of Nigeria, now known as the Nigeria Computer Society, the National Information Technology Professionals Association and the Association of Licensed Telecommunication Companies in Nigeria (ALTCON), as well as all Nigerians in the diaspora.

increase indigenous participation in the oil and gas industry by prescribing minimum thresholds for the use of local services and materials and by promoting the employment of Nigerian staff. The Local Content Act derives from the Nigerian Content Policy, which seeks to promote active participation by Nigerians in the petroleum sector without compromising standards. The policy also focuses on promoting value addition in Nigeria through the utilization of local raw materials, products and services in order to stimulate the growth of endogenous capacity.

Rwanda

Rwanda's new development strategy, as elaborated in reports like *Vision 2020* and the *National Investment Strategy*, shows the country's determination to adopt S&T as a fundamental tool to achieve economic development. Key government measures to promote STI include improvements to the country's S&T infrastructure through public investment and South–South co-operation, the promotion of a knowledge economy through information technology and the application of science, as well as the development of a small number of world-class institutions of higher education, including the National University of Rwanda and the Kigali Institute of Science, Technology and Management.

At the African Union Summit in January 2007, Rwandan President Paul Kagame announced that his country had boosted expenditure on S&T from less than 0.5% of GDP a few years ago to 1.6%. He also said his country would increase investment in R&D to 3% of GDP by 2012. That would make Rwanda's GERD/GDP ratio higher than that of most developed countries. A country teetering on collapse less than a decade ago and still living in the shadow of genocide has embarked on a path that could lead to science-based sustainable development.

In 2008, the government evoked the possibility of establishing an endowment fund for innovation which would also serve to build R&D capacity in Rwanda's centres of excellence. A first for Rwanda, the fund would be a public–private partnership, with research teams being entitled to apply for funding collectively, a move which would facilitate the composition of multidisciplinary research teams. At present, each researcher has to apply for funding from individual ministries. However, at the time of writing in early 2010, no specific amount had been confirmed for the fund and the project was still under consideration (Niyonshuti, 2010).

Senegal

In Senegal, agriculture earns around 14% of GDP and employs three-quarters of the labour force (Figure 5). As in many other African countries, it occupies the lion's share of research activities. In all, nine institutes conduct agricultural research, the two core ones being the Senegalese Institute for Agricultural Research (ISRA) and the Institute of Food Technology (ITA), which employ 70% and 5% of Senegalese researchers respectively.

Given the importance of agriculture, the government has deployed a lot of energy in funding and re-organizing agricultural research over the past decade. In 1999, it created the National Fund for Agricultural and Agro-Food Research (FNRAA) to serve as a mechanism for channelling competitive funding during the first phase of the World Bank's PASAOP programme offering support to farmers' organizations. This fund has since become an instrument for harmonizing and promoting institutional collaboration in agricultural R&D and related sectors. FNRAA has been the major initiator of the National Research System for Agriculture, Forestry and Animal Husbandry (SNRASP) launched in June 2009. This system has considerably strengthened co-operation among major institutions operating in this sector. SNRASP derived from a decree issued in November 2008, which itself emanated from the Orientation Law adopted in June 2004 to implement a 20-year vision for the agriculture sector. SNRASP aims to rationalize agricultural R&D and foster inter-institutional collaboration, as well as the setting-up of an efficient S&T information network for agriculture and related sectors.

The Ministry of Scientific Research adopted a *Strategic Research Plan* for 2006–2010 in June 2006. However, this plan has not been implemented as expected, mostly due to frequent cabinet reshuffles. The ministry merged with the Ministry of Higher Education in October 2009 to form the Ministry of Scientific Research and Higher Education. In 2010, the ministry was putting together a formal STI policy with UNESCO's assistance.

Founded in 1999, the National Academy of Science and Technology of Senegal is an independent body that provides evidence-based advice to the government and alerts public opinion to S&T issues. The academy is divided into four sections: agricultural sciences; health sciences; science and technology; and economic and social sciences.

The academy has clocked up a number of achievements. For example, it has adopted a draft programme for the development of science teaching in Senegal called the National Indicative Programme. In parallel, it has reviewed innovative experiences and trends at home and abroad as a preamble to elaborating a science education policy. Following a fact-finding mission to Saint-Louis, members of the academy staged a special scientific session on the theme of Floods and Management: the Case of Saint-Louis, which resulted in the submission of a paper on a Flood Control and Urban Management Strategy to the Ministry of Hydraulics and Water Resources. The academy has also organized a number of intercontinental conferences in recent years, in partnership with the African Regional Centre for Technology and within both the African Science Academy Development Initiative (Box 5) and the Knowledge Management Africa Initiative (Box 6).

In May 2008, the National Agency for Applied Scientific Research came into being. It operates directly under the presidency with its own agenda. One of its main programmes is the development of a science park supported by the United Nations Department of Economic and Social Affairs (UNDESA), which is supporting a similar park in Ghana. The park in Senegal will focus on four areas: ICTs; biotechnologies; the garment industry and; aquaculture. The agency also organized a sub-regional exhibtion on research and innovation in March 2010.

South Africa

Just two years after the election of the country's first democratic government, a White Paper on Science and Technology was published in 1996. Entitled *Preparing for the 21st Century*, it pinpointed a number of systemic failures (OECD, 1999):

- a fragmented and inadequately co-ordinated science system;
- the erosion of innovative capacity;
- poor knowledge and technology flows from the science base into industry;
- poor networking both within the region and in the global context;
- low investment in R&D;
- imbalances created by past policies and actions;
- a lack of competitivity within the global environment.

The White Paper made a number of policy recommendations for developing South Africa's national innovation system, including: the re-allocation of government spending according to new priorities to promote innovative solutions for the disadvantaged, in particular; the introduction of processes to challenge government research institutions to derive more support from competitive sources of funding; the promotion of the diffusion of the results of R&D to make R&D expenditure more efficient; and the introduction of longer-term perspectives in planning and budgeting for R&D (OECD, 1999).

Six common themes emerged from the White Paper's review of policy documents (OECD, 1999):

- Promoting competitiveness and job creation;
- Enhancing the quality of life;
- Developing human resources;
- Working towards environmental sustainability;
- Promoting an information society;
- Producing a greater volume of knowledge-embedded products and services.

In 2002, the government adopted the National Research and Development Strategy. This document has since formed the basis for the development of South Africa's national innovation system. To promote South Africa's competitiveness, the strategy identified key technology missions and science platforms. The former include biotechnology, nanotechnology and ICTs, and the latter Antarctic research, marine biology, astronomy and palaeosciences.

The National Research and Development Strategy recognized the need to develop synergies among the public and private components of the science system to create wealth, improve the quality of life, develop human resources and build R&D capacity. It also fixed the objective of attaining a GERD/GDP ratio of 1%. One of the measures implemented by the government to realize this goal is the R&D Tax incentive Programme launched in 2008 (*see page* 315).

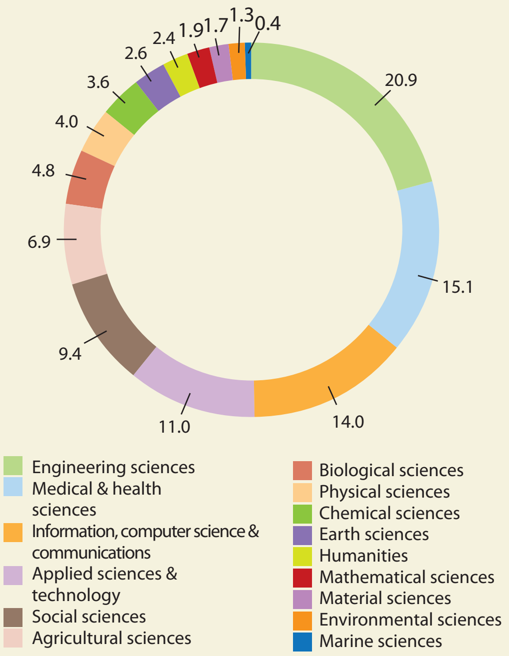
Another objective of the National Research and Development Strategy was to scale up the number of skilled researchers and technologists by adopting a dual upstream (existing R&D personnel) and downstream (school learners) approach. Upstream, the government has since put in place a South African Research Chairs Initiative, a Centres of Excellence Programme and a

Postdoctoral Fellowship Programme. Downstream, it has introduced Bursary Initiatives, Youth into Science and the Science and Engineering and Technology Awareness programmes.

Since the National Research and Development Strategy was adopted, statistics gathering and analysis have been reinforced and new indicators have been introduced to assess how well the national innovation system is performing. The role of the National Advisory Council on Innovation (NACI) is to provide a diagnosis and propose ways of improving the national innovation system.

NACI is comprised of 22 members. Established by law in 1997, the council advises the Minister of Science and Technology and, through the minister, the Cabinet, on the role and contribution of science, mathematics, innovation and technology in promoting national objectives. NACI also identifies R&D priorities. The council groups the full spectrum of sectors and organizations involved in the South African national innovation system and is supported by a professional secretariat based within the Department of Science and Technology in Pretoria, as well as by three specialized advisory committees: Science, Engineering and Technology for Women; the National Biotechnology Advisory Committee and; the Indicators Reference Group.

Figure 6: Breakdown of government expenditure on R&D in South Africa by field of research, 2006 (%)



Source: DST (2009) *National Survey of Research and Experimental Development*

Trends in R&D investment in South Africa

South Africa has managed to increase GERD from 0.7% at the time the National Research and Development Strategy was adopted to 0.9% in 2006. The business sector funded 44.8% of GERD in 2006 and performed 57.7%. Investment is not evenly spread around the country, however, as just three out of nine provinces concentrate four-fifths of the total. A *National Survey of Research and Experimental Development* undertaken in 2006 and 2007 by the Department of Science and Technology (DST, 2009) revealed that more than half (51%) of the country's R&D expenditure in the private and public sectors was concentrated in the Gauteng Province. The Western Cape (20.4%) and KwaZulu-Natal (11.0%) Provinces ranked second and third respectively.

South Africa's R&D effort can be broken down into 15 broad fields. In 2006, the lion's share of government funding went to the engineering sciences (Figure 6). There may be a correlation between this high level of funding and the numerous breakthroughs in engineering by South Africa in recent years, one example being the Southern African Large Telescope (Box 10). Other fields receiving a large allocation are medical and health sciences and information, computer science and communications.

Towards a knowledge economy in South Africa

In July 2007, the DST adopted a ten-year innovation plan (2008–2018). *Innovation towards a Knowledge-based Economy* builds on the foundations laid by the National Research and Development Strategy adopted in 2002. The purpose of the ten-year plan is to help drive South Africa's transformation towards a knowledge economy, one in which the production and dissemination of knowledge lead to economic benefits and enrich all fields of human endeavour. The plan is underpinned by five grand challenges:

- *The 'Farmer to Pharma' value chain to strengthen the bio-economy*: over the next decade, the goal is for South Africa to become a world leader in biotechnology and pharmaceuticals, based on the nation's indigenous resources and expanding knowledge base (Box 8);

Box 10: The largest telescope in the Southern Hemisphere

The Southern African Large Telescope (SALT) is the largest single optical telescope in the Southern Hemisphere (*see photo, page* 278) with a hexagonal mirror array 11 m across. It is located in the semi-desertic region of Karoo in South Africa.

SALT is a facility of the South African Astronomical Observatory established in 1972 and run by South Africa's National Research Foundation. Inaugurated in November 2005, SALT has been funded by a consortium of partners from South Africa, the USA, Germany, Poland, India, the UK and New Zealand.

The telescope will be able to record distant stars, galaxies and quasars a billion times too faint to be seen with the naked eye, as faint as a candle flame at the distance of the Moon.

In 2010, the South African Astronomical Observatory won a bid to host the International Astronomical Union's Office for Astronomy Development, which will play a key role in taking astronomy to the developing world by co-ordinating and managing all educational activities.

South African astronomy celebrated another milestone in 2010 when the first four telescopes of the KAT-7 demonstrator radio telescope were linked together as an integrated system to produce Africa's first interferometric image of an astronomical object. Interferometry refers to a technique by which radio signals collected at the same time by a system of networked radio telescopes are processed into a single high-resolution image. This milestone augurs well for the African bid to host what will be the world's largest radio telescope, the Square Kilometre Array, because it demonstrates that Africans have the technical expertise to build such a complex working instrument.

Source: www.salt.ac.za; www.saao.ac.za/; SouthAfrica.Info (2010*a*; 2010*b*)

- *Space science and technology*: South Africa should become a key contributor to global space science and technology, with the founding of the National Space Agency in 2009, a growing satellite industry and a range of innovations in space sciences, Earth observation, communications, navigation and engineering;

- *Energy security*: South Africa must meet its medium-term requirements in terms of energy supply while innovating for the long term in clean-coal technologies, nuclear energy, renewable energy and the promise of the hydrogen economy;

- *Global climate change science*: South Africa's geographical position enables it to play a leading role in climate change science;

- *Human and social dynamics*: as a leading voice among developing countries, South Africa should contribute to a greater global understanding of shifting social dynamics and the role of science in stimulating growth and development.

The government launched an R&D Tax incentive Programme in 2008 to help reach the target stated in the National Research and Development Strategy of a 1% GERD/GDP ratio. The aim of the programme is to encourage businesses to invest in R&D and innovation (NACI, 2009). It encourages private companies to acquire capital assets, labour and technology for R&D in the manner they consider most productive then to claim the tax incentive. The incentive includes a tax deduction of 150% in respect of actual expenditure incurred for eligible activities and provides for an accelerated depreciation of assets used for R&D over three years at the rate of 50:30:20.

The government has also introduced a scheme allowing it to assess the impact of the R&D Tax Incentive Programme on the economy and society. The Income Tax Act requires the DST to report on the aggregate expenditure on R&D activities and direct benefits of such activities in terms of economic growth, employment and other government objectives.

In 1999, the DST set up an Innovation Fund. It invests in late-stage R&D, intellectual property protection and the commercialization of novel technologies. Among the selection criteria, applicants are expected to form a consortium and to propose a programme for diffusing their new technology to small, medium-sized and micro-enterprises. From 2010 onwards, applications for funding will be administered by the newly created Technology Innovation Agency.

Among other measures to foster university–industry linkages, science councils themselves are now entitled to engage in high-tech spin-offs, either via their own R&D or via the commercialization of research results acquired from universities. The Department of Trade has also introduced the Technology for Human Resources in Industry Programme. Administered by the National Research Foundation, it matches the funding provided by university–industry research projects (OECD, 1999).

In 2008, South Africa exported most of its high technology to Germany, followed by France, Nigeria and Zambia. Most of its high-tech imports came from China, followed by the USA, Germany and Sweden (NACI, 2009).

Internet remains unaffordable for many South Africans, a factor which hampers the development of a knowledge economy. Just 8.2% of the population had access to Internet in 2007. In a speech before Parliament in April 2010, the Minister of Communications stated that 'for the past five years, the cost of communicating and doing business in South Africa has been impeded by exorbitant charges.' He said that 'consultation towards developing a comprehensive ICT policy framework has begun'. He also announced that the Department of Communications had developed an ICT Small and Medium Enterprise Strategy for the establishment of ICT business incubation centres in the Limpopo, Mpumalanga and KwaZulu provinces (Minister of Communications, 2010).

South Africa is active in pan-African collaboration. It chairs the Southern African Development Community (SADC) S&T group, which recently drafted a 10-year plan for the SADC. South Africa also supports three NEPAD flagship projects: the African Institute for Mathematical Sciences, the African Laser Centre and the Southern African Network for Biosciences. South Africa also participates in the NEPAD/Southern African Regional Universities Association roundtable discussions on implementation of the CPA and on engineering capacity-building for manufacturing. It has also offered to host the African Observatory of Science, Technology and Innovation (*see page* 299).

Uganda

Manufacturing, construction and mining are Uganda's main industries. The industrial sector accounts for about 25% of GDP and is estimated to have grown by 7.0% in 2007, up from 6.4% a year earlier. The discovery of commercially viable oil deposits has prompted hopes that Uganda will soon become a net oil exporter.

It has been argued that it is not the level of innovation of a country that is paramount but rather its ability to adopt, adapt and absorb technologies. However, many industries in Uganda are operating below capacity because 1) they have imported obsolete technology or for lack of regular maintenance of machinery, 2) some technologies are unsuited to local conditions or even 3) because some technologies have been imported without the technical know-how to use them, rendering them useless – especially when they break down. A further bottleneck stems from the fact that a number of bodies mandated to oversee technology transfer, assessment and forecasting have not been given the means to carry out their mission. These include the Uganda Investment Authority, the Uganda Registration Services Bureau, the Uganda Industrial Research Institute and the Uganda National Council for Science and Technology.

The National Industrialization Policy of 2008 aims to create a business-friendly environment for private sector-led, environmentally sustainable industrialization to help industries improve their productivity and the quality of their products through innovation. It contains provisions for developing domestic resource-based industries such as the petroleum, cement, fertilizer and agro-processing industries (leather goods, dairy products, garments, etc.), as well as such knowledge-based industries as ICTs, call centres and pharmaceuticals. Strategies include encouraging foreign direct investment in industry and industry-related services, the creation of a framework to support public–private partnerships for the production of higher value-added goods and services for domestic consumption and export, a wider tax base and greater integration with agriculture to produce value-added niche products.

In 2008 the Atomic Energy Act established the Atomic Energy Council. The act also provided a framework for the promotion and development of nuclear energy for use in power generation and other peaceful purposes.

Uganda's Information and Communication Technology Policy dates back to 2003. Although Internet access has since grown to 2.5% (2006), Internet infrastructure remains largely confined to the cities, with rural locations depending primarily on VSAT applications. Phase One of the National Backbone Infrastructure (NBI) initiative ended in 2008 after covering Kampala with 900 km of high-capacity fibre optic cables. Phase Two covered an additional 1 500 km in 2009. As a result, the core telecommunications infrastructure network in and around Kampala is relatively well developed, with some fibre optic infrastructure and microwave links. New ICT enterprises and training facilities have proliferated in the form of handset sellers and airtime vendors that include Midcom and Simba Telecom. ICT-related courses like telecommunications engineering are also now being offered at universities that include the Makerere University IT Centre and the ICT incubation park of the Uganda Investment Authority.

Although GERD remains low in Uganda at around 0.3–0.4% of GDP, all of government expenditure on R&D is used for civil purposes, unlike many other countries where it also encompasses defence spending (UNCST, 2007; 2009).

In Uganda, there is little that would qualify as R&D according to the strict definition in the *Frascati Manual* but the government is investing in a wide range of R&D-based programmes. These include programmes to support R&D performed in the higher education sector, with funding from the Millennium Science Initiative and the Swedish International Development Agency. The government also funds R&D programmes executed by government departments and agencies which include the Uganda Industrial Research Institute, the National Agricultural Research Organisation and the Joint Clinical Research Centre.

The government is also funding projects administered by the National Council for Science and Technology and Makerere University to help businesses develop R&D. The 2010–2011 budget announced in June 2010 brings a breath of fresh air to the university. It foresees an extra US$ 2.2 million for Makerere University and US$ 1.8 million to nurture a venture capital fund for start-up companies launched by university graduates. Ugandan scientists are also to receive a 30% rise in salary, the Uganda Industrial Research Institute an extra US$ 540 000 and Enterprise Uganda, a fund supporting entrepreneurship, a further US$ 450 000 (Nordling, 2010c).

In 2006, Uganda received a US$ 25 million loan from the World Bank to support S&T within the country, including the creation of centres of scientific excellence that will serve not only Uganda but the entire region. The grant was given, in part, because of Uganda's efforts to build its own S&T capacities, particularly in the fields of agricultural science and public health, including via the Uganda National Health Research Organization Act (2006).

The National Agricultural Research Policy was released in 2003 in line with the principles of the *Plan for Modernization of Agriculture*, in order to guide the generation and dissemination of research and improved technologies for agricultural development and promote the uptake thereof. The policy includes guidelines for the formulation and prioritization of agricultural research programmes. Priority areas for R&D are:

- technology development and multiplication, including the importation, adaptation and adoption of high-yielding disease- and pest-resistant planting and storing materials;
- socio-economic research, including participatory needs assessment, technology adoption and impact studies, policy research and analysis, cost-benefit studies and gender-responsive technologies;
- research on agriculture-related aspects of poverty and food security;
- application of information technologies in developing decision support systems, such as crop modelling;
- farm power and post-harvest technologies, including animal traction, solar and wind energy and biogas;
- storage and preservation of perishable commodities and agro-processing;
- land and water resources management, including soil fertility, land degradation, production systems (for crop, livestock, aquaculture, agro-forestry), water harvesting techniques and irrigation;
- sustainable natural resource utilization, including capture fisheries, biodiversity conservation and environmental-friendly technologies.
- integration of indigenous knowledge into modern and improved technologies, including disease and pest control, food preservation and the improvement of food palatability.

In 2008, Uganda's cabinet approved the country's first National Biotechnology and Biosafety Policy. The policy provides objectives and guidelines for the promotion and regulation of biotechnology use in the country (Box 8).

The National Council for Science and Technology submitted a comprehensive national STI policy to the Cabinet for approval and implementation in July 2006. The broad objectives of this policy are to:

- increase public awareness and appreciation of STI;
- increase investment in STI;
- support R&D;
- strengthen the national system for technology transfer and intellectual property management;
- improve the information management system;
- build and maintain STI human capital and infrastructure;
- strengthen systems for ensuring safety, ethics and high standards in STI;
- strengthen the framework for STI co-ordination.

The national STI policy came a year after the government introduced measures to improve scientific literacy and attract more young people to scientific careers. Under the Science Education Policy adopted in 2005, classes in biology, chemistry and physics have become compulsory for all secondary school pupils. First-year university students are also obliged to take some science courses towards their degree. The policy allocates nearly three-quarters of government scholarships to students studying towards a science degree at university and other institutions of tertiary education.

CONCLUSION

While it appears that the majority of African leaders are convinced that only through science-driven development can their nations overcome poverty and achieve the Millennium Development Goals, there is an urgent need for single-minded political leadership to translate this conviction into an articulated plan of action and for a strong government commitment to implement it. There are seven levels of action that require the attention of governments:

Firstly, it is essential that a national science policy based on the technological and industrial needs of society be appropriately designed in collaboration with the local scientific leadership. For a country to have a clear and effective science policy, it is imperative that an efficient science policy organ be formed involving knowledgeable and capable science managers and advisors with sufficient responsibility and power to enable it to design and execute the national science plan and co-ordinate all the country's S&T activities. The number of African countries with science policy organs has, fortunately, substantially increased in recent years, particularly at the ministerial level. There are currently over 40 ministries responsible for national S&T policies in the region. Nevertheless, a number of critical problems have to be resolved before these bodies can render the services expected of them. These problems are largely caused by a shortage of funds and inefficiency in the management and organization of S&T.

Secondly, it is essential that the science policy be fully integrated into the nation's development plan. This will ensure that the S&T knowledge generated by various research institutions is linked to the country's socio-economic and industrial needs. Furthermore, ensuring a close relationship between the national development plan and the national S&T policy will expand industrial involvement and that of the productive sectors in R&D, on the one hand, and promote mission-oriented R&D in support of economic sectors, on the other. This is well-illustrated by the case of the Republic of Korea where concerted action by the government and private sector has helped the country to achieve remarkable progress in S&T and industrial development (*see page* 415).

Thirdly, the government must ensure that adequate, stable funding is provided for the implementation of the national S&T policy. As indicated earlier, without a firm commitment by the majority of African governments to raising the level of R&D funding from its current level of less than 0.3% of GDP to at least 1%, no science policy will be effective in generating and sustaining endogenous research. The average proportion of GDP allocated to R&D in Africa is about one-tenth the proportion in industrialized countries. This is in stark contrast to the large percentage of GDP spent on the military.

Fourthly, to counteract brain drain and ensure a critical mass of highly qualified experts in S&T, a number of world-class research and training institutions in critical areas such as food security, energy supply, tropical diseases, soil erosion, water quality, deforestation and desertification must be established and sustained on the continent. In addition, African states and donor organizations need to act collectively to establish high-level research and training centres in key areas of frontier science and technology, such as molecular biology, biotechnology, informatics, nanotechnology and new materials. The African Academy of Science, which groups eminent scientists from all over Africa and has facilitated the establishment of a Network of Academies of Science on the continent, can play a key role in developing regional programmes in S&T. Both the Academy of Science and the network deserve strong support from African governments.

Fifthly, every African country should strive to produce at least 1 000 scientists per million population by 2025. To facilitate this trend, African governments and donor organizations should fund a major scholarship programme to enable African students to pursue postgraduate education at high-level scientific institutions on the continent and in other scientifically advanced developing countries. Such a programme could be implemented in collaboration with the Academy of Sciences for the Developing World. Special attention should be paid to the discovery and development of talent. Special programmes, such as the Olympiads aimed at identifying students with exceptional scientific abilities, should be supported at the national, sub-regional and regional levels. Gifted students selected through these programmes should be nurtured in an environment conducive to accelerating the development of their talent. This can be achieved through the establishment of national or regional elite schools and colleges for gifted students, as has been done in Central Asia (*see page* 240), or through the design of intensive, challenging additional school and university courses in basic sciences and mathematics.

Sixthly, there is an urgent need to restructure the systems of secondary and higher education to make science more interesting and attractive to the young. This means devising a more hands-on approach to scientific study in the classroom, emphasizing learning by doing rather than the rote memorization that has historically characterised scientific learning, especially in biology. *La main à la pâte* initiative launched by the French Academy of Sciences a few years ago has become a much emulated strategy for educational reform in science.

Last but not least, African countries must support programmes to increase scientific literacy among both children and adults. As science gains prominence among African countries, it is important to create and support institutions for lifelong learning that enable people to understand what science-based development means for them and the role that science can play in poverty alleviation and sustainable growth. Of the 2 400 science centres and science museums worldwide, just 23 are in Africa, where they are concentrated in five countries: Egypt, Tunisia, Botswana, Mauritius and, most notably, South Africa, which hosts 17 such centres. There is an urgent need to establish at least one science centre or museum in every African country.

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African Peer Review Mechanism: www.aprm.org.za

African Ministerial Council on Science and Technology: www.nepadst.org

African Regional Intellectual Property Organization: www.aripo.org

African Technology Policy Studies Network (Kenya): www.atpsnet.org

Africa's Science and Technology Consolidated Plan of Action: www.nepadst.org

Council for Scientific and Industrial Research (Ghana): www.csir.org.gh

Innovation Fund (South Africa): www.innovationfund.ac.za

National Advisory Council on Innovation (South Africa): www.naci.org.za

National Biotechnology Development Agency (Nigeria): www.nabda.gov.ng

Nigeria Vision 20: 2020. See National Planning Commission: www.npc.gov.ng

Organisation africaine de la protection intellectuelle: www.oapi.wipo.net

Parliamentary Monitoring Group (South Africa): www.pmg.org.za

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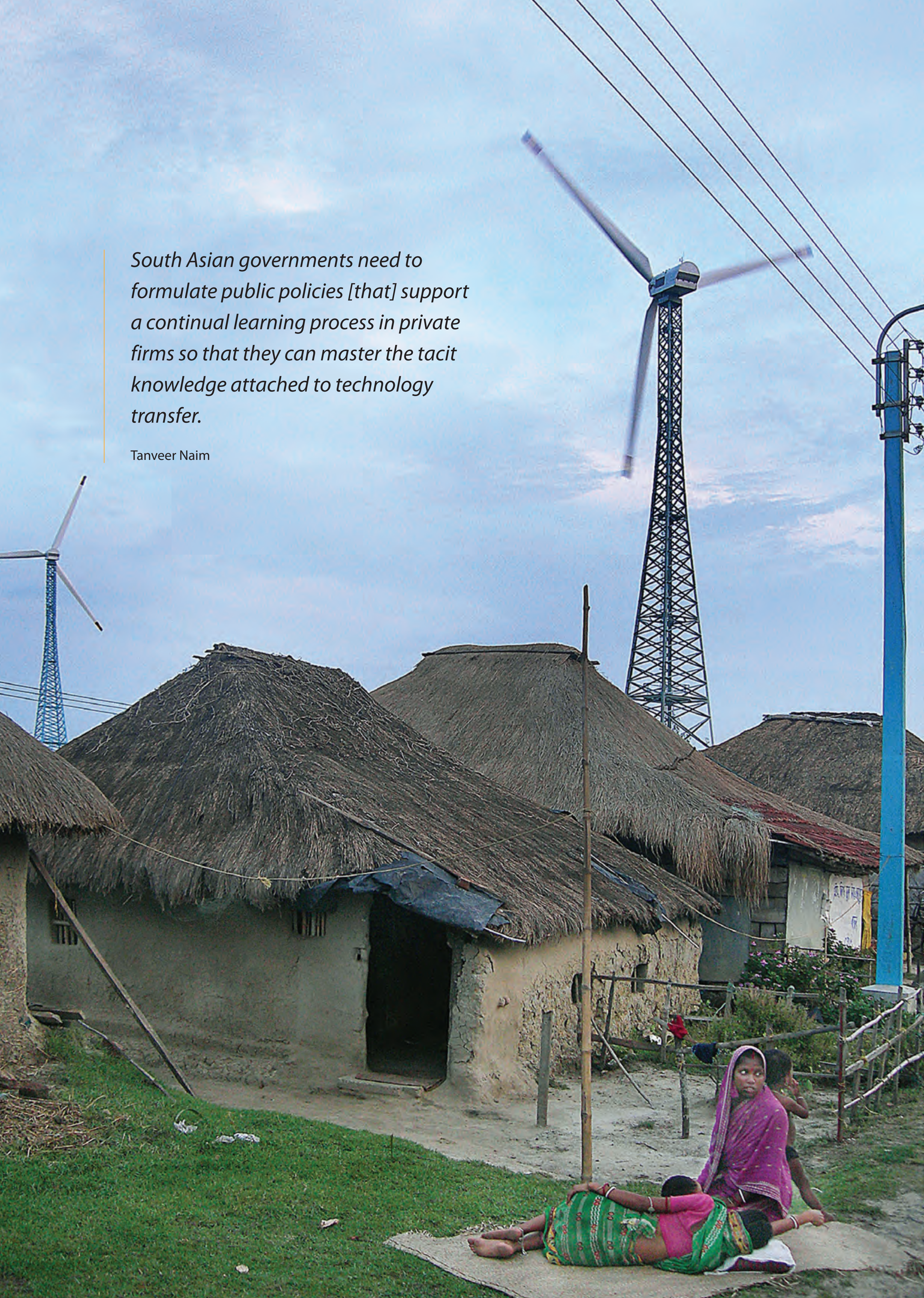
Former researcher and Director-General (1981–1986) of the Institute of Food Technology in Senegal and Executive Director (1997–2009) of the African Regional Centre for Technology, Dr Kane has chaired the Commission of Relations with Partners of the *Académie des sciences et techniques* of Senegal since retiring in October 2009.

He has worked extensively on issues related to technological Innovation and the ties between research and socio-economic development. He has also advised several African countries on the elaboration of their STI policies, including the Central African Republic, Mali and Senegal.

South Asian governments need to formulate public policies [that] support a continual learning process in private firms so that they can master the tacit knowledge attached to technology transfer.

Tanveer Naim



15 · South Asia

Tanveer Naim

INTRODUCTION

South Asia's average economic growth of 6–7% in the past decade compares poorly with the economic growth of the countries of East Asia during the same time period. A small country like Singapore, with a population of 5 million, earns ten times the export income (US$ 391 billion) of Pakistan and Bangladesh (US$ 33 billion) with their combined population of 326 million in 2008. South Asian countries continue to suffer from low human development, gender discrimination and social inequalities. Historical, geographical and demographic factors have partly contributed to this disparity but the fact remains that the massive income and productivity gap between South Asian countries and Singapore, the Republic of Korea or other developed economies can primarily be attributed to the lack of technological progress in these countries.

The South Asian countries discussed in the present chapter[1] are also characterized by political instability, regional conflicts, civil war and terrorism, not to mention natural disasters. In Pakistan, the continuing conflict in the northern regions of Swat and Waziristan has resulted in the destruction of infrastructure and a large number of displaced people. The army action to combat terrorism continues at the time of writing this report in 2010. The country also suffered flooding in 2010 which left about 25 million homeless and an earthquake in 2005 which killed over 70 000. India, the Maldives and Sri Lanka were all hit by a tsunami in 2004. Nepal's protracted civil war ended in 2008 with the country officially abandoning the monarchy and the Maoists giving up armed resistance before going on to win the elections. Afghanistan is still at war but Sri Lanka's three decades of civil war ended in 2009 with hope for future economic growth.

The current global economic recession has inevitably slowed growth rates and foreign capital inflows, resulting in an increase in the number of people living below the poverty line in South Asia.[2] The economic slowdown is more visible in Pakistan than elsewhere in the region owing to the increasing incidence of terrorism, political instability, energy shortages and an ongoing army operation that consumes more than half of Pakistan's annual development budget. Pakistan's GDP growth of 6.8% in 2007 declined to 2.7% in 2009. The economies of Sri Lanka, Bangladesh and Nepal, which had also shown signs of fatigue in 2008, have bounced back in the last quarter of 2009, showing relative resilience. As for Bhutan, its economy was not affected due to its weak integration in the global economy.

Among competing priorities, the governments of these countries are compelled to divert a large amount of resources towards addressing rehabilitation, meeting increased military expenditure, immediate infrastructure needs and security issues. Furthermore, debt repayments also subtract a substantial amount from national incomes. Within this resource-constrained environment, the region faces enormous challenges in achieving progress towards the Millennium Development Goals (Annex II) and simultaneously addressing the opportunities and risks of globalization, technological change and economic growth. According to Mahroum (2008), the current global recession can be turned into an opportunity if there is greater scientific collaboration both within the region and on a global scale.

The scarcity of investment capital in South Asian countries should not be an excuse, however, for budget cuts in human development and scientific research. It is a demonstrated fact that S&T capabilities are essential for meeting the challenges of development. S&T can provide solutions for eliminating poverty, hunger and disease, for combating natural disasters and preserving the environment. The wide technology and innovation capability gap of the South Asian countries will widen further if timely action is not taken to:

- increase investment in human development;
- develop infrastructure for scientific research and information technology (IT);
- introduce incentives to build the absorptive capacity of firms through contract research;
- promote entrepreneurship.

The integration of public institutions and private enterprises locally and within global knowledge networks can help reduce the knowledge and innovation gap in these countries. Policies and strategies need to be designed collectively to address common regional problems such as lagging social development, environmental degradation and infectious diseases, as well as to improve economic competitiveness in general.

1. Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan and Sri Lanka. Iran is discussed in Chapter 16 and India in Chapter 17.

2. Defined as living on less than US$ 2 a day

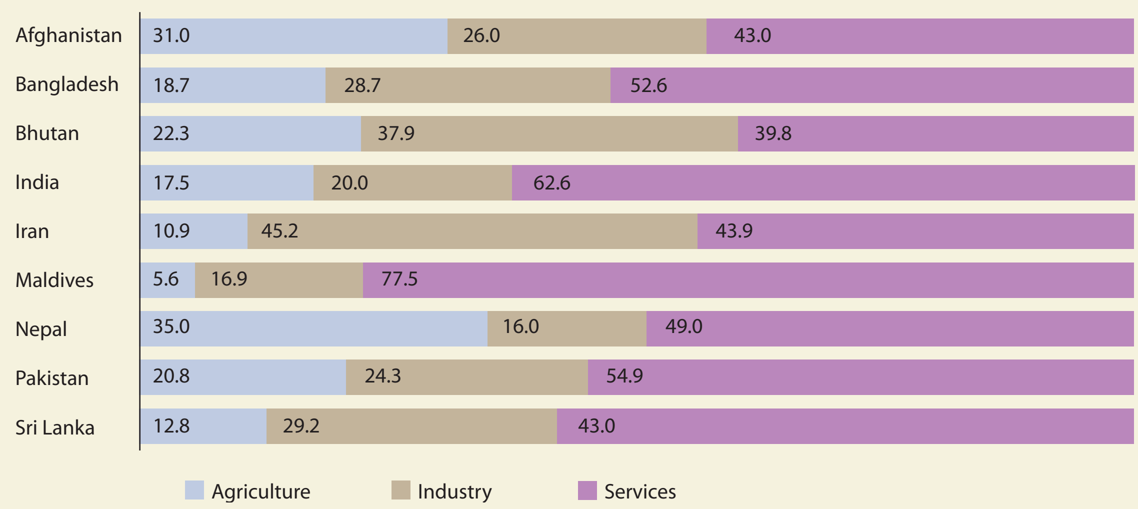
A village in West Bengal

Photo: UNESCO/Abhijit Dey, prize-winner in UNESCO's Changing Face of the Earth Contest in 2008

STRUCTURE OF SOUTH ASIAN ECONOMIES

The structure of South Asian economies and their relative share of GDP are shown in Figure 1. The share of agriculture ranges from a high of 35% in Nepal to a low of 6% in the Maldives. Despite a continual decline in the share of agriculture in GDP, almost 70% of people in the region remain dependent on agriculture for their livelihoods. Furthermore, many of them work in the informal services sector, which demands little knowledge input. The knowledge-intensive sectors are relatively small, as innovation in both the formal and informal sectors remains concentrated within a small segment of the economy.

Figure 1: Composition of GDP in South Asia by economic sector, 2009



Source: estimates from Central Intelligence Agency's World Factbook, June 2010: www.cia.gov

Table 1: Socio-economic indicators for South Asia, 2000 and 2008

Country	Population (millions)		GDP (US$ billions)		GDP per capita (current US$)		Merchandise exports (US$ billions)		High-tech exports (% of manufactured exports)		FDI, net inflows, balance of payments (current US$ millions)	
	2000	2008	2000	2008	2000	2008	2000	2008	2000	2005	2000	2008
Afghanistan	23.6	29.0	2.46^{+1}	10.62	102^{+1}	366	0.14	0.68	–	–	242^{+6}	300
Bangladesh	140.8	160.0	47.10	79.55	335	497	6.39	15.37	0.2	0.8^{+1}	280	973
Bhutan	0.6	0.7	0.43	1.28	762	1 869	0.10	0.58	4.1^{+5}	0.1	-0.1	30
India	1 015.9	1 140.0	460.18	1 159.17	453	1 017	42.38	179.07	4.8	5.7	3 584	41 169
Iran	63.9	72.0	101.29	286.06	1 584	4 028	28.74	116.35	1.9	5.9^{+5}	3.2	1 492
Maldives	0.3	0.3	0.62	1.26	2 293	4 135	0.11	0.34	–	–	13	15
Nepal	24.4	28.8	5.49	12.61	225	438	0.80	1.10	0.03	0.12	-0.5	1.0
Pakistan	138.1	166.1	73.95	164.54	536	991	9.03	20.38	0.4	1.9	308	5 438
Sri Lanka	18.7	20.2	16.33	40.56	873	2 013	5.43	8.37	2.2^{+1}	1.8	173	752

-n/+n = data refer to *n* years before or after reference year

Note: Merchandise exports for Afghanistan do not include illicit exports or re-exports and for Nepal do not include unrecorded border trade with India.

Source: World Bank's World Development Indicators database, July 2010; Central Intelligence Agency's World Factbook, July 2010

South Asia contributes less than 2% of world exports, in comparison to 12% by East Asian countries. The composition of exports shows a small share of high-tech products of less than 6%, compared to an average of 34% for East Asia. The recent growth in exports has been mostly confined to manufactured primary goods, with the exception of India whose exports are increasingly driven by skill-intensive manufacturing and services (Table 1). Due to lack of co-operation within the region, South Asia has been unable to leverage its regional trade potential of an additional US$ 20 billion per annum.

The *Global Competitiveness Report* of the World Economic Forum has benchmarked the following stages in the economic development of a country: i), Factor-driven, ii) Transition, iii) Efficiency-driven, iv) Transition, and v) Innovation-driven. This classification is based on 12 pillars for which a number of indicators have been developed. These 12 pillars are: institutions; infrastructure; macro-economic stability; health and primary education; higher education and training; goods market efficiency; labour market efficiency; financial market sophistication, technological readiness, market size, business sophistication and innovation. Within this framework, the economies of all countries in South Asia, including India, are classified as Factor-driven (WEF, 2009). *(See Figure 1 on page* 185 *for a comparison with Southeast Europe.)*

R&D INPUT

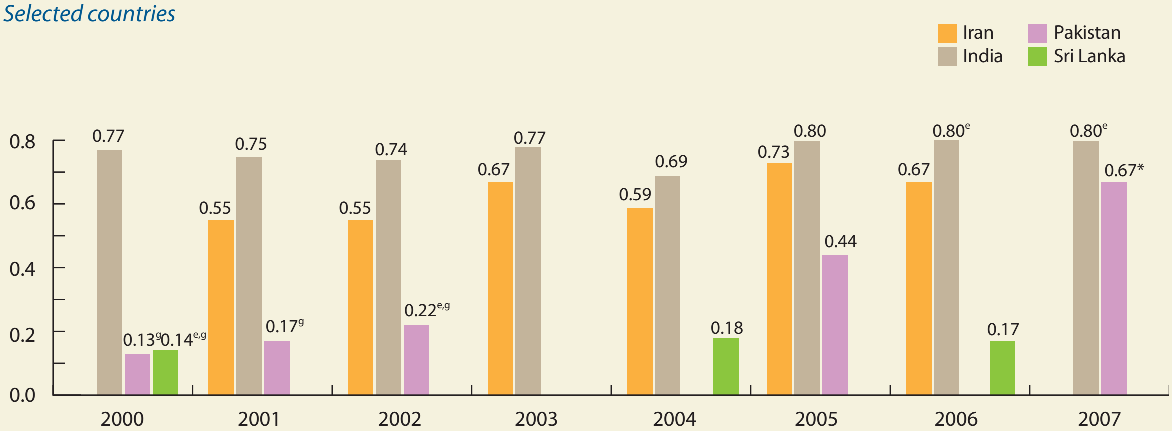
Trends in R&D expenditure

While global expenditure on research and development (R&D) has been rising consistently, two of the ten countries which contribute 78% of the total are now emerging economies: China (9.2%) and India (2.2%).[3] South Asia's contribution to global R&D expenditure is estimated at a pitiful 4% of the total and even this expenditure mostly comes from public development budgets and is utilized primarily to fund public universities and research bodies.

Within the South Asian region, Pakistan experienced the fastest growth in gross domestic expenditure on R&D (GERD) and funding allocation for IT and higher education during 2002–2008. President Musharraf's commitment resulted in unprecedented growth in the budgets of higher education and science and technology (S&T). Public R&D expenditure, which had fluctuated for several years between 0.2% and 0.4% of GDP, was boosted to nearly 0.7% of GDP in 2007, according to the UNESCO Institute for Statistics (Figure 2). Most of the R&D budget was spent on modernizing the dilapidated R&D

3. The others are the USA (32.4%), Japan (13.0%), Germany (6.1%), France (3.8%), Republic of Korea (3.7%), UK (3.3%), Canada (2.1%) and Russia (2.1%), according to the UNESCO Institute for Statistics.

Figure 2: GERD/GDP ratio in South Asia, 2000–2007 (%)
Selected countries



* Civil R&D only, for civil and military R&D combined, the GERD/GDP ratio for Pakistan is 0.9%. *Source:* author

e = estimation *g* = underestimated or partial data

Note: For Bangladesh, there are no recent data. Its GERD/GDP ratio was 0.01% in 1995.

Source: for GERD: UNESCO Institute for Statistics, July 2010; for GDP: World Bank, World Development Indicators, May 2010

Box 1: Social research and the Pakistan Atomic Energy Commission

The Pakistan Atomic Energy Commission (PAEC) in Islamabad manages several research laboratories in different parts of Pakistan. Almost 50% of the budget allocated to PAEC is spent on social research in the fields of nuclear energy, renewable energy, health, agriculture and environment. In the health sector, PAEC has established 14 centres in various parts of the country where patients requiring radiation-related treatment receive medical care. PAEC also has four agriculture and biotechnology centres which have discovered several new varieties of wheat and cotton.

The efforts of the PAEC Chair, Dr Ishfaq Ahmad (1991–2001), led to the establishment of the Global Change Impact Studies Centre in 2002. The centre conducts research on the impact of global climate change on Pakistan in such areas as water resources and agriculture, environment, biodiversity, health and energy. It is also responsible for identifying appropriate adaptation measures. In January 2005, it was designated the secretariat for the newly established Prime Minister's Committee on Climate Change grouping relevant ministers. The centre has established collaboration with several research organizations both in Pakistan and in Bangladesh, India, Nepal and Sri Lanka, as well as beyond the immediate region.

Source: author; www.gcisc.org.pk/

infrastructure in universities and promoting information and communication technologies (ICTs), biotechnology and engineering research. Defence R&D consumes 60% of public expenditure on R&D in Pakistan. Unlike the USA where the findings of defence R&D is widely diffused for the benefit of economic and social institutions, most of this research remains classified in South Asian countries. An exception is the Pakistan Atomic Energy Commission, which has made remarkable contributions to agriculture and health research (Box 1).

The private sector use of public R&D expenditure is low in South Asia in general and particularly low in the countries under discussion: Afghanistan, Bangladesh, Bhutan, the Maldives, Nepal, Pakistan and Sri Lanka. This is due to the fact that these countries have followed a linear S&T policy model. The linear model encouraged research in public institutions, on the assumption that local industry would use this knowledge. There have been no incentives for university–industry collaboration or for the promotion of contract research by industry, even though the promotion of R&D in private enterprises is vital for innovation and consequently for economic development.

South Asian countries should foster public policies that support a continuous learning process in firms. At the initial stages of the development of the Republic of Korea and Japan, private companies were encouraged by government subsidies in the form of tax incentives and subsidized bank loans to import capital technology for manufacturing. Firms were encouraged to reverse-engineer imported technology and to promote learning-by-doing practices. In the second phase, firms were motivated to develop their own design capabilities and a learning culture to enable them to absorb and adapt imported technology. As firms advanced in their learning curves, they realized the importance of in-house R&D and continual upgrading of the skills of their technical, management and marketing personnel if they were to survive in increasingly competitive global markets. The rise in private R&D expenditure in these countries has accompanied a shift in the composition of exports, from low value-added agriculture-based products to value-added manufacturing in agriculture, automobiles, electrical and electronic goods.

The growing role of transnational companies in R&D

According to UNCTAD's *Global Investment Report* (2005), transnational companies are major contributors to global GERD. Over 80% of the 700 biggest-spending firms on R&D come from just five countries: the USA, Japan, Germany, UK and France. Since R&D is a capital-intensive activity, the number of transnational companies expanding their R&D activities in developing countries is growing. These large firms are seeking low-cost, highly skilled R&D personnel, on the one hand, and access to centres of excellence in developing countries, on the other. The potential benefits for the host country depend on the quality of its infrastructure and the availability of highly skilled R&D personnel.

Private R&D expenditure in India represents 20% of total expenditure, according to the UNESCO Institute for Statistics, and is rising, due to the fact that a large number of multinationals have recently moved their R&D activities to India. Large firms in India working in the pharmaceutical, steel and automobile sectors are investing in R&D. Among local R&D investors, there are Ranbaxy and Dr Reddy's Labs in pharmaceuticals and Tata Motors in the automobile sector (*see page* 363). These companies rank among the world's top 1 250 companies in terms of R&D investment.

In Pakistan and Iran, the pharmaceutical and automobile sectors are showing significant growth but no reliable statistics are available on private R&D expenditure in these countries.

Table 2: Gross enrollment ratio in South Asia for secondary and tertiary education, 2007 (%)
Selected countries

	Secondary (2007)			Tertiary (2007)		
	MF	M	F	MF	M	F
Afghanistan	29	41	15	1^{-3}	2^{-3}	1^{-3}
Bangladesh	44	43	45	7	9	5
Bhutan	56^{+1}	58^{+1}	54^{+1}	7^{+1}	8^{+1}	5^{+1}
India	57	61	52	13	16	11
Iran	80^{+1}	80^{+1}	79^{+1}	36^{+1}	34^{+1}	39^{+1}
Maldives	$84^{**,-1}$	$81^{**,-1}$	$86^{**,-1}$	–	–	–
Nepal	$43^{**,-1}$	$46^{**,-1}$	$41^{**,-1}$	6^{-3}	8^{-3}	3^{-3}
Pakistan	33^{+1}	37^{+1}	28^{+1}	$5^{*,+1}$	$6^{*,+1}$	$5^{*,+1}$
Sri Lanka	87^{**-3}	86^{**-3}	88^{**-3}	–	–	–

-n/+n = data refer to *n* years before or after reference year
* national estimation
** estimation by UNESCO Institute for Statistics

Source: UNESCO (2009) *Global Education Digest 2009: Comparing Education Statistics across the World;* for Sri Lanka: UNESCO (2008) *Global Education Digest 2008: Comparing Education Statistics across the World*

Trends in human resources

General trends in education

South Asia has the world's highest number of adult (392.7 million) and young (67.1 million) illiterates, 63% of whom are female. The majority of the illiterate population lives in Afghanistan, Bangladesh, India and Pakistan. Only half of the region's secondary school age group of 242 million is currently enrolled in school. Secondary enrollment ratios in the region range from 87% for Sri Lanka to just 29% for Afghanistan, with female secondary enrollment across the region being significantly lower than for males in some countries (Table 2).

Only Iran, the Maldives and Sri Lanka have achieved significant improvements in literacy in recent years. Sri Lanka and the Maldives can now boast of universal primary literacy. Iran has also made big strides in improving adult literacy rates and narrowing the gender gap (*see page* 350).

At 3.4% of GDP on average, South Asia's expenditure on education remains lower than that of East Asian and Caribbean countries, which devote 4–9% of their much larger GDP to education. Table 3 shows a modest increase in

Table 3: Priorities for public spending in South Asia, 1990 and 2008

Countries	Public expenditure on education as % of GDP		Military expenditure as % of GDP		Total debt service as % of GDP		Present value of external debt as % of GNI	
	1990	2008	1990	2008	1990	2008	2004	2008
Afghanistan	–	–	–	2.2	–	0.1	–	4
Bangladesh	1.6	2.4	1.1	1.1	2.4	1.2	26	20
Bhutan	3.3^{-1}	5.1	–	–	1.8	6.3	100	55
India	3.7	3.2^{-2}	3.2	2.5	2.6	2.7	18	18
Iran	4.1	4.8	2.1	2.9^{-1}	0.6	1.0^{-1}	9	4
Maldives	3.8	8.1	–	–	4.6	5.4	42	83
Nepal	2.3	3.8	1.1	1.5	1.9	1.3	37	21
Pakistan	2.6	2.9	6.8	3.3	4.6	1.8	35	24
Sri Lanka	2.7	–	2.1	3.0	4.8	3.1	50	35

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

Source: UNESCO Institute for Statistics, July 2010, for public expenditure on education: World Bank, World Development Indicators, July 2010 expenditure on education since 1990 in all but India and a corresponding decrease in military expenditure in all but Iran, Nepal and Sri Lanka. Pakistan's expenditure on education has remained static for several years, partly due to relatively high military expenditure attributed to regional tensions, a prolonged Afghan war and expanding terrorism, and a higher ratio of debt repayment to GDP than its neighbours. Expenditure on higher education in Pakistan did, however, witness unprecedented growth of almost 2 000% between 2002 and 2008.

Researchers in South Asia

In the contemporary global knowledge economy, higher education is viewed as a critical economic resource. Universities are expected both to produce a flexible labour force with multidisciplinary skills and a quest for lifelong learning and play an entrepreneurial role by transferring and applying the knowledge generated to support industrial processes and increase the endogenous competitive advantage. In most South Asian countries, the systems or institutions which transfer knowledge to economic advantage are either non-existent or underdeveloped. Consequently, existing knowledge, be it tacit or codified, is seldom integrated in the development system. Although the region trains a large number of scientists and engineers – India has the third-largest body of scientists in the world – all countries face an extreme shortage of highly skilled university teachers and researchers, managers and other skilled personnel. Thomson Reuters' Science Citation Index (SCI) provides information on 5 000 highly cited researchers in 22 scientific fields the world over. These scientists are selected on the basis of maximum received citations within a prescribed period. The database includes just 13 researchers from South Asia. Among these, 11 come from India and just one each from Iran and Pakistan.

Table 4: Researchers and S&T enrollment in South Asia, 2007
Other countries are given for comparison

Countries	Researchers in R&D per million population 2007 (in FTE)	Science and engineering enrollment ratio (%) 2007
Bangladesh	$46^{-10,\,HC}$	13.81
India	$137^{-2,e}$	–
Iran	706^{-1}	41.01^{+1}
Nepal	$59^{-5,e}$	–
Pakistan	152^{-1}	10.21^{+1}
Sri Lanka	93	–
Finland	$7\,707^{+1}$	35.86^{+1}
Republic of Korea	4 627	35.99^{+1}
USA	$4\,663^{e}$	16.61^{+1}

-n/+n = data refer to *n* years before or after reference year
e = estimation; HC = headcount instead of full-time equivalent

Source: for enrollment: UNESCO Institute for Statistics, July 2010; for population: United Nations Department of Economic and Social Affairs (2009) *World Population Prospects: the 2008 Revision*

The number of researchers per million population in the region varies from 706 per million in Iran to just 46 per million in Bangladesh (Table 4). As concerns the number of researchers working in private enterprises, this information is unfortunately not documented for South Asian countries, despite being an important measure of innovation activity.

In sum, South Asian countries are faced with the dual challenge of widening access to higher education and ensuring it is of quality and relevance to their economy. An additional challenge will be to retain the talented scientists and engineers they train in an expanding global labour market for highly skilled personnel. A 2008 study by the UK Parliamentary Office cited data from the Organisation for Economic Co-operation and Development (OECD) indicating that, of the 59 million migrants living in OECD countries, 20 million were highly skilled. This migration is not only depriving South Asian countries of much-needed skills but is also a burden on their fragile economies. Since higher education receives generous subsidies from the state in most South Asian countries, brain drain means that the benefits of these subsidies go to the developed host countries. Data from the Pakistan Bureau of Emigration show that 2.82 skilled and semi-skilled workers emigrated between 1970 and 2000. This number soared to 4.50 million during 2000–2005. Of these, 88 572 were highly skilled. Bangladesh and Sri Lanka are experiencing a similar exodus. The Bangladesh Bureau of Migration, Employment and Training reports that 6.57 million skilled and semi-skilled workers left Bangladesh for employment abroad between 1976 and 2008, 4% of whom were highly qualified professionals. A 2006 survey by Sri Lanka's National Science Foundation found that the number of economically active scientists in Sri Lanka had decreased between 1996 and 2006 from 13 286 to 7 907.

In response to the growing demand for highly skilled personnel and the threat of persistent brain drain, South Asian countries have begun taking steps to reform their higher education systems, as we shall see in the country profiles beginning on page 386. In this regard, India and China can serve as models. Although both have suffered extensive brain drain in recent decades, they have successfully used their diaspora as a 'brain reserve' abroad to stimulate high-tech industries at home. Today, expatriates are even beginning to return, drawn by a booming economy and exciting professional opportunities.

R&D OUTPUT

Trends in scientific papers

South Asia contributes just 2.7% of research papers published in international journals abstracted from the database of Thomson Reuters' Web of Knowledge. Eight-year publication data show a rising trend in research publications from 2002 onwards for India, Iran and Pakistan which can be attributed to the substantial rise in public R&D expenditure in these countries (Table 5).

While the number of research papers contributed by a country is a quantitative indicator, the number of citations received by these papers is considered as reflecting the quality of research. In its bimonthly newsletter, Thomson ScienceWatch.com produces a listing of scientists, institutions and countries that have achieved the highest percentage increase in total citations in a given period. From December 2007 to February 2008, Iran and Pakistan consistently appeared in the list of countries ranked as 'rising stars' for achieving maximum citations of papers published in multiple fields.

According to Thomson Reuters' Web of Science database, almost 87% of research articles by Bangladeshi scientists came from just seven institutions, listed in descending order as: Bangladesh University of Engineering and Technology, University of Dhaka, International Centre for Diarrheal Diseases, Rajshahi University of Engineering and Technology, Bangladesh Agriculture University, Jahangirnagar University and the Chittagong University of Engineering and Technology. An a analysis of the research output of these universities reveals priority areas to be predominantly in the realms of agriculture and engineering.

Collaboration in scientific research

Scientific collaboration within and beyond national borders is considered vital for enhancing scientific capabilities through the pooling of the best scientific expertise and of funding. It also reduces wastage from duplication in a resource-constrained environment. Regional scientific collaboration may result not only in lower project costs for large projects of common interest but also in the sharing of technical risks. International scientific collaboration is growing and is considered a preferred method of building scientific capacity in developing countries.

One method of measuring collaboration is through mapping of co-authored scientific papers published from the institutions of South Asian countries. The Thomson Reuters database provides information on the percentage of co-authored research papers published by the scientists of South Asian countries in international journals. India, Iran

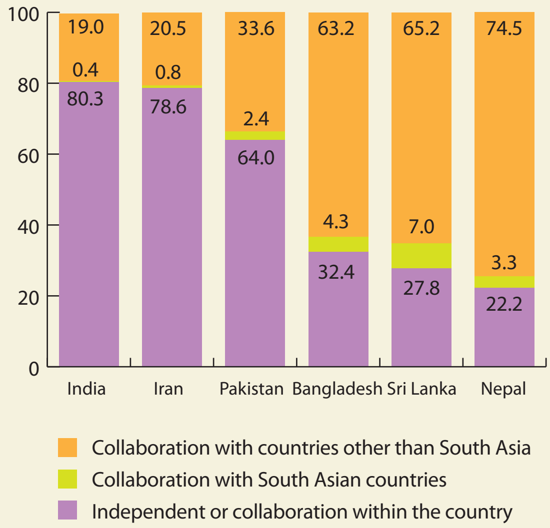
Table 5: Scientific publications in South Asia, 2000–2008

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Afghanistan	–	–	–	3	8	7	7	6	16
Bangladesh	335	377	385	430	446	474	554	614	729
Bhutan	3	2	7	5	11	8	22	5	6
India	16 650	17 635	18 911	20 772	22 375	24 422	27 418	32 041	36 261
Iran	1 296	1 571	2 102	2 869	3 534	4 610	6 000	8 770	10 894
Maldives	1	2	1	2	–	1	3	5	3
Nepal	103	113	117	134	148	148	196	193	223
Pakistan	553	535	703	808	885	1 104	1 525	2 303	2 994
Sri Lanka	158	159	185	256	226	266	265	305	400

Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

and Pakistan publish 20–30% of research articles with scientists abroad, mostly in Western countries (Figure 3). Only 3% of research articles are published in collaboration with scientists working in South Asia.

Figure 3: Scientific collaboration involving South Asian authors, 2007 (%)



Note: Data concern published articles and proceedings only from the Science Citation Index Expanded, Social Sciences Citation Index and Arts and Humanities Citation Index.

Source: Thomson Reuters Web of Science database

Table 6: Patent applications in South Asia, 2008 or most recent year

	Resident	Non-Resident
Afghanistan	–	0
Bangladesh	29^{-1}	270^{-1}
Bhutan	–	–
India	$5\,314^{-2}$	$23\,626^{-2}$
Iran	691^{-7}	–
Maldives	–	–
Nepal	3^{-13}	5^{-13}
Pakistan	91^{-2}	$1\,647^{-2}$
Sri lanka	201	264

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

Note: Counts are based on the patent filing date.

Source: WIPO Statistics database, December 2009

Patent applications from South Asia

Patent applications filed by public research organizations and local and foreign firms are an indication of the dynamism of innovation. Foreign firms undertaking innovation in a country protect their inventions through patents to block competitors and imitators, so as to exploit the right to market their innovation either locally or for export. For both India and Pakistan, patent applications from non-residents are much higher than those filed by residents (Table 6).

In Bangladesh, the recent growth in international publications has not been matched by greater patenting activity or by other efforts to commercialize research produced in public laboratories. University–industry collaboration appears to remain limited and there seems to be no concerted effort to integrate knowledge produced in public R&D organizations in the productive sector. A study commissioned by the United Nations Conference on Trade and Development (UNCTAD) to evaluate the impact of intellectual property rights (IPRs) on innovation in Bangladesh in textiles, agro-processing and generic drugs found that innovation capabilities were very low in all three sectors (Sampath, 2007). The study demonstrated that local firms did not consider technology transfer from the public sector to the private sector as being important for innovation. Rather, process innovations at the firm level were limited to imitation.

UNIVERSITY–INDUSTRY COLLABORATION

Innovation is an interactive process requiring dynamic networks between the users and producers of knowledge. Several studies have mentioned the huge potential for commercialization of the untapped scientific knowledge that exists in the public laboratories of South Asian countries, particularly those of India, Iran, Pakistan and Sri Lanka. In almost all the countries of the region, incentives for public sector laboratories to work with industry are either ineffective or missing altogether. The service structures of scientists and engineers need to become changed to motivate them either to seek careers in industry or be actively involved in solving problems of industry. Increasing the mobility of scientists via appropriate incentive measures is the best route for knowledge transfer from university to industry.

Box 2: The story of CASE and CARE

The Centre for Advanced Studies in Engineering (CASE) and its sister organization, the Centre for Advanced Research in Engineering (CARE), offer a model in Pakistan for university–industry partnerships.

CASE is a project of the Engineering Education Trust. It was developed by a devoted group of Pakistani and US qualified engineers as a self-financing school in Islamabad in 2001. The centre primarily studies chip design, control systems, computer networks, digital signal processing, lasers and optics, as well as various areas of engineering management. CASE graduates find employment in prestigious national and international institutions. The centre has 50 PhD students, the first of whom graduated in 2008.

CARE is located in the vicinity of its sister organization. CARE generates funding by providing services to industry in software design, digital hardware design, electronic design automation tools, systems design, verification and compliance testing. CARE has also provided services to national defence bodies. The organization recently (2007) won an R&D grant of US$180 million from the Pakistani army on a competitive basis for a military project.

The young founders of CASE and CARE were decorated by the Government of Pakistan with the Pride of Performance award in 2008.

Source: Interview by author

Science parks, industrial parks and technology incubators act as intermediary institutions to foster technology spin-offs from public research laboratories. South Asian countries are making efforts to establish these. There are 176 information technology parks operating in India. Iran has established 12 technology parks and 40 technology incubators. These have helped 3 500 students create 500 new start-up companies (Mansouri, 2006). Pakistan has 11 information technology parks and just two business incubators: one at the National University of Science and Technology and the other, privately operated, at the Fauji Foundation in Rawalpindi (see also Box 2).

Technology-based start-ups also require venture capital and funding by business angels. Public research institutes themselves need help in business planning and product marketing. In South Asia, however, both venture capital and business angels are in short supply.

INFORMATION INFRASTRUCTURE

Information and communication technologies (ICTs) are playing an increasingly important role in development. ICT's provide the means for bridging the knowledge gap between developed and developing countries. As enabling technologies, ICTs help stimulate innovation and increase economic productivity through e-governance, e-commerce and e-education. The availability and quality of ICT infrastructure is the determining factor in exploiting the full potential of these technologies. Figure 4 shows the relative Internet connectivity in South Asia. Iran has better Internet access than other countries in the region. Pakistan was a late starter in building ICT infrastructure; however, an investment-friendly ICT policy launched in 2001 has resulted in a rapid increase in Internet connectivity and access to mobile phone coverage, with 80 million users in 2009. Bangladesh has extremely low Internet access but this may change with the adoption of an ambitious Information and Communication Technology Policy in 2009 (*see page* 337).

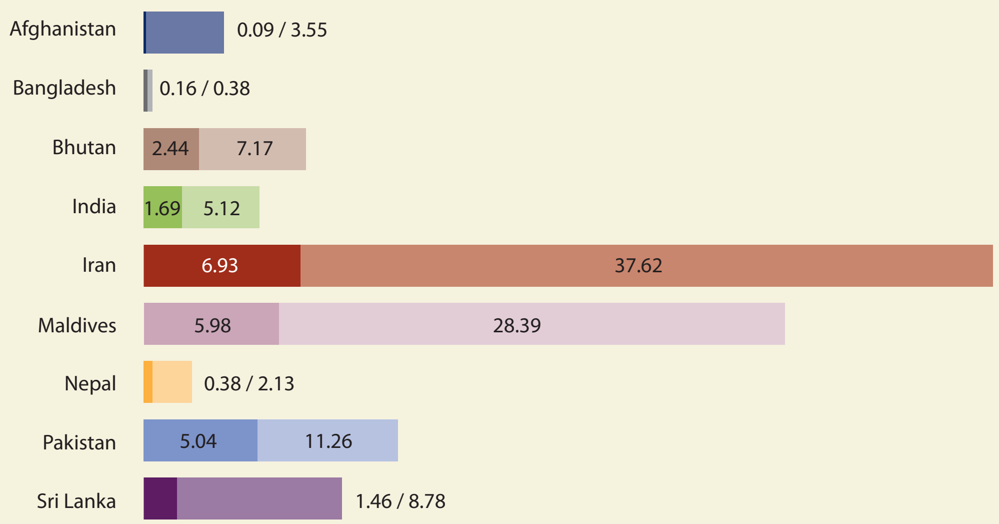
Broadband connectivity is still limited to a small number of people in South Asia. ICTs provide all countries with opportunities not only to maximize their own R&D input by connecting researchers within the country but also to tap into the international pool of knowledge and research. National research and education networks are now considered an essential part of R&D infrastructure (Box 3).

PROMOTING COLLABORATION FOR TECHNOLOGY DEVELOPMENT

Technology purchases through licensing

The global purchasing of technology through the payment of license fees (or royalties) is often used as a comparative indicator for measuring the inward flow of technology. In South Asia in 2007, the maximum amount of licensing fees for the purchase of foreign technology was paid by India (US$ 949 million), followed by Pakistan

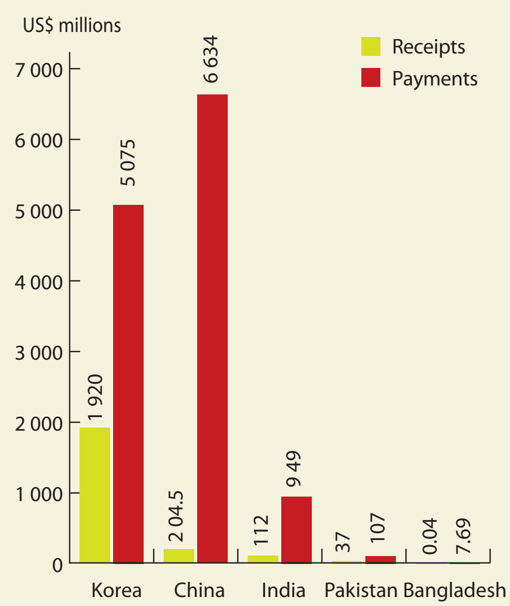
Figure 4: Internet users per 100 population in South Asia, 2003 and 2009



Source: International Telecommunications Union, World Telecommunications/ICT Indicators database, July 2010

(US$ 107 million). This is a pittance compared to the amount paid by China and the Republic of Korea in the same year. The licensing of foreign technology for the purpose of production or services by local firms needs to be combined with incentives for learning and innovation, which should result in license fees or royalties earned through technology exports. India and Pakistan both earned small amounts in license fees from the sales of their technologies in 2007, especially in comparison to the Republic of Korea (Figure 5).

Figure 5: Royalties and license fees in Asia, 2007
Selected countries



Source: World Bank
http//info.worldbank.org/etools/kam2/KAM_page3.asp

Foreign direct investment

Foreign direct investment (FDI) is not just a source of capital and employment creation. Successful FDI policy not only creates employment opportunities but also results in technology transfer and knowledge spillovers. FDI that benefits the local economy through forward and backward linkages can contribute to the transfer of knowledge and sustained economic growth. Vertical and horizontal effects can help local firms raise productivity as a result of improvements in human capital and industrial management skills, efficiency in production processes, technological capabilities and R&D. China, for example, has attracted FDI in knowledge-intensive, export-oriented manufacturing and has encouraged linkages between

Box 3: Two examples of e-networks for education and research

Pakistan Education and Research Network

Implemented in 2002, the Pakistan Education and Research Network (PERN) is connected with 60 public sector universities via a fibre-optic broadband network. A digital library service provides access to over 23 000 research journals and 45 000 graduate-level books for all universities free of charge.

PERN has integrated Pakistani scientists and researchers and encouraged national knowledge networks on 155 Mbps connectivity.

PERN2 was launched in 2008 with the increased bandwidth of 10 Gbps. It connects PERN with international research networks operating in East Asia, Europe and the USA.

Nepal Research and Education Network

The Nepal Research and Education Network (NREN) is a public–private initiative established in 2007 to check brain drain and develop research infrastructure. It is using ICTs to create a national network for advanced research and education that will also give researchers access to information and data around the world.

In 2008, NREN obtained a grant from the Information Society Innovation Fund in Asia for a project to develop the high-speed backbone for the Nepal Research and Education Network. This network is developing e-learning for higher education in villages and remote areas in the local language and creating an Intranet portal and telemedicine for health posts in villages.

NREN networks with its counterparts elsewhere in South Asia and beyond. Its activities are supported by the Network Start-up Resource Center at the University of Oregon in the USA and by Keio University in Japan, among others.

Source: Interview by author for PERN; for Nepal: www.nren.net.np

transnational companies and local universities. The productivity of firms operating in China's export zones is reported to be three times higher than that of firms operating on the mainland.

Within the Asian continent, South Asia remains an unattractive destination for FDI. In 2008, India received the highest amount (US$ 41.5 billion), partly due to the size of its economy but above all because of the relatively higher number of scientists and engineers trained in India than elsewhere. This amount may sound substantial but it pales in comparison with the US$ 187 billion China received in 2008. India's ICT and pharmaceutical sectors have attracted FDI in R&D services. Hundreds of foreign firms have established R&D units in India (*see page* 363). While it is too early to assess the spillover effect of these transnational corporations on R&D investment in India, the gains are already visible in terms of additional employment and the size of the diaspora returning home to seize employment opportunities with multinationals.

Pakistan's attractiveness for FDI improved between 2005 and 2006, with Pakistan climbing from 114th to 83rd place. Since 2005, Pakistan has also had the highest Inward FDI Performance Index[4] ranking in the region (Table 7). FDI declined in 2007–2008, however, not only due to the global economic recession but also on account of developments in domestic politics and security issues.

Table 7: Inward FDI Performance Index of South Asia, 2005–2007

Rank	Economy	Score	FDI inflows (US$ billions) 2008
83	Pakistan	1.12	5.44
106	India	0.63	41.55
113	Sri Lanka	0.54	0.75
121	Bangladesh	0.41	1.09
133	Iran	0.10	1.43
136	Nepal	0.01	0.03

Source: UNCTAD (2009) *World Investment Report 2009*

4. The Inward FDI Performance Index is based on FDI inflows. It represents a country's average score for eight variables: GDP per capita; real GDP growth; exports; number of telephone lines per 1000 population; commercial energy use per capita, R&D expenditure as a percentage of gross national income; students in tertiary education as a percentage of the total population and country risk.

COUNTRY PROFILES

Afghanistan

Higher education reforms

Afghanistan has begun the process of re-opening and reconstructing universities since the fall of the Taliban in 2001 but the overall capacities of these institutions are limited and do not meet the overwhelming demand for access from the increasing number of high-school graduates.

Higher education is one of the eight pillars of the Afghan National Development Strategy for 2008–2014. In December 2009, the Ministry of Higher Education launched the *National Higher Education Strategic Plan* for 2010–2014, after organizing a series of consultation workshops with Afghan universities earlier the same year with support from UNESCO and the World Bank. The *Plan* builds on an earlier framework for the reform of higher education developed by the Ministry of Higher Education with the support of UNESCO's International Institute for Educational Planning in 2004. This already covered a wide spectrum of reform, spanning the institutional structure of universities, questions of governance, recruitment and retention of staff and students, the relationship between teaching and research, management, finance and the procurement of equipment, land and textbooks.

The *National Higher Education Strategic Plan* for 2010–2014 outlines two broad programmes. Programme I seeks to educate and train skilled graduates to meet the country's socio-economic development needs. It includes various sub-programmes for developing infrastructure and for building human capacity in the higher education sector, including curriculum development and the participation of graduate students in regional and international research partnerships. The *Plan* affirms that research policy and practice should focus on S&T as a cornerstone of development. In 2010, UNESCO was supporting the Ministry of Higher Education in developing an S&T policy.

Programme II aspires to lead and manage a co-ordinated system of higher education comprising universities, institutes and community colleges. It focuses on governance and developing capacity both in the Ministry of Higher Education and universities. It also tackles the issues of access to university and the expansion and structure of the higher education system. It plans to redesign the national admissions examination, a task that has been entrusted to a committee set up for the purpose in early 2010. The national admissions system will be computerized to make it efficient and user-friendly. It will also be configured to ensure that applicants with optimum potential are admitted to university, taking into account national needs. Programme II will also establish a self-assessment process for universities and found an agency responsible for quality assurance and accreditation in Afghanistan.

The *Plan* will establish a national research and education network linking all universities and institutes in Afghanistan to the Ministry of Higher Education and the Internet, in order to allow data-sharing and provide access to a digital library.

Another challenge for the ministry will be the development and institutionalization of a Higher Education Management Information System (HEMIS) to ensure proper planning and monitoring of the *National Higher Education Strategic Plan* over the next five years.

Specific targets of the *Plan* to 2014 include:

- increasing the number of faculty members with master's degrees by 60% and faculty members with PhDs to at least 20%[5];
- establishing five comprehensive research universities;
- reaching a target of at least 30% female university students;
- increasing the number of students enrolled in universities from 62 000 at present to 110 000;
- establishing five community colleges with a total enrollment of at least 5 000 students, giving a total of 115 000 students and 800 additional staff.

Another important aspect of the *Plan* is its funding strategy for universities. The Ministry of Higher Education will continue to decentralize financial control to universities and other institutes, and to push for legislation allowing universities to raise and spend funds from non-government sources. The ministry will also facilitate fundraising from non-governmental sources for higher education and work to establish scholarships for poor students.

5. In 2008, 5.5% of the 2 526 faculty members at Afghan universities held PhDs, 30.1% a Master of Arts or MSc and 63.8% a Bachelor of Arts.

Bangladesh

Challenges for higher education

A higher level of investment in education in general and higher education in particular has shown tangible results in Bangladesh. The number of universities has expanded from just seven in the 1980s to over 80 today, with total enrollment in the tertiary sector of about 2 million students. There are deepening concerns, however, about the quality of graduate education.

The problem of poorly educated graduates from tertiary institutions in Bangladesh is attributed to the structure of tertiary education. Most tertiary enrollment in Bangladesh takes place in degree colleges and public and private universities. Degree colleges attract the lion's share of enrollment at the tertiary level. These colleges suffer, however, from poor infrastructure and a dearth of trained teachers. Public universities are themselves hampered by an inadequate financial allocation that prevents them from upgrading their research and information infrastructure. This forces them to raise tuition fees to narrow the funding gap. The limited number of places at public universities and the high tuition fees charged by private universities block access to the university system in Bangladesh. Moreover, public and private universities compete for the limited number of highly trained faculty. This staffing shortage obliges private universities to draw upon the faculty strength of public universities on a part-time basis. University faculty are consequently unable to devote sufficient time to teaching and research, resulting in the transmission of an education of uncertain quality.

This state of affairs culminates in graduates who turn out to be uncompetitive by market standards. It also leads to weak linkages between public universities and employers in the job market. Consequently, university graduates produced at considerable cost to the nation remain unemployed for a long period of time. Even when they do find employment, it is often in areas outside their field of study.

In 2003, the Ministry of Education proposed a 20-year plan for higher education formulated with the help of six expert groups. This reform is coupled with the promotion of ICTs, as Internet coverage remains low in Bangladesh compared to other countries in the region, at just 0.32% in 2008 (Figure 4).

Industrial development in Bangladesh

Agriculture has long been the backbone of the economy and the chief source of income for the majority of people in Bangladesh, even though it contributes just 19% to GDP (Figure 1). The government plans to reduce poverty by increasing agricultural productivity and achieving self-reliance in food production. It also plans to increase income from non-agricultural exports through industrialization. As part of the implementation strategy for this industrialization plan, industries have been rapidly established in the following areas: textiles, light engineering, pharmaceuticals, ship-building, leather goods, ICTs and agro-based and agro-supportive sectors. In the chemical sector, a large number of industries have been set up, including tanneries, dying, printing and soap production (see also Box 4).

The government plans to develop 79 industrial estates in different districts of Bangladesh. Sixty of these industrial estates were in the initial stages of development in 2009 as part of the first phase. Industries involving investment of up to Taka 10 crores (approx. US$ 1.4 million) are being set up on these estates. They concern mainly food and allied products, chemicals, engineering and textiles. A number of the industrial estates have been supported by private initiatives.

Two export processing zones were in the early stages of development in 2009. The Export Processing Zone Authority is creating four zones in the cities of Dhaka, Chittagong and Khulna. Two additional export processing zones are to be established via private initiatives. Both medium-sized and large export-oriented industries are being established via joint ventures with foreign firms. The government also plans to establish industrial parks and garment factories. The major exporting sectors of the country are now textiles, garments, jute and jute products, leather and leather products and tea. The contribution of the industrial sector to GDP is about 29% (Figure 1).

In recent years, Bangladesh has managed not only to increase its exports substantially but also to diversify them. At the time Bangladesh achieved independence in 1971, jute and tea were the major export-oriented industries. Exposed to frequent flooding which reduced jute yields, as well as falling jute fibre prices and a considerable decline in world demand, the role of the jute sector in the country's economy has declined. Consequently, the focus has shifted towards textile manufacturing and the garment industry in particular.

The **garment industry** has been a major source of foreign exchange for the past 25 years. At present, the country generates about US$ 5 billion from exports of garments and apparel. The industry employs about 3 million workers,

Box 4: The City Cluster Economic Development Initiative

The Asian Development Bank's City Cluster Economic Development initiative attempts to activate industrial clusters by supporting their growth. Research conducted for the initiative measured and compared attributes of competitiveness for more than 30 cities and towns across Bangladesh, India and Sri Lanka. Researchers identified, mapped and analysed sectoral and spatial changes in urban industry and economic activities.

Three competitive industries that have formed spatial clusters but are still at a dormant stage were identified in the capital of each country. Commonly, these industrial clusters require support in several critical areas: R&D, vocational skills training, knowledge-sharing, marketing (software infrastructure) and basic urban infrastructure, such as a water supply, waste management, electricity, IT, roads, transportation and logistics (hardware infrastructure).

After helping to identify clusters that are either at a dormant stage or involve environmental improvements and waste management, such as the tannery industry in Dhaka, the initiative plans to help jump-start these industrial clusters by providing support in the areas identified above, with private-sector participation. The project will also allow policy-makers to make informed decisions on 'where to invest first' and 'what to invest in,' so as to maximize economic impact with limited resources.

Source: Asian Development Bank (2009)

Competitive industries in three South Asian capitals, 2009

Delhi, India	Dhaka, Bangladesh	Colombo, Sri lanka
General metal engineering industry	Building construction materials industry	Apparel industry
Auto component industry	Tannery industry	Rubber industry
Ready-made garment industry	Food processing industry	IT industry

Source: Choe, K.A. and Roberts, B. (forthcoming) *City Cluster Economic Development in South Asia: a Framework Approach*. Asian Development Bank Urban Development Series, Manila

90% of whom are women. Bangladesh has benefited from the trend of relocating production to developing countries. Two vital non-market elements have contributed to the garment industry's success: (a) quotas under the Multi-Fiber Arrangement in the North American market and (b) special access to European markets.

In 2008, the **shipbuilding industry** emerged as a sector with great potential for development. The industry aimed to fetch over US$ 1 billion through exports of ocean-going ships in 2009. The industry had export orders worth over US$ 800 million in 2008 for about 50 ocean-going vessels. The Ananda Shipyard, a local ship-building company, has received orders from various European and African countries for the construction of 40 ships and ferries worth a total of US$ 450 million. A second local ship-building company, the Western Marine Shipyard Ltd, is exporting 12 ships each weighing 5 200 tonnes to Denmark, Germany and the Netherlands by 2010.

The **pharmaceutical sector** has emerged as one of Bangladesh's most developed high-tech sectors, with potential for further growth. The sector not only meets 97% of domestic demand but also exports medicines to markets worldwide, including Europe. Leading pharmaceutical companies are expanding their businesses with a view to developing the export market. A number of new pharmaceutical companies have been established recently which are equipped with high-tech facilities and skilled professionals.

The **light engineering sector** is playing an important role in employment generation and poverty alleviation through endogenous technology. It consists of small and medium-sized light engineering industries scattered across the country which have been producing import-substitution products. The product lines consist of 25 245 diverse items. Machinery and spare parts produced by entrepreneurs are supplied to various mills and factories. Other products include ferries, railways, power plants and vehicles for the transport sector. Around 40 000 light engineering industries are operating all over the country. They are engaged in the production and manufacturing of highly value-added engineered goods and services with an annual turnover of more than US$ 1.2 million. In recognition of this fact, the government declared light engineering a 'thrust sector' in its Industrial Policy of 2005. Moreover, in the government's Export Policy of 2007, light engineering was identified as one of the 'highest priority sectors'. The policy provided a 10% cash incentive for the export of light engineering products.

Bangladesh has a substantial domestic **leather industry** that is mostly export-oriented. Some leather is exported in the form of ready-made garments but this tends to be confined to a small export-trade in 'Italian-made' garments for the US market. Footwear is more important in terms of added value and is the fastest-growing sector for leather products. Presently, Bangladesh meets the leather requirements of 2–3% of the world market. Most of the livestock base for this production is domestic: it is estimated that 1.8% of the world's cattle and 3.7% of the world's goats are raised in Bangladesh. Their hides and skins have a good international reputation. FDI in this sector and in the production of tanning chemicals appears to be highly rewarding. Bangladesh has the potential to become an off-shore location for the manufacture of low-cost, high-quality leather and leather goods. It has the basic raw materials, a large and inexpensive labour force and enjoys a tariff concession facility under the agreements mentioned earlier which limits the size of tariffs that major importing countries can impose.

Weaving S&T into the national culture

The Ministry of Science and Information and Communication Technology is promoting S&T as a way of bringing about positive social change and balanced socio-economic development in Bangladesh. S&T is being harnessed to foster sustainable use of the environment, ecosystem and resources, on the one hand, and contribute to the global pool of knowledge, on the other. The overall aim is make S&T part of the national culture.

In 2009, the government approved the country's Information and Communication Technology Policy. It falls within the national vision of raising the profile of the nation to that of a middle-income country within a decade, a feat that would require more than doubling the current level of per-capita GNP. The policy considers that the country's annual growth rate can be pushed to above 7.5% of GNP through extensive use of ICTs.

The ten objectives of the policy are to:

- ensure social equity;
- increase productivity across all economic sectors, including agriculture;
- foster transparency, accountability and efficiency in the delivery of services to citizens;
- ensure computer literacy at all levels of education and public service;
- facilitate innovation and the creation of intellectual property;
- enlarge the pool of world-class ICT professionals to cater to both local and overseas employment opportunities;
- strengthen exports in software;
- improve health care and ensure universal access as a public service obligation;
- enhance the creation and adoption of environment-friendly green technologies, ensure the safe disposal of toxic wastes and minimize disaster response times;
- enable effective climate-change management programmes.

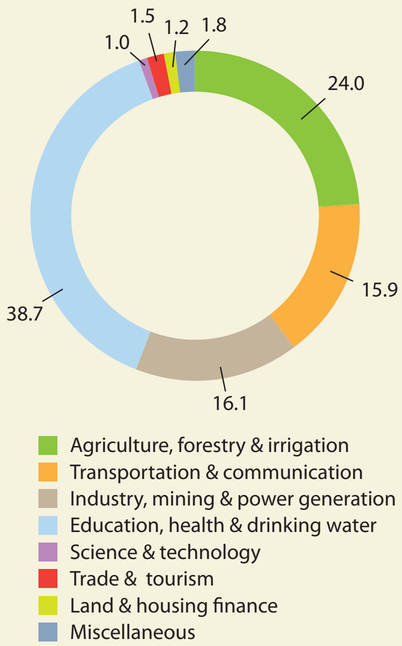
Nepal

Challenges for higher education

The significance of basic sciences in strengthening the overall S&T capability has not yet been properly recognized in Nepal, according to Bajracharya *et al.* (2006). For them, 'little priority is given to higher education in basic sciences, compared to higher education in technical subjects such as engineering, medicine, agriculture and forestry'. They argue that this attitude has been largely responsible for the lack of development of an adequate S&T capability in Nepal. Moreover, despite the growing opportunities for higher education in technical subjects, many students still venture abroad to India, China, Bangladesh, Australia and the USA. Despite this trend, the number of scientists and engineers in Nepal quadrupled between 1995 and 2008 from 8 236 to 34 880 (Nepal Academy of Science and Technology, 2009).

Until 1986, Tribhuvan University was Nepal's only university offering higher education and research in S&T fields. In 1991, this public institution was joined by a

Figure 6: Total outlay for Tenth Development Plan in Nepal, 2002–2007 (%)



Source: Bajracharya et al. (2006) *Science, Research and Technology in Nepal*

private university, Kathmandu University, followed by two other private institutions in 1994: Purbanchal University and Pokhara University. The most recent addition is the Nepal Academy of Medical Sciences, set up by the government in 2004.

Today, Tribhuvan University still produces over three-quarters of S&T personnel and nearly 40% of the country's master's and PhD holders in S&T fields, most of whom are destined for university teaching. The low number of PhD students is a problem (Bajracharya *et al.,* 2006).

Three-quarters of the Nepalese students enrolled in S&T fields attend Tribhuvan University, where they represent nearly 16% of student admissions. Demand for higher education is growing: in 2004, the university counted 25 564 students enrolled in S&T fields, up from 19 056 in 2000. The university conducts academic programmes in S&T through its five technical institutes: the Institutes of Science and Technology, Engineering, Medicine, Agriculture and Animal Sciences, and Forestry.

The Institute of Science and Technology had by far the highest student enrollment in 2004 (18 891), followed by the Institute of Engineering (4050) and the Institute of Medicine (1 543) [Bajracharya *et al.,* 2006].

Between 1990 and 2004, the government made 'huge investments' (5.7 billion rupees) in the Institutes of Medicine, Engineering, Forestry and Agriculture to build infrastructure, with the lion's share going to the Institute of Medicine (40%). Although the Institute of Science and Technology received the second-biggest budgetary allocation (26%), its student roll is also much higher than that of the other four institutes (Bajracharya *et al.,* 2006).

There are as many as 75 campuses under the Institute of Science and Technology. They offer programmes in zoology, botany, chemistry, physics, mathematics, statistics, microbiology, meteorology, geology, environmental science, computer sciences and food technology. In 2005, the institute planned to introduce programmes in energy studies and technology; material sciences; remote sensing; water resource studies; biotechnology; dairy technology; mountain risk engineering and computer applications.

Tribhuvan University attracts the bulk of students because its tuition fees are lower than those of private institutions. This forces most of the university's campuses to admit more students than they can actually accommodate. The overall percentage of investment in higher education has been declining even as the cost of science education has risen. This obliges the university to generate revenue itself but any proposal to raise tuition fees has met with opposition from the student unions. The lack of investment has resulted in poor laboratory and library facilities on most of the science campuses. It has also meant that the university could not diversify academic programmes, leading to an oversupply of graduates in some disciplines. The low salaries of university professors have also affected morale and encouraged professors to take on part-time jobs on different campuses – including private campuses – to make ends meet (Bajracharya *et al.,* 2006).

Fostering development-oriented research

A mountainous country, Nepal has little arable land, yet the majority of the active population works in agriculture and forestry. About one-third of Nepal's export earnings come from agriculture and forest products. The other major sources of revenue are tourism and remittances from Nepalese living abroad. The small manufacturing

Box 5: The Nepal Development Research Institute

A non-profit, non-governmental organization, the Nepal Development Research Institute (NDRI) was established in 2007 to conduct quality research on issues of relevance to Nepalese society. It also provides consultancy and training services.

Research focuses on four multidisciplinary areas: policy analysis on the national economy; infrastructure policy and planning; poverty reduction and sustainable livelihoods; climate change, agriculture and renewable natural resources.

In October 2009, NDRI was implementing the following key projects:

- an assessment of the role of community forests in CO_2 sequestration, biodiversity and land use change. This project was being carried out in the Teraj and Hills Districts of Nepal, with funding from the Asia–Pacific Network for Global Change Research in Japan;
- an evaluation of assistance for vulnerable populations living in 18 districts who were affected by high food prices, conflict and natural disasters. The study was being carried out by NDRI in partnership with the United Nations World Food Programme;
- household surveys for the World Food Programme's research projects on food markets in mid-western Nepal and cash for work in Far West Nepal;
- hazard and vulnerability mapping, as well as the documenting of good practices in disaster risk management and adaptation to climate change adaptation. This project was being implemented in partnership with the United Nations Food and Agriculture Organization.

Source: www.ndri.org.np/main/activities.htm

sector tends to be limited to labour-intensive industries such as handicrafts, garment- and carpet-making, agri-products and the like (Bajracharya *et al.,* 2006).

Nepal has set itself the target of reducing the number of people living below the poverty line from over 38% in 2004 to 10% by 2017. Poverty alleviation was a special focus of the *Tenth Plan* (2002–2007), which sought to attain this goal by 'enhancing production and productivity through the maximum utilization of S&T' (Figure 6). The budget amounted to 234 million rupees (*circa* US$ 1.3 million), up from 190 million rupees for the previous *Plan*.

The *Tenth Plan* focused on:

- mobilizing available physical and human resources and giving special priority to S&T in tertiary education;
- strengthening the institutional and administrative sector to activate research agencies;
- attracting private-sector participation in research;
- encouraging development-oriented, competitive research;
- incorporating information technology and biotechnology;
- creating an environment conducive to technology transfer and foreign investment;
- disseminating information on the results of scientific research and its applications;
- producing highly skilled personnel;
- enhancing local technology;
- expanding the water sector and meteorological services (Bajracharya *et al.*, 2006).

Despite its abundant rivers, Nepal uses only a small percentage of its hydro-electric potential, which reaches less than 40% of the population. A major project to develop hydropower was concluded with India in 2006 but the project never got off the ground. In 2007, Nepal won the prestigious Ashden Award for replacing diesel-powered mills with water-powered ones. It had won a similar award two years earlier for making biogas out of cow dung. The biogas project even sold carbon credits to the World Bank under the Clean Development Mechanism of the Kyoto Protocol (Khadka, 2009).

Nepal formed a high-level Commission on Climate Change in 2009 under the chairmanship of the Prime Minister which was charged with preparing an action plan for adaptation. The plan will emphasize the concept of sustainable and clean development and accord high priority to renewable energy to generate 'green' employment. In presenting its programmes and policies for 2009–2010 to Parliament, the government observed that it would accord high priority 'to the expeditious implementation of some large-scale hydropower projects' (Government of Nepal, 2009).

The government decided to prepare a three-year Interim Development Plan (IDP) in place of an Eleventh Five-Year Plan, in order to map the country's development to 2010 during the transition period from a monarchy to a parliamentary democracy. The IDP's main objectives are to contribute to the national goal of poverty alleviation by improving living standards through the development and utilization of S&T. The IDP also aims to build national capacity by strengthening the institutional framework of the S&T sector and making production and services more competitive via R&D. With a target of annual economic growth of 5.5%, the IDP has adopted a strategy of involving stakeholders in the institutional development of S&T by mobilizing academia and the private sector.

In terms of institutional capacity, Nepal counts some 170 organizations involved in S&T, the majority of which fall under government ministries (see also Box 5). As we have seen earlier, Nepal now has five institutions of higher learning and research related to S&T (*see page* 337). The Research Centre for Applied Science and Technology (RECAST) is the main R&D wing of Tribhuvan University. RECAST conducts R&D into renewable sources of energy (solar energy, biomass briquetting, biofuels and improved cooking stoves), natural dyes and other natural products, crop science and medicinal chemistry. Recent major research activities include: exploration and utilization of renewable oil resources; bioprospecting of ethno-medicinal plants of Nepal for conservation of biological and cultural resources; development of a gassifier stove for domestic use; and dissemination of a programme of appropriate technology for micro- and small enterprise development in Nepal (Bajracharya *et al.,* 2006).

In recent years, the private sector has been contributing to building technological capability in the energy sector via solar water heaters, water turbines and multi-purpose power units. Companies include Balaju Yantra Shala, the Development Consulting Service and Butwal Technical Institute. Private businesses have emerged in software development and IT, telecommunications and cable technology (Bajracharya *et al.*, 2006).

The Ministry of Environment, Science and Technology set up an Information Technology Park at Dhulikhel in 2003. For several years, the 270 million rupees (circa US$ 3.6 million) facility lay idle until International Business Machines (IBM) Corporation decided to set up a research centre within the park. The centre was inaugurated in October 2009 by Prime Minister Madhav Kumar Nepal and the chairman of Nepal's Information Technology High-Level Commission. IBM has employed eight researchers in the centre to develop new software for use in business (Tech Nepalko Info, 2009).

In 2005, the Ministry of Environment, Science and Technology[6] promulgated a national S&T policy after presenting the draft policy to the Fourth National Conference on Science and Technology organized by the Nepal Academy of Science and Technology[7] (Bajracharya *et al.,* 2006). In 2010, this S&T policy was under revision.

Pakistan

Higher education reforms

Pakistan is the world's sixth-most populous nation with 166 million inhabitants, more than half of whom are younger than 19 years. This demographic situation is a challenge but also an opportunity. Amid a host of problems related to regional conflicts, natural disasters, political instability and the turmoil and violence that have gripped the country in recent years, one positive trend has emerged: the nation has dramatically increased its investment in higher education and scientific research (Rahman, 2009).

Pakistan's reforms in higher education were initiated in 2003, a year after the Higher Education Commission (HEC) was established by Presidential Ordinance to reform the country's ailing higher education system. The plan of action implemented by the HEC over the past five years has focused on addressing issues related to access, quality and relevance.

Access is being addressed by providing talented students with greater opportunities for higher education through the expansion of universities from 94 in 2005 to 128 in 2008, as well as the promotion of high-quality distance learning programmes through a virtual university established in 2001. This virtual university has since expanded its programmes and counted 35 000 enrolled students in 2009.

To address other challenges, a core strategic plan was drafted in 2002–2003 to implement reforms which include the following:

- programmes to reverse brain drain, under which the monthly salaries of faculty members increased to an

6. The ministry was subsequently divided into the Ministry of Environment and the Ministry of Science and Technology.
7. Previously the Royal Nepal Academy of Science and Technology

average of US$ 3 000–5 000. Under its Foreign Faculty Hiring Programme, the HEC has managed to attract about 500 highly qualified faculty from abroad to take up positions at universities across the country, including expatriate Pakistani scholars and international experts;

- the faculty development programme is being aggressively pursued by providing merit-based scholarships for training approximately 2 400 PhD students per year at universities in developed countries;

- the HEC has also established a Quality Assurance Agency and Quality Assurance Cells in the country's universities to enforce sound standards in higher education and encourage continual upgrading through the implementation of international benchmarks. HEC funded 742 development projects at a cost of US$ 4.2 billion from 2007 to 2008. Figure 7 outlines priority sectors and fields of research.

Centralized equipment facilities providing access to advanced scientific instrumentation have been established at 20 national centres for researchers from universities across the country. Moreover, to ensure the relevance of higher education to national objectives, the HEC has also promoted endogenous PhD programmes at local universities, resulting in a 56% increase in the enrollment of researchers. Joint research projects between university and industry are encouraged.

The past five years of targeted reforms in the fields of engineering, IT and biological sciences have left their mark: there has been a leap in university enrollment from 135 123 students in 2003 to 741 009 in 2008. Female enrollment grew from 36% of the total student cohort in 2001 to 48.7% in 2007. Women comprise as much as 70% of total enrollment in MPhil and PhD programmes. A substantial rise in the number of postgraduate research students has resulted in a 60% increase in internationally co-authored publications from Pakistani institutions of higher learning (see also Box 6).

Figure 7: Distribution of project cost for higher education reform in Pakistan, 2007–2008 (%)

Source: HEC Report 2002–2008, Pakistan www.hec.gov.pk

Knowledge hubs in Pakistan

Despite a long history of developments in philosophy, science, technology and manufacturing predating Roman times, modern science was brought to the South Asian region by colonial rulers. During the British Raj in India, the British established a number of universities and about 30 research laboratories in the agriculture and health sectors across the region. Following partition in 1947, Pakistan inherited just one university and three small agriculture stations.

The scientific research infrastructure has since expanded in Pakistan. Within this framework of institutions, regional knowledge hubs have emerged in the cities of Karachi, Lahore, Faisalabad, Sialkot (Box 7) and Islamabad. Karachi, Pakistan's most densely populated port with a population of 21 million, is the largest industrial city with a focus on the

Box 6: Pakistan's research collaboration with China and the USA

Pakistan and China have enjoyed strong political and economic ties for the past few decades. Both countries have also collaborated on a number of research projects in various fields of S&T. One landmark project was the construction of the world's highest highway, the Karakoram Highway, considered the eighth wonder of the world. Pakistani and Chinese engineers jointly constructed this highway in the Himalayan mountains connecting Pakistan and China through the old Silk Road over a period of 20 years. The project was completed in 1986.

A second landmark project is the recent joint production of a jet fighter, *Thunder*, which, after successful completion of its test flight in 2008, has been approved for commercial production.

Pakistani and US scientific collaboration is facilitated by an agreement signed by the presidents of both countries in 2003. Under this agreement, both countries contribute to a common S&T fund which is jointly managed by the National Academy of Sciences in the USA and by the Higher Education Commission and Ministry of Science and Technology in Pakistan. Each year, proposals for research collaboration are invited with at least one US and one Pakistani scientist as principal investigators. The proposals undergo peer review in both countries and are selected on merit.

This programme has resulted not only in capacity-building of Pakistan's laboratories but also in the joint discovery of a vaccine to prevent a deadly disease caused by tick bites which afflicts those working with animal herds in the southern region of Sindh in Pakistan.

Another success story is the Pakistan telemedicine programme. Two Pakistani doctors were trained by US specialists to be master trainers who in turn trained a critical number of medical professionals. Telemedicine services are now being offered to patients living in remote villages via 28 centres. Telemedicine also helped save several lives in the earthquake-hit cities and towns in 2005.

Source: author

textile, leather and automobile industries. The city houses 29 universities and degree-awarding institutes operating in both the public and private sectors. These include the famous Aga Khan University of Medical Sciences and Sindh Urology Institute, which are recognized the world over for training high-quality medical graduates and for research in renal diseases respectively. The Institute for Business Administration and HEJ Research Institute of Chemistry at Karachi University are known respectively for training high-quality management graduates and for top-quality researchers in chemistry. The 32 R&D organizations in Karachi include the laboratories of the Space and Upper Atmospheric Research Commission (SUPARCO), the National Oceanography Institute and the laboratories of the Pakistan Council for Scientific and Industrial Research (PCSIR) working in the areas of energy, biomedical and leather research.

Box 7: Initiatives to promote industry in Sialkot

The city of Sialkot in Pakistan is well-known for the production and export of surgical instruments, leather goods, textiles, musical instruments and cutlery. Sialkot is the third-largest industrial hub in the province of Punjab after Lahore and Faisalabad. It is Pakistan's second-largest export-earner after Karachi.

Sialkot's entrepreneurs have collaborated on a number of successful projects to make the city a highly desirable location for industry. These include setting up a dry port in Sambrial; raising private funds to improve city roads and drainage; sealing roads on industrial estates; locating tanneries in a specialized zone; and providing toxic waste treatment. Sialkot's commercial and industrial interests are being served through the building of an international airport for cargo flights completely financed by the private sector.

Source: World Bank (2005)

The city of Lahore, situated at the heart of the province of Punjab, is home to 25 universities, institutes and 20 R&D organizations. This city has emerged as the regional IT hub and has attracted a significant amount of foreign investment in this field. Two centres have been liberally funded from the public purse. The first is the Abdus Salam School of Mathematical Sciences at Government College University in Lahore; it has attracted top-class mathematicians from different countries to form a knowledge cluster. The second is the Centre of Excellence in Molecular Biology at Punjab University; it has several postgraduate students on its roll and has established a world-class virology laboratory.

Jointly funded by the provincial government of Punjab and the federal government, the Abdus Salam School of Mathematical Sciences was established in 2003 to honour Pakistani scientist Abdus Salam, who was awarded the Nobel Prize for Physics in 1979 jointly with Steven Weinberg and Sheldon Lee Glashow. The institution has made remarkable progress in a short period. It has an international faculty of 36 PhDs, most of whom come from Eastern Europe. The school had 93 PhD students on its roll in 2009 and has attracted a large number of doctoral and postdoctoral students from different countries.

The privately funded Lahore University of Management Sciences produces top-class graduates in management-related studies. The Metal and Material Science Laboratories of the PCSIR provide services to light engineering industries located in the neighbouring cities of Sialkot, Gujranwala and Gujrat. These three cities are known for their traditional strengths in light engineering sectors and are commonly referred to as the technology triangle of Pakistan.

Islamabad, the federal capital, and its twin city, Rawalpindi, had only three universities until 1990. These have now expanded to 16 universities and 34 R&D organizations, including laboratories of the National Agriculture Research Commission, the Pakistan Atomic Energy Commission and the laboratories of the National Defense Complex.

Faisalabad is known for agro-based industries and textile manufacturing industries. It has four universities, including the Agriculture University of Faisalabad and a Textile University. In addition, 20 research institutes, mostly involved in research in the fields of agriculture and biotechnology, provide services to agro-based industries.

Sri Lanka

Towards a framework for higher education reforms

Like most South Asian countries, Sri Lanka faces the challenge of improving the quality of education at all levels. The challenge is particularly acute for higher education, where issues encompass not only improving access, quality and relevance but also wider reforms to introduce international standards, better management and governance, as well as greater flexibility and adaptability to meet labour market demands.

Sri Lanka loses many of its highly qualified professionals to brain drain. According to a recent World Bank study (2009), Sri Lanka's higher education enrollment of 6% of the age cohort is underestimated. The recent promotion of distance education programmes is expected to have increased access to higher education to almost 23% of the 18–25 age group. The quality and relevance of higher education remains a matter of concern, as few institutions are providing education that is up to international standards. Research efforts are also concentrated in just three or four universities, the Industrial Technology Institute and some research institutes conducting agricultural research.

The Sri Lankan government has realized the importance of human capital for survival in an increasingly competitive, knowledge-based global economy. It has entrusted the National Education Commission – established in 1991 – with the task of developing a policy framework in collaboration with the Ministry of Planning, Ministry of Finance and the University Grants Commission. In 2009, the Commission was consulting all stakeholders, such as academics, researchers and development planners, with a view to formulating a framework for higher education reforms (World Bank, 2009).

A vision for Sri Lankan science

Sri Lanka is an island economy with a population of 20 million and GDP of US$ 40.6 billion (2008). It has the highest per capita income (US$ 2 013) in the region after the Maldives and Iran (Table 1).

Sri Lanka was the first country in South Asia to liberalize its economy in 1979. Its share of global exports in 2003 exceeded its share of global GDP, indicating that it is an export-driven economy (Dahlman, 2007). Over the past 20 years, the composition of the economy has changed, with the share of the services sector rising to the detriment of the agriculture sector, which contributed just 13% to GDP in 2009 (Figure 1). The potential for further economic growth will depend on the country's ability to overcome internal political problems, bridge regional inequalities by widening access to economic gains and increase investment in ICT infrastructure, education and scientific research to achieve productivity gains through innovation (World Bank, 2009).

The higher education and research infrastructure currently comprises 62 institutions. The 19 state-controlled universities include one university working under the Ministry of Defense. There are 11 R&D centres, the remainder of infrastructure being made up of colleges and institutes. For many years, Sri Lanka was credited with providing some of the best higher education in the region. This achievement could not be sustained, however, due to decades of internal conflict which resulted in the major share of GDP being spent on combating terrorism. Expenditure on education and on R&D also stagnated for several years, resulting in lower standards of education and having an adverse impact on skills development programmes and the training of engineers and scientists.

Of note is that Sri Lanka leads other countries in the region for the World Bank's Knowledge Economy Index (KEI) [Table 8]. The KEI is calculated using four pillars of the knowledge economy, namely: incentive and the institutional regime; education and human resources; the innovation system and; ICT infrastructure. Iran and Pakistan have also shown progress in these four areas since 1995.

In 2009, the Ministry of Science and Technology launched its *Vision 2020* for transforming Sri Lanka into a scientifically and technologically advanced country. Within this vision, a new STI policy was formulated which was in the process of review and consensus-building at the time of writing the present chapter in early 2010. The new policy lays emphasis on:

- fostering a science and innovation culture for every citizen;
- training a higher number of scientists and technologists;
- achieving self-reliance in S&T by acquiring technology and adapting and developing it for increased competitiveness;
- ensuring quality standards of S&T institutions and national certification and accreditation bodies;
- ensuring sustainable development through the conservation of the country's natural resources and environmental protection;
- promotion of basic and applied research in the fields of nanotechnology, biotechnology, materials science and electronics;

Table 8: South Asia's innovation capacity and competitiveness, 1995 and 2009

Countries	Knowledge Economy Index	
	1995	2009
Bangladesh	138	138
India	108	109
Nepal	119	131
Pakistan	127	118
Sri Lanka	94	88
Iran	102	98

Note: The KEI evaluates 146 countries. Bangladesh, for example, ranks 138th out of 146 countries.

Source: World Bank: http://info.worldbank.org/etools/kam2/KAM_page5.asp

Box 8: The Sri Lanka Institute of Nanotechnology

Established in 2008, the Sri Lanka Institute of Nanotechnology (SLINTEC) is a joint venture between the National Science Foundation and Sri Lankan corporate giants that include Brandix, Dialog, Hayleys, Loadstar and MAS. The Institute is housed within a futuristic complex in the Blyagama Export Promotion Zone. SLINTEC laboratories are equipped and staffed with some of the most advanced, cutting-edge research equipment and a research staff that includes 20 PhDs who qualified abroad.

Research at SLINTEC focuses on the integration of nano-scale devices and materials into complex nanosystems that will elevate the global competitiveness of products. SLINTEC claims access to a global resource base and takes an industry-focused approach. The institute aims to become the regional hub for nanotechnology research and intellectual property rights acquisition.

Source: author. For details: www.susnanotec.lk/

- encouraging science-based entrepreneurship through appropriate incentives and regulations, including intellectual property rights and the promotion of S&T at the grassroots level.

Current GERD in Sri Lanka is reported to be about 0.2% of GDP (Figure 2), 70% of which is considered non-development expenditure. The new STI policy envisages raising GERD to 1% of GDP and increasing the number of researchers from 93 per million population (Table 4) to at least 948 per million population. Enrollment in engineering will be encouraged to achieve a fourfold increase in the number of graduates. Four institutions under the Ministry of Science and Technology have been assigned the task of implementing the STI policy. These are the National Engineering and Development Corporation, the Industrial Technology Institute, the National Science Foundation and the Arthur C. Clark Institute of Modern Technologies. The ministry has posted the implementation strategy for the STI policy and progress achieved thus far on its website.

The initiative for establishing a world-class institute of nanotechnology as a public–private partnership has received positive feedback from international agencies like the World Bank review team, which termed it a step in the right direction (Box 8).

Another initiative promotes S&T at the grassroots level. The Sri Lankan government is implementing 300 Science and Technology Vidatha Centers in villages. Staffed by science graduates, these centres are expected to provide training and consultancy services to entrepreneurs for the commercialization of local research and locally developed technologies.

Sri Lanka's new STI policy and plans were reviewed by World Bank experts and their findings were presented at a conference held on 15 October 2009 in Colombo. The study identifies weaknesses in organizations implementing the policy. These organizations are unable to hire talented staff owing to low salary structures and minimal opportunities for training due to lack of funds, the study observes. There are also problems related to the fact that institutions employ an inadequate number of technicians and a proportionally high number of non-technical support staff. The World Bank study recommended major reforms in the higher education sector to create a merit-based national cadre of researchers that would involve the Sri Lankan diaspora in reforming higher education institutions and restructuring R&D organizations to make them market-driven rather than supply-oriented. The study also suggested strengthening Sri Lankan institutes providing accreditation services related to metrology, standards, quality and testing.

Concerning the establishment of a national innovation system, the study recommended that STI policy be aligned with the overarching national development policies. It proposed creating demand for STI by promoting risk-sharing between government and industry through public–private partnerships, the promotion of contract research and the provision of tax credits, tax deductions and investment allowances to the productive and services sectors for the purposes of fostering R&D and innovation.

In 2009, the Sri Lankan government approved a project assigned to the Munasinghe Institute for Development (MIND) for aligning the national technology and innovation policy with the National Sustainable Development Strategy (2007). This project is intended to support the implementation plan and facilitate formal adoption of the STI policy. The project strives to orient STI towards meeting socio-economic challenges related to sustainable development, improving health and education and the general well-being of the population, as well as other challenges such as ethnic conflict, environmental issues and natural disasters.

CONCLUSION

The building of S&T capabilities is considered essential for economic growth and development. The technology gap between South Asia and the developed world cannot be bridged by simply importing technology from other countries. Rather, it requires that the governments of South Asian countries invest in:

- building sound educational and scientific infrastructure;
- training a critical mass of scientists, engineers and skilled technicians;
- appropriate regulation for the protection of IPRs and;
- the formulation of public policies to support a continual learning process in private firms so that they can master the tacit knowledge attached to technology transfer.

In addition, South Asia has been unable to exploit its regional trade potential. The cultural and linguistic ties and geographical proximity of South Asian countries should facilitate regional trade. Trade creates a demand for technology and innovation and links people in many different ways. South Asian countries have a competitive edge in a variety of services and products with potential for trade within the region. Furthermore, there are location-specific advantages in the industrial clusters that exist in all South Asian countries, particularly in India and Pakistan. Most of these clusters require new management and organizational techniques to integrate existing knowledge and new technologies in their production processes. They need to seek technological alliances regionally and globally to gain a competitive advantage (Dahlman, 2007).

The national innovation systems of South Asian countries remain underdeveloped. Overall, Pakistan, Bangladesh and Sri Lanka seem better at producing basic knowledge than commercializing it. In general, the emphasis of public-funded R&D has been on military and space research rather than on industrial research, health or other areas of research where innovation can improve the quality of life for most of the population. South Asian countries require aggressive STI and competition policies and strong institutional infrastructure to improve co-ordination and cohesion between the various public and private institutions and enterprises. Building strong knowledge networks within each country and at the regional level, and linking these to international networks, may result in the knowledge transfer and knowledge accumulation countries need to become competitive in an increasingly knowledge-intensive global economy.

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Sri Lanka Institute of Nanotechnology: www.susnanotec.lk/

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In 2000, Dr Naim was appointed Chair of the Pakistan Council for Science and Technology (PCST), where she was instrumental in formulating strategic plans and policies for revamping Pakistan's S&T, R&D and higher education systems, and integrating them in national development plans and policies. As Chair of the PCST, she implemented incentives and programmes for the promotion of scientific research and brain drain reversal. In addition Dr. Naim played a pivotal role in linking the Pakistan Research and Education Network with the GLORIAD network of the US National Science Foundation. She also played a key role in securing the landmark Agreement on Science and Technology Collaboration between Pakistan and the USA in 2003. She then co-ordinated a multidisciplinary group of experts from the public and private sectors in the preparation of the Technology-Based Development Vision for Pakistan approved by the Cabinet in August 2007.

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Basing the economy on oil could prevent a strong relationship from developing between science and wealth.

Kioomars Ashtarian

16 · Iran

Kioomars Ashtarian

INTRODUCTION

In Iran, science, technology and innovation (STI) policy hinges on the country's status as an oil economy. Home to the second-biggest known reserves in the world after Saudi Arabia, Iran has invested in the oil industry to the point where receipts now represent more than four-fifths of GDP. No discussion of the evolution of STI policy in Iran since 2000 would thus be complete without an analysis of the impact of Iran's oil economy on STI policy.

In the present chapter, we shall argue that oil receipts can play a perverse role in S&T policy and development. This is because the windfall from oil revenue tends to stimulate consumerism and create a schism between consumers and the scientific community. With S&T policy relegated to the back seat, bureaucratic preferences take precedence over the development of science as a public good.

We shall also argue that an oil economy need not be an obstacle to the development of science and technology (S&T). Recent trends in planning and public policy-making demonstrate that Iranian officials plan to foster S&T, although the effectiveness of this policy will depend on its socio-economic orientation.

Iranians have a positive attitude towards science, so there is no major cultural barrier to the evolution of S&T. Scientific advances are easily accepted within the religious and political spheres. Yet, despite this positive attitude, science is neither an important part of economic life, nor considered an intellectual right.

Attitudes towards science are largely influenced by cultural and, to some extent, political considerations. As science is recognized as being the determining factor in the efficiency of Iran's political system, the elite has tended to mainstream scientific progress in its political discourse. As a consequence, expenditure on research and development (GERD) and research budgets in higher education have largely been spared from cuts, even in hard times.

Over the past decade or so, Iran has reacted to the imposition of trade embargoes by some Western countries by developing its own scientific and economic infrastructure. This has entailed expanding higher education and spawned the Southern Pars Oil Projects, national projects for the production of steel, cement and so on, and the local production of goods for domestic consumption, such as cars or electrical appliances. Nevertheless, research and development (R&D) have failed to target market needs. Iran has instead chosen to focus on such fields as peaceful nuclear technology, nanotechnology, satellite launching, the reproduction of stem cells, animal cloning and so on. As a result, S&T policy remains insulated from changes in the economic conjuncture.

High oil receipts in recent years have been a boon for science. At the same time, however, this natural wealth has divorced science from socio-economic needs and favoured government intervention in S&T policy: as much as 73% of research is government-funded. As we shall see later, the steep climb in oil revenue in 2004–2005 has been followed by a spending spree on science and social welfare but also by a burgeoning bureaucracy. This situation has not only favoured a science pull instead of a technology push; it has also nurtured the domination of S&T policy by a scientific elite in academia. This dual phenomenon explains the low contribution of S&T policy to industrial development and the high rate of resource-based exports for an industrial economy, about 50% (Iranian Centre for Statistics, 2004).

In addition to the country's economic dependence on oil, S&T policy in Iran is typified by an interventionist bureaucracy which can lead to wastage of public funds. The greatest weakness, however, is the lack of orientation of STI policy towards problem-solving. Although the focus of scientific research is gradually shifting towards national problems, much of policy research in Iran demonstrates no strong relevance to national issues. Demand push for research and technology, a knowledge economy and problem-oriented research are all fashionable concepts in S&T policy, yet it would seem that the interrelation of these concepts and their integration into the economy receive little consideration in the policy-making process in Iran, despite their social relevance.

S&T policy-making in Iran needs to pay attention to such notions as technology diffusion, standardization, legal system reform, commercialization of research, establishing a trade-off system, institutional reform, communication and so on, if it is to make a real connection between scientific research and society. In the policy agenda, government preferences and the science pull approach should come after the demand push for research. Iran needs to take progressing towards a knowledge economy more seriously because basing the economy on oil could prevent a strong relationship from developing between science and wealth.

High oil receipts in recent years have been a boon for Iranian science but have divorced science from socio-economic needs.

Photo: © Ricardo Azoury/ iStockphoto

SOCIO-ECONOMIC SITUATION

Healthy growth in GDP

Iran has enjoyed a healthy rate of economic growth since 2001, with a peak in 2007 of 7.8% (Tables 1 and 2). Overshadowing this performance, however, is an inflation rate that has fluctuated between 10% and 25% since 2000. As a result, Iran's standing among its neighbours, such as Saudi Arabia, Turkey and Pakistan, has oscillated at times.

GDP per capita has grown rapidly, from PPP US$ 6 820 in 2000 to PPP US$ 11 844 in 2007. Over the same period, Iran's human development ranking likewise improved from 98th to 88th place. This places Iran near the top of the list of countries with medium human development, between Georgia and Thailand (UNDP, 2009).

Slower population growth and better literacy

In the past decade, population growth has slowed from 1.6% per annum in 2000 to 1.4% in 2008. It is estimated that this rate will further decline to 1.3% by 2015 when Iran will have a population of about 79.4 million. Iran's young population could be an opportunity for the country's development but the high rate of unemployment could also cause socio-economic problems.

According to UNESCO (2010), 82% of Iranians over the age of 15 years were literate in 2007, a figure projected to rise to 88% by 2015. It is also expected that the literacy gap between men and women will shrink: 23% of women were illiterate in 2006, compared to 12% of men; the projected figures for 2015 are 12% and 8% respectively. At university, women made up two-thirds of the student body in 2009.

An economy dominated by oil

The share of non-oil economic activities in GDP has dropped during Iran's fourth *Five-Year Economic, Social and Cultural Plan* (2005–2009), compared to the previous plan. In parallel, oil revenue has climbed to US$270 billion since President Ahmadinejad took office in August 2005. One-third of the economy is now dependent on oil, especially since the downturn in the construction sector in 2009 caused by the global recession (Figure 1).

The proportion of non-oil industrial sectors shrank to less than one-fifth of total gross national income (GNI) between 2002 and 2007 (Iranian Central Bank, 2007*a*). These sectors include agriculture, industry and mining, electricity, gas, water and construction (Figure 2). Only mining managed to hold its own, even though it was progressing from a low starting point: 0.7% of GDP in 2002 and 0.8% five years later. The share of oil, on the other hand, nearly doubled, climbing from 15.1% in 2000 to 27.9% in 2007 (Iranian Central Bank, 2007*b*).

Imports represent an estimated 30% of GDP and exports 39% of GDP (2007). The share of goods and services in imports has not changed since 2006 but has risen more than 7% for exports. Exports of goods and services can be broken down into raw materials (88%), industrial products (9%) and advanced technologies (3%) [Iranian Central Bank, 2008].

Between 2004 and 2008, the share of oil revenue allocated to the government rose to US$60 billion. By 2007, the increase represented four times that forecast for the period of the *Fourth Plan* (2005–2009). Since the revolution of 1979, reducing government funding via taxes and non-oil revenue had become a priority. This led successive

Table 1: Socio-economic indicators for Iran, 2000–2007

	2000	2001	2002	2003	2004	2005	2006	2007
GDP per capita (PPP) US$	6 820	7 125	7 672	8 264	8 796	9 314	9 906	11 844
GDP growth (%)	5.14	3.66	7.51	7.11	5.08	4.31	4.57	7.82
Inflation rate (%)	–	–	15.8	15.6	15.2	12.1	11.9	18.4 **
Population (millions)	63.93	64.97	66.01	67.04	68.06	69.08	70.09	71.02
Population growth (%)	1.64	1.61	1.58	1.54	1.51	1.48	1.45	1.30
Human development index	0.721	0.719	0.732	0.736	0.746	0.773	0.777	0.782
Public expenditure on education (as % of GDP)	4.4	4.4	4.9	4.8	4.9	4.7	5.1	5.5
Gini* 0.4		0.4	0.39	0.38	0.40	0.39	0.4	0.39

* The Gini coefficient index is used to measure inequality of income or wealth. The coefficient varies between 0 (complete equality) and 1 (complete inequality).
** The inflation rate jumped to 25.4% in 2008 before dropping back to 16.7% in 2009 and about 10% in 2010; for HDI: UNDP (2009) *Human Development Report* and earlier reports

Source: UNESCO Institute for Statistics database, November 2009; Iranian Central Bank (2009) *National Accounting Report 2001–2009*

Table 2: Socio-economic indicators for Iran and other South West Asian countries, 2000 and 2007

	GDP (current PPP US$ millions)			GNI* per capita (current international dollars PPP)			High-tech exports (% of manufactured exports)		Internet users (% of population)	
	2000	2007	average growth rate (%)	2000	2007	average growth rate (%)	2000	2007	2000	2007
Afghanistan	19 429	27 139	5.7	–	–	–	–	–	0.1	1.84 $^{+1}$
Armenia	9 733	17 139	10.9	2 080	5 870	26.03	4.54	2.03	1.30	5.74 $^{-1}$
Azerbaijan	23 634	64 082	24.4	2 080	6 570	30.84	5.37	3.94	0.15	10.83
Bahrain	10 053	24 245	20.2	20 030	–	–	0.03	0.05	6.15	33.21
Georgia	–	–	–	2 150	4 760	17.34	10.77	7.12	0.49	8.18
Iran	374 582	776 538	15.3	6 790	10 840	8.52	1.89	6.17	0.98	32.38
Jordan	125 841	185 883	6.8	3 260	5 150	8.28	7.98	1.12	2.65	19.70
Kazakhstan	19 380	28 038	6.4	4 480	9 600	16.33	3.94	23.25	0.67	12.27
Kuwait	87 293	167 467	13.1	35 010	–		0.78	–	6.85	33.80
Kyrgyzstan	31 351	114 597	37.9	1 250	1 980	8.34	17.64	2.44	1.05	14.33
Lebanon	18 647	41 431	17.5	7 510	10 040	4.81	2.34	2.39	7.95 $^{-2}$	38.32
Oman	29 018	51 019	10.8	14 440	–		3.09	0.46	3.75	13.08
Pakistan	266 159	409 973	7.7	1 690	2 540	7.19	0.39	1.37	–	10.77
Qatar	43 811	56 303	4.1	–	–		0.00	0.01	4.86 $^{-1}$	41.98
Saudi Arabia	235 563	554 250	19.3	17 490	22 950	4.46	0.40	0.61	2.23	26.41
Syrian Arab Republic	57 561	89 759	8.0	3 150	4 430	5.80	0.53	0.82	0.18 $^{-1}$	17.45
Tajikistan	7 105	11 821	9.4	800	1 710	16.25	41.77	–	0.05	7.18
Turkey	455 336	922 189	14.6	8 600	12 810	6.99	4.85	0.38	3.71	16.45
Turkmenistan	20 567	22 607	1.4	–	–	–	4.89	–	0.13	1.41
United Arab Emirates	48 855	195 396	42.8	41 500	–	–	0.69	0.66 $^{-1}$	23.56	51.78
Uzbekistan	60 431	65 167	1.1	1 420	2 430	10.16	–	–	0.49	9.08 $^{+1}$
Yemen	15 634	52 285	33.4	1 710	2 200	4.09	–	–	0.09	1.61 $^{+1}$

-n/+n = data refer to *n* years before or after reference year

* Gross national income is made up of a country's GDP plus any income earned abroad, such as dividends or interest on loans, from which is subtracted similar payments made to other countries.

Note: The countries selected for this table correspond to Iran's 20-year vision of topping this list of countries by 2025 for various socio-economic indicators. Only Iraq is missing, for lack of data.

Source: World Bank, World Development Indicators, July 2009

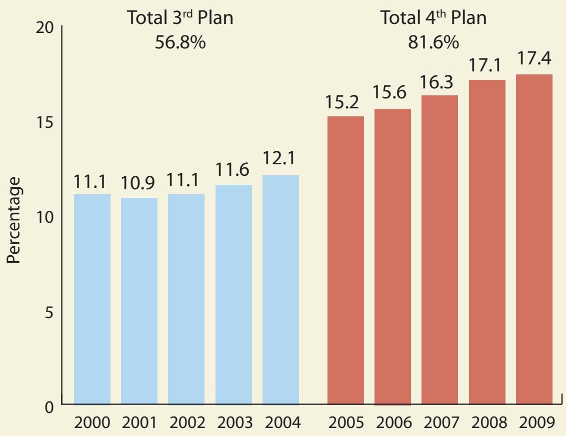
governments to assign a US$16 billion ceiling for government withdrawals of oil revenue during the country's successive development programmes, especially those since 1990. Oil revenue in the eight years of President Khatami's government (1996–2004) climbed to US$193 billion and in the first four years of President Ahmadinejad's government (2005–2009) to US$258 billion.

A trend towards privatization

More than 60% of industrial production in Iran is supplied by government companies. In 2006, the government announced an ambitious Industrial Privatization Programme to sell off the country's major companies to the private sector, such as the Ahwaz Steel Company or Iran's Communication Company.

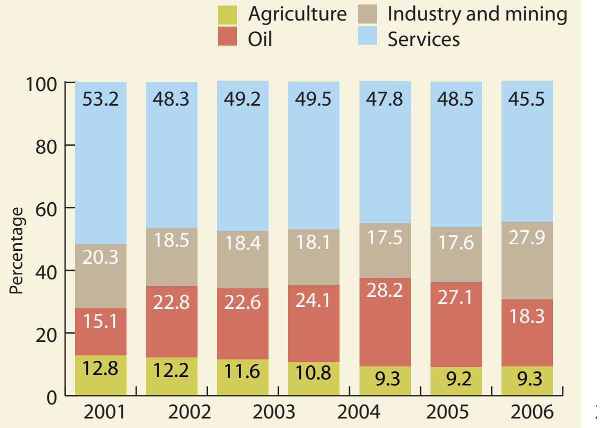
The financial sector remains dominated by state banks, even though four private banks were established in early 2000 and major public banks were gradually being privatized in 2009. Banks have become an important source of funding for the private sector. In 2007, they provided 94% of liquidities to private companies, compared to just 4% in 1990. This increase implies that the largely state-controlled banking system has been a significant contributor to economic growth. Borrowing facilities have grown along with the increase in the money supply: 60% of deposits held in Iranian banks were made available to borrowers in 1998, a share which had risen to 85% by 2007. The Iranian banking system has been harnessed to help the country improve its competitive advantage, upgrade technology and stimulate

Figure 1: Share of oil revenue in Iran's budget, 2000–2009 (%)



Source: Iranian Central Bank (2007*a*) *Economic Evolution*. Report. Tehran

Figure 2: Share of economic sectors in Iranian GDP, 2001–2007 (%)



Source: Iranian Central Bank (2007*b*) *National Accounting Report 2001–2007*, p.16

productivity and economic growth. As a consequence of being indexed on the economy, however, the banking system has also become dependent on the oil economy.

A slowly shrinking income gap

The income gap is shrinking in Iran but remains wide. Whereas the richest citizens earned 22 times as much as the poorest in 1990, this ratio had dropped to 17 by 2004. This is higher than the ratio for Pakistan (8:1), Indonesia (7:1) or Thailand (12:1). The picture is the same if we take some developed countries: France (9:1), Switzerland (10:1) and Germany (7:1) [Iranian Central Bank, 2008].

Some 4.5 million Iranians, or 1.5 million poor households, are covered by government social welfare networks and charities. Subsidies have a major impact on the economy. One of the most important challenges for the Iranian economy in recent years has been to reduce non-targeted energy subsidies, which constitute 10% of GDP and do not always go to those most in need.

In all, 48 million Iranians are entitled to health insurance provided by their private or government employer. A non-governmental charity, the Comit-e Emdad Imam Khomeini, provides additional coverage for four million poor. The country's social security system includes health care, training, retirement and unemployment benefits, as well as subsidies for energy, food, housing and other social services.

S&T POLICY CHANGES AND TRENDS SINCE 2000

Even after 60 years of experience, there remains a lack of methodological studies and critical reviews in policy-making and planning in Iran, particularly when it comes to technology policy. This dearth of action plans, programmes and overarching policies seems to be one of the main factors behind the difficulties encountered in implementing public policies up until now. S&T planning, like other areas of policy-making in Iran, is dominated by a comprehensive planning model which ignores priorities, thereby preventing a focus on the most important problems. By refusing to prioritize, this model leads to an unfair system of budget allocation (Tofigh, 2006).

The other characteristic of S&T policies is their inadequate orientation towards problem-solving. A centralized, bureaucratic approach to S&T policy-making allows academic, bureaucratic or political elites to impose their own priorities on the science agenda. Theories and models for S&T policies are 'imported' from abroad and consequently ignore Iran's socio-economic situation, be it the business world's preoccupations, trade, international collaboration or social problems. This weakens the private sector and could be a determing factor in the inefficacy and inefficiency of S&T policies.

As Shahmirzaii (1999) observes, 'because of the presence of a science pull approach in technological development, aspects like industrial standardization, the engineering regulatory system, support for design companies, collaborative research between industrial enterprises, the technical inspection system, export of technical and engineering services, spreading new technologies to industries … are ignored'.

As the highest authority for public policy-making in Iran, it is the Expediency Council which develops these 'grand policies' for the Leader of the Islamic Republic of Iran, including in the area of S&T.[1] Grand policies are elaborated to achieve the goals of the *Vision* document, which identifies the mains goals of Iranian society for the coming 20 years.

Once the grand policies have been developed by the Expediency Council, they are officially communicated by the Leader of the Islamic Republic of Iran to the legislative, executive and judicial branches. The grand policies for S&T in the *Fourth Development Plan* (2005–2009) are:

- Development of the higher education system, research centres, basic science and applied research;
- Optimization of education and research infrastructure, together with improving scientific productivity and efficiency;
- Education and training of researchers and university professors and, for those already in employment, development of their scientific and practical skills and ideological quality;
- Design of a system for ranking universities and researchers based on criteria such as efficiency and effectiveness, scientific productivity, applied research and technological development, or the problem-solving nature of their research;
- Collection of governmental and non-governmental statistics, development of a scientific information system. Creation of structures for applying the results of scientific research;
- A greater role for universities and research centres in promoting effective government and defending religious beliefs;
- Development of technological capacities and improvement of Iran's position in global technology, knowledge production, etc.

The *Plan* sets out to achieve these goals via action plans and policy packages collectively known as 'development documents' and a one-year budgeting system prepared by the Management and Planning Organization, which was renamed the President Deputy for Strategic Monitoring[2] in 2009.

As we have seen above, the centralization of S&T policy-making is one of the characteristics of government. The aim of this centralization is to co-ordinate all agencies and ministries. This is reflected in the transformation of the Ministry of Science and Higher Education into the Ministry of Science, Research and Technology (MoSRT) in the *Third Development Plan* (2000–2004) and its new mandate as co-ordinator of all scientific activities. However, in order to co-ordinate different activities and avoid overlap with the Ministry of Health and Medical Education, the Ministry of Energy and the Ministry of Agriculture, not to mention the many other institutions with a mandate for S&T, a new post was created in 2005, that of President Deputy for Science and Technology. This deputy reports to the president and is responsible for co-ordinating all S&T activities for which the budget and planning are centralized. Up until the creation of this post, the ministerial Supreme Council of Science, Research and Technology had fulfilled this role but had failed to fully achieve its objectives.

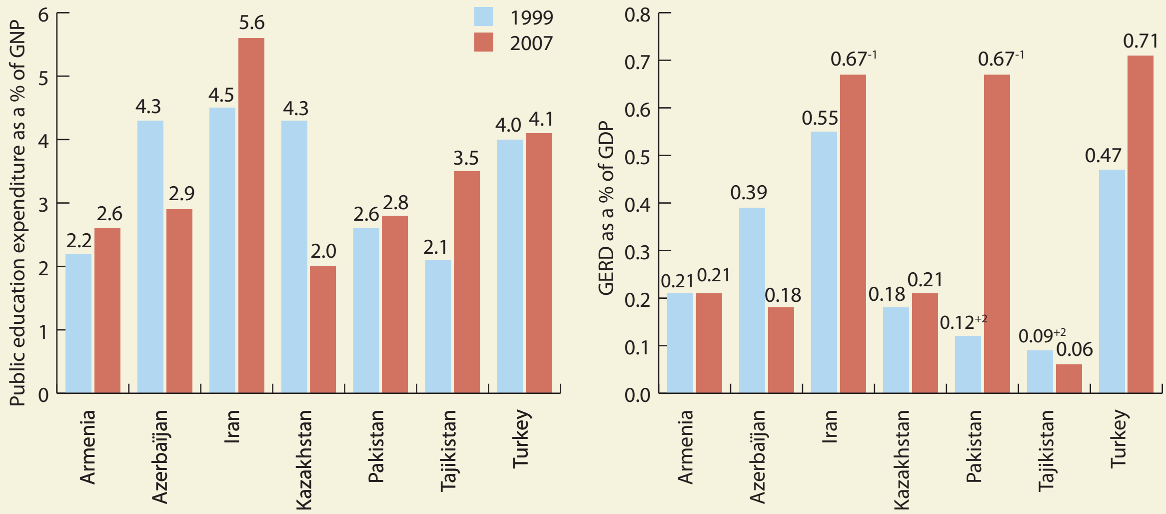
The other objective of centralization is to strengthen the national innovation system. This system is perceived as a means of avoiding the dispersal of public policies and budget wastage by facilitating interaction between

1. According to the *Constitution*, the Leader ratifies grand policies after 'consultation with the Expediency Council' (Article 110). The members of the Expediency Council are nominated by the Leader (Article 112), currently Ayatollah Ali Khamenei. They are political personalities drawn from different factions, as well as experts and officials such as the president, the chief of the judiciary and the speaker of Parliament.

2. The President Deputy is a full administration that is not subordinated to any ministry. On the contrary, the various ministries are expected to co-ordinate their work with that of the President Deputy.

Figure 3: Public expenditure on education and GERD in Iran, 1999 and 2007 (%)

Other countries are given for comparison



-n/+n = data refer to *n* years before or after reference year

Source: for education: UNESCO (2010) *Reaching the Marginalized. Education for All Global Monitoring Report*, Table 11; for R&D: UNESCO Institute for Statistics database, February 2010

multiple systems and sub-systems such as the national education and economic systems.

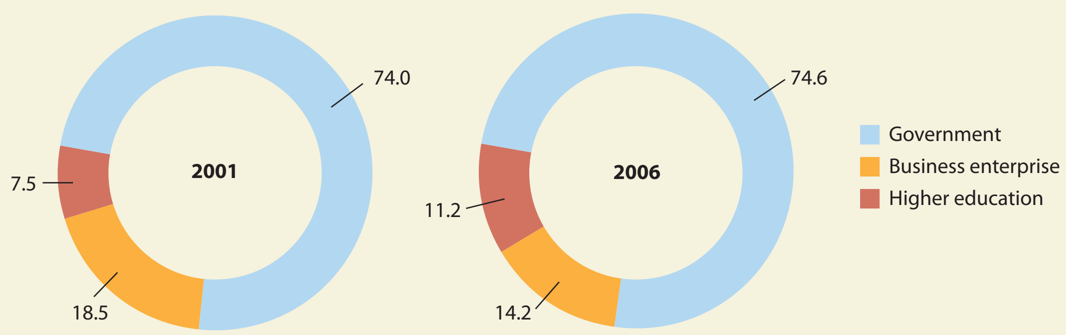
Policy-making in S&T is executed by different institutions that include the President Deputy for Science and Technology, MoSRT and the Ministry of Health and Medical Education. Although this demonstrates broad-based attention to S&T issues, the complex co-ordination mechanism and division of tasks this necessitates can complicate the execution of S&T policy.

R&D INPUT

Growth in R&D expenditure

GERD rose by 41% in 2004, 64% in 2005 and 65% in 2006. According to the UNESCO Institute for Statistics, Iran devoted 5.1 billion rials to R&D in 2002, 8.3 billion in 2004 and as much as 13.7 billion in 2006. This translates into a GERD/GDP ratio of 0.67% in 2006, compared to 0.55% seven years earlier (Figure 3). More than 74% of GERD is provided by the government, the remainder coming from business

Figure 4: GERD by source of funds in Iran, 2001 and 2006 (%)



Source: UNESCO Institute for Statistics database, February 2010

(14%) and higher education (11%). Interestingly, the role of business R&D has even declined somewhat in recent years, in favour of the higher education sector (Figure 4).

When we compare Iran with a non-oil economy like Turkey, the reality supports the hypothesis that an oil economy has a negative impact on the business sector. In Turkey, business expenditure on R&D made up 48% of total GERD in 2007 (up from 41% in 2002), compared to just 14% in Iran (*see page* 205).

TRENDS IN HUMAN RESOURCES

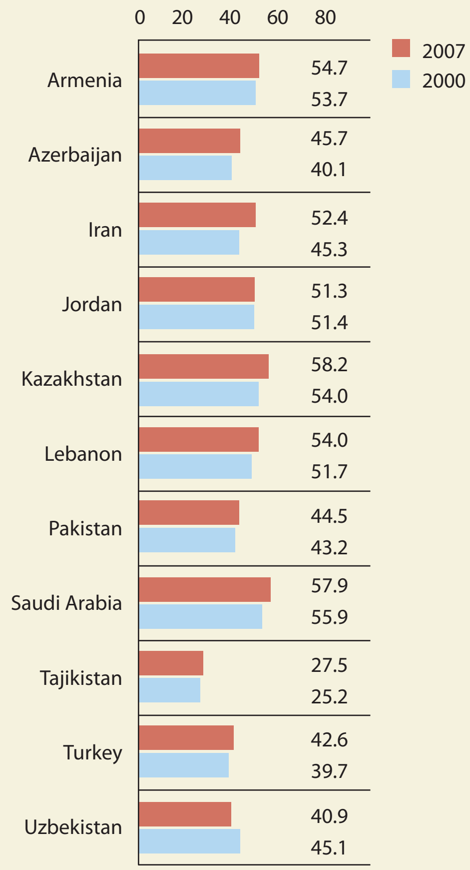
A gender imbalance that favours women

The share of female students in higher education has risen steadily from 45% in 2000 to 52% in 2007 (Figure 5) and even more than 65% in 2009, according to preliminary data. Consequently, public policy-makers need to acknowledge the changing roles of men and women in Iranian society by facilitating career opportunities for women and fostering a supportive cultural climate for women wishing to combine a career with raising a family.

A strong demand for higher education

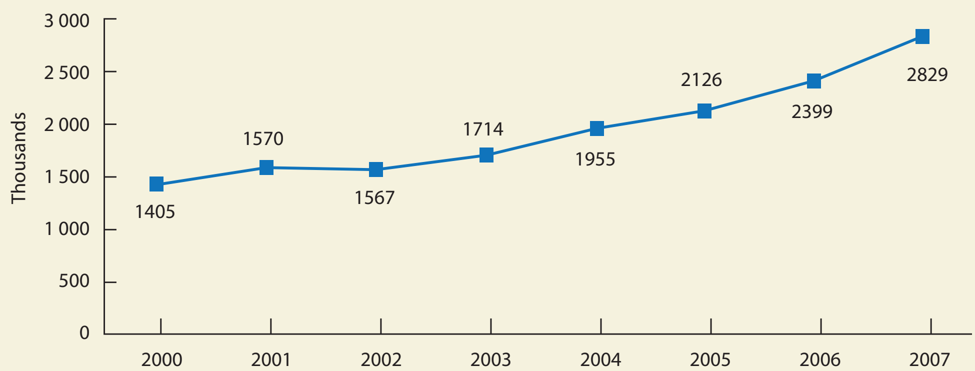
For the past 30 years, Iran has been expanding its university admission capacity. By the turn of the century, universities had a capacity of about 160 000 students. By 2009, this number had risen to 1 500 000 students. At the graduate level, the increase has been nearly as spectacular: 10 000 graduates in 2000 and 81 000 in 2009. Full and part-time enrollment in both public and private tertiary institutions doubled between 2000 and 2007 from 1 404 880 to 2 828 528 (Figure 6).

Figure 5: Female university students in Iran, 2000 and 2007 (%)
Other countries are given for comparison



Source: MoSRT

Figure 6: Trends in university enrollment in Iran, 2000–2007



Note: Data encompass both public and private universities and full and part-time study.

Source: MoSRT (2008) *Report for Scientific Road Map*

In the past 20 years, Iran has deployed students and researchers abroad, either to study or to present their scientific achievements in international scientific conferences. One example is collaboration between the UK and Iran in higher education and research (British Council *et al*., 2005). Today, numerous Iranian students are pursuing their studies abroad in different disciplines. The cost is borne mainly by the students themselves but the government also offers study grants.

R&D OUTPUT

Trends in scientific publishing

The expansion of higher education in general (Figure 6) and graduate studies in particular has in turn improved Iran's standing in international journals. The number of Iranian articles published in the natural and social sciences and engineering rose by 123% between 1995 and 2005, according to Thomson Reuters' Science Citation Index (SCI). In the seven months to July 2009, Iranian scientists published 10 991 articles in international journals. This compares with 10 361 in 2007 for the entire twelve-month period and 13 569 in 2008, according to MoSRT (Figure 7). Not surprisingly, the number of researchers per million population has similarly risen from 500 in 2000 to 850 in 2007, according to MoSRT.

Figure 8 illustrates the contribution of different scientific disciplines over the past sixteen years. Iran has been consistently strong in engineering but clinical medicine has replaced chemistry as the second most prolific field of Iranian science in recent years.

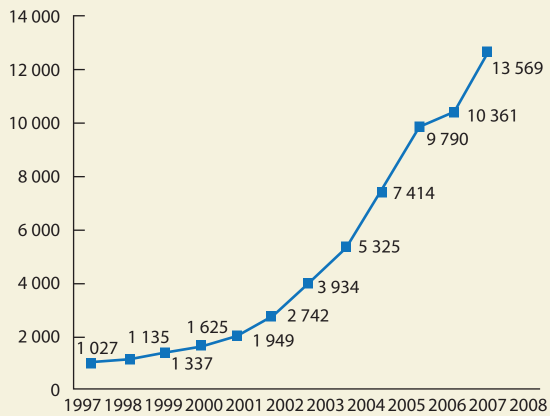
Since 1999, Iran has overtaken Pakistan, Malaysia and South Africa in scientific publishing. According to MoSRT, scientific publishing has grown faster in Iran than anywhere else in the world in recent years. International collaboration as measured by scientific articles has also increased markedly (Figure 9).

Today, the Iranian government is attempting to use another international index known as the Islamic World Citation Database (ISC). This database recorded more than 73 000 articles for Iranian scientists from 2000 to 2008. The Council of the Cultural Revolution and the MoSRT have put incentives in place to encourage scientists to submit papers to the ISC, such as the promise of promotion to a higher grade for university professors.

POLICY ENVIRONMENT FOR BUSINESS R&D

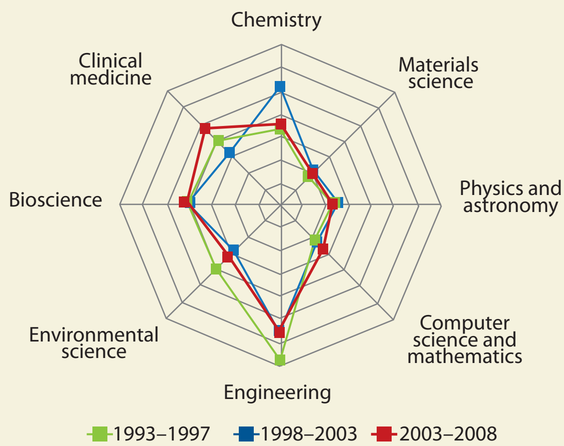
Progress in developing new technologies is hampered in Iran by the cost of setting up a business, weak intellectual property rights and government domination of large enterprises. Over the past 15 years, the government has set up high executive councils in nanotechnology, biotechnology, fuel cell technology and information and

Figure 7: Articles published in international journals by Iranian scientists, 1997–2008



Source: MoSRT (2008) *Report for Scientific Road Map*

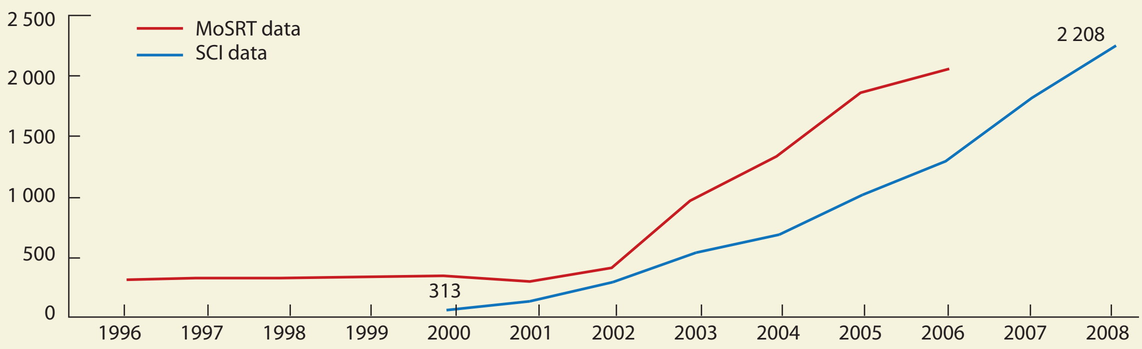
Figure 8: Share of scientific disciplines in Iranian publishing, 1993–2008



Source: MoSRT (2008) *Report for Scientific Road Map* communication technologies (ICTs) to support the development of new technologies and protect them from market fluctuations (see also Box 1).

The Centre for New Industries was established within the Ministry of Mining and Industry during the *Third Development Plan*. The role of this centre is to define

Figure 9: International scientific co-authorship in Iran, 1996–2008



Source: MoSRT (2008) *Report for Scientific Road Map; Thomson Reuters Science Citation Index*. Compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

Box 1: Biolarvicides and beauty products from biotechnology research

The Persian Gulf Biotechnology Research Centre was set up on the island of Qeshm in southern Iran in 1997 by Nasrin Moazami, founder of the Biotechnology Research Centre at the Iranian Research Organization for Science and Technology (IROST) in Tehran in 1982. The plant develops plant propagation using the tissue culture of bananas, orchids and date palms to increase agricultural productivity. It also explores the qualities of coral for health applications. Coral is strikingly similar to bone, with a 98% degree of compatibility. This makes coral a potential substitute for bone transplants in patients, as there is no risk of rejection by the human body.

The sea offers endless possibilities for product development using biotechnology. Algae, for example, can be used as a biofertilizer for agriculture; it can be fermented to produce methane and methanol for use in cooking and to fuel cars. Algae can also be marketed on the food, health and beauty markets.

The centre is also exploring the potential of *Aloe vera*. This plant can be marketed as a highly nutritious supplement or even in the form of a moisturizing cream. As it stimulates the body's immune system, it is also effective in healing intestinal diseases.

Qeshm island has also been the theatre of trials to test a biolarvicide known as *Bacillus thuringiensis M-H-14*, which was also successfully tested elsewhere in southern Iran and in Sudan before being registered at the European Patent Office in 2003. This toxin hones in a on a receptor in the gut that only the *Anopheles* mosquito possesses, making the biolarvicide innocuous to all other living species, including human beings. The bacterium was isolated from dead *Anopheles stepehensis* larvae, a major vector of malaria in Iran. The biolarvicide was developed by a research team led by Nasrin Moazami at the Biotechnology Research Centre in Tehran. Since November 2004, it has been manufactured under the trademark of Bioflash by the Iranian Nature Biotechnology Company, founded in 1999.

The Biotechnology Research Centre is a member of UNESCO's global network of microbial resource centres in developed and developing countries, which co-operate in microbiological and biotechnological research.

Source: Moazami (2005)

For details: moazami@hotmail.com

Box 2: Developing high-tech industries via IDRO

Since its inception in 1967, Iran's Industrial Development and Renovation Organization (IDRO) has established and developed general contractor companies in different fields. Today, it promotes domestic and foreign investment in minority holdings it owns in new, high-tech and export-oriented industries in particular. These high-tech areas include ICTs, advanced materials, biotechnology and life sciences, electronics, micro-electronics and nanotechnology.

According to Article 44 of Iran's Constitution, all large-scale industries are public property. IDRO controls about 290 companies, making it one of Iran's largest holding companies. Major companies owned by IDRO include Industrial Projects Management of Iran (IPMI), the Rail Transportation Industries Company (RTI), Pars International Development and Engineering Company (PIDECO), the Iranian Offshore Engineering and Construction Company (IOEC), Construction Projects Management of Iran (MAPSA), the Langroud Gas Production Company (GTL), the Arya Oil and Gas Development company (ARYA) and the Iran Industrial Consultant Engineering Company (IIC).

IDRO supports high-tech development from the earliest stages of a project, when it is still no more than an idea, through to the delivery of products and services to the market. IDRO develops an entrepreneurship development plan and innovation development plan for affiliated companies wishing to set up pilot plants to scale up research projects. It also runs a Small Business Development Centre.

As part of its mission for attracting local and foreign investors to high-tech industries, IDRO prepares a feasibility study and business plan, and identifies potential investors and technology providers in order to establish partnerships and joint ventures. IDRO also sets up small and medium-sized enterprises with local and foreign partners to execute approved projects and commercialize technology. Partners invest in industrial plants set up through technology transfer.

IDRO has founded special-purpose companies in each high-tech sector to co-ordinate investment and business development. These entities are the Life Science Development Company (LIDCO), Information Technology Development Center (MAGFA), Iran InfoTech Development Company (IIDCO), Advanced Materials Industrial Development Company (AMIDCO) and the Emad Semiconductor Company.

In 2009, IDRO was planning to set up a venture capital fund to finance the innovation cycle. The fund will focus on the intermediary stages of product and technology-based business development. One of IDRO's subsidiaries, the Entrepreneurship Development Company of Iran, has done a lot of preparatory work for this fund.

By March 2010, it is expected that IDRO will have offered private investors shares in 150 industrial companies. IDRO has privatized 140 of its companies in the past for a value of about 2000 billion rials (about US$ 200 million). This strategy follows an amendment to Article 44 of the Constitution in 2004 which set in motion a ten-year plan to privatize 80% of Iran's state-owned assets

Source: www.idro.org ; Press TV (2009)

policies and implement strategies to develop new industries in high technologies in particular. It also promotes a business climate for private enterprises.

The centre's first step has been to prepare a strategic plan for electronic industries encompassing communication technology, micro-electronics, the automation industry and so on, as well as for new materials, biotechnologies, information technologies, civil airspace, laser technology and optics, and nanotechnologies.

Iran's Industrial Development and Renovation Organization (IDRO) has established joint ventures with the private sector since the beginning of the *Third Development Plan* to develop new industries (Box 2). As of 2002, five foreign investment projects had been set up with a budget of US$ 300 million (MPO, 2003).

With regard to infrastructure, the government had planned to develop the country's technology parks, incubators, visionary technology institutions, techno-markets and clusters during the *Third* and *Fourth Development Plans*.[3] The success of this kind of policy

3. As of 2010, Iran had 21 science and technology parks and more than 60 technology incubators.

Box 3: The Iranian Fisheries Research Organization

One of the country's major research centres is the Iranian Fisheries Research Organization (IFRO).

IFRO performs applied research to determine how best to protect aquatic organisms and their environment. The aim is to replenish fish stocks and exploit them sustainably in Iranian waters. This goal is mentioned in Article 3 of the constitution of the Iranian Fisheries Company, adopted in 1985. It also figures in the second law governing the protection and exploitation of aquatic resources, adopted by Parliament on 5 September 1995.

IFRO pursues scientific co-operation with the United Nations Food and Agricultural Organization, INFOFISH, the Southeast Asian Fisheries Development Centre, FISHBASE, the World Conservation Union's NACA network of aquacultural research centres across 18 countries in the Asia–Pacific region, the Indian Ocean Tuna Commission, World Fish Centre (GOFAR), the Convention on International Trade in Endangered Species of Wild Fauna and Flora, and Gent University in Belgium. IFRO is also a member of the European Aquaculture society, Marine Technology Society, Asian Fisheries Society, World Aquaculture Society and World Sturgeon Conservation Society.

Source: IFRO

depends on macro-economic conditions, intellectual property regimes, international co-operation and trade to reduce the risks, particularly for small and medium-sized enterprises and the broader private sector. To create conditions that will be conducive to the development of infrastructure, you need to improve supporting networks and providers, and to develop R&D in the private sector. Without these foundations, the private sector remains weak, increasing the need for government intervention. As the government itself is faced with budgetary limitations, this creates a major problem. Moreover, centralized public policy breeds supply-oriented – as opposed to demand-driven – S&T policy, as stated earlier.

Both public and private enterprises are involved in international co-operation in licensing and technology transfer in various areas, such as ICTs and the oil industry. Examples are the involvement of the Mouj enterprise in point-to-point radio and digital switch technology in collaboration with the Republic of Korea and the sale of the *Samand* automobile license belonging to the Iranian Khodro company.

Iran is developing scientific co-operation with the Organization of Islamic Countries (OIC). It also plays an active role in the Indian Ocean Rim Association for Regional Co-operation[4] and in the Economic Cooperation Organization (ECO),[5] for which it was the host country in 2004, 2005 and 2006. Iran is also spearheading an agricultural biotechnology network to connect national biotechnology institutes, researchers, scientists, engineers, and policy-makers from ECO member countries and promote the continual exchange of knowledge and research results (see also Box 3).

PROGRESS TOWARDS AN INFORMATION SOCIETY

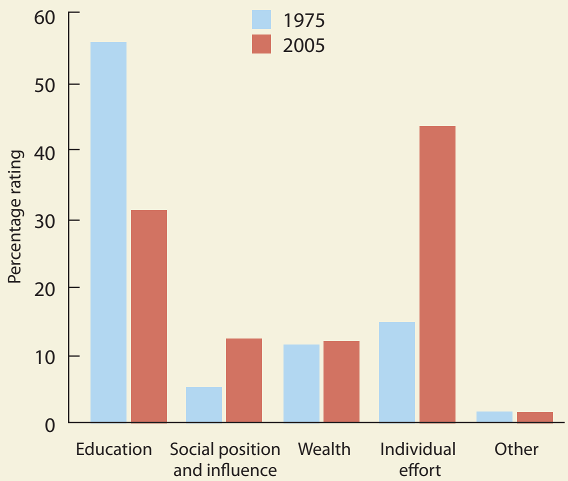
E-readiness refers to the state of play of a country's ICT infrastructure. In this index, Iran ranked 69th in 2007 and 65th a year earlier (Economist Intelligence Unit, 2007). This index has been developed by the Economist Group. 'The ranking model evaluates the technological, economic, political and social assets of 69 countries and their cumulative impact on their respective information economies.' Iran's ranking might improve if scientific and educational criteria were factored into the model. The index for high-tech acquisitions by developing countries ranges from 0.51 to 0.74. On this scale, Iran is indexed at 0.26 among active acquisition countries like India, Brazil, and Egypt (MPO, 2003).

In terms of access to technology, Iran has made rapid progress. About 32% of the population used Internet in 2007, for example, up from barely 1% seven years earlier (Table 2).

4. The association promotes linkages between businesses in member states (see Annex I for a list of countries). Projects and programmes are run under the umbrella of three separate working groups: the Working Group on Trade and Investment; the Indian Ocean Rim Business Forum; and the Indian Ocean Rim Academic Group.

5. See Annex I for the ECO and OIC member states.

Figure 10: Iranian attitudes toward towards success in life, 1975 and 2005



Source: Goodarzi (2008) *National Survey on Cultural Change and Social Attitudes of Iranians* 2005, p.214.

PUBLIC ATTITUDES TOWARDS SCIENCE

Among residents of Tehran, as many as 85.8% of respondents to *A National Survey on Socio-cultural Attitudes* in the 1990s considered science and knowledge to be 'a very important social value' (Mohseni, 1996). A further 13.7% considered them to be 'more or less important' and just 0.6%, or 15 respondents out of 2320, 'not important at all.' These results were mirrored in the rest of the country. In the respondents' ranking of social values, science came after reputation, health or honesty but before wealth, position and fame.

Another national survey in 2005 studied cultural changes within Iranian society. It found that Iranians equated success in life first with individual effort then with education, followed by position then familial influence and, lastly, wealth. In a similar survey in 1975, Iranians had placed education ahead of individual effort, education being still a scarce resource at the time (Goodarzi, 2008). Thanks to improvements in education, equality has progressed in Iran, making individual effort more important than before (Figure 10).

In sum, we can conclude that Iranian society greatly values science and that this has been one of the main factors behind the development of both public and private higher education in Iran. In spite of economic difficulties, people spend a large share of their budget on private tertiary education. Privately owned Azad University has even become one of the biggest universities in the world thanks to its paying students.

CONCLUSION

We have seen in these pages that the particularity of an oil economy is that it can invest in S&T regardless of the social and scientific contexts. S&T policy should insist on the role of the private sector in R&D. A move towards participatory planning with the co-operation of the private sector could offer a valid alternative to centralized, bureaucratic planning in S&T policy. This would create an environment conducive to substituting the current science pull for an orientation towards technology push, thereby allowing socio-economic factors to play a role in S&T policy.

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The main challenge facing the country will be to improve both the quality and quantity of S&T personnel. Fortunately, policy-makers are seized of this problem and have taken energetic steps to remedy the situation.

Sunil Mani

17 · India

Sunil Mani

INTRODUCTION

The impressive performance of India's economy since liberalization of the economy got under way in 1991 – and especially since 2005 – has been much talked about. Along with China, India has become one of the fastest-growing economies in the world, strong enough to withstand the brunt of the global recession since 2008. If growth in GDP dipped from 9.4% in 2007 to 5.7% in 2009, it was expected to climb back to 8.8% in 2010 (IMF, 2010). A number of studies have identified technological development as one of the drivers of India's strong economic growth. The country's science system has undergone perceptible changes over the past five years or so:

- Although India's R&D intensity increased only slightly between 2003 and 2007, from 0.80% to 0.88% of GDP, the share of the business enterprise sector in gross domestic expenditure on research and development (GERD) leapt from 18% to an estimated 28%. As the government share of GERD remained stable at 0.61% of GDP over the same period, the 10% rise in the GERD/GDP ratio can be attributed to the dynamism of the private sector;

- The state continues to accord great importance to public research and development (R&D) in certain high-tech areas, such as space, information technology (IT) and pharmaceuticals; moreover, public R&D itself has become more commercial and market-driven;

- The state has come to recognize the need to improve both the quantity and quality of scientific personnel by inaugurating a host of new tertiary institutions focusing on science and engineering education. This issue is discussed further on page 366;

- There has been a tremendous increase in the number of foreign R&D centres, which have grown from fewer than 100 in 2003 to about 750 by the end of 2009. Most of these R&D centres relate to information and communication technologies (ICTs) and the automotive and pharmaceutical industries;

- Indian companies have been investing abroad and acquiring important technology-based companies in medium-tech and high-tech sectors. Examples are Tata Steel's takeover of the British industrial giant Corus, Bharat Forge's takeover of forging companies in Germany, the UK and the USA, and Suzlon's takeover of wind turbine companies in Germany.

These five factors are slowly but steadily remodelling the science and technology (S&T) landscape in India. In the pages that follow, we shall survey developments since 2005 to the extent that data availability allows.

THE RISE OF INNOVATION IN INDIA

In recent years, there has been much discussion in the popular press about the rise of innovation in India. This has most likely been precipitated by the following factors:

- **India's rank in the Global Innovation Index[1] has improved.** According to EIU (2009), India's rank in the Economist Group's Global Innovation Index for 82 countries progressed from 58th place in 2006 to 56th in 2008, with a further progression predicted to 54th place by 2013. India has emerged as the fifth-largest economy in the world in purchasing power parity (PPP) dollars (World Bank, 2008). However, in relative terms, India's economy is just half the size of China's, which is growing at a faster rate: 8.7% in 2009 after progressing by 10% or more for six years in a row. India's GDP growth slipped back to 7% in 2007 and to less than 6% in 2009, after climbing from 5% in 2002 to a steady 9% in 2005–2007 (IMF, 2010).

- **There are many instances of innovation in the services sector, especially as concerns health care.** Currently, the services sector accounts for two-thirds of GDP in India (*see page* 324). Both the services and manufacturing sectors have been performing very well. For a very long time, Indian policy-makers avoided using the explicit term of 'innovation' in policy documents dealing with technological activities. The word 'innovation' appears in a policy document for the first time in 2008, in the draft National Innovation Act. This development reflects a broad sentiment in both policy and business circles that the country is becoming more innovative – or at least certain industries. In the manufacturing sector, the release of Tata's Nano brand in 2008 hailed the advent of 'the world's cheapest car', at US$ 2 200[2]. In the health sector, the MAC 400 machine produced by General Electric's

1. This index measures innovation performance in 82 countries, based on the number of patents awarded to inventors from different countries by patent offices in the USA, European Union and Japan. It also takes into account factors that help or hinder the ability to innovate, such as the GERD/GDP ratio and technical skills of the country's labour force. The index was created by the Economist Group, publisher of *The Economist* magazine.

A boy holds a phone to his mother's ear.

Photo: © UNESCO / Pankaj Arora

Table 1: Share of knowledge-intensive production in India's GDP, 2005–2009
In Rs millions, 2005 prices

	GDP	Knowledge-intensive manufacturing	Knowledge-intensive services	Knowledge-intensive production	Knowledge-intensive production (%)
2005	29 675 990	1 207 670	1 334 650	2 542 320	8.57
2006	32 491 300	1 454 220	1 651 780	3 106 000	9.56
2007	35 646 270	1 677 740	2 034 320	3 712 060	10.41
2008	38 934 570	1 822 770	2 483 210	4 305 980	11.06
2009	41 549 730	1 926 630	2 873 500	4 800 130	11.55

Note: Knowledge-intensive manufacturing refers to chemical and metal products and machinery, including electrical machinery and means of transport. Knowledge-intensive services refer to telecommunications and computer-related services plus R&D services. The data for 2006 exclude telecommunications, as the Central Statistics Organization did not report this information for this year.

Source: Indian Central Statistics Organization, 2010

John F. Welch Technology Centre in Bangalore records a patient's electrocardiogram; as it is portable, it can be used in rural areas to diagnose heart disease.

- **The knowledge-intensity of India's overall output has expanded.** Currently, about 14% of India's net domestic product[3] is composed of knowledge-intensive production (Table 1), much of it from the services sector. Also noteworthy is that growth in knowledge-intensive production surpasses that of the economy overall. Data show that the majority of new companies belong to knowledge-intensive sectors and that the number of knowledge-intensive enterprises has mushroomed over the past seven years or so. This trend is corroborated by the technology content of all industrial proposals implemented since the first economic reforms in 1991. Once again, with the exception of the textile industry and a few others, the majority of new proposals emanate from technology-oriented industries in areas such as chemicals, energy, electrical equipment and so on.

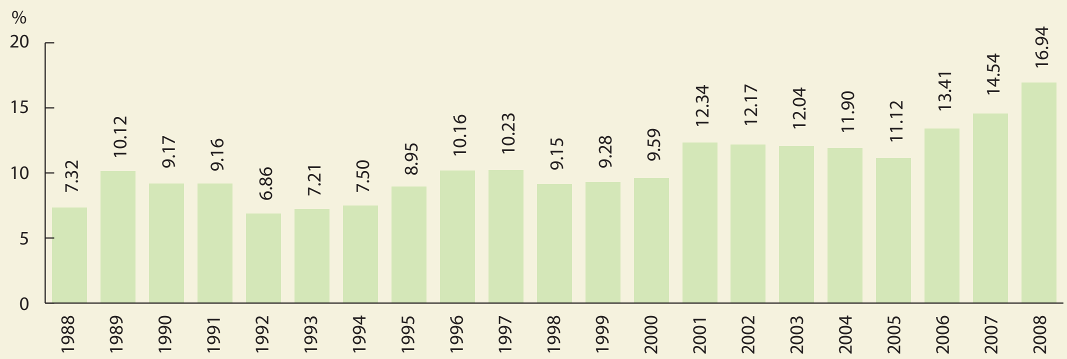
- **Foreign direct investment (FDI) from India has grown from just US$ 2 million in 1993 to about US$ 19 billion in 2009.** This includes some high-profile technology-based acquisitions abroad by Indian companies. However, information on the rate of survival of these ventures is unavailable. The amount of FDI flowing from India had always been insignificant until the trickle became a torrent from about 2005 onwards. Most of these investments have gone to technology-based ventures in the manufacturing sector of developed economies. According to Nayyar (2008), 'Indian firms could not have become international without the capacity and the ability to compete in the world market. The attributes of Indian firms, which created such capacities and abilities, are embedded in the past and have emerged over a much longer period of time'. According to *The Economist* (2009), the pursuit of technology is a powerful motive for foreign acquisitions. Before Tata Steel's purchase of Corus, Europe's second-largest steel producer with annual revenues of around £12 billion, the Indian steelmaker did not hold a single American patent. The takeover brought it over 80 patents, as well as almost 1 000 research staff. Thus, the growing number of foreign acquisitions of 'active targets', in technological jargon, has given Indian companies considerable access to the technological capacity of the acquired firms without their having to build this up assiduously from scratch. The same goes for mergers.

- **India has become more competitive in high-tech areas.** Although manufactured exports are still dominated by low-tech products, the share of high-tech products has doubled in the past 20 years (Figure 1). India has become the world's largest exporter of IT services since 2005 and exports of aerospace products

2. The Nano car was designed at Italy's Institute of Development in Automotive Engineering with component parts manufactured by an Indian subsidiary of the Germany company Bosch. Approximately two-thirds of the technology for Bosch products used in the Nano car is sourced from India. The initial production target is for 250 000 units per year.

3. Net domestic product is equivalent to gross domestic product minus depreciation.

Figure 1: High-tech content of India's manufactured exports, 1988–2008 (%)



Source: United Nations Comtrade database, applying the UNIDO (2009) definition of high-tech exports

have been increasing at a rate of 74% per year, compared to 15% for world exports of these products. India is acknowledged to have considerable technological capability in the design and manufacture of spacecraft and is now an acknowledged global leader in remote sensing (Box 1). According to Futron's 2009 ranking of ten entities in its Space Competitiveness Index[4], India ranks better than the Republic of Korea, Israel or Brazil. However, in India, the bulk of innovation in this area comes entirely from the government rather than from industry. By evoking the security angle, the government seems to have thwarted all attempts to create a sectoral system of innovation in the aerospace industry. This has prevented the country from emerging as a serious player in the civilian aerospace sector, despite possessing all the requisite ingredients. However, this situation is now set to change. Aerospace exports from India have increased manifold in recent years, even if these tend to be confined to aircraft parts or components. With approximately 300 small and medium-sized enterprises active in this area[5], India is slowly emerging as one of the few developing countries to have a high-tech industry of the calibre of its aerospace industry.

4. Futron Corporation in the USA offers a comparative assessment of ten leading players in space: Brazil, Canada, China, Europe, India, Israel, Japan, Korea (Rep.), Russia and the USA. The index assesses more than 50 individual metrics across three underlying dimensions of competitiveness: government, human capital and industry.

5. The Society of Indian Aerospace Technologies and Industries had over 300 members in 2009. Formed in 1991 and based in Bangalore, it brings together R&D, manufacturing and support services in aerospace. Members are drawn from both public- and private-sector industries and institutions dealing in one way or another with the aerospace industry.

A PROPITIOUS POLICY ENVIRONMENT

India has a long history of policies related to technology development, although no distinction was made initially between science and technology. The earliest attempt to support technical change in industry was the adoption of a Scientific Policy Resolution by Parliament in 1958. This policy laid the groundwork for training S&T personnel on a sufficient scale to satisfy the needs of the various economic sectors. This move was followed by a Technology Policy Statement in 1983, the main aim of which was to develop endogenous technology and ensure efficient absorption and adaptation of imported technology corresponding to national priorities and available resources.

In January 2003, the Prime Minister formally announced a new Science and Technology Policy, the main objective of which was to raise India's overall research intensity from 0.80% of GDP in 2003 to 2.0% of GDP by the end of the *Tenth Five-Year Plan* in 2007. Although this target has not been reached – the GDP/GERD ratio stood at 0.88% in 2007 – this policy contained four refreshingly new features:

- for the first time, a clear recognition of the extremely low density of scientists and engineers, even though a populous country like India counts a large number;
- an explicit statement on the need to manage brain drain;
- an emphasis on increasing the number of patents at home and abroad;

- an explicit mention of monitoring implementation of the policy, for instance stating that, 'effective, expeditious, transparent and science-based monitoring and reviewing mechanisms will be significantly strengthened and, if not available, will be put in place. It will be ensured that the scientific community is involved in, and responsible for, the smooth and speedy implementation'. This said, statistical indicators for measuring policy outcomes are still very rudimentary in India and what is meant by 'science-based monitoring' remains unclear. Another difficulty relates to the fact that the 11 strategies outlined in the policy document are extremely general. Much work needs to be done to give them a more concrete form. Only then will it be possible to evaluate whether or not the 2003 policy is a real improvement over its predecessor in 1983.

India's *Eleventh Five-year Plan* (2007–2012) contains provisions for a massive rise in the public outlay for S&T of 220% over the previous plan. It fixes eight primary objectives which confirm the growing emphasis on innovation:

- a national mechanism is to be set up to develop policies and provide orientations for basic research;
- the pool of S&T personnel is to be enlarged and infrastructure reinforced (*see below for details*); in parallel, efforts are to be made to attract and retain young people to careers in science;
- ten national flagship programmes are to be launched in areas ranging from the rural water supply, sanitation and health to telephony and education, with a direct bearing on India's technological competitiveness;
- globally competitive research facilities and centres of excellence are to be established (*see below*);
- an innovative spirit is to be kindled among scientists to encourage them to translate R&D leads into technologies that can be scaled up;
- new models of public–private partnership are to be developed in higher education, particularly as concerns university research and research in high-tech areas;
- ways and means are to be identified of catalysing industry–university collaboration;
- linkages with advanced countries are to be encouraged, including via participation in international megascience initiatives like the Large Hadron Collider at the European Organization for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor project (ITER) [*see page* 158] or the rice genome sequencing project. The latter is based at the Indian Agricultural Research Institute and involves collaboration with Brazil, Japan, the Republic of Korea and the USA, among others.

A key element of the policy are the linkages the government is seeking to establish between innovation and development. This is exemplified in the implementation of the national flagship programmes for improving the quality of primary education through schemes like Sarva Sikhya Abhayan[6] and in the intention to develop the private sector's role in establishing research-based universities. The plan also stresses the oft-repeated maxim of improving university–industry ties.

As we near the end of the period covered by the plan, to what extent has the policy lived up to its promise? One major outcome of the S&T chapter within the *Eleventh Five-Year Plan* has been the initiation of a system-wide consultation of stakeholders on a draft National Innovation Act by the Department of Science and Technology within the Ministry of Science and Technology. The main objective of this Act is to facilitate public or private initiatives and public–private partnerships to build an innovation support system; develop a national integrated science and technology plan; and codify and consolidate the law of confidentiality to protect confidential information, trade secrets and innovation. The proposed Act focuses on increasing investment in R&D and enacting data confidentiality clauses to make India a preferred destination for research-oriented companies in sectors like IT, pharmaceuticals and engineering. However, the draft Act is yet to come before Parliament and, as such, remains of purely academic value for the moment.

Improving the quality and quantity of human resources in science and engineering is another area of great importance to the government. In higher education, the

6. This scheme strives to give all children eight years of primary schooling and bridge the gender gap in elementary education by 2010, via community ownership of the school system.

government is seeking to raise the gross enrollment ratio from 11% in 2007 to about 15% by 2012 and 21% by 2017. To achieve the target of 21 million students by 2012, compared to 14.8 million in 2007, enrollment in universities and colleges will need to grow by an annual rate of 8.9%. This does not seem unattainable, as tertiary enrollment grew by 15% between 2006 and 2007. One-quarter of the student body is now enrolled in S&T fields, according to the UNESCO Institute for Statistics.

To this end, the government has opted to establish 30 new central universities which will be owned and managed by the central government: 16 new universities for those 16 states which did not have a central university

Box 1: A space odyssey

India has had a very dynamic space programme since 1969 when the Indian Space Research Organization (ISRO) was founded with headquarters in Bangalore and facilities spread throughout the country. The size and importance of India's space programme can be gauged from the fact that it is second only to the USA in terms of the public budget committed to space research: approximately 0.10% of GDP. Space research alone accounts for about 12% of GERD in India.

The history of the space programme since 1969 falls into two phases. During the first phase (1970–1980), ISRO used experimental satellite programmes like Aryabhatta, Bhaskara, Rohini and Apple for experimental learning. During the second phase in the post-1980 period, ISRO introduced endogenous satellite and launch vehicle design programmes.

ISRO's activities cover four areas of space research:

- Earth observations and remote sensing;
- satellite communications and navigation;
- space science and environment: spacecrafts Chandarayan 1 and 2 were the first to confirm the presence of water at the poles on the Moon in September 2009;
- launch vehicles.

Of these four areas, India excels in remote sensing, where it is considered a world leader, and in the design and manufacture of satellites and launch vehicles.

One important innovation in the area of remote sensing has been the development and launch of the beta version of its web-based three-dimensional satellite imagery tool, Bhuvan, in August 2009. Bhuvan will offer imagery of Indian locations superior to that provided by other Virtual Globe software like Google Earth and Wiki Mapia, with spatial resolutions ranging from 10 m to 100 m. For the moment, Bhuvan is available only for the observation of Indian locations, although it is capable of offering images of the entire planet. It is claimed to possess a number of characteristics which give it an edge over its immediate competitor, Google Earth. This said, given the large number of technical glitches from which the software suffers, its actual diffusion rate has been limited. Nevertheless, Bhuvan brings a new arc to ISRO's bow by combining both astronautic and software capabilities.

Between its inception in 1975 and 2009, India's satellite launch programme sent 55 satellites into orbit, about half of them for Earth observation and the remainder for communication. ISRO has also developed the technological capability to design and manufacture both Polar Satellite Launch vehicles and Geostationary Satellite Launch Vehicles (GSLV), although it has a better record for the former. Recently, it has managed to design highly complex cryogenic engines for its GSLV, although the technology has yet to be perfected.

Two aspects of India's space programme are worth noting. Firstly, ISRO has institutionalized an excellent procedure for learning from past failures in technology development. Secondly, it has managed to use this high technology for the benefit of the civilian, through the establishment of Village Resource Centres. This concept integrates the capabilities of communications and Earth observation satellites to provide information emanating from space systems and other IT tools, in order to address the changing and critical needs of rural communities. One example is the EDUSAT programme, launched by the GSLV in September 2004. EDUSAT is India's first satellite devoted exclusively to educational services, providing one-way television broadcasts, interactive television and video and computer conferencing, among other services. Networks have been set up in at least 24 states and programmes reach more than 35 000 classrooms, including schools for the blind via a specialized network.

Source: Mani (2010c)

Box 2: The incredible feat of Indian pharma

The pharmaceutical industry is one of India's foremost science-based industries, with wide-ranging capabilities in the complex field of drug manufacture and technology. The country produces pharmaceutical formulations – the process of combining different chemical substances to produce a drug – and over 400 active chemicals for use in drug manufacture, known as Active Pharmaceutical Ingredients (APIs).

Industry turnover has grown from a modest US$ 300 million in 1980 to about US$ 19 billion in 2008. India now ranks third worldwide after the USA and Japan in terms of the volume of production, with a 10% share of the world market. In terms of the value of production, it ranks 14th for a 1.5% global share.

A kaleidoscope of foreign and Indian firms of varying sizes occupy the manufacturing landscape. In all, there are about 5 000 firms engaged in manufacturing pharmaceuticals in India, which employ directly about 340 000 individuals.

Much of industrial growth is fuelled by exports. Between 2003 and 2008, exports grew by an average rate of 22%. India currently exports drug intermediates, bulk drugs, APIs, finished dosage formulations, biopharmaceuticals and clinical services. The top five destinations in 2008 were, in descending order, the USA, Germany, Russia, the United Kingdom and China.

The industry has four key characteristics:

- it is dominated by formulations;
- it is very active in the global market for generics, supplying even developed countries;
- it enables India to be self-sufficient in most drugs, as witnessed by a growing positive trade balance;
- it is one of the most innovative industries in India, in terms of R&D and the number of patents granted, both in India and abroad.

This fourth characteristic may very well be the most important for India, accounting for one out of every four abbreviated new drug applications (generic product approvals) in 2007 and 2008. The Indian pharmaceutical industry also accounts for approximately 25% of the drug master files with the US Food and Drug Administration (USFDA). India has the highest number of USFDA-approved plants of any foreign country.

What explains the dynamic growth of Indian pharmaceuticals in the past few decades? According to one hypothesis, the 1970 Indian Patents Act allowed Indian pharmaceutical companies to come up with very cost-effective processes for imitating known products, by not recognizing product patents for pharmaceutical products. Favourable to intellectual property rights, this policy thus afforded the industry a long learning period through a process of reverse-engineering essentially. A second hypothesis is that the pharmaceutical industry benefited from the availability of highly trained personnel with a solid scientific background. In fact, for many years, the Indian higher education system was biased in favour of science to the detriment of engineering. As a science-based industry, pharmaceuticals are purported to have benefited from this apparent bias.

One spin-off of India's innovative capability in pharmaceuticals is that it has become a popular destination for clinical trials, contract manufacturing and R&D outsourcing. These capabilities hold great promise for the Indian pharmaceutical industry, as an estimated US$ 103 billion of generic products are at risk of losing patents by 2012. Furthermore, the global market for contract manufacturing of prescription drugs is estimated to grow from US$ 26 billion to US$ 44 billion by 2015 or so. According to experts, the country has 'good' to 'high' skills in preclinical trials and Phase I clinical trials and 'very high' skills in Phase II and Phase III clinical trials.

A very recent trend observed in India's pharmaceutical industry is the wave of cross-border mergers and acquisitions in which Indian companies have taken over foreign ones and foreign firms have in turn taken over Indian companies. The pharmaceutical industry has become one of India's most globalized industries. One of the most high-profile takeovers concerns Ranbaxy, India's largest pharmaceutical company and the country's biggest producer of generic drugs. In 2008, the Japanese pharmaceutical giant Daiichi Sankyo acquired a majority stake (35%) in Ranbaxy, at a cost of up to US$ 4.6 billion.

Source: Mani (2010c)

before and 14 world-class universities. The Ministry of Human Resource Development plans to set up these 14 'innovation universities' across the country from 2010 onwards to build 'disciplinary foci' and drive R&D. Each 'innovation university' is expected to focus on one area or problem of significance to India, such as urbanization, environmental sustainability and public health. Two private companies have announced plans to build world-class universities of their own, Reliance and Anil Agarwal. The latter has even donated US$ 1 billion to get the Vedanta University project off the drawing board.

In parallel, the government is in the process of doubling the number of Indian Institutes of Technology to 16 and establishing 10 new National Institutes of Technology, three Indian Institutes of Science Education and Research, and 20 Indian Institutes of Information Technology to improve engineering education. These new universities and institutes are at various stages of creation. In 2006, the ministry founded the Indian Institute for Science Education and Research and the National Institute of Science Education and Research. The Indian Institute of Space and Technology followed a year later.

In addition, in 2010, the government was in the process of adopting a policy permitting foreign universities to enter the higher education system in India by establishing their own campuses or joint ventures with existing universities and institutes.

All of these changes augur well for the further development of science and engineering education in India.

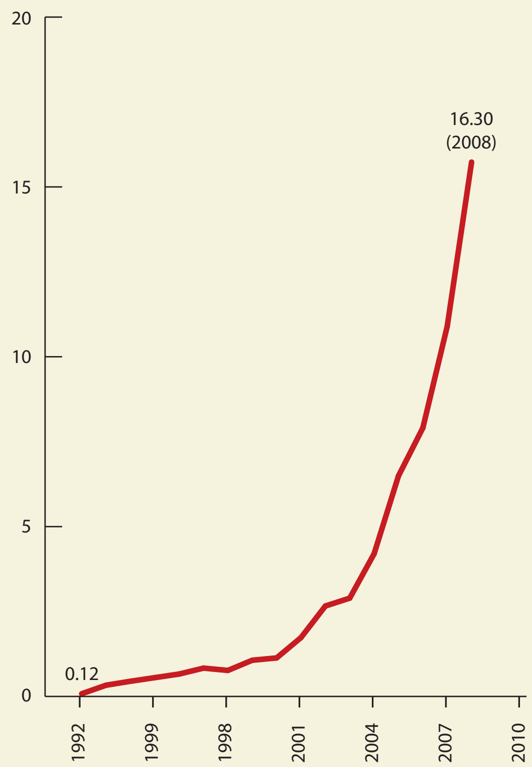
The impact of the Indian Patent Act

One important policy change in recent years has been the adoption of the Indian Patent Act, which took effect on 1 January 2005. This ordinance sought to bring the country into compliance with the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization. The most distinguishing feature of this policy change is the recognition of both product and process patents, as opposed to solely process patents in the earlier Act of 1970. In bringing India into compliance with TRIPS, the intention was to restrict innovation in the pharmaceutical industry in particular, where the lack of product patents had allowed firms to reverse-engineer known products at little cost. This 35-year learning period seems to have given the pharmaceutical firms the time they needed to acquire the skills that are crucial to inventing new chemical entities (Box 2).

After the adoption of the Indian Patent Act, it was expected that R&D spending by the pharmaceutical industry would slump. This reasoning was based on the belief that much of Indian R&D in pharmaceuticals consisted of reverse-engineering. By requiring recognition of both product and process patents, it was thought that the amended act would effectively reduce the space for this type of R&D. However, it turns out that private pharmaceutical companies in India have actually been registering an increase in R&D investment since 2000 of almost 35% per year (Figure 2).

In fact, some of the provisions in the Indian Patent Act have protected Indian pharma, even if the ordinance imposes a 20-year protection period for product patents.

Figure 2: Average R&D expenditure per firm in India's pharmaceutical industry, 1992–2008
In Rs Crores



Source: Author's compilation based on Prowess Dataset

For example, there is a provision for granting compulsory licenses for the export of medicines to countries that have insufficient or no marketing capacity, to meet emergent public health situations, in accordance with the *Doha Declaration on TRIPS and Public Health*. This allows Indian companies to produce and export AIDS drugs to African and Southeast Asian countries. Another safeguard has been the introduction of a provision making patent rights for mailbox applications available only from the date of granting the patent rather than retrospectively from the date of publication. This provision has saved many Indian companies from being attacked for infringement of patent law by multinational companies that might otherwise have obtained patents for drugs already put on the market by Indian companies (UNESCO, 2005).

As for the impact of the Indian Patent Act on innovation in the agriculture, biotechnology and IT sectors this still requires in-depth analysis.

R&D INPUT

Complex trends in R&D expenditure

Both the nominal and real growth rates of GERD have declined in India since liberalization of the economy began in 1991. The country's overall research intensity has remained virtually constant at about 0.78% (Table 2). In China, on the other hand, the GERD/GDP ratio has more than doubled to 1.54% (*see page* 389).

Care must be exercised in interpreting these figures to mean that overall investment in R&D has declined, owing to the peculiarities of Indian research. Even now, the government accounts for over two-thirds of R&D performed in the country, although this share has declined over time. This trend has been accompanied by an increase in R&D investment by business enterprises, which now account for about 28% of GERD, compared to just 14% in 1991. In China, business enterprises have come to perform as much as 71%, with government research institutes accounting for only 19%. The growing share of R&D performed by the private sector is generally considered to be a desirable trend, as enterprises tend to transform the results of their research into products and processes more rapidly than the government sector.
As concerns the breakdown of GERD by type of research, the share devoted to basic research has increased quite substantially since 2003 (Figure 3).

Government expenditure on R&D in India tends to focus on nuclear energy, defence, space, health and agriculture (Figure 4). In the *Eleventh Five-Year Plan*, the public-sector outlay on S&T increased by a whopping 220% in nominal terms compared to actual expenditure on S&T in the *Tenth Plan*. The biggest beneficiary has been the Department of Atomic Energy, the budget of which nearly tripled from Rs 3 501 to Rs 11 000 Crores. Part of this amount will go towards funding India's participation in the ITER project, which India joined in 2005. The Council of Scientific and Industrial Research has also enjoyed a massive increase (from Rs 2 575 to Rs 9 000 Crores), as has the Department of Biotechnology (from Rs 1 450 to Rs 6 389 Crores). The rise in the public-sector plan outlay for renewable energy may have been less dramatic (from Rs 7 167 to Rs 10 460 Crores) but nevertheless represents a growth rate of about 46%.

The spillover of government research to civilian use is very limited in the Indian context, although conscious efforts have been made by the government recently to orient research more towards socio-economic goals. This is slowly beginning to produce results, especially in the area of space research with the development of environmental monitoring, satellite communications and so on.

One interesting result highlighted by the above analysis is that the higher education sector constitutes only a fraction of R&D performed in India, despite the fact that this sector encompasses the prestigious Indian Institute of Science dating back to 1909, the eight Indian Institutes of Technology and over 300 universities. In other words, the higher education sector in India is not a source of technology for industry. This may come as a surprise, as the Indian Institutes of Technology do collaborate with private industry. Unfortunately, however, cases of actual technology generation are few and far between, as much of R&D relates to basic research. Moreover, the institutes tend to be extremely teaching-intensive institutions. It is estimated that the entire higher education sector in India contributes no more than 5% of GERD. It does act as an important reservoir of skilled personnel, however, for the other actors in India's national innovation system.

Thus, the only sector performing more R&D than before is industry and the private sector in particular. Currently, private companies spend approximately four times more

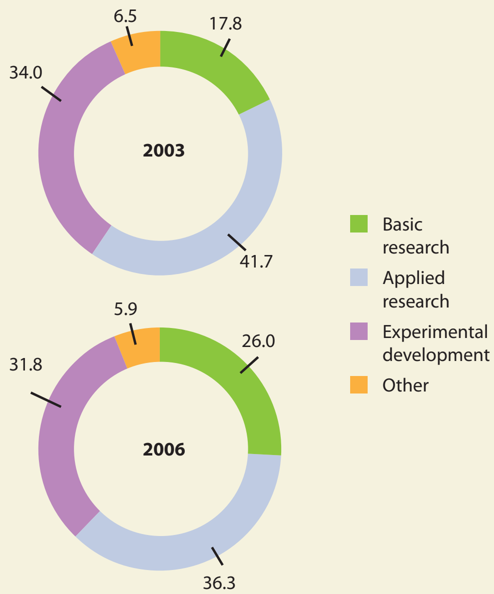
Table 2: Trends in GERD in India, 1992–2008

	GERD (current Rs millions)	Nominal growth rates (%)	GERD (constant 2 000 Rs millions)	Real growth rates (%)	GERD/ GDP ratio
1992	45 128	14	83 476	-0.16	0.76
1993	50 046	11	85 038	1.87	0.73
1994	60 730	21	93 824	10.33	0.77
1995	66 224	9	93 197	-0.67	0.72
1996	74 839	13	96 510	3.55	0.69
1997	89 136	19	106 647	10.50	0.71
1998	106 113	19	119 081	11.66	0.76
1999	124 732	18	129 542	8.78	0.77
2000	143 976	15	143 976	11.14	0.81
2001	161 988	13	156 879	8.96	0.84
2002	170 382	5	160 219	2.13	0.81
2003	180 002	6	163 037	1.76	0.80
2004	197 270	10	172 756	5.96	0.78
2005	216 396	10	179 600	3.96	0.75
2006	287 767	33	229 538	27.80	0.88
2007	329 416	14	248 954	8.46	0.87
2008	377 779	15	274 128	10.11	0.88

Note: The GERD/GDP ratio here differs from that in the Statistical Annex because the DST data are for the fiscal year from 1 April to 31 March, whereas UNESCO has allocated these to the previous year. The source of the GDP data used by UNESCO to calculate the GERD/GDP ratio is the World Bank's World Development Indicators, whereas the DST uses national data.

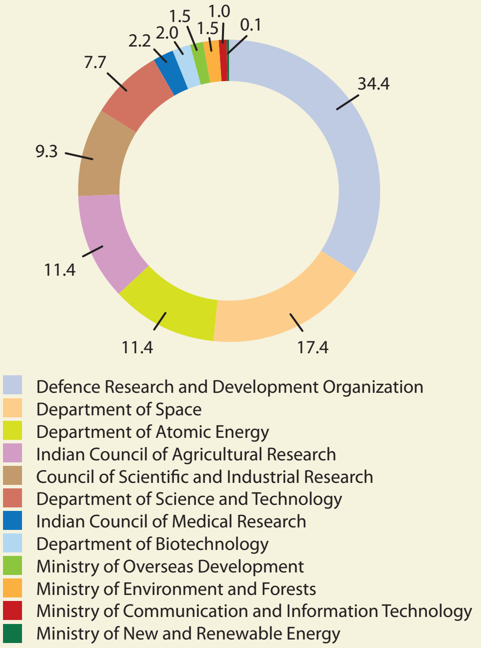
Source: Department of Science and Technology (2009) *R&D Statistics*

Figure 3: Distribution of GERD in India by type of research, 2003 and 2006 (%)



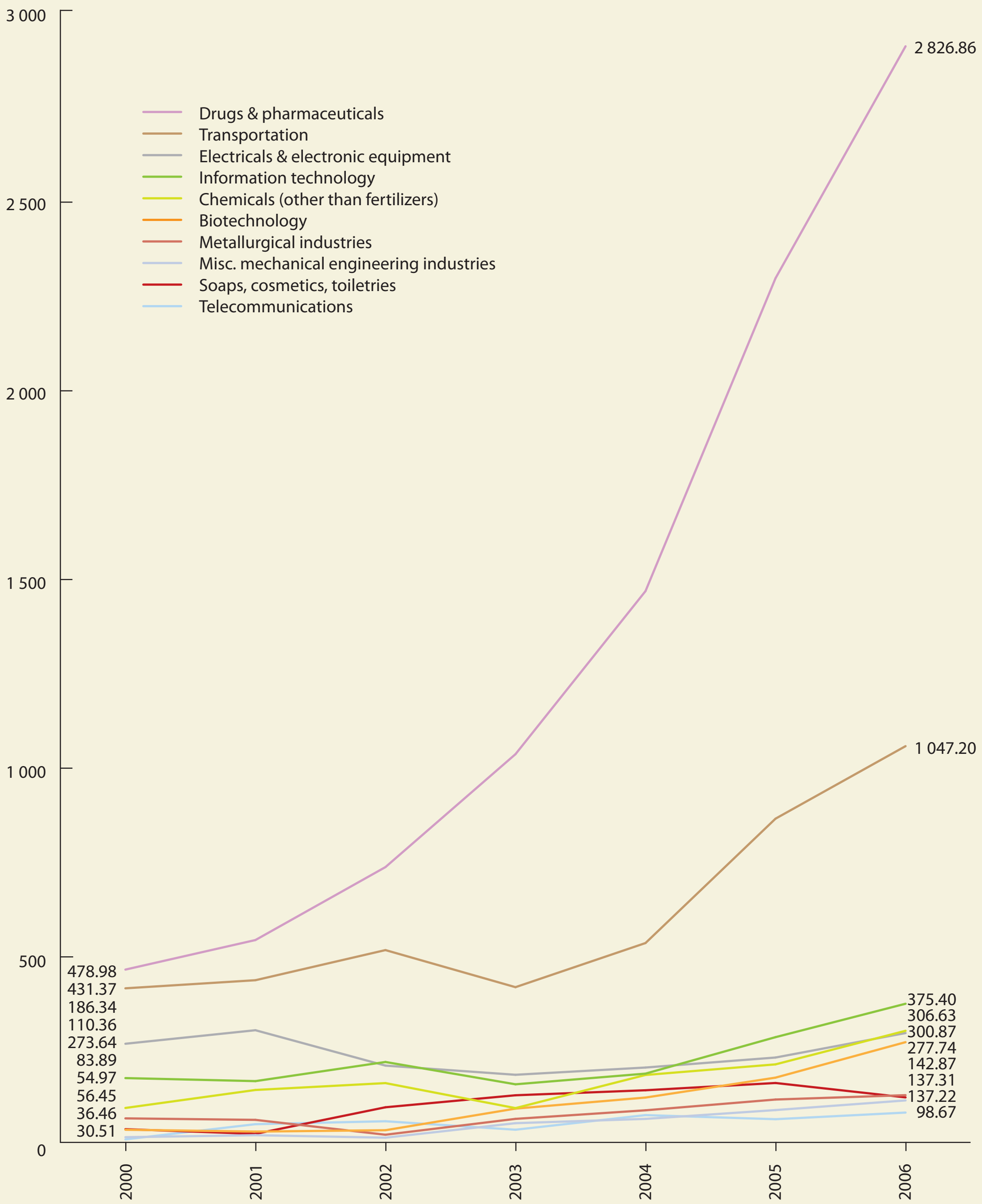
Source: Department of Science and Technology (2009) *R&D Statistics*

Figure 4: Government outlay for the major science agencies in India, 2006 (%)



Source: Department of Science and Technology (2009) *R&D Statistics*

Figure 5: Distribution of GERD in India by industrial sector, 2000–2006
In Rs millions at current prices



Source: Department of Science and Technology (2009) *R&D Statistics* than public enterprises on R&D and nearly three times more when compared to government research institutes. In other words, private enterprises in India are moving towards the core of India's innovation system.

The veracity of this trend is sometimes questioned on the grounds that business enterprises reporting R&D expenditure to the Department of Science and Technology may be tempted to exaggerate their R&D expenditure to gain tax incentives available in India to any business enterprise investing in R&D. These tax incentives are linked to the volume of R&D performed – hence the temptation to overstate it. However, this suspicion would appear to be unfounded if one compares R&D investment as reported by the Department of Science and Technology with the dataset available from the Centre for Monitoring the Indian Economy's Prowess for the period 1991–2003. This comparison shows that, although the level reported by the Department of Science and Technology is higher over most of the years under consideration than in the early 1990s, the difference has tended to decrease over time. Moreover, both series have followed a similar curve. The argument that the increase in R&D expenditure by private companies is a mere statistical artifice would thus appear to be false.

Four industries account for the lion's share of investment in R&D, with the pharmaceutical and automotive industries topping the list (Figure 5). In fact, it is sometimes claimed that India's national system of innovation is led by the pharmaceutical industry. It can therefore be safely concluded that, although GERD may not have risen, the pharmaceutical industry has been at the helm of an impressive rise in R&D expenditure by the private sector. Based on this one indicator, the more correct statement would be that there is insufficient evidence to show that the entire industrial sector in India has become more innovative since 1991 but sufficient evidence to posit that India's pharmaceutical industry *has* become more innovative. We shall confront this statement later with trends in the number of patent applications and grants in India (*see page* 375).

Scientists and engineers in short supply

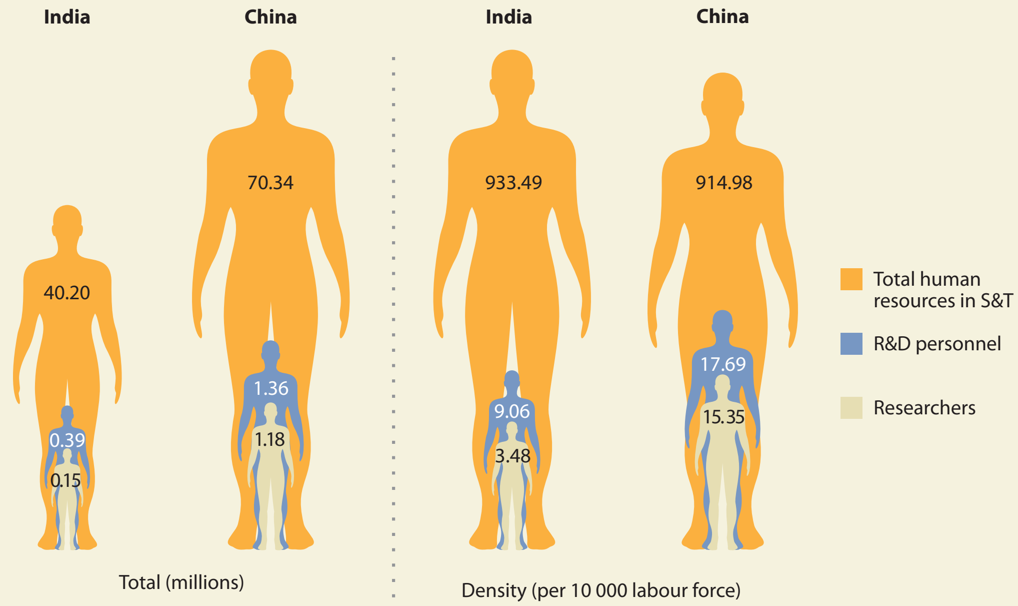
It is generally held that India has a copious supply of scientists and engineers, yet the actual density of personnel engaged in R&D and innovation is fairly modest, at just 137 per million population (*see page* 328).

The recent growth of knowledge-intensive industries is prompting many commentators to profess that India is becoming a knowledge economy. India's 'copious supply' of technically trained personnel is considered one of the key drivers of this growth. However, of late, industry has been complaining of serious shortages in technically trained personnel. For instance, a study by the Federation of Indian Chambers of Commerce and Industry (FICCI, 2007) has revealed that rapid industrial expansion in a globally integrated Indian economy has stimulated a huge demand for skilled personnel. However, the lack of quality higher education has become a hindrance to satisfying this demand. Based on a study conducted in 25 industrial sectors, the survey also revealed that there is currentlya 25% shortage of skilled personnel in the engineering sector. Figure 6 compares the present supply and density of scientists and engineers in India with the situation in China.

Two issues have an impact on the potential supply of scientists and engineers for domestic businesses in particular. The first is the long-standing issue of the migration of highly skilled personnel from India to the West primarily, with every indication that this brain drain has increased recently (Mani, 2009). According to some estimates, the emigration by highly skilled Indians as a share of those in tertiary education has increased from 2.6% in the 1990s to about 4.2% in the early 2000s. The second issue concerns the growing amount of FDI flowing into R&D. Foreign R&D centres are able to offer domestic researchers and R&D personnel better incentives, both pecuniary and otherwise, than domestic businesses. As a result, India's small stock of scientists and engineers may be lured to the foreign R&D centres, causing a 'crowding out' of sorts to take place. Lan and Liang (2006) have already observed this phenomenon in China. In addition to the supply question, doubts have been expressed as to the quality of education in science and engineering in India, although quality is often a difficult parameter to measure objectively.

The central government in particular has reacted by putting in place a number of measures which combine quantity and quality, not only in higher education but also in technical education. For details of these ambitious schemes, see page 366.

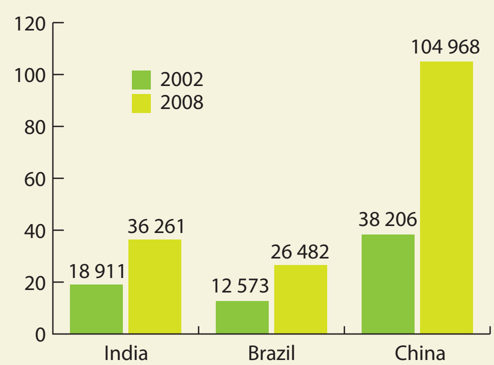
Figure 6: Stock of scientists and engineers engaged in R&D in India, 2005
China is given for comparison



Note: The definition of human resources in S&T is broad and covers 'people actually or potentially employed in occupations requiring at least a first university degree' in S&T, which includes all fields of science, technology and engineering. The term R&D personnel, as defined by the OECD *Frascati Manual* (2002), covers 'all persons employed directly on R&D', which includes those providing direct services such as R&D managers, administrators and clerical staff. The *Frascati Manual* defines researchers as 'professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and in the management of the projects concerned'.

Source: Computed from OECD (2008) *Reviews of Innovation Policy: China*; Department of Science and Technology (2009) *R&D Statistics;* NCAER (2005) *India Science Report, Science Education, Human Resources and Public Attitudes towards Science and Technology*

Figure 7: Total scientific publications in India, 2002 and 2008
Brazil and China are given for comparison



Source: Thomson Reuters. Science Citation Index Expanded, compiled for UNESCO by the Canadian Observatoire des sciences des techniques

R&D OUTPUT

A sharp rise in scientific publications

According to Thomson Reuters data, India's publication record shows a steep rise, especially since 2003 (Table 3 and Figure 7). If this growth rate is maintained, India's publication record will be on par with most G8 nations within 7–8 years. India could even overtake them between 2015 and 2020.

India's publications are evenly distributed between the physical and life sciences. The most recent data confirm earlier findings that India's strength truly lies in the basic sciences such as chemistry, physics, pharmacology and toxicology (Figure 8).

The USA continues to be India's top research partner but the level of international collaboration – defined as a fraction of GDP – is much lower for India than for other emerging

Table 3: India's scientific publication record, 1999–2008

	1999–2003		2004–2008	
	Count	Word share (%)	Count	Word share (%)
Chemistry	21 206	4.42	33 504	5.71
Agricultural sciences	4 303	5.91	5 634	5.65
Materials science	6 960	4.08	11 126	4.81
Pharmacology & toxicology	2 034	2.80	3 866	4.25
Plant & animal science	8 132	3.58	10 190	3.77
Physics	11 700	3.00	17 295	3.7
Engineering	8 101	2.69	14 103	3.57
Geosciences	2 839	2.64	4 266	3.13
Space science	1 322	2.44	1 665	2.79
Microbiology	1 078	1.62	2 273	2.79
Total for the top 10 fields	67 675		103 922	

Source: Thomson Reuters (2009) *Global Research Report: India*

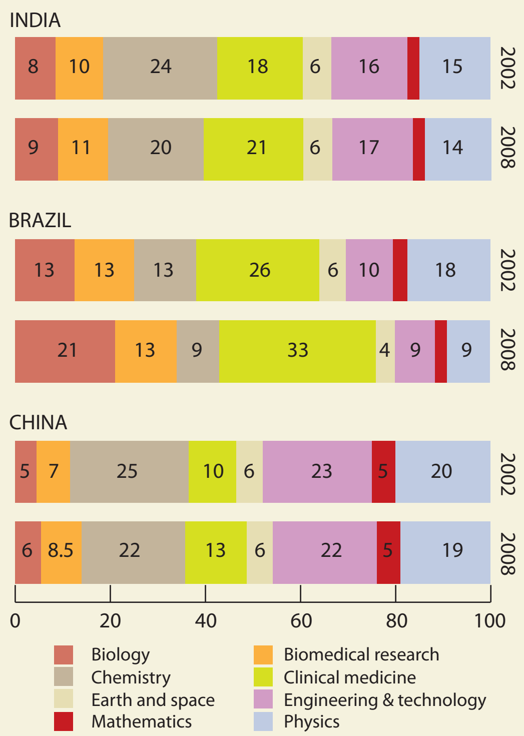
economies like Brazil. However, the period since 2004 has seen greater collaboration with Asian countries, notably Japan and the Republic of Korea. One important finding is the relatively sparse collaboration with European partners and especially the UK. This shortcoming is now being explicitly addressed by the European Union (EU) and British government through a host of new partnerships. The UK–India research partnership and recent initiatives under the EU's Seventh Framework Programme for Research and Technological Development (2007–2013) are two illustrations of research partnerships between India and the developed world in a host of S&T areas ranging from health to space and nanotechnology.

Foreign companies dominate patents

India has improved its patenting record in the USA, with an acceleration over the past decade. Most Indian patents are utility patents, defined as being those for new inventions (Figure 9). However, most of these patents are in chemistry-related areas and the great majority are being granted to foreign companies located in India, based on R&D projects they have carried out in India, in a growing trend (Mani, 2010*a*).

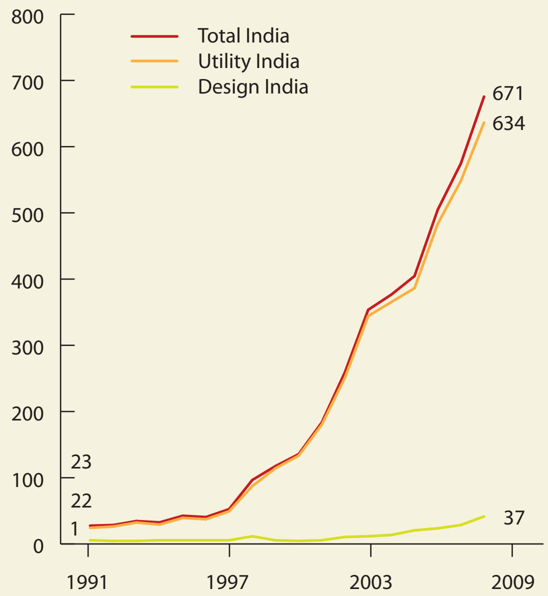
Similarly, the number of national patents granted by the India Patent Office has increased tremendously but over three-quarters are still being granted to foreign entities. Once again, most of these patents concern chemistry and pharmaceutical-related areas. Thus, although the TRIPS compliance of the Indian Patents Act appears to have had a positive effect on patenting by Indian inventors, most of the

Figure 8: Focus of Indian publications by major field of science, 2002 and 2008 (%)
Brazil and China are given for comparison



Source: Thomson Reuters, Science Citation Index Expanded, compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

Figure 9: Trends in the number of patents granted to Indian inventors in the USA, 1991–2008



Source: Mani (2010*b*) *Have China and India become more innovative since the onset of reforms in the two countries?*

patents granted to Indian inventors both in India and abroad are going to foreign companies.

CONCLUSION

We have seen that economic growth has taken off in India, especially in the past five years. This performance has been very lopsided, however, tending to favour certain regions and income groups over others. In order to make economic growth more inclusive, the government has been placing greater emphasis on S&T, as witnessed by the massive increase in the budget allocation to S&T during the Eleventh Five-year Plan (2007–2012). It is also making an effort to orient innovation in the government sector more towards socio-economic goals.

The country has certainly made great strides in space research, life sciences and especially in biopharmaceuticals and information technology. Although domestic science continues to dominate, there is also a growing presence of foreign entities in India's technology system. The main challenge facing the country will be to improve both the quality and quantity of S&T personnel. Fortunately, policy-makers are seized of this problem and have taken energetic steps to remedy the situation. The future success of India's STI system will depend on how well they succeed.

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Dr Mani's research interests include innovation indicators, innovation policy instruments and the telecommunications industry. He has published extensively in these areas and in 2010 was invited to edit a special issue of the *International Journal of Technology and Globalization* on the theme of the Rise of Innovation in India (Vol. 5, Nos 1 and 2, 2010).

The innovation risk of enterprises needs to be shared via incentive policies and the development of public infrastructure to support innovation.

Mu Rongping

18 · China

Mu Rongping

INTRODUCTION

China has made great strides in system reform and economic development over the past decade. The world's fastest-growing large economy, it will overtake Japan by the end of 2010 to become the world's second-biggest economy in terms of GDP[1].

The country has emerged more or less unscathed from the global economic recession triggered by the sub-prime crisis in the USA in 2008. After an initial slump in employment caused by falling demand for exports to Europe and the USA, China's economy bounced back in 2009, growing by 8.7% (IMF, 2010). The key driver of this growth is government-led investment. For example, the government has implemented a plan for injecting an additional 4 trillion Yuan (*circa* US$ 590 billion) into the economy over a two-year period. According to this plan, the central government is investing 1.18 trillion Yuan to leverage local governments and private firms to spend more than 2.82 trillion Yuan. Another government plan aims to restructure and invigorate ten key industries: automobile, iron and steel, textiles, equipment manufacturing, shipbuilding, petrochemicals, light industry, electronic information, non-ferrous metal and logistics. The central government's investment rose from 420.5 billion Yuan in the previous year's budget to 924.3 billion Yuan (*circa* US$ 62.8 billion) in 2009. Of this, 16% was earmarked for innovation, restructuring, energy-saving, reducing greenhouse gas emissions and environmental protection. This not only effectively compensated for the shortfall created by shrinking external demand but also strengthened weak links and laid a solid foundation for long-term socio-economic development (Wen Jiabao, 2010).

The government has given environmental protection high priority in the *Tenth* (2001–2005) and *Eleventh Five-Year Plans* (2006–2010). It has imposed the mandatory objective of reducing energy consumption per unit of GDP by 20% and emissions of major pollutants by 10% by the end of the *Eleventh Five-Year Plan* in 2010, in order to reverse the trend of ecological and environmental deterioration over the past two decades. In April 2010, Chinese Premier Wen Jiabao announced plans to adopt a binding target for cutting carbon dioxide emissions (Box 1). Local government leaders and entrepreneurs are expected to assume a greater role than before in achieving these targets and will be evaluated for their performance in saving energy and reaching emission-reduction targets.

Over the past decade, China has not only multiplied gross domestic expenditure on R&D (GERD) by a factor of six but also improved its capacity for generating intellectual property rights (IPRs) via scientific papers and patents. Today, only the USA publishes more scientific articles (*see page* 10). The *Eleventh Five-Year Plan* for capacity-building in innovation foresees the rapid development of infrastructure to implement the knowledge innovation programme and the programme for science and technology (S&T) platforms: 12 megafacilities are to be established by 2010, as well as about 30 national science centres and national laboratories[2] and 300 national key laboratories.

In 2005, the government issued the *Outline of the Medium- and Long-Term Plan for National Science and Technology Development* (2006–2020), which proposed that China become an innovation-driven country by 2020 (State Council, 2006). The government then issued a series of supportive policies to encourage endogenous innovation, as well as 76 detailed policy documents for implementing these supportive policies by the end of 2008. This series of policies has had a great impact on innovation in China and especially on the innovative capacity of enterprises. It shall thus be discussed in detail in the following section.

China's goal of becoming an innovation-driven country by 2020 is a highly ambitious one. Today, the R&D intensity of high-tech industry remains much lower in China than in developed countries. China faces daunting challenges in narrowing this innovation gap, not least of which will be to find the right balance between economic development and capacity-building in science, technology and innovation (STI).

Shanghai Synchrotron Radiation Facility

Photo: © Shanghai Synchrotron Radiation Facility

1. China ranks third in terms of annual output measured in US dollars but, in terms of purchasing power parity (PPP), it has been the world's second-largest economy for years.

2. National laboratories are designed to conduct complex research and innovation, whereas national key laboratories usually focus on research in a specific discipline. Some national laboratories consist of several national key laboratories.

Box 1: Accelerating development and use of renewable energies

At the first meeting of the National Energy Commission in Beijing on 22 April 2010, Chinese Premier Wen Jiabao called for greater efforts to enhance the country's innovative capacity in energy technology to cope with rising domestic fuel demand and severe energy shortages. 'We must accelerate the development and use of renewable energies to ensure the country's energy security and better cope with climate change,' he said.

Wen went on to say that China ought to take measures to ensure that non-fossil fuels accounted for 15% of China's energy consumption by 2020. He also stated that the country would make it a binding target to cut carbon dioxide emissions per unit of GDP by 40–45% by 2020 from 2005 levels. 'The target will be incorporated into the country's long-term economic and social development plan,' he said.

The government set up the National Energy Commission in January 2010 to improve co-ordination of energy policy .The commission is responsible for drafting the national energy development plan, for reviewing energy security and major energy issues and for co-ordinating domestic energy development and international co-operation.

Source: Xinhua News Agency, 22 April 2010

A PLAN FOR MAKING CHINA INNOVATION-DRIVEN BY 2020

Priority areas for R&D to 2020

Experts have played an important role in the elaboration of the *Outline of the Medium- and Long-Term Plan for National Science and Technology Development (2006–2020)*, the eighth in China's history. Once the 20 strategic issues had been selected in 2003 by the State Council and an expert consultation group composed of 20 scientists, more than 2 000 experts were invited to conduct studies on these topics. A broader consultation was also undertaken via e-mail, workshops and other means to enable people from all walks of life to contribute ideas. The *Outline* groups all technologies into five high-priority clusters:

- technologies in the fields of energy, water resources and environmental protection;
- information technology (IT), advanced materials and manufacturing;
- biotechnologies and their applications in the fields of agriculture, industry and human health;
- space and marine technology;
- basic sciences and frontier technology.

The *Outline* launches 16 megaprojects in S&T. These projects have been selected according to five basic principles. *Firstly,* each project should correspond to socio-economic needs, in order to cultivate strategic industries. *Secondly,* each project should focus on key common technologies that will have a profound impact on industrial competitiveness. *Thirdly,* each project should be capable of absorbing the main bottlenecks of socio-economic development. *Fourthly,* each should protect and enhance national security. *Last but not least,* each should be affordable for the Chinese government. In 2008, the government invested 3.6 billion Yuan in 8 of the 16 special megaprojects for civil S&T, corresponding to about 167 smaller projects. Thirteen of the 16 mega projects are listed in the *Outline*:

- core electronic devices, high-end generic chips and basic software;
- extra large-scale integrated circuit manufacturing technology and associated technology;
- next-generation broadband wireless mobile communication;
- advanced computerized numerical control machinery and basic manufacturing technology;
- large-scale oil and gas fields and coal-bed methane development;
- advanced large-scale pressurized water reactors and nuclear power plants with high-temperature, gas-cooled reactors;
- water pollution control and governance;
- cultivation of new varieties of genetically modified organisms;
- development of major new drugs;
- prevention and treatment of AIDS, viral hepatitis and other major infectious diseases;
- large aircraft;
- high-resolution Earth observation systems;
- human space flight and the Moon exploration programme.

In recent years, there have been a number of breakthroughs in priority areas for R&D. In 2003, China became the third country after Russia and the USA to send astronauts into space, for example, and there are plans to land a rover on the Moon by 2012. In information technology, a team at the University of Science and Technology of China built the world's first photonic telephone network in April 2009 (Box 2), six months before China's fastest supercomputer was released in Changsha (Box 3). Also of note is the completion of the Shanghai Synchrotron Radiation Facility in April 2009, the biggest scientific platform in China so far (Box 4).

Policies for building an innovation-driven nation

Since the adoption of the *Outline of the Medium- and Long-Term Plan for National Science and Technology Development*, the government has issued a series of innovation policies with a view to establishing an enterprise-centred national innovation system and making China an innovation-driven nation by 2020. Capacity-building for innovation has become the core of the country's national strategies, marking an important shift in policy. This shift in focus is reflected in the eight primary thrusts of the innovation policies described overleaf.

Box 2: The world's first photonic telephone network

Quantum communication possesses the feature of absolute security which traditional means of communication lack. However, due to the imperfect nature of real systems and the lack of true quantum single-photon sources, the secure communication rate of quantum communication systems declines sharply with increasing distance. This meant that, for a long time, quantum communication was stuck at the laboratory stage.

In April 2009, Professor Pan Jianwei and his research group from the University of Science and Technology of China built the world's first photonic telephone network in Hefei. This shows that absolutely secure quantum communication can be applicable to daily life. The group successfully developed a quantum phone prototype and constructed a photonic telephone network which can be freely expanded based on the commercial fibre network.

This research has taken the lead worldwide in the field of practical quantum communication. As *Science* put it, 'With such a presentation, "quantum privacy" will not be a very distant future in your own home'.

As long ago as 2008, the group established quantum entanglement between two ensembles of cold atoms connected by 300 m fibres, perfectly realizing 'quantum repeaters', which is vital to long-distance quantum communication. This significant outcome was published in the issue of *Nature* dated 28 August 2009. It was listed as one of China's top ten achievements in S&T for 2008.

Source: MOST; University of Science and Technology of China

Box 3: China's supercomputers

China's fastest supercomputer, Tianhe-1 (TH-1), was released in Changsha on 29 October 2009. With a theoretical peak performance of 1.206 PetaFlop per second, TH-1 makes China only the second country after the USA to develop a supercomputer on such a scale. In 2009, TH-1 ranked fifth worldwide on the Top500 organization's list of supercomputers. By 2010, it had climbed to second place, according to a Nebulae report, with a Linpack performance of 1.271 PFlop per second. TH-1 was voted one of China's top ten achievements in S&T for 2009 by 563 academicians of the Chinese Academy of Sciences and Chinese Academy of Engineering.

Funded by the National Programme for High-tech R&D (the 863 programme), the TH-1 project was launched in 2008. TH-1 represents a hybrid design with Intel Xeon processors and GPUs from Advanced Micro Devices Inc. It has wide applications in the fields of resource exploration, biological medicine development, aircraft and space craft development, financial engineering and new materials development.

Source: Xinhua News Agency; www.top500.org/lists/2010/06/press-release

Box 4: The Shanghai Synchrotron Radiation Facility

The Shanghai Synchrotron Radiation Facility (SSRF) was competed in April 2009 after 52 months of construction. It is the biggest scientific platform in China so far and represents an investment of about 1.43 billion Yuan by the central government.

With electron beam energy of 3.5GeV, it is one of the best third-generation light sources in the world. SSRF consists of a 150MeV linear particle accelerator, a booster that can increase the electron energy from 150MeV to 3.5GeV in 0.5 seconds, as well as a 3.5GeV electron storage ring.

SSRF has the capacity to serve hundreds of scientists and engineers in various disciplines from universities, institutes and industry every day.

Source: http://ssrf.sinap.ac.cn/

First thrust: a boost for investment in R&D

- The government has established a diversified investment system for S&T development to ensure that government investment in S&T maintains a faster growth rate than that of regular government revenue, in order to guarantee the implementation of national megaprojects in science and engineering and national S&T programmes.

- The government has optimized the structure of government expenditure on R&D by focusing on basic research, public goods research and frontier technology research and by providing the requisite preferential policies to solve major challenges for national, regional and industrial development. Expenditure on basic research nearly doubled between 2004 and 2008, from 11.72 to 22.08 billion Yuan. Despite this effort, the share of GERD devoted to basic research actually dropped from 5.96% to 4.78% over the same period (*see page* 389).

- The government has devised a new mechanism for managing government expenditure on R&D, in order to improve efficiency and effectiveness, with a focus on expenditure on scientific research, the development of talent and national S&T programmes. It has also established a performance evaluation system to assess government expenditure on R&D.

Second thrust: tax incentives for investment in STI

- The government has formulated additional preferential policies to enable enterprises to upgrade their experimental facilities and instruments, by speeding up the depreciation of imported facilities and instruments for R&D. For example, the government shares 12.5% of enterprise expenditure on R&D by means of tax deductions.

- Government policy provides tax incentives for the technology development centre of enterprises[3] , national engineering research centres[4] , national megaprojects for S&T and national R&D projects involving sophisticated technological equipment, to build innovation capacity in enterprises. Enterprises are entitled to deduct the tariff and related value-added tax from imported goods that are to be used in R&D and when undertaking projects within national S&T programmes.

- The policies devised by the Ministry of Finance and the State Administration of Taxation in 2006–2007 promise to waive the income tax of transformed research institutes[5] to strengthen their capacity for innovation (Box 5). In order to promote the development of small and medium-sized enterprises, tax incentives extend to venture capital and service organizations active in S&T, such as science parks on university campuses and incubators of technology-based enterprises. The policy also encourages social organizations to support innovation via tax-deductible donations.

Third thrust: a government procurement policy to promote innovation

- The government has established a system for purchasing the product of endogenous innovation using government funds. This scheme includes setting

3. Creation of a technology development centre within an enterprise is authorized by the National Development and Reform Committee and three other government agencies.

4 . The term national enterprise research centre also refers to a national engineering technology research centre.

5. Transformed research institutes have been transformed from state-owned research institutes into enterprises (see Box 5).

up a system for authorizing endogenous innovation and giving high priority to the product of endogenous innovation in major national construction projects and other relevant projects.

- The government has taken administrative steps to purchase initially and order products arising from endogenous innovation, in order to encourage enterprises to invest more in innovative product development and capacity-building.

- The government is establishing a scheme that will give high priority to foreign companies prepared to transfer technology to China[6] ; this scheme will comprise a system for authorizing domestic goods and an auditing system for the purchase of foreign goods.

Fourth thrust: innovation based on assimilating imported advanced technology

- Henceforth, key national projects are required to draw up a plan for building innovation capacity based on the assimilation of imported advanced technology.

- The government has modified the list of technologies for which importation is either encouraged or restricted. Enterprises and other bodies are encouraged to import advanced technology for the purposes of design and manufacture.

- The government is giving high priority to key national projects leading to the manufacture of a first batch of equipment in China based on the assimilation of imported advanced technology.

- The government is supporting co-operation among industries, universities and research institutes in assimilating imported advance technologies and innovation. It is also giving high priority to the technology platform in the national programme for S&T infrastructure.

Fifth thrust: capacity-building in generating and protecting IPRs

- In 2007, the Ministry of Science and Technology compiled a list of key technologies and products for which China should hold related patents and which the country should develop within national S&T programmes (MOST, 2007*a*). The ministry also established a platform for an IPR information service to support enterprises in applying for patents.

- The government supports technology standard-setting and is encouraging enterprises to set endogenous technology standards jointly with universities and research institutes, and to integrate these standards in R&D, design and manufacture.

- The government has created an environment conducive to IPR protection by making laws and regulations more effective and by rewarding inventors and major contributors to the commercialization of IPRs held by public organizations.

- The government has shortened the examination cycle for invention patents.

Sixth thrust: building national infrastructure and platforms for STI

- The government has constructed infrastructure and platforms for R&D, including scientific facilities, large equipment and scientific databases. These have been established for use by national laboratories, national engineering laboratories and national engineering research centres.

- By fostering co-operation between enterprises, universities and research institutes, the government is supporting enterprises in their efforts to establish a technology development centre and national engineering laboratories in their midst in key R&D fields. The greatest beneficiaries of this scheme so far have been the transformed research institutes and large enterprises. National engineering laboratories tend to focus on developing pre-competitive technology and frontier technology.

- The government has established a mechanism for sharing platforms for S&T and innovation among users and for evaluating the openness and effectiveness of these platforms.

Seventh thrust: cultivate and utilize talents for STI

- In order to cultivate home-grown talents that are world-class and give them an international perspective, China has recruited more than 800 top foreign scientists and other experts working in China

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6. One example is the opening of the Airbus (Beijing) Engineering Centre in early 2006, within a joint venture between Airbus and China's two largest aviation companies, the China Aviation Industry Corporation I and II.

Box 5: Milestones on the road to a national innovation system

In 1978, China initiated the first of a series of far-reaching reforms and began opening up to the outside world. The first reform as far as the science system was concerned consisted in extending the decision-making power of R&D institutes and reforming the R&D funding system. This was followed by the gradual introduction of a market mechanism into the S&T system and by S&T-related legislation. The last stage has seen the establishment of a national innovation system favouring S&T-based socio-economic development. The reform of the science system can be divided into four historic stages.

Reconstructing the scientific management system (1978–1985)

The National Science Conference in March 1978 marked a turning point in China. The conference emphasized that 'S&T is the productive force' and that 'the modernization of S&T is the key of the four modernizations', the other three being industry, agriculture and defence. The 1978 conference laid vital ideological and theoretical foundations for the rediscovery of the position, function and influence of S&T in promoting economic development. The conference approved the *Outline of the National Science and Technology Development Plan* (1978–1985) and issued three complementary documents: *Main Tasks of Scientific and Technological Research*, a *National Plan for Basic Science* and a *National Plan for Technological Sciences*. Two critical measures were adopted in this period: the national examination system for higher education was restored in 1978 to develop qualified S&T personnel and the National Leading Group for Science and Technology of the State Council was established in December 1981 to strengthen scientific management.

Reforming the science system (1985–1992)

In March 1985, the Central Committee of the Communist Party of China (CCCPC) proposed a strategic guideline that 'economic development must rely on S&T, while the development of S&T must be oriented towards serving economic development' (CCCPC, 1985). This guideline served as a roadmap for the reform of the science system. It had five main thrusts, namely to:

- reform the funding system for S&T and manage funding;
- implement a technology contract system, so as to develop the market for technology and promote the commercialization of research results;
- introduce a market mechanism and adjust the organizational structure of S&T, in order to strengthen enterprises' capacity for technology development;
- empower research institutes by giving them the right to self-determination and independent status;
- reform the system of S&T personnel management and implement a merit-based pay system.

Between 1982 and 1990, China promulgated several laws and regulations that included the Trademark Law (1982), Patent Law (1984), Technology Contract Law (1987) and Copyright Law (1990).

It also improved the national S&T awards system by adjusting existing awards and setting up new ones, including the: National Natural Science Award, National Invention Award and National Science and Technology Progress Award. In parallel, China adopted a series of important policy measures to adapt institutions and policies to the needs of socio-economic development, including: establishing the National Natural Science Foundation of China; initiating the National High-Tech R&D Programme, also known as the 863 programme because it was proposed by four top Chinese scientists in March 1986; creating high-tech industrial development zones and; encouraging the development of technology-based enterprises.

Making S&T an integral part of the economy (1992–1998)

In 1992, China proposed establishing a socialist market economy. In order to make S&T an integral part of the economy, the government proposed adjusting the allocation pattern for resources destined for S&T. A key policy measure was the instigation of the Combination Development Project for Industries, Universities and Research Institutes in April 1992 by the State Economic and Trade Commission, in tandem with the State Education Commission and Chinese Academy of Sciences.

The Science and Technology Progress Law, promulgated in July l993, resolved some fundamental legal issues. For instance, it defined the objective and key tasks of S&T activities and related policies. To make sure R&D was not ignored in the process of integrating S&T in the economy, the CCCPC and State Council issued the Decision on Accelerating the Progress of Science and Technology (1995), which emphasized, as in 1985, that 'economic construction must rely on S&T, while the development of S&T must be oriented towards serving economic development' but, significantly, added to this the mention 'towards scaling the heights of world S&T'.

In order to promote the economic integration of S&T, China formulated the Law on Promoting the Transformation of Scientific and Technological Achievements in May 1996. This law provides legal protection for the commercialization of research results. Thereafter, the government advocated orienting scientific research institutes towards economic development by having them: join an enterprise as a technology development arm for the enterprise or an industrial sector; function according to the operational mechanism of corporations; set up enterprises or become an enterprise themselves; become a technological service organization (State Council, 1996).

In order to 'scale the heights of world S&T', the government initiated the National Key Basic R&D Programme. This is also known as the 973 programme because it was approved by the State Leading Group for Science and Education[11] of the State Council in March 1997.

Building a national innovation system (1998–2005)

In June 1998, the State Leading Group for Science and Education decided to initiate the Knowledge Innovation Programme (KIP) by supporting the pilot project of the Chinese Academy of Sciences, in order to create a national innovation system and knowledge economy. The goal of KIP was to build the Chinese Academy of Sciences into a leading academic institution and comprehensive R&D centre in the natural and engineering sciences and in high-tech innovation, turn it into a scientific research base of international standing, an incubator of talented S&T personnel and a springboard for the development of China's high-tech industries.

In order to strengthen linkages between the different actors of S&T and develop an enterprise-centred technological innovation system, the government decided to transform 242 state-owned research institutes into state-owned enterprises in February 2009. This process can only two take forms: either the institute joins an existing enterprise or it becomes a state-owned enterprise itself.

These 242 research institutes were affiliated to 10 former ministries that included the Ministry of Machine Building, the Ministry of the Metallurgy Industry and the Ministry of Coal. By the end of 1999, all had been transformed into state-owned enterprises: 131 had joined large enterprises, 40 had become enterprises, 18 had become technological service organizations and 29 had been transformed into 12 large self-supporting, technology-based enterprises owned by the central government. In order to support the industrialization of these 242 institutions, the central government adopted preferential policies concerning taxation, loans, subsidies and personnel.

In June 1999, the government established the Innovation Fund for Technology-based Small Enterprises. It also implemented a Strategy for Rejuvenating Trade by Means of Science and Technology, with a view to promoting quality high-tech exports. The Decision issued by CCCPC and State Council in August 1999 on *Strengthening Technological Innovation to Develop and Industrialize High-tech* gave an additional boost to the commercialization of research results. In June 2000, the government adopted preferential policies concerning investment, financing, taxation, talented personnel and the intellectual property protection to promote the development of software and integrated circuit industry (State Council, 2000).

In June 2002, China promulgated the *Outline of the National Talents Construction Plan (2002–2005)* and proposed a Strategy for Reinvigorating China with its Talented Human Resources. In December 2003, the CCCPC and the State Council issued a *Decision on Further Strengthening the Work of Talented Personnel*. It emphasized that 'China must incorporate the work of talented personnel in the overall planning of national socio-economic development, vigorously develop human resources and reinvigorate the nation by using its talent'.

Source: author

11. Consisting of the National Development and Reform Commission, Ministry of Education, Ministry of Science and Technology, Ministry of Finance, Ministry of Agriculture, Ministry of Traffic and Transportation, Chinese Academy of Sciences, Chinese Academy of Social Sciences, Chinese Academy of Engineering, National Natural Science Foundation and Chinese Association for Science and Technology.

via its Recruitment Programme of Global Experts, known as the Thousand Talents Programme. This programme plans to recruit 2 000 overseas experts over the next five to ten years for national laboratories, leading enterprises and selected research institutes, as well as a number of universities.

- In order to woo talented Chinese scientists and engineers living abroad in particular, the government is backstopping efforts by enterprises to reform income distribution and incentive measures for staff by implementing preferential policies that include special government subsidies, tax breaks and benefit-sharing arrangements for original patents.

Eighth thrust: support endogenous innovation via financial measures

- The government has instructed policy-oriented funding bodies to give priority to financing national megaprojects for S&T, national projects for the industrialization of high technology, the assimilation of imported advanced technology and the export of high-tech products.

- To ease the financial burden on small and medium-sized enterprises, the government has improved the financial services available to them for innovation, established a credit system for them and facilitated venture capital. In parallel, it has improved the legal framework for innovation by making it easier for venture capital to invest in start-ups.

- The government has established multiple capital markets to support endogenous innovation, including a stock market for technology-based small and medium-sized enterprises, stock transactions for high-tech enterprises and a regional transaction market for property rights.

THE NATIONAL S&T PROGRAMMES

China's national S&T programmes encompass three major programmes:

- the **National Programme for High-tech R&D** (the 863 programme), which received an allocation from the central government of 5.6 billion Yuan (US$ 805.2 million) in 2008;

- the **National Programme for Key Technology R&D**, which received an allocation of 5.1 billion Yuan (US$ 729.5 million) in 2008;

- the **National Programme for Key Basic R&D** (the 973 programme), which received 1.9 billion Yuan (US$ 273.6 million) in 2008.

In 2008, these three programmes represented two-thirds (12.6 billion Yuan) of the central government's allocation to national S&T programmes (17.6 billion Yuan). A further 1.8 billion Yuan went to the national programme for the construction of basic infrastructure like national key laboratories, which consumed most of its budget (1.6 billion Yuan).

A further 3.2 billion Yuan went to national policy-oriented programmes and special programmes. Their budget encompasses the:

- Innovation Fund for Small Technology-based Firms (1.462 billion Yuan);
- International S&T Co-operation Programme (400 million Yuan);
- Agricultural S&T Transfer Fund (300 million Yuan);
- Special Technology Development Project for Research Institutes (250 million Yuan);
- Spark Programme[7] (200 million Yuan);
- Torch Programme[8] (152 million Yuan);
- National New Products Programme (150 million Yuan);
- Soft Science Programme[9] (25 million Yuan);
- other special programmes (300 million Yuan).

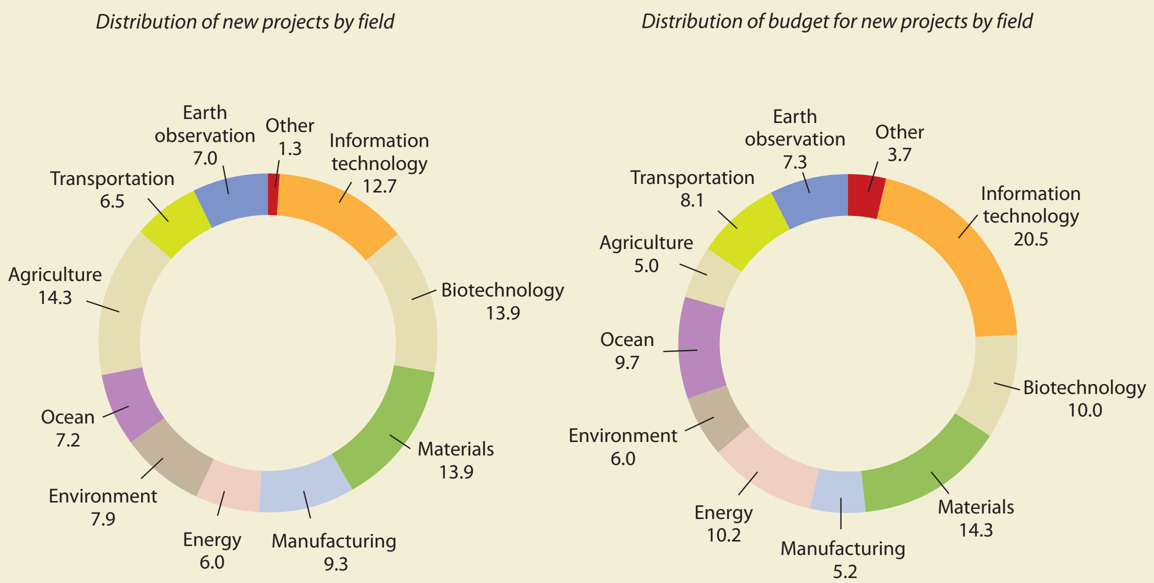
Last but not least, the National Natural Science Foundation of China increased its project funding for basic research from 4.1 billion Yuan in 2006 to 6.3 billion Yuan in 2008. However, the growth rate of expenditure on basic research remains lower than that of R&D expenditure because of the rapid expansion of experimental development in enterprises (*see page* 389).

7. The Spark Programme was launched in 1986 to promote S&T development in rural areas, raise rural productivity and promote an S&T-based rural economy.

8. Launched in August 1988, the Torch Programme focuses on the development of high-tech industries. Implemented via project demonstration, the Torch Programme aims to commercialize those high-tech products with good market prospects and to develop new products in high-tech and related industries. This includes establishing some high-tech industrial development zones around China.

9. Soft science is interdisciplinary research involving natural and social sciences, engineering and mathematics in support of the decision-making process.

Figure 1: Priorities of China's National Programme for High-tech R&D, 2008 (%)



Source: MOST (2009*b*) *Annual Report of the State Programs of Science and Technology Development*

The R&D priorities of the three main programmes

China's national S&T programmes have set their priorities for R&D according to the five strategic areas identified in the *Outline of the Medium- and Long- Term Plan for National Science and Technology Development* (2006–2020). During 2006–2008, the central government's appropriation for these five strategic areas accounted for 90% of the budget allocated to the three major national S&T programmes (MOST, 2009*b*):

- Energy resources and environmental protection: 10.1 billion Yuan (19.8% of the total appropriation);
- IT, new materials and manufacturing: 12.2 billion Yuan (23.8% of the total appropriation);
- Agriculture, population and health: 11.9 billion Yuan (23.8% of the total appropriation);
- Space and ocean technology: 2.5 billion Yuan (4.9% of the total appropriation);
- Basic sciences and frontier technology: 9.7 billion Yuan (19% of the total appropriation).

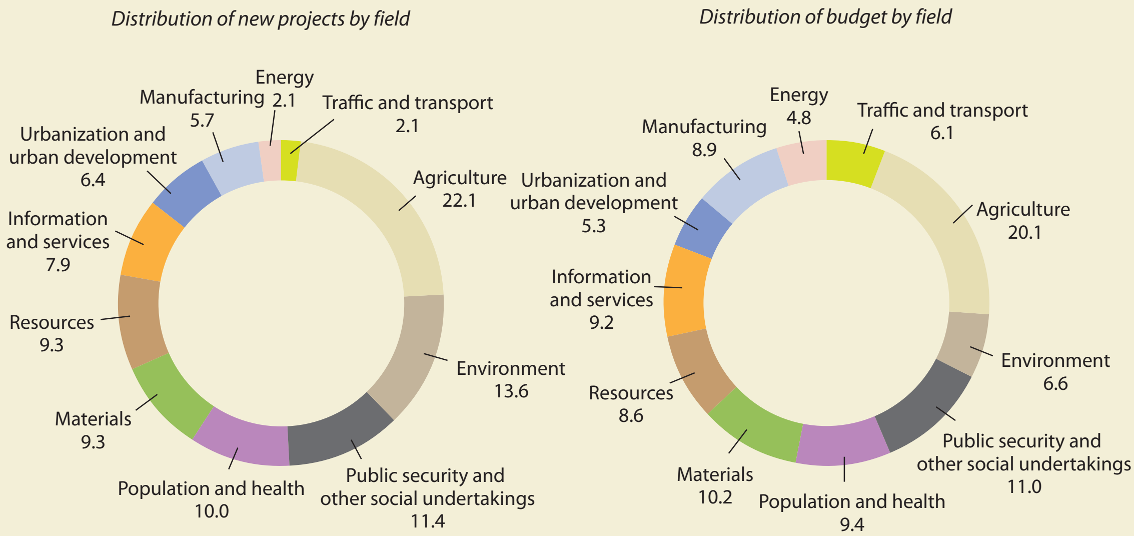
National Programme for High-tech R&D

The 863 programme covers 10 fields of technology. In 2008, the programme approved 1 220 new projects spread fairly evenly across all 10 fields, half of the projects being related to agriculture, materials science, biotechnology and IT. Funding, on the other hand, tended to favour IT (see, for example, Box 3), followed by materials science, energy, biotechnology and ocean science (Figure 1). Universities undertake 57.9% of ongoing projects within the 863 programme, compared to 28.5% for research institutes and just 13.5% for enterprises. Interestingly, enterprises fund much more R&D than they perform within the 863 programme: (24.4%), compared to 43.7% for universities and 31.7% for research institutes.

National Programme for Key Technology R&D

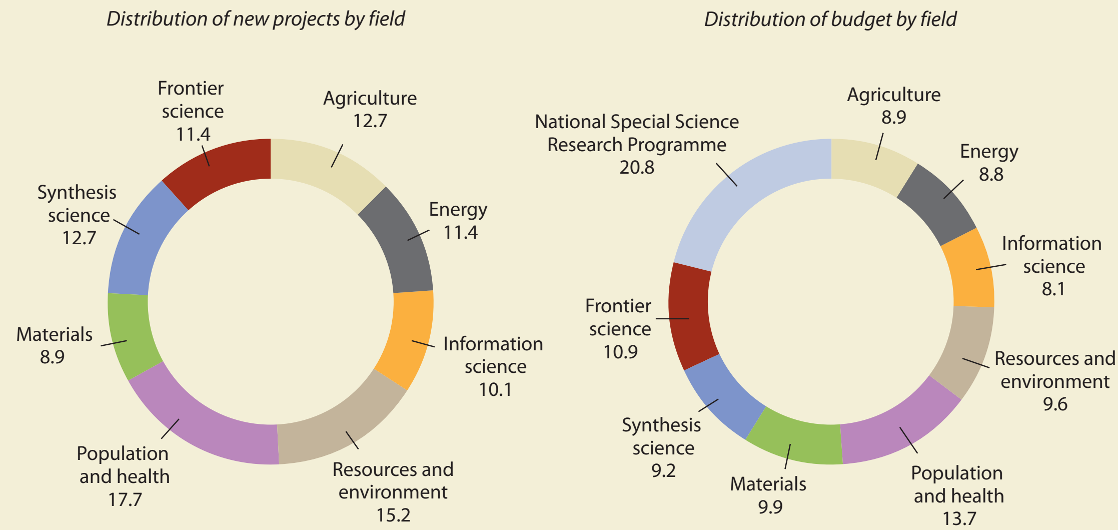
The National Programme for Key Technology R&D covers 11 fields. In 2008, it approved 140 new projects (Figure 2). The central government appropriation was largest by far for agriculture (20.1%). Within this programme,

Figure 2: Priorities of China's National Programme for Key Technology R&D, 2008 (%)



Source: MOST (2009*b*); *Annual Report of the State Programs of Science and Technology Development*; NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*

Figure 3: Priorities of China's National Programme for Key Basic R&D, 2008 (%)



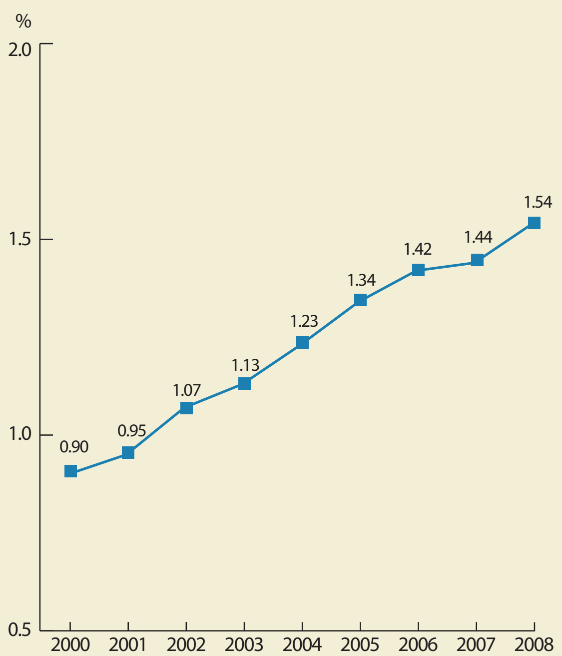
Note: The new projects here do not include those within the National Special Science Research Programme, the breakdown of which is as follows: nano-research (34.3%), development and reproduction research (25.7%), protein research (22.9%) and quantum manipulation (17.1%).

Source: MOST (2009*b*) *Annual Report of the State Programs of Science and Technology Development* universities undertake 26.4% of projects, compared to 18.1% for research institutes and 44.4% for enterprises. Other players account for 11.1% of these projects.

National Programme for Key Basic R&D

The 973 programme covers eight fields. Since, 2006, it has also been supporting the National Special Science Research Programme, which consists of four evenly balanced key research projects: nano-research, development and reproduction research, protein research and quantum manipulation. In 2008, the National Special Science Research Programme accounted for 20.8% of the government appropriation (Figure 3). The same year, the 973 programme approved 79 new projects in the eight traditional fields and 35 new projects within the National Special Science Research programme. In addition to these new projects, there were 274 ongoing projects within the 973 programme in the eight traditional fields and 82 within the National Special Science Research Programme. Universities undertake more than half (54.5%) of all ongoing projects within the 973 programme, research institutes and enterprises performing 41.9% and 3.1% of R&D respectively.

Figure 4: GERD/GDP ratio in China, 2000–2008 (%)



Source: Adams *et al.* (2009) *Global Research Report China: Research and Collaboration in the New Geography of Science.* Thomson Reuters

R&D INPUT

A steep rise in R&D expenditure

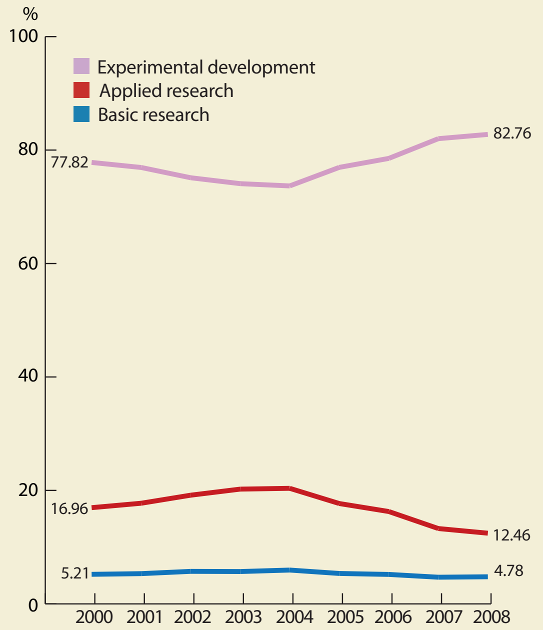
In less than a decade, China has become one of the world's biggest spenders on R&D[10]. Between 2000 and 2008, GERD leapt from 89.6 billion Yuan (US$ 10.8 billion) to 461.6 billion Yuan (US$ 66.5 billion), at an average annual growth rate of 22.8%. The ratio of GERD to GDP in China has likewise increased: from 0.90% in 2000 to 1.54% 2008 (Figure 4). Despite this performance, China's R&D intensity still lags behind that of most developed countries. At US$ 368.1 billion, GERD in the USA was about 5.5 times that of China in 2007, for example, and 58.5 times that of India (World Bank, 2009). In 2008, the GERD/GDP ratio was 2.67% in the USA, 3.40% in Japan and 1.80% in the UK (*see page* 62). The *Medium- and Long- Term Plan* does, however, fix the target of raising China's GERD/GDP ratio to 2.50% by 2020.

In China, the lion's share of GERD goes to experimental development (83%), compared to just 5% for basic research (Figure 5). Despite basic sciences and frontier research being one of the five strategic areas for R&D to 2020, the share of GERD devoted to basic research actually dropped in China between 2004 and 2008 from 5.96% to 4.78%, even if expenditure on basic research nearly doubled from 11.72 to 22.08 billion Yuan over the same period. Although the R&D expenditure of enterprises leapt from 131.40 billion to 338.17 billion Yuan over the same period, the majority of this expenditure goes to experimental development. Among industrial enterprises with total revenue from product sales of over 5 million Yuan for example, R&D expenditure amounted to 307.31 billion Yuan in 2008, 98.55% of which was destined for experimental development (NBS and MOST, 2010).

Business enterprises have become big R&D spenders, contributing 59.95% of GERD in 2000 and 73.26% in 2008 (Table 1). There are two reasons for this rapid growth. *Firstly,* more and more enterprises have come to regard innovation capacity as a core competence. Some Chinese firms are expanding their R&D activities globally. For example, Huawei has set up five research institutes in Silicon Valley and Dallas (USA), Bangalore (India), Sweden and Russia to access

10. R&D expenditure in the present chapter refers to intramural R&D expenditure.

Figure 5: GERD in China by type of research, 2000–2008



Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*

world knowledge (OECD, 2008). Other enterprises like Lenovo and GEELY are accessing foreign R&D resources by means of transnational acquisitions. This phenomenon is also being observed in India (*see page* 363). Secondly, many public research institutes have been transformed into technology-based enterprises and are thus also playing a role in improving the innovation capacity of industry.

One of the world's biggest reservoirs of R&D personnel

China has become one of the world's biggest reservoirs of R&D personnel. The number of scientists and engineers more than doubled between 2000 and 2008 to 1.59 million (Table 2). Over the same period, both the share of GDP and the share of GERD spent on each researcher likewise increased. Despite this feat, the density of researchers in China remains lower than that of developed countries, even if China is rapidly closing the gap. In 2007, there were 1 071 researchers per million population in China, compared to 5 573 in Japan, 4 663 in the USA (2006), 3 532 in Germany and 4 181 in the UK (*see page* 8).

Table 1: GERD in China by performing sector, 2000–2008

	Total (Yuan billions)	R&D institutes (Yuan billions)	Enterprises (Yuan billions)	Higher education (Yuan billions)	Other (Yuan billions)	Enterprises (% of total)
2000	89.6	25.8	53.7	7.7	2.4	59.96
2001	104.3	28.8	63.0	10.2	2.2	60.43
2002	128.8	35.1	78.8	13.1	1.8	61.18
2003	154.0	39.9	96.0	16.2	1.8	62.37
2004	196.6	43.2	131.4	20.1	2.0	66.83
2005	245.0	51.3	167.4	24.2	2.1	68.32
2006	300.3	56.7	213.5	27.7	2.4	71.08
2007	371.0	68.8	268.2	31.5	2.6	72.28
2008	461.60	81.13	338.2	39.0	3.3	73.26

Sources: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*

Table 2: Researchers in China, 2000–2008

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Researchers (thousands)	695.10	742.70	810.50	862.11	926.20	1 118.70	1 223.76	1 423.40	1 592.40
GDP per researcher (million Yuan)	14.27	14.76	14.85	15.75	17.26	16.38	17.32	17.53	18.88
GERD per researcher (thousand Yuan)	128.85	140.36	158.87	178.59	212.30	219.00	245.40	260.66	289.88

Note: Here, the term 'researcher' refers to scientists and engineers among R&D personnel in Chinese statistical yearbooks, a comparable indicator to 'researchers' in OECD statistics.

Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*; NBS (2010) *China Statistical Yearbook 2009*

Table 3: Citation rate for Chinese scientific papers, 1998–2008

	USA	Japan	Germany	UK	China	France	Italy	India	Korea
ESI papers	2 959 661	796 807	766 146	678 686	573 486	548 279	394 428	237 364	218 077
Citations	42 269 694	7 201 664	8 787 460	8 768 475	2 646 085	5 933 187	4 044 512	1 088 425	1 256 724
Citation rate	14.28	9.04	11.47	12.92	4.61	10.82	10.25	4.59	5.76

Note: These data cover Essential Science Indicators for the period from 1 January 1998 to 31 August 2008.

Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*; OECD (2009) *Main Science and Technology Indicators*, Volume 2009/1

Table 4: China's global share of publications by major field of science, 1999–2008

	1999–2003		2004–2008	
	Count	World share %	Count	World share %
Materials science	20 847	12.22	48 210	20.83
Chemistry	44 573	9.29	99 206	16.90
Physics	31 103	7.97	66 153	14.16
Mathematics	7 321	7.37	16 029	12.82
Engineering	19 343	6.42	43 162	10.92
Computer science	3 943	4.54	16 009	10.66
Geosciences	5 322	4.95	12 673	9.30
Pharmacology & toxicology	2 259	3.11	6 614	7.28
Environment/ecology	3 171	3.26	9 032	6.85
Space science	2 055	3.80	3 514	5.8b
Biology & biochemistry	6 697	2.66	15 971	5.86
Plant & animal science	5 915	2.61	14 646	5.42
Agricultural sciences	1 082	1.48	4 872	4.88
Microbiology	921	1.38	3 863	4.74
Molecular biology & genetics	1 642	1.43	6 210	4.49
Immunology	493	0.87	2 114	3.51

Source: Adams *et al.* (2009) *Global Research Report China: Research and Collaboration in the new Geography of Science*

R&D OUTPUT

Only the USA and Japan now publish more

China has become one of the world's most prolific countries for scientific authorship. In 2000, it ranked eighth in the world, according to the database of Thomson Reuters' Science Citation Index (SCI). By 2007, it had climbed to third place. Over the same period, the number of SCI papers published by Chinese researchers nearly tripled from 30 499 to 89 147, representing an average growth rate of 17.3% (NBS and MOST, 2010). However, the average citation rate for Chinese papers in the Essential Science Indicators database during the period 1999–2008 was only 4.61 (Table 3). This indicates that there is still a wide gap in the quality of scientific publications between China and the world leaders in S&T. Of note is that China and India share a similar citation rate. (See pages 374 and 375 for a comparison of Brazilian, Indian and Chinese papers recorded in the SCI database between 2000 and 2008.) China is most influential in materials science, where it represented 20.83% of global output between 2004 and 2008 (Table 4).

Rapid growth in patents

China has become one of the most prolific countries in terms of applications for, and grants of, domestic resident invention patents (Figure 6). Moreover, in 2008, a total of 77 501 domestic resident invention patents were granted in the USA, about 1.66 times as many as in China.

The efficiency of Chinese researchers in terms of invention patents is much lower than that of most developed countries. Some 22.4 domestic resident invention patents were granted per thousand researchers in China in 2007, compared to 412.9 in the Republic of Korea, 204.3 in Japan, 45.6 in Germany and 63.0 in the USA (2006). The landscape for filing within the Patent Co-operation Treaty (PCT) offers almost the same view. In 2007, China filed 3.8 PCT patents per thousand researchers, far fewer than Germany (62.7), Japan (39.1) or the USA (36.0) [Table 5].

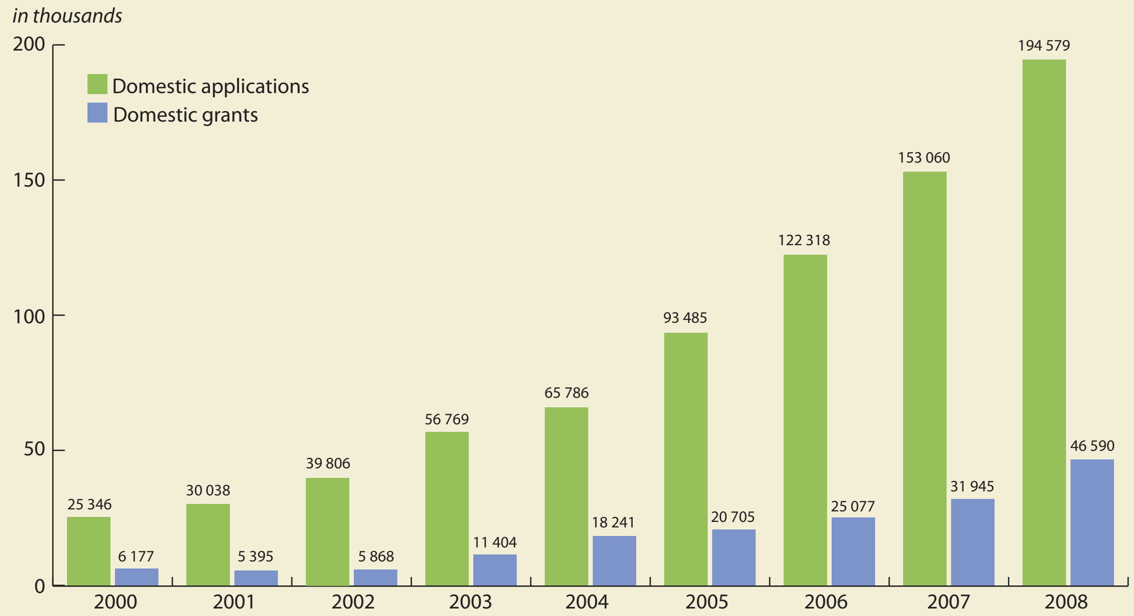
A CLOSER LOOK AT HIGH-TECH INDUSTRIES

Rapid growth in high-tech industries since 2000

High-tech industries in China consist in the manufacture of:

- medicines, medical equipment and measuring instruments;
- aircraft and spacecraft;
- electronic equipment;
- telecommunications equipment;
- computers and office equipment.

Figure 6: Growth in Chinese domestic resident invention patents, 2000–2008



Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*

Table 5: Domestic invention patent grants and PCT patent filings in China, 2007

	Japan	Korea	USA	China	Russia	Germany	France	UK
Domestic invention patents granted	145 040	91 645	89 823	31 945	18 431	12 977	10 697	2 058
PCT patent filings	27 749	7 065	51 296	5 465	735	17 825	6 264	5 539
Researchers (thousands FTE)	710.0	221.9	1425.6	1423.4	469.1	284.3	211.1	175.5
Domestic invention patents granted per thousand researchers	204.3	412.9	63.0	22.4	39.3	45.6	50.7	11.7
PCT filing per thousand researchers	39.1	31.8	36.0	3.8	1.6	62.7	29.7	31.6

Note: Data are 2006 for the USA and France.

Source: WIPO database; OECD database

High-tech industries in China have experienced rapid growth in the past 10 years. The value of gross industrial output of high-tech industries leapt between 2000 and 2008 from 1 041.1 billion Yuan (US$ 125.8 billion) to 5 708.7 billion Yuan (US$ 822.0 billion). Over the same period, the number of employees more than doubled from 3.9 million to 9.5 million.

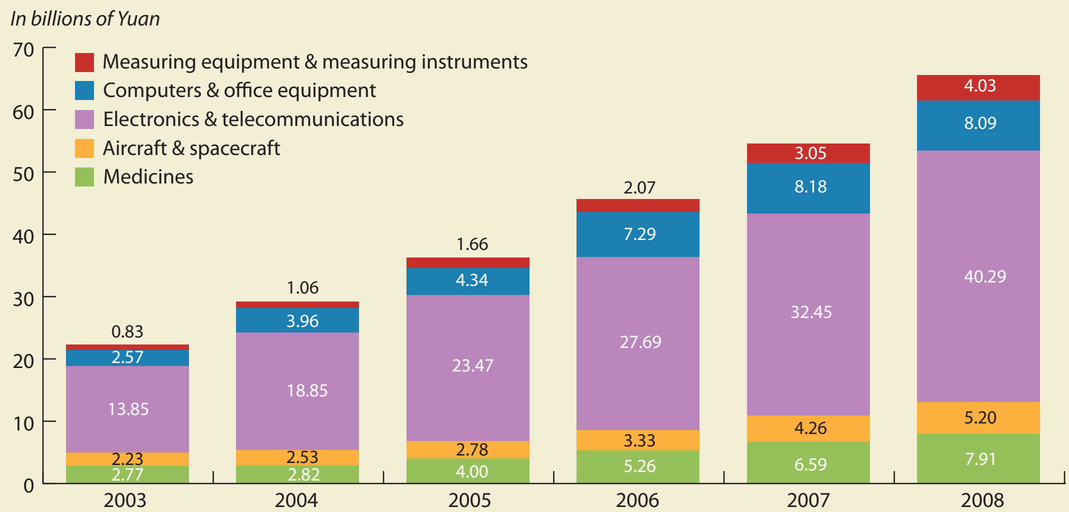
R&D expenditure by high-tech industries tripled in just five years: from 22.2 billion Yuan in 2003 to 65.5 billion Yuan in 2008, growing at an average annual rate of 24.1%. Electronics and telecommunications accounted for 61.5% of all high-tech expenditure on R&D in 2008 (Figure 7). Despite these impressive figures, the R&D intensity of high-tech industry in China remains much lower than that of developed countries. In 2008, the ratio of R&D expenditure to the value of gross industrial output of high-tech industries was just 1.15% in China. This was much lower than the 2006 ratio for the USA (16.41%), the UK (11.04%), Japan (10.64%), Germany (8.34%) or the Republic of Korea (5.98%), according to the 2008 databases of the Organisation for Economic Co-operation and Development (OECD) on Structural Analysis Statistics (STAN) and Analytical Business Enterprise Research and Development (2009).

R&D personnel in high-tech industries in China has experienced remarkable growth, after a fleeting dip from 2003 to 2004. In 2008, there were 285 100 full-time equivalent researchers, more than twice the number in 2003. Not surprisingly, 60.4% of R&D personnel working for high-tech industries were employed in electronics and telecommunications in 2008 (Figure 8).

The number of applications for invention, utility model and design patents in high-tech industries grew annually by 36.8% during 2003–2008. Again, electronics and telecommunications accounted for 65.3% of the total in 2008. However, the fastest annual growth (50.6%) concerned medical equipment and measuring instruments (Figure 9).

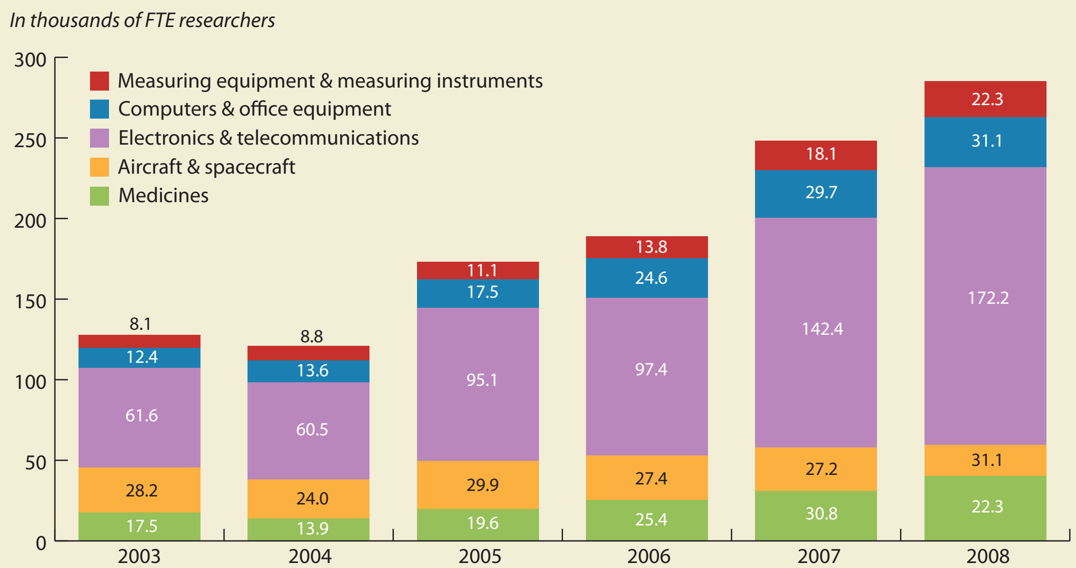
The share of high-tech exports in manufactured exports grew steadily in China between 2000 and 2008, at 8.1% per year. Many dominant players in S&T saw this percentage decline over the same period (Figure 10). Notwithstanding this, China is still a net technology importer. In 2008, China paid US$ 10.3 billion in royalties and license fees, earning receipts of only US$ 570.5 million (State Administration of Foreign Exchange, 2010). The same year, China spent US$ 27.1 billion on imported technology from 82 countries. Of this, US$ 23.5 billion corresponded to technology and US$ 3.6 billion to equipment. Four countries account for two-thirds of China's technology imports: the USA (18.71%), Japan (17.93%), Republic of Korea (12.15%) and Germany (11.75%).

Figure 7: Intramural expenditure on R&D by China's high-tech industries, 2003–2008



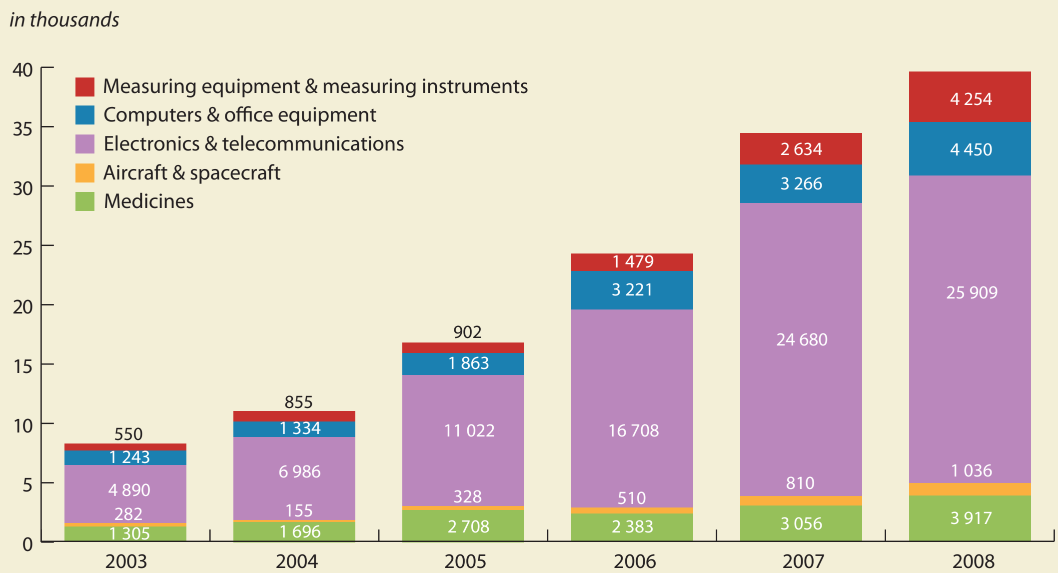
Source: NBS, NDRC and MOST (2008) *China Statistics Yearbook on High Technology Industry*; NBS, NDRC and MOST (2009) *China Statistics Yearbook on High Technology Industry*

Figure 8: R&D personnel in China's high-tech industries, 2003–2008



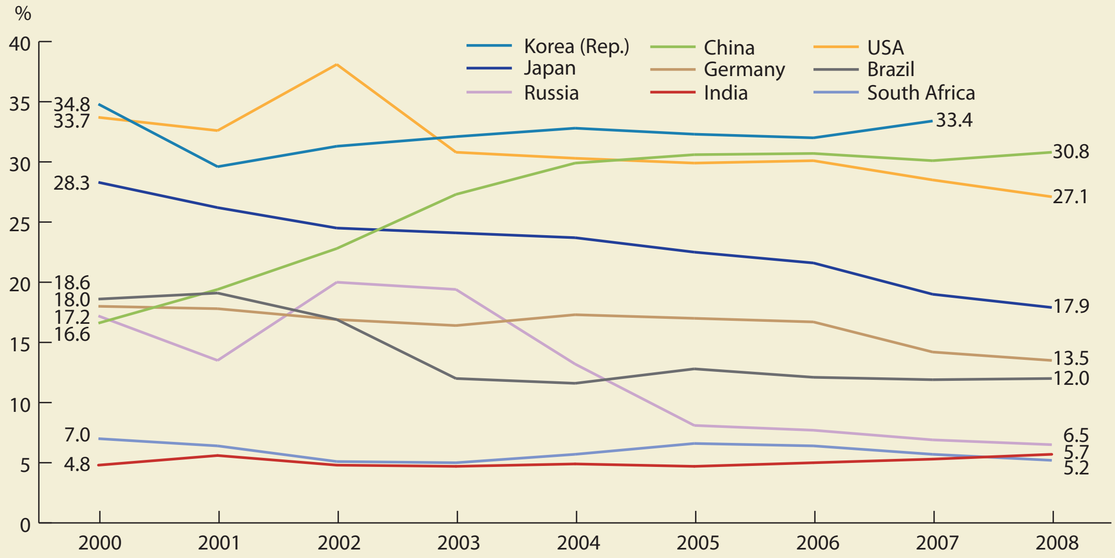
Source: NBS, NDRC and MOST (2008) *China Statistics Yearbook on High Technology Industry*; NBS, NDRC and MOST (2009) *China Statistics Yearbook on High Technology Industry*

Figure 9: Domestic patent applications by Chinese high-tech industries, 2003–2008



Source: NBS, NDRC and MOST (2008) *China Statistics Yearbook on High Technology Industry*; NBS, NDRC and MOST (2009) *China Statistics Yearbook on High Technology Industry*

Figure 10: Share of high-tech exports in manufactured exports in China, 2000–2008
Other countries are given for comparison



Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*; for other countries: World Bank (2010) *High-technology Exports*

Measuring China's capacity to innovate

The National Innovative Development Index

The National Innovative Development Index (NIDI) covers five areas, namely:

- Industrialization: this represents the transition from a rural economy to an industrial economy characterized by a high S&T content, good economic returns, lower resource consumption, less environmental pollution and a wide spectrum of human resource advantages;
- 'Informationization': this refers to the development of an information society via the utilization of information technology, information exchange and knowledge sharing.
- Urbanization;
- Education and health;
- Science, technology and innovation.

According to the *China Innovation Development Report* (CAS, 2009), China's NIDI experienced fairly rapid growth between 2000 and 2006 of 5.3% per annum. Even so, there remains a yawning gap between China and developed countries for this index. China's NIDI amounted to just 20.94, placing it far behind the leader, Sweden (67.01), and 32nd out of the 34 countries studied in 2006, which included the member states of the European Union, Canada, Japan, the Republic of Korea and USA. China ranked higher than South Africa (33rd) and India (34th) but trailed Brazil (27th), Mexico, Russia,Turkey and Romania. China performed best for education (28th) and worst when it came to industrialization that was respectful of the environment (34th).

The National Innovation Capacity Index

In a broad sense, a country's national innovation capacity is its ability to transform STI into wealth. The National Innovation Capacity Index (NICI) is determined not only by the efficiency and intensity of innovation but also by the scale of it. According to the *China Innovation Development Report* (2009), China's NICI shot up from 6.96 in 2000 to 19.59 in 2007. This performance was more the result of greater intensity in innovative activity than a reflection of its efficiency. Between 2000 and 2006, China experienced the fastest growth in national innovation capacity of all 38 countries under study, with an annual growth rate of over 16% which saw it climb to 17th place by 2006, between Ireland and Austria. However, China's NICI still fell far short of the countries which topped the index, the USA (56.96), Japan (36.75) and Sweden (26.63). For this indicator, Russia ranked 25th, Brazil 32nd, South Africa 33rd and India 37th.

INTERNATIONAL CO-OPERATION IN S&T

In recent years, China has expanded the scale and scope of international co-operation considerably. By the end of 2008, China had established collaborative partnerships in S&T with 152 countries and regions, and signed 104 agreements with the governments of 97 countries and regions (MOST, 2009*a*).

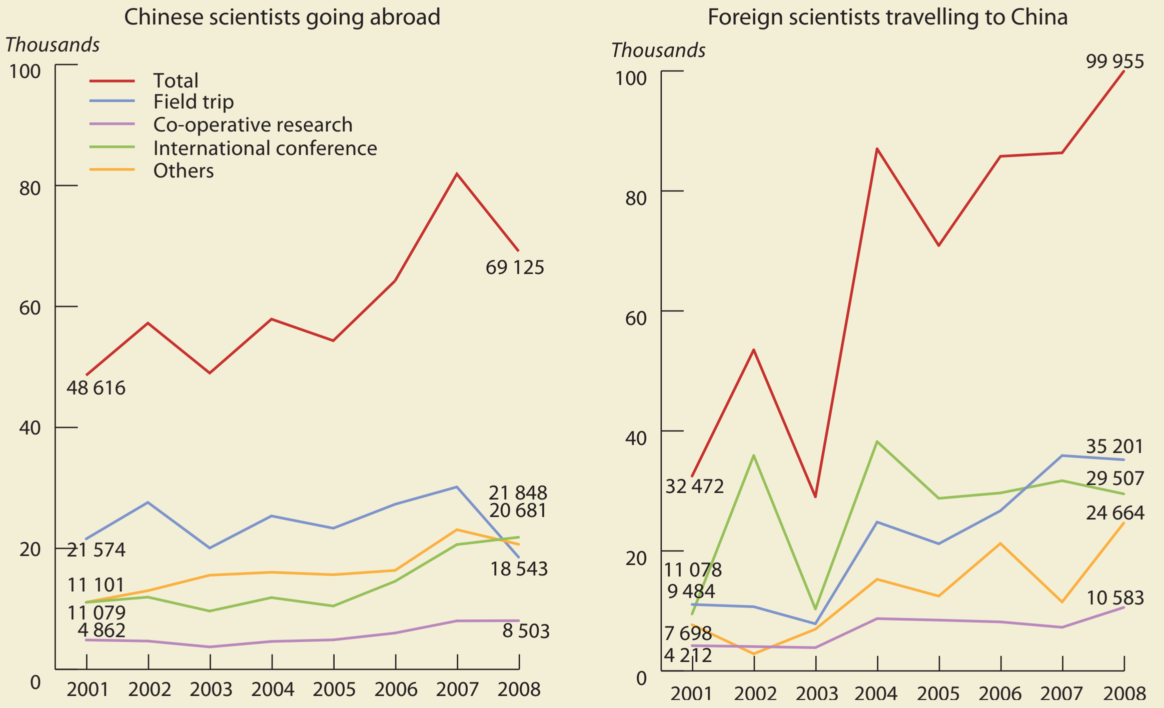
The Chinese government is paying great attention to developing international co-operation in order to improve the country's capacity for innovation. In 2006, it issued the *Outline for the Eleventh Five–Year Plan for Implementing International S&T Cooperation* to diversify the fields covered by co-operation and improve the effectiveness of these partnerships.

In 2001, the government launched the International Science and Technology Co-operation Programme (ISTCP). The ISTCP budget increased steadily over the next seven years from 100 million Yuan to 400 million Yuan in 2008 (NBS and MOST, 2009). In 2001, the National Natural Science Foundation of China created a special fund for international S&T co-operation, the budget of which had nearly doubled by 2008 from 63.9 million Yuan to 144.4 million Yuan.

Over the same seven-year period, the flow of foreign scientists to China exceeded the number of Chinese scientists going abroad, even if the number of mobile Chinese scientists increased gradually from 48 616 in 2001 to 69 125 in 2008. A growing number of Chinese scientists are attending international conferences and participating in international collaborative research. The number of scientists coming to China has almost tripled from 32 472 in 2001 to 99 955 in 2008 (Figure 11).

International co-operation in China has gradually evolved from personal exchanges, communications among academics and the importation of technology to joint research projects, the joint establishment of research institutions and Chinese participation in, or initiation, of megaprojects. China has participated, or is participating, in major international projects that include the European Union's Galileo Global Navigation Satellite System,

Figure 11: Travel by Chinese and foreign scientists by type of project, 2001–2008



Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009.*

the Human Genome Project, the Global Earth Observation System, the Integrated Ocean Drilling Programme and the International Thermonuclear Experimental Reactor (Box 6).

Among programmes initiated by China, both the International S&T Co-operation on Traditional Chinese Medicine Programme launched in 2006 and the International S&T Co-operation on New and Renewable Energy Programme launched in 2007 are noteworthy.

International co-operation has produced some remarkable results, as manifested by the rapid growth in joint scientific publications and the rise in both patent applications and technology trade. Chinese scientists co-author articles mostly with their peers from the USA, Japan, the UK, Germany, Canada and Australia. However, co-publications are growing fastest with scientists from Sweden and the Republic of Korea, followed by Canada, Singapore, Australia and the USA (Figure 12).

Box 6: China's role in an international clean energy project

First proposed in 1985, the International Thermonuclear Experimental Reactor (ITER), the second-biggest international science and engineering project after the International Space Station, is due to be completed in 2011.

ITER is also the most ambitious international project in which China has taken part so far. China began negotiating its participation in ITER in 2003 before officially signing the ITER Agreement in November 2006. As one of the discretionary and independent members, China will assume 9.09% of the cost of construction and spend over US$ 1 billion in total. Some 1 000 Chinese scientists will participate in the ITER project.

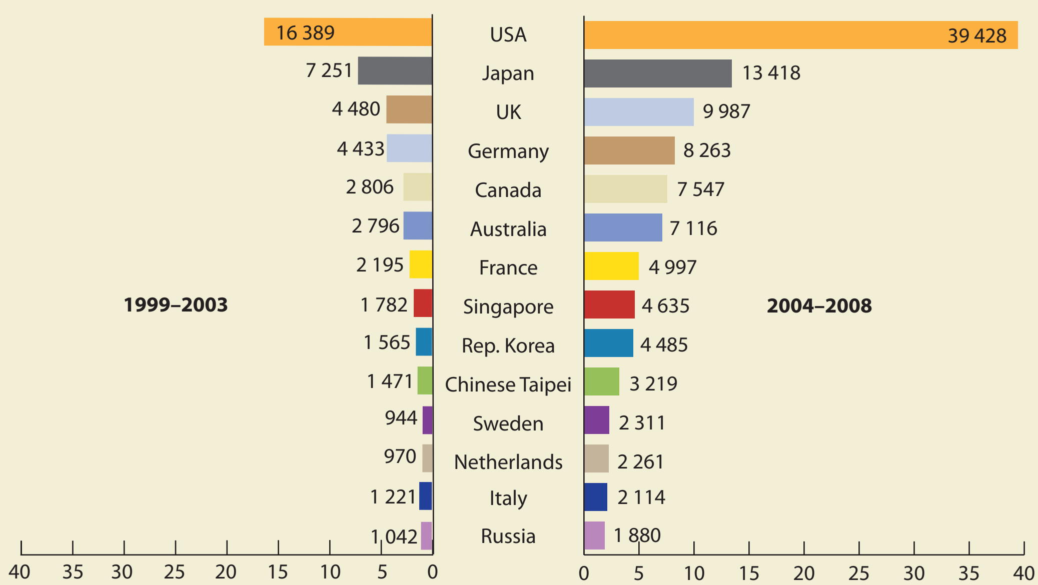
According to the Procurement Arrangement, China will be in charge of developing, installing and testing 12 components, including magnet supports, correction coils and feeders. In February 2007, the State Council authorized the launch of a domestic support programme to fulfil China's obligations vis-à-vis ITER and make full use of the facility once construction has been completed in 2018 or thereabouts.

ITER Director-General Kaname Ikeda has commented that, 'Like other big powers in the world, China, realizing fully the significance of clean energy, is actively taking part in this ITER project, which I think is key to the success of the project'.

Source: www.iterchina.cn/; http://news.xinhuanet.com/

For details of ITER, see page 158.

Figure 12: China's leading international research partners, 1999–2008



Source: Adams *et al.* (2009) *Global Research Report China: Research and Collaboration in the New Geography of Science.* Thomson Reuters

CONCLUSION

The series of policies issued by the Chinese government in the past four years for making China an innovation-driven nation by 2020 provide a wide spectrum of measures for inciting enterprises to invest more in innovation and wooing talented scientists living overseas back to serve their homeland.

However, a host of barriers still restrain the development of national innovation capacity in China, especially that of enterprises. This supposes paying greater attention to the three following factors in promoting the development of STI:

- *Firstly,* the innovation risk of enterprises needs to be shared via incentive policies and the development of public infrastructure to support innovation. In parallel, it should be made difficult for enterprises to generate enormous profits without investing massively in innovation.
- *Secondly,* systematic innovation and the exploration of emerging technology must be supported so that breakthroughs become commonplace and Chinese industry is able to leapfrog over leading or emerging industries elsewhere.
- *Thirdly,* the government should continually increase investment in innovation and shape favourable market demands for technology, in order to stimulate the flow of innovative talents from universities and research institutes to enterprises.

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Whether Japanese manufacturers can retain their unique strengths will be a vital question for the future of Japanese industry.

Yasushi Sato

19 · Japan

Yasushi Sato

INTRODUCTION

Japan's socio-economic system underwent a major structural reform in the first decade of the 21st century. The top priority for the nation at the turn of the century was to recover from the prolonged economic distress caused by the collapse of the 'bubble economy' in the 1990s. In an effort to regain its industrial vigour in an increasingly competitive global environment, Japan opted for small government. By streamlining the public sector and promoting market competition, it sought to rebuild its economic strength.

The central figure in the reform was Junichiro Koizumi, Prime Minister of Japan from 2001 to 2006. Backed by strong public support, Koizumi made bold policy moves. First and foremost, his Cabinet accelerated the disposal of the huge bad debts that Japanese banks had accumulated in the 1990s, by supplying them with taxpayers' money. This initiative actually succeeded in mending Japan's financial system. Other factors, such as near-zero interest rates, depreciation of the yen (which favours Japan's export industry) and expansion of the foreign economy, also contributed to a gradual, yet sustained recovery of Japan's economy. In February 2002, Japan entered a period of economic upturn which lasted until October 2007.

Japan would not escape the global recession, however. The financial crisis triggered by the upset of the US financial market, along with the rising prices of oil and other natural resources, has seriously affected Japan's economy: Japan's real GDP growth, which had hovered around 2% from 2003 to 2007, plunged below zero in 2008.[1] The world's largest automobile manufacturer, Toyota, which in 2007 had made its biggest profit ever, suddenly found itself in the red in 2008. A number of major companies filed for bankruptcy and the unemployment rate rose from 3.9% in 2007 to over 5% in 2009.

Apart from this acute crisis, Japan's economy faces more fundamental, long-term challenges. In the past 20 years and particularly during the second half of the 1990s, the Japanese government has spent extravagantly on public works to stimulate the economy. As a result, government debt has soared to the point where it easily exceeds annual GDP. In addition, the cost of social security has been rising rapidly because of the steady growth in the aged population[2] (Table 1). This critical fiscal situation is becoming a serious hindrance to policy planning and implementation in Japan.

Today, Japan is struggling to identify the right approach to cope with these impending and long-term problems. The reform promoted by Koizumi temporarily buoyed Japan's economy but it also brought about grave social changes. Whereas large corporations have benefited from the deregulation of labour policies, many young people are discovering employment insecurity. Income disparities are growing, eroding the stable consumption capacity of the large middle class that has long characterized Japanese society. The Koizumi reform has also magnified disparities between large cities like Tokyo and rural areas, which now suffer from depopulation and ageing.

Since Koizumi resigned in 2006, Japan's prime minister has changed often, leaving Japanese policy-makers still searching for the right policy direction.

Adding to the uncertainty has been the surprise ousting of the Liberal Democratic Party in the elections of August 2009, after half a century of nearly unbroken rule. The new Japanese Prime Minister Yukio Hatoyama of the Democratic Party vowed to radically change how the country was run, declaring an end to bureaucratic control over policy-making. However, Hatoyama's political and diplomatic inexperience led to his resignation in June 2010. The formidable array of political and economic problems facing Japan were thus passed on to the new Prime Minister Naoto Kan.

In this period of uncertainty, however, there is a firm consensus among Japanese politicians, bureaucrats and industrialists on the cardinal importance of science and technology (S&T) and the need to foster innovation. They all consider that the survival and prosperity of Japan, a country lacking in natural resources and now facing a shrinking labour force, critically depends on its capacities in S&T. Even in today's extremely tight fiscal situation, S&T receives a high priority in the nation's public spending. At the same time, shaping effective S&T and innovation policies has climbed to the top of the national agenda.

Solar and wind energy used to power street lighting in Tokyo. This localised power generation is being used widely

Photo: © T Kimura/ iStockphoto

1. According to the International Monetary Fund's forecast published in October 2009, Japan's economy contracted by 5.4% in 2009 and would achieve only 1.7% growth in 2010.

2. The United Nations estimates that those aged over 60 years will represent 31% of the Japanese population by 2020.

Table 1: Socio-economic indicators for Japan, 2003 and 2008

Year	Real GDP growth (%)	Government debt per GDP (%)*	Population (millions)	Aged dependency ratio (%) **
2003	1.4	158.0	127.7	28.5
2008	-0.7	172.1	127.7	34.3

* general government gross financial liabilities
** this ratio is calculated by dividing the number of those aged 65 years and more by the number of those aged 15–64 then multiplying this figure by 100

Source: Economic and Social Research Institute, Cabinet Office, System of National Accounts; OECD (2009) *Economic Outlook No. 85*; Statistics Bureau, Ministry of Internal Affairs and Communications (2009) *Japan Statistical Yearbook 2009*

POLICY ENVIRONMENT

The *Third Basic Plan* for S&T

In Japan, it is the Council for Science and Technology Policy (CSTP) which draws up the *Science and Technology Basic Plan*, the most fundamental document on S&T policy in Japan. The Science and Technology Basic Law (1995) stipulated that the government should formulate such a plan every five years. The one currently in effect is the *Third Science and Technology Basic Plan*, issued in 2006 to cover the fiscal years 2006–2010. It is a comprehensive programme for the promotion of S&T in Japan, dealing with such issues as government funding, development of human resources, university–industry collaboration and so on.

The *Third Science and Technology Basic Plan* has inherited some key policies from its predecessor issued in 2001. Both plans pledged to promote basic research on a broad front, while setting differentiated priorities for research and development (R&D) corresponding to national and social needs; both prioritized funding for four areas (life sciences, information/telecommunications, environmental sciences and nanotechnology/materials science) over four others (energy, manufacturing technology, social infrastructure and frontier exploration [oceans and space]). Both plans also specified the amount of necessary government funding for R&D; the *Second Basic Plan* called for 24 trillion yen (PPP US$ 185 million) for fiscal years 2001–2005 and the *Third Basic Plan* for 25 trillion yen (PPP US$ 193 million) for 2006–2010. The actual spending for 2001–2005 was 21 trillion yen (PPP US$ 162 million), however; that for 2006–2010 is also expected to fall short of the target.

With regard to the development of human resources, both *Basic Plans* have highlighted the need to increase the mobility of researchers and promote the activities of young, female and foreign researchers.

The *Third Basic Plan* did contain some new policy initiatives, however. While it granted funding priorities to the same four areas as the *Second Basic Plan*, it also introduced such new concepts as 'a critical R&D topic', 'strategic prioritized S&T' and 'key technology of national importance,' for the purpose of detailed prioritizing. Then, in a separate policy document, CSTP specified 273 'critical R&D topics', from which it selected 62 under the category of 'strategic prioritized S&T'. CSTP also specified five 'key technologies of national importance' requiring focused funding: the next-generation supercomputer, the space transportation system, the marine–Earth observation and exploration system, fast-breeder reactor-cycle technology and the X-ray free electron laser. Thus, the *Third Basic Plan* created an elaborate framework for focused R&D investment.

Another key feature of the *Third Basic Plan* has been the heavy emphasis on returning the fruits of R&D to taxpayers through innovation. For that purpose, the plan called for the further expansion and refinement of competitive R&D funds, active support for high-risk research and innovative R&D, and closer collaboration between universities, industry and government.
The plan also pointed to the goal of 'enhancing the competitiveness of universities', envisioning Japanese universities as leading the world in S&T and attracting foreign scholars and students.

These basic policies materialized in some new funding programmes. In 2006, the programme for the Creation of Innovation Centres for Advanced Interdisciplinary Research was launched to build human and institutional R&D capacities through close co-operation between universities, industry and government. In 2007, the Global Centres of Excellence Programme succeeded the 21st Century Centres of Excellence Programme to provide 150 centres of excellence with support for five years.

The same year, the World Premier International Research Centre Initiative was launched to focus investment on just five institutions to make them truly prominent research centres with high visibility in the international community. These five institutions are the: Advanced Institute for Materials Research at Tohoku University; Institute for the Physics and Mathematics of the Universe at the University of Tokyo; Institute for Integrated Cell-Material Sciences at Kyoto University; Immunology Frontier Research Centre at Osaka University; and the International Centre for Materials Nanoarchitectonics at the National Institute for Materials Science.

As a whole, the *Third Basic Plan* reflected the global trends encoded in the *Science Agenda – Framework for Action*, adopted by governments at the World Conference on Science in Budapest, Hungary, in 1999. As the *Science Agenda* called for a closer partnership between science and society, the *Third Basic Plan* made a commitment to 'S&T supported by society and people, and returning fruits to them'. The *Plan* also adopted basic stances that are consistent with the *Science Agenda*, such as the promotion of international collaboration and the building-up of human resources. Such principles structure Japan's S&T policies today.

Promoting innovation

In keeping with the *Third Basic Plan*'s policy of promoting innovation, the Japanese government has taken a wide range of measures. In October 2006, the Cabinet Office established a committee to deliberate on a long-term strategy dubbed *Innovation 25*. Authorized by the Cabinet in June 2007, this strategy envisioned what Japanese society would look like in 2025 and produced a roadmap of the innovation needed to realize this vision. Meanwhile, the Ministry of Economy, Trade and Industry (METI) launched the Innovation Superhighway Initiative in 2006; this scheme set out to accelerate innovation through transdisciplinary R&D, a smooth flow of knowledge between the R&D side of product development and the market side, and close collaboration among industry, universities and government. This initiative led to an amendment of the Industrial Technology Capability Enhancement Act in 2007, which now mandates the government to reinforce the nation's capability in technology management.

Some parliamentarians are also greatly concerned with promoting innovation. In June 2008, the Japanese parliament, the Diet, passed the Research and Development Capability Enhancing Act. In Japan, most new bills are introduced to the Diet by the relevant ministries; in the case of this particular bill, it was drafted by parliamentarians, like the Science and Technology Basic Law of 1995. On the whole, its content was consistent with the policies presented in the *Third Science and Technology Basic Plan*: improving science education; fostering the mobility of researchers; harnessing the capabilities of young, female and foreign researchers; promoting international collaboration and exchanges; allocating R&D funds strategically; augmenting the flexibility of fiscal regulations and so on. The overall aim of the Act was to shape an efficient R&D system that would constantly generate innovation. Parliamentarians have also taken initiatives in specific S&T areas. The Aerospace Basic Act passed in May 2008 called for a new regime to shape strategies for Japan's space activities, urging a shift in the focus of Japan's space efforts from the development of new technologies *per se* to using these technologies for the sake of society. Space technologies can be used for environmental monitoring, for disaster prevention via hazard mapping and monitoring of earthquakes and volcanoes, for telecommunications, global positioning and so on.

The promotion of innovation is a global trend but it takes on special significance in the context of Japanese industrial policy. Japanese manufacturers have traditionally excelled in steadily improving production processes and accumulating production know-how within their organizations, ultimately achieving a high performance and quality at competitive costs. But this Japanese model is losing its effectiveness in many industrial fields, as China, the Republic of Korea and other nations with gross advantages in terms of labour costs emerge as tough competitors. Under such circumstances, Japanese manufacturers have come to believe that they must constantly innovate to survive in the global market. In short, they are experiencing a fundamental shift in the premise of their enterprises.

One can see some clear signs of change in Japan's innovation system. For example, collaboration between universities and industry has greatly expanded in recent years. The number and scale of joint research projects and contract research projects between the two sectors more than doubled in the period 2002–2007. As we shall see later, the number of patent licenses and transfers from universities to industry has also increased dramatically. On the other hand, the number of new university

Table 2: Collaboration between universities and industry in Japan, 2002 and 2007

Year	Number of joint research projects	Amount of money received by universities in joint research projects (yen millions)	Number of contract research projects	Amount of money received by universities in contract research projects (yen millions)	Number of new university start-ups
2002	6 767	15 773	6 584	40 618	190
2007	16 211	40 126	18 525	160 745	131

Source: MEXT (2008) *The Status of University-Industry Collaboration in Financial Year 2007;* NISTEP (2008*a*) *Survey of the Present Status and Problems of University Start-ups in Financial Year 2007*

start-ups has begun to drop after peaking at 245 in 2004; venture capitalists are becoming less willing to invest in new start-ups. Also, many university start-ups are facing financial difficulties, despite multifaceted support from the government. University–industry collaboration will continue to be a key issue in the reform of Japan's innovation system (Table 2).

Reforming universities: a sector under intense pressure

Currently, universities in Japan are under intense pressure to change their mode of operation. In 2004, all national universities in Japan were semi-privatized and transformed into 'national university corporations'. While these universities still receive taxpayers' money, they have adopted new accounting systems incorporating corporate accounting principles. They have strengthened their internal governance by augmenting the authority of their presidents, by setting up boards of directors whose membership includes some members selected from beyond the university walls and by subjecting themselves to a system of external evaluation. Many regulations have been abolished and both faculty and staff have lost their status as public servants. This reform has increased the financial autonomy and flexibility of national universities, as well as that of their personnel, thereby encouraging university–industry collaboration. It was also in line with Japan's national effort to promote innovation and, more generally, with the nation's fundamental policy of streamlining the public sector and realizing small government.

In point of fact, however, many national university corporations are now facing financial difficulties. In the tight fiscal situation of recent years, the government has begun cutting back the amount of money regularly allocated for their operating costs by 1% each year. As these universities rely on this funding source for nearly half of their total income, this policy has dealt them a severe blow. They have been expected to make up the difference by collecting more donations and obtaining more R&D funds but only a small number have actually been able to make up the loss. While powerful universities such as the University of Tokyo and Kyoto University now prosper, thanks to a deluge of competitive funds, others have slowed the pace at which they hire new faculty and are spending less on R&D.

The amount of government subsidies for private universities also began to decrease in 2007. With the 18-year-old population shrinking in Japan, many private universities will be forced to close down or merge with one other. The academic sector as a whole is deeply concerned about all of these trends and policy-makers themselves are now re-examining the proper balance between regular and competitive funding.

International co-operation: using S&T for soft power

CSTP has always stressed the importance of international co-operation in S&T but, in the past few years, it has gone a step farther. After calling for the 'strategic promotion of international activities' in the *Third Basic Plan*, CSTP issued *Towards the Reinforcement of Science and Technology Diplomacy* in May 2008. In this document, CSTP proposes a new rationale for international activities: linking S&T and diplomacy. In other words, it proposes enhancing Japan's 'soft power' by actively utilizing its capacity in S&T to help resolve global issues and carry out co-operative programmes with other countries. Thus, the idea of 'S&T diplomacy' reflects Japan's national interests – but also espouses the ideals set out in the *Science Agenda* adopted in Budapest in 1999 to use S&T for the welfare of humankind. Ultimately, the goal of S&T diplomacy is to contribute to the world's sustainable development and construct mutually beneficial relationships with partners.

To materialize the concept of S&T diplomacy, relevant ministries have begun designing new frameworks for international co-operation. In 2008, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of Foreign Affairs (MoFA) launched a joint programme called the Science and Technology Research Partnership for Sustainable Development. Under this scheme, researchers from Japan and developing countries co-operate to tackle problems in such areas as environment, energy, natural disasters and infectious diseases. These ministries have also launched a programme to send Japanese researchers to developing countries. In order to expand the reach of international co-operation in S&T, Japan is now actively participating in dialogue with Asian and African countries in a variety of high-level meetings.

R&D INPUT

Rising R&D expenditure

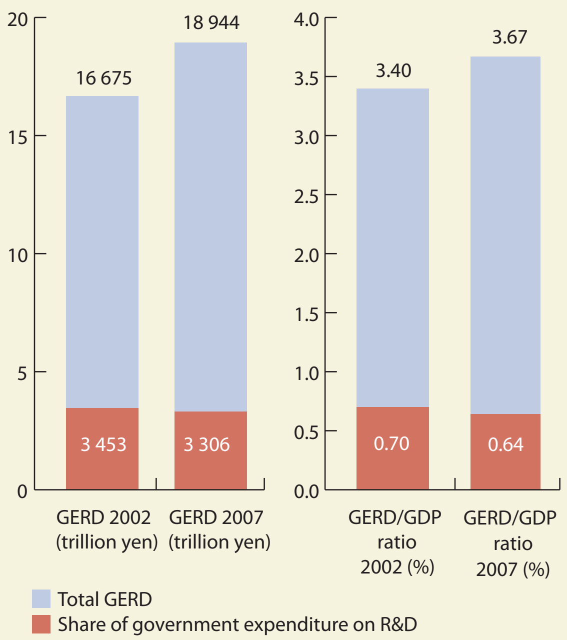
Japan's gross domestic expenditure on R&D (GERD) climbed steadily between 2002 and 2007. This reflects the economic upturn of the period and the growing awareness by Japanese firms of the critical role R&D plays in their competitiveness. As a result, Japan's GERD/GDP ratio, which had long been high by international standards, climbed even higher to 3.67% in 2007.

A drop in government funding

In parallel, government expenditure on R&D decreased over the same period. This is largely due to fluctuating extraordinary spending: the Diet frequently approved large supplementary budgets around the turn of the century to stimulate the lagging economy but such extra spending became modest after 2003. Nevertheless, regular government spending on R&D, which had consistently risen up until the turn of the century, has certainly stopped growing in recent years, reflecting the nation's increasingly tight fiscal situation. As a result, Japan is becoming more and more dependent on R&D funding from the private sector (Figures 1 and 2).

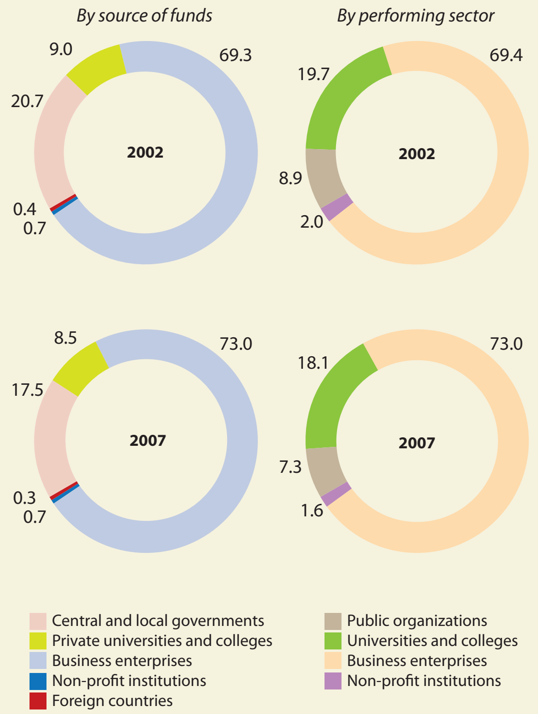
As regards the focus of government spending on R&D, the *Second* and *Third Science and Technology Basic Plans* stated that basic research should be steadily promoted in all areas

Figure 1: GERD and government R&D expenditure in Japan, 2002 and 2007



Source: MEXT (2009c) Indicators of Science and Technology

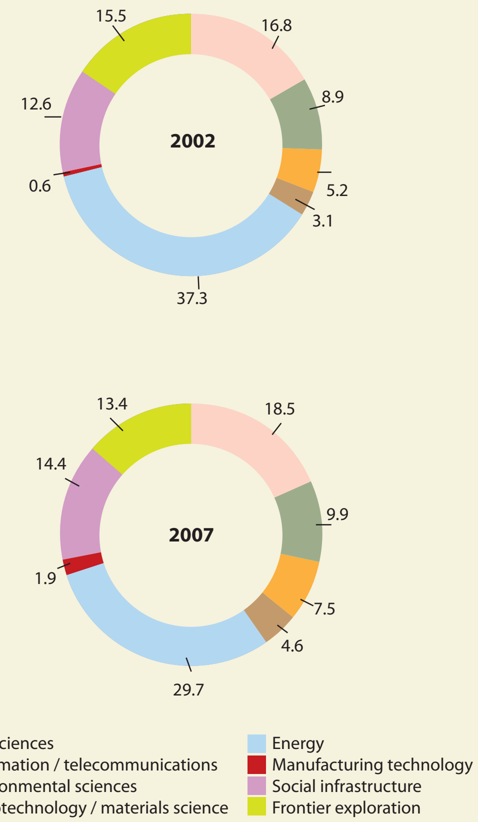
Figure 2: GERD in Japan by performing sector and source of funds, 2002 and 2007 (%)



Source: MEXT (2009c) Indicators of Science and Technology

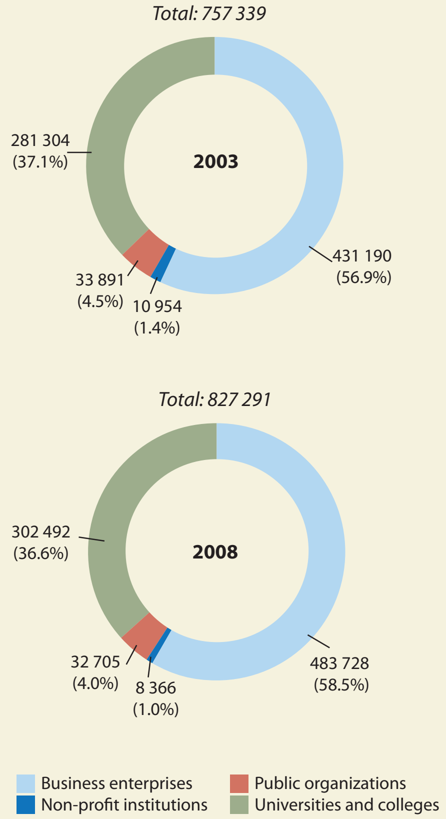
Figure 3: Government spending on R&D by major fields of science, 2002 and 2007 (%)

Excludes basic research



Source : Materials presented by MEXT before CSTP's Expert Panel on Basic Policy Promotion, 18 March 2009

Figure 4: Numbers of researchers in Japan, 2003 and 2008



Source: MEXT (2009c) *Indicators of Science and Technology*

of S&T, while specifying four priority areas that responded to the needs of the nation and society. As we have seen above, these areas are the life sciences, information/telecommunications, environmental sciences and nanotechnology/materials science. This policy has been steadily reflected in the actual spending pattern. The ratio of basic research funding to total government R&D funding has risen from 39.6% (2002) to 42.3% (2007). Over the same period, spending for non-basic research has decreased and its allocation pattern has changed. The four high priority areas have seen their shares rise to the detriment of two of the other four areas: energy and frontier exploration. A gradual cutback in spending on both nuclear power development and space development has contributed to this trend. Overall, a 'macroshift' is evident in the allocation of government R&D funding in Japan (Figure 3).

Rapid growth in competitive funds

Another important change in the structure of government R&D funding is the rapid growth in the number and size of competitive funds, allocated on the basis of merit. The total amount of competitive R&D funds increased from 344 billion yen in 2002 to 477 billion yen in 2007. Many new funds were instituted by MEXT, METI and other ministries to cover various types of R&D activities. The largest competitive fund in Japan, the Grants-in-Aid for Academic Research, grew from 170 to 191 billion yen over this five-year period; the fund is administered by MEXT and the Japanese Society for the Promotion of Science.

This expansion in competitive funding reflects CSTP's intention to render Japan's R&D environment more vigorous and competitive. CSTP has also adopted a policy of increasing the proportion of indirect costs in competitive R&D funds to stimulate competition between universities. In fact, the ratio of indirect costs to direct costs in all competitive R&D funds grew from 7.7% in 2002 to 17.9% in 2007. Now, many universities see indirect costs as a significant source of revenue and are encouraging their faculty to apply for competitive R&D funds.

A growing pool of researchers

There were 827 291 researchers in Japan in 2008, an increase of 9.2% since 2003 (Figure 4). Most of this increase has been borne by the industrial sector, although universities and colleges have also taken on faculty. The number of researchers per 10 000 population in Japan in 2008 was 64.8, one of the highest proportions in the world. Any international comparison for this indicator should inspire caution, however, since the method of counting researchers varies greatly from one country to another.

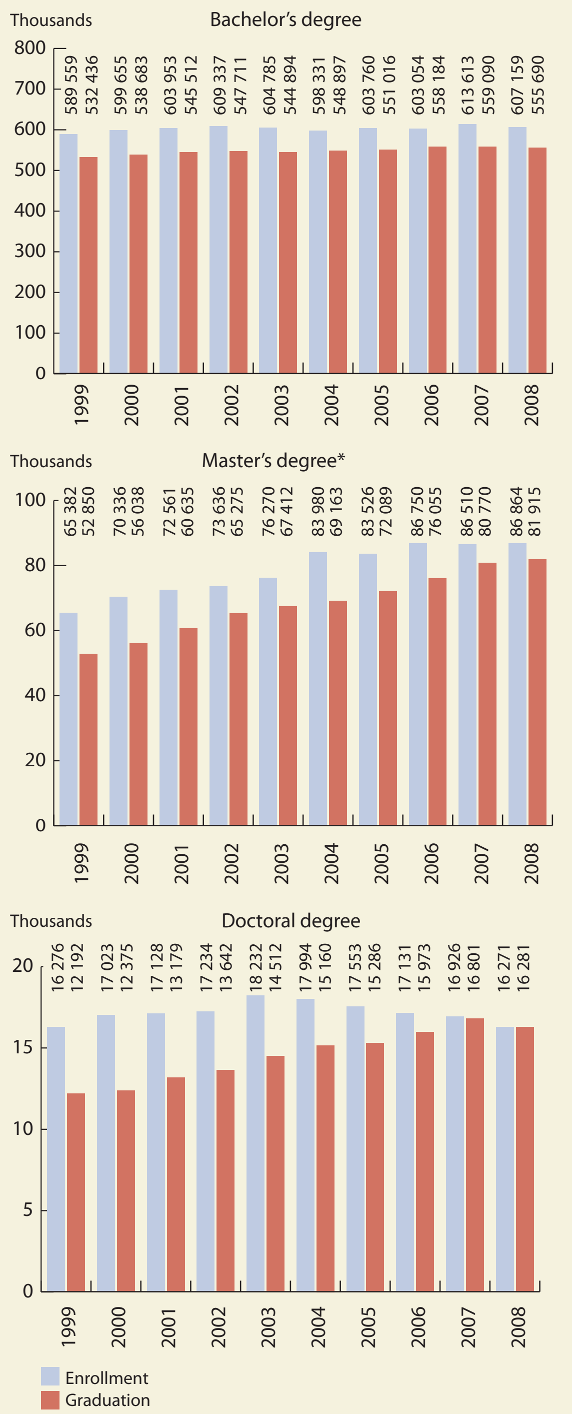
The number of female researchers in Japan has been growing steadily but is still low compared to other countries. In the *Third Basic Plan*, CSTP stated that one in four researchers in Japan should be female. The government has taken various measures to move towards this goal. For example, a fellowship was created for female researchers wishing to resume research activities after giving birth and raising children. However, the actual ratio has only grown from 11.2% (2003) to 13.0% (2008). Similarly, the proportion of foreign researchers in Japan has remained modest. In 2008, just 3.5% of university faculty members were foreign-born.

Decreasing numbers of doctoral students

The training of researchers in Japan is now at a crossroads. Whereas the 18-year-old population in Japan has been declining since the early 1990s, enrollment in higher education has only tailed off recently after progressing steadily until 2002. Since 2003, enrollment at the bachelor's level has stagnated and, at the doctoral level, has begun a fairly rapid decline. Thus, from the perspective of Japan's S&T capacity, the problem of a shrinking younger generation has entered a critical phase (Figure 5).

The recent decline in the number of doctoral students is a manifestation of a crisis in human resources in S&T. There was a great expansion in graduate education in Japan in the 1990s, in response to the expectation that demand for highly educated talents would grow in the emerging knowledge society. In reality, no such demand has eventuated in the academic, public or private sectors,

Figure 5: Trends in enrollment and graduation in higher education in Japan, 1999–2008



* Includes Professional Degree Courses, which were instituted in Japan in 2003

Source: MEXT (2009c) *Statistical Abstract*

Table 3: International exchange of Japanese and foreign-born researchers, 2001 and 2006

Year	Foreign students studying in Japan	Foreign researchers working in Japan for less than 30 days	Foreign researchers working in Japan for longer than 30 days	Japanese students studying abroad	Japanese researchers working abroad for less than 30 days	Japanese researchers working abroad for longer than 30 days
2001	78 812	17 037	13 030	78 151	96 261	6 943
2006	117 927	22 565	12 518	80 023*	132 588	4 163

* Number in 2005

Source: MEXT (2009*a*) *White Paper on Science and Technology;* MEXT (2009*d*) *The General Status of International Research Exchanges*

especially for those with doctoral degrees. As a result, many doctorate-holders have been left without stable employment. The number of postdoctoral positions and other non-permanent positions has grown, due to a consistent increase in competitive R&D funds. But these positions have not guaranteed job security and many doctorate-holders cannot even accede to these positions. As word has got round, many students have simply stopped applying for doctoral programmes, despite the government schemes expanding financial support for them.

In an effort to solve this problem, the Japanese government has launched various initiatives to develop diverse career paths for doctoral students and postdoctorates. New programmes have allowed them to acquire a broad range of skills and to experience internships, in order to smooth their transition to the private sector. They have also been expected to seek opportunities at the interface between S&T and society. For example, there is a growing demand for S&T experts in the intellectual property departments of universities. Strengthening these departments would accelerate university–industry collaboration and lead to more innovation. Another area where doctorate-holders could use their expertise is science communication; this would not only earn public support for S&T but also attract young students to S&T professions. In reality, however, such new paths for doctoral students and postdocs have done little to solve the problem of employment insecurity. The overwhelming imbalance between supply and demand for doctorate-holders will take many years to absorb.

As for the Japanese government's efforts to promote the international exchange of researchers, these have yielded mixed results. The number of foreign students studying in Japan has grown considerably since 2001, thanks to fellowships designed especially for them. Yet, the number of foreign researchers staying in Japan for longer than 30 days has actually decreased, as has the number of Japanese researchers who stay abroad for more than 30 days (Table 3). These figures indicate that Japanese researchers are becoming increasingly inward-looking and are being left out of the international network of researchers. According to a survey conducted by MEXT in 2007, Japanese researchers, especially young ones, hesitate to go abroad mainly because they worry about finding positions on their return to Japan and do not see a possible economic return on their investment. Within the government, there is a growing sense of crisis about this trend, even if the government has not yet managed to take effective measures to remedy the situation.

R&D OUTPUT

Trends in scientific publications

Japan's world share of scientific publications has dropped in the past few years. Whereas the nation produced 10.0% of the world's scientific papers in 2002, according to the Science Citation Index, its share had dropped to 7.6% by 2007 (*see page* 10). Although this is largely due to the rapid growth of scientific publications in China, Japan's share has declined faster than that of other member countries of the Organisation for Economic Co-operation and Development (OECD). It is difficult to analyse here precisely what factors contributed to such a decline but stagnating R&D input in Japan has possibly played a role. As discussed above, the amount of government expenditure on R&D fell between 2002 to 2007, while the number of researchers in Japanese universities grew only slowly over the same period. Japan's share of the top 10% of scientific publications also fell, from 8.2% in 2002 to 7.5% in 2007.

Table 4: Japan's world share of scientific publications, 2007 (%)

	Japan's share of publications	Japan's share of top 10% publications
Chemistry 9.1		10.0
Materials science	9.3	11.5
Physics/space science	11.4	11.7
Computer science/mathematics	5.2	4.5
Engineering 7.2		7.1
Environmental/Earth sciences	5.1	5.5
Clinical medicine	6.7	5.3
Biological sciences	8.3	7.2

Note: The 'top 10% publications' are measured in terms of the number of received citations.

Source: Data provided to the author by NISTEP

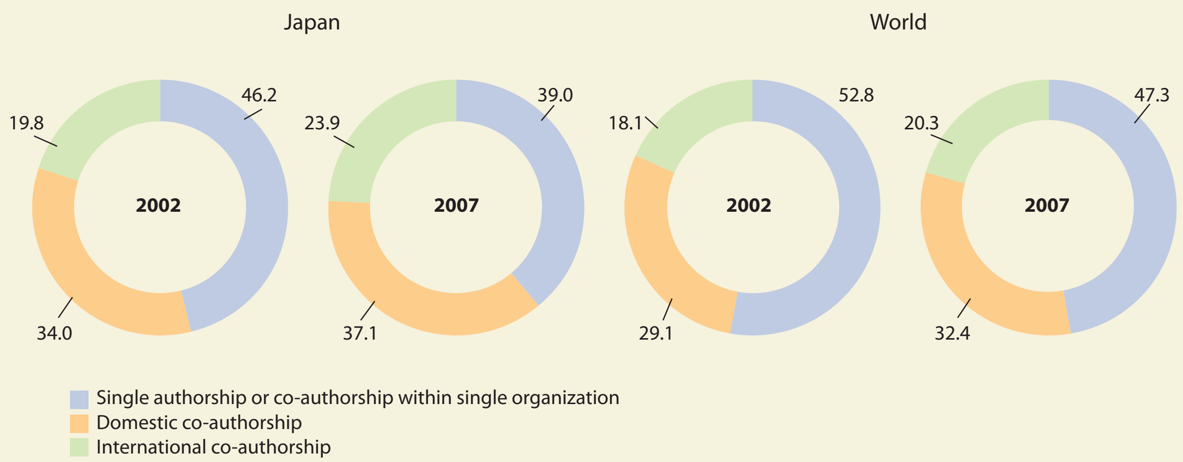
Japan remains strong in chemistry, materials science, physics and space science. In each of these fields, Japan's world share of publications is around 10.0% and its world share of the top 10% of publications is even higher. Japan's performance is less impressive in other fields, such as computer science and mathematics or environmental and Earth sciences. Japan is also traditionally weak in clinical medicine, although its performance has improved slightly in recent years (Table 4).

Reflecting the trend towards internationalization of R&D, researchers throughout the world are producing greater numbers of internationally co-authored publications and the Japanese are no exception. Scientific papers co-authored with non-Japanese scientists represented 23.9% of all scientific papers in Japan in 2007. This percentage is a little higher than the world average but significantly lower than that for most OECD countries. This is mainly because European nations enjoy geographical and institutional advantages that allow them to form a huge network of researchers, as in the USA. Again, Japanese researchers appear to be less tightly integrated in the international network of researchers than their foreign counterparts (Figures 6 and 7).

Patents: from quantity to quality

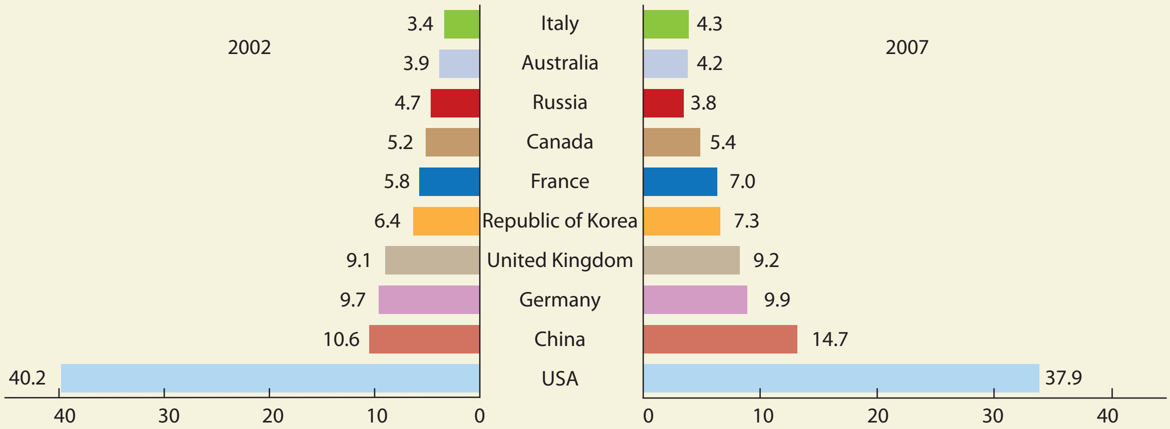
The total number of patent applications to the Japan Patent Office has been gradually falling. Whereas there were 421 000 applications in 2002, this number had dropped to just 396 000 by 2007. Behind this trend lies a fundamental

Figure 6: Single authorship and co-authorship in Japan and the world, 2002 and 2007 (%)



Source: NISTEP (2009a) *Science and Technology Indicators*

Figure 7: Share of other countries in Japan's internationally co-authored scientific publications, 2002 and 2007 (%)



Note: These percentages do not total 100% because some papers have been written by researchers from three or more countries and thus may have been counted more than once. Moreover, the figure does not include Thailand, Brazil and other countries where there is very little co-authorship with Japanese researchers.

Source: NISTEP (2008*b*) *Benchmarking R&D Capacity of Japan Based on Dynamic Alteration of Research Activity in the World*

change in the patent strategies of Japanese firms. Many have been refraining from filing large quantities of patents for mainly defensive purposes, instead focusing their efforts on obtaining high-quality patents to help develop their core businesses. Also, firms have adopted the strategy of not applying for patents, choosing instead to hide new technologies within their organizations whenever this would appear to secure their competitive edge.

At the same time, Japanese firms are now placing greater emphasis on filing patents overseas. Their patent strategies are evidently acquiring a global perspective. If the share of Japanese applicants in total patent applications to the Japan Patent Office fell from 87.7% in 2002 to 84.2% in 2007, Japanese firms applied for many more patents to the USA, Europe, China and elsewhere in 2007 than in 2002 (Table 5). The number of Japanese patent applications under the Patent Co-operation Treaty, which was concluded in 1970 to facilitate international applications, also increased from 14 000 in 2002 to 27 000 in 2007. These figures indicate a steady trend towards internationalization.

Another notable trend in patent activity in Japan is the deepening involvement of the academic sector. In 1999, the Diet passed legislation granting Japanese universities the right to pursue intellectual property rights arising from government-funded R&D. This legislation, also known as the Japanese version of the Bayh-Dole Act[3], spurred the patent activities of Japanese universities. The number of patent applications, patent licenses and transfers by universities showed impressive growth from 2002 to 2007. However, the growth in total income earned by universities through patents was less spectacular. So far, patent activities have not become a significant source of income for Japanese universities (Figure 8).

Table 5: Japanese patent applications and grants in Japan, USA, Europe and China, in thousands, 2002 and 2007

	Japan		USA		Europe		China	
Year	Applications	Grants	Applications	Grants	Applications	Grants	Applications	Grants
2002	369 109		58.7	34.9	15.9	8.2	15.4	5.9
	(87.7%)	(90.4%)	(17.6%)	(21.3%)	(15.0%)	(17.4%)	(19.1%)	(27.6%)
2007	333 145		78.8	33.4	22.9	10.7	32.9	16.2
	(84.2%)	(87.9%)	(18.0%)	(21.2%)	(16.3%)	(19.5%)	(13.4%)	(23.8%)

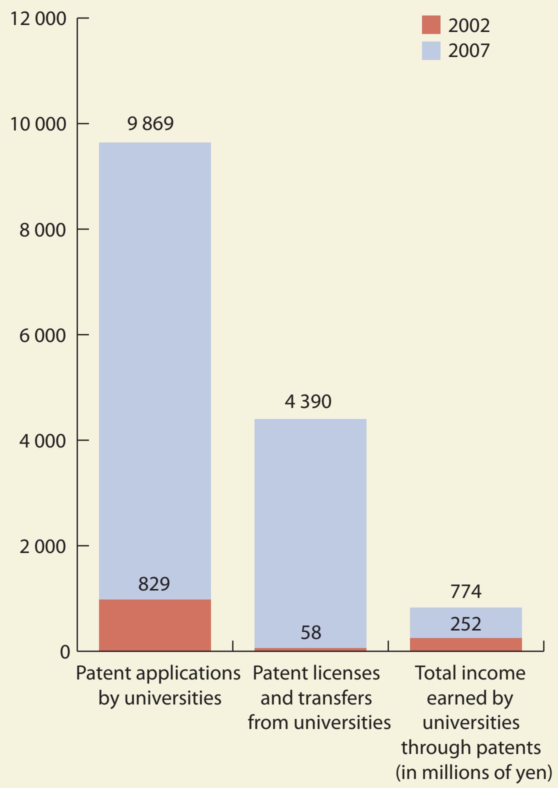
Source: MEXT (2009c) *Indicators of Science and Technology*

CONCLUSION

Since the turn of the century, S&T in Japan has been metamorphosed by the changing socio-economic environment in which it operates. Under severe fiscal pressure, the government has begun capping growth in government R&D expenditure, striving to allocate its limited resources in a strategic manner. CSTP has been the architect of this strategy. As we have seen, particular areas have received priority over others and the number and size of competitive R&D funds have grown.

These policy initiatives have not visibly improved Japan's performance in the academic sector, however; Japan's share of scientific publications has even declined in recent years. Nor has the training of the next generation of researchers been going smoothly. The number of doctoral students has begun dropping, as has the number of long-term international exchanges of researchers. It is apparent that Japan's S&T policy has not fully met the challenges posed by the evolution of society in a changing world.

Figure 8: Patent activity of Japanese universities, 2002 and 2007



Source: MEXT (2008) *The Status of University–Industry Collaboration in Financial Year 2007*

An entirely new approach to policy-making may be necessary. Over the past decade, Japanese policy-makers have embraced competitive R&D funding, supported centres of excellence and expanded non-permanent positions in the academic sector. All of these initiatives, however, were essentially appropriated from existing foreign schemes, especially American ones. Introducing such schemes quickly into Japan without taking into consideration the wider socio-cultural context of Japanese academia may have undermined the unique strengths of the nation's university system, which has its own history and tradition, even if it may have also had the merit of alleviating some of the university system's weaknesses. For example, the government's policy of focusing investment on the nation's top universities may have improved their performance but, at the same time, damaged the R&D capacities of other universities, thereby destroying the domestic networks of researchers along with the diverse capabilities and approaches these have to offer. Similarly, expanding non-permanent academic positions through project-type competitive R&D funds may have enhanced the domestic mobility of researchers but also driven them into reckless competition, thereby eroding the attractiveness of the academic profession.

As such concerns are increasingly being voiced in the academic community and among S&T policy researchers in Japan, it may be necessary to reconsider thoroughly the basic policies of the past 10 years. More generally, the Japanese government would do well to exercise caution in introducing foreign schemes; the strengths and weaknesses of current schemes require more thoughtful analysis and the impact of new initiatives needs to be carefully assessed.

S&T in Japan's private sector appears to be in better shape than in the academic sector. Owing to the economic upturn between 2002 and 2007, both R&D expenditure and the number of researchers in the private sector have

3. Adopted in the USA in 1980, the Bayh-Dole Act, or University and Small Business Patent Procedures Act, gave universities, small businesses and non-profit organizations in the USA the right to file for ownership of their inventions and other intellectual property resulting from R&D funded by the government. Prior to 1980, such intellectual property had basically belonged to the government.

grown considerably. Although the number of patent applications has recently been falling, this is largely due to the changing patent strategies of corporations rather than the weakening of their R&D performance. University–industry collaboration has expanded greatly and many new university start-ups have emerged, albeit with uncertain financial prospects. Overall, Japanese industry is investing heavily in R&D and making vigorous efforts to generate innovation.

Japanese industry is also facing new challenges. Since the 1990s, competitive pressures from emerging nations such as China and the Republic of Korea have driven many Japanese firms to target the high end of the market. Yet recently, the high end of the global market has been shrinking rapidly, especially since the global recession hit wealthy consumer countries in Europe and North America in 2008. In this new market environment, developing high-quality, high-performance, expensive products through intensive R&D investment ceases to be an effective strategy. Japan's world share of mostly electronic products has dwindled, in fact, in the past 10 years.

Japan nevertheless maintains its predominant position in such areas as automobiles, machine tools, digital cameras and electronic components. These products typically have a tightly integrated architecture; their development requires exercising tacit know-how and intricate co-ordination, both areas in which Japanese firms excel. Here again, however, Japan faces a new challenge, as engineers and craftsmen with this expertise begin retiring *en masse*. Whether Japanese manufacturers can retain their unique strengths will be a vital question for the future of Japanese industry.

In today's world, Japan should be fully aware of global trends and standards in shaping its S&T policies but that does not mean foreign schemes and systems should be quickly and blindly imported into Japan. Many of the problems that Japan now faces in S&T seem to require original strategies that take into consideration the nation's own unique strengths and weaknesses. Up until now, Western policy models in general have had an almost invincible power of persuasion among Japanese policy-makers. A fundamental change in mindset is needed for the sound and sustained development of S&T in Japan.

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Korean STI policy needs to nurture and utilize its world-class human resources and to strengthen global S&T co-operation.

Lee Jang-Jae

20 · Republic of Korea

Lee Jang-Jae

INTRODUCTION

In the Republic of Korea, the present government considers science and technology (S&T) to be the core element for achieving a number of national goals[1]. These goals include acquiring the dual status of 'advanced country' and world power. The government also hopes that assigning a central role to S&T will help to ensure economic growth, strategically concentrate national resources on creative, original research, build a more equitable and progressive society, and promote prosperity in northeast Asia.

Although, in the past, economic growth in the Republic of Korea relied on imitation, the country was able to assimilate advanced technologies and improve on these by considerably increasing investment in research and development (R&D). Today, Korea aims to use innovation to create added value and to increase gross domestic expenditure on R&D (GERD) to 5% of GDP by 2012. This target has become one of the country's top priorities.

The timetable for meeting this target has been contraried by the global slowdown caused by the US sub-prime mortgage crisis, which plunged the Korean economy into a severe recession at the end of 2008. According to the Bank of Korea, GDP shrank by 5.6% in the fourth quarter of 2008.

However, thanks mainly to the government-led stimulus packages to minimize the economic downturn, the Korean economy expanded by 0.2% in 2009, the third-highest growth rate among the 21 members of the Organisation for Economic Co-operation and Development (OECD), which unveiled preliminary growth figures in February 2010. The OECD expects the Korean economy to grow by 4.4% in 2010, the highest growth rate among OECD countries (OECD, 2009). This is much higher than the OECD average of a 1.9% growth rate.

Despite the global economic recession, GERD in 2008 amounted to 34 498.1 billion Korean won (KRW, about US$ 31.3 billion), an increase of 10.2% over the previous year. R&D expenditure as a percentage of GDP was a healthy 3.37%, an increase of 0.16% over 2007, equivalent to US$ 644 per capita.

The Korean government has tried to raise R&D expenditure during the global economic recession, in order to stimulate national R&D and innovation. As a result, R&D investment in 2008 and 2009 by the government and public sector increased by 13.5% and 11.4% respectively over the previous year.

S&T POLICY INITIATIVES

In 2003, the Roh Moo-Hyun government established the Planning Committee for a Science and Technology-oriented Society and placed it within the Presidential Advisory Council on Science and Technology. The Planning Committee's chairperson was the presidential secretary for S&T. It was she who drafted the *Roadmap for Building a Science and Technology-oriented Society*. The Ministry of Science and Technology (MoST) set up its own Planning Committee for a Science and Technology-oriented Society. After many meetings and public hearings, this body prepared a proposal and drafted general plans, including a detailed methodology for building an S&T-oriented society.

As a result of these efforts, the Initiative for Establishing a National Technology Innovation System, the government's practical strategy for building an S&T-oriented society, was implemented in July 2004. Ministries identified five major innovation areas with 30 priority tasks on which to focus. This constituted the basic framework for Korea's S&T innovation policy under the Roh government (2003–2008).

The Science and Technology Basic Plan for 2008–2013 (known as the 577 Initiative[2]) of the new Lee Myung-Bak government, which took office in February 2008, was finalized by the National Science and Technology Council (NSTC) in December 2008. This *Plan* consists of 50 priority tasks for the next five years.

A few months earlier, in August 2008, President Lee Myung-Bak had declared a Low Carbon, Green Growth policy as a key national agenda. Both the *Science and Technology Basic Plan* and the Low Carbon, Green Growth policy constitute the basic framework for the S&T policy of the Lee government.

1. Much of this chapter is based on the White Paper on *National Science and Technology Policy* from 2003 to 2007, published by the Korean Ministry of Science and Technology in December 2007, and on the *Science and Technology Basic Plan* of the Lee government, published in December 2008.

2. '577' is a reference to three key digits: total R&D investment will reach 5% of GDP by 2012; the Korean government will focus GERD on seven priority S&T areas; and it will promote seven policy sectors, such as nurturing human resources in S&T, promoting basic research and so on.

Crowded street in Seoul

Photo: Getty Images

Main thrusts of national S&T policies from 2003 to 2012

After the basic S&T policy frameworks of the new governments had been established, the Roh and Lee administrations both prepared basic plans for the implementation of these frameworks. Drafted in May 2003 and December 2008 respectively, these basic plans for S&T set goals for key S&T sectors with quantified targets and input and output categories (Table 1).

As for the Low Carbon, Green Growth policy, it aims to promote the development of competitive green industries, while at the same time improving the quality of life by reducing CO_2 emissions and saving resources and energy through 'green' technological innovation (Korean National Commission for UNESCO, 2009).

Main S&T policy focus and actions

Government action in the five main S&T policy areas from 2003 onwards can be summarized as follows. *Firstly,* the Roh government elevated the Minister of Science and Technology (MoST) to the level of Deputy Prime Minister in 2004 and created the semi-autonomous Office of Science and Technology Innovation within MoST to support the NSTC and the S&T Deputy Prime Minister. In order to pursue national policy initiatives through S&T

Table 1: R&D indicators for the Republic of Korea, 2001 and 2007, and targets for 2012

Category			2001 (attained)	2007 (attained)	2012 (target)
INVESTMENT	**GERD**	in KRW trillions	16.1	30.3	–
		in US$ billions	12.0	28.6	–
		as a percentage of GDP	2.6	3.2	5.0
	Government expenditure on R&D	in KRW trillions	4.3	35.3	66.5
		in US$ billions	3.2	26.6	–
		Share of basic research in government R&D budget (%)	17.3	25.0+1	50.0**
	Human resources	Total number of researchers	178 937	–	–
		Number of researchers per 10 000 population	37.8	53.1	100.0
OUTPUT	**Patents**	Ratio of patents registered domestically by Koreans in comparison to foreigners (%)	63.0	74.0+1	–
		Number of overseas patent registrations*	7942+1	25 000	10 000
	Papers	Number of articles published in Science Citation Index	14 673	33 000	35 000
	Technology trading	Ratio of technology revenue to expenditure (%)	0.07-1	0.33	0.7
STAGE OF NATIONAL TECHNOLOGICAL INNOVATION			Entry stage of creative technological innovation	Growth stage of creative technological innovation	Becoming one of seven major powers in S&T through creative technological innovation

* The number of overseas patent registrations is based on Patent Cooperation Treaty registration.
** including some applied research
-*n*/+*n* = data refer to *n* years before or after reference year

Source: Government of Republic of Korea (2003) *Science and Technology Basic Plan, 2003–2007;* Government of Republic of Korea (2008) *Science and Technology Basic Plan, 2008–2012* policy, the S&T Deputy Prime Minister co-ordinated industrial, human resource and regional policies.

The S&T Deputy Prime Minister is responsible for overall co-ordination of science, technology and innovation (STI) policy, while serving as Vice-chair of the NSTC (Korean National Commission for UNESCO, 2009).

Secondly, the Roh government chose a knowledge-based technology development strategy. This entailed increasing R&D investment in basic research in order to strengthen the capacity to create new, high value-added knowledge industries. In the past, S&T policies had relied on imitation and R&D strategies for independent development.

Thirdly, the Roh government advocated an S&T policy ensuring both economic progress and a better quality of life in Korea, including by meeting social demands.

Fourthly, the Roh government took a more global perspective on S&T than the domestically centered policy the government had adopted in the past. It sought to liberalize S&T policy and strengthen international co-operation, in particular with Northeast Asia, as well as reduce the gap among regions caused by a regional bias in the distribution of resources. The objective was not only to reinforce the global competitiveness of Korean industries and regions but also to increase domestic cohesion and solidarity.

Fifthly, the Roh government promoted private-sector participation and appealed to society at large to develop S&T. This approach was a departure from past practice when S&T policy and participation had centered on scientists and engineers. The government considered the development of S&T to be an economic, social and cultural reality in which all sectors of society should participate and which called for high standards in ethics, transparency and responsibility.

After the inauguration of President Lee Myung-Bak in February 2008, the new government set about reorganizing the system of S&T administration and prepared the 577 Initiative. The main S&T policy areas of the Lee government can be summarized as follows:

Firstly, the Lee administration plans to increase R&D investment to 5% of GDP by 2012. It will commit a total of KRW 66.5 trillion (equivalent to about US$55.4 billion) over a five-year period (2008–2012). Also, tax incentives for investment in R&D will be provided to foster private expenditure on R&D, corporate research institutes will be deregulated and the tax deduction rate of 7–10% will be extended to a greater number of beneficiaries to facilitate investment in R&D, among other measures.

Secondly, the Lee government will invest in strategic areas for national R&D, such as basic research, emerging areas of industrial technology and technology related to global issues. Korea will also become a leading nation in the 'green market', which will be worth KRW 3 000 trillion (equivalent to about US$ 2.5 trillion) by 2020, by more than doubling R&D investment in green technologies.

Thirdly, the Lee administration's STI policy emphasizes nurturing scientists and engineers who are capable of conducting world-class research, along with a strategic concentration of R&D resources on creative, original research. In this context, the government plans to double the share of basic research in total government expenditure on R&D, while stepping up its efforts to produce creative talents by integrating education with S&T (Government of Republic of Korea, 2008).

Promoting innovation

From 2003 to 2009, more than 40 laws and ordinances relating to S&T innovation were enacted. These involve developing human resources; ensuring a safe research environment; and establishing a system to promote innovation and support technological innovation as a basis for building an S&T-oriented society and becoming one of the seven major S&T powers in the world by 2012. Key laws passed or amended during this period include the Law on Government Organizational Structure, the Basic Laws on Science and Technology and the Basic Laws on Human Resources Development.

The government has also implemented policies to create a favourable environment for technological innovation in order to attract the best brains to science and engineering and promote the development of new technologies (Box 1). For instance, it introduced a system encouraging public institutions to employ scientists and engineers. As a result, the number of new recruits in public service at Level 5 (director level) holding degrees in science and engineering has increased from 158 (23.5%) in 2002 to 185 (34.7%) in 2006.

Furthermore, the Lee government has introduced plans to improve R&D performance in specific areas, including bio-engineering, the national satellite navigation system, the integrated establishment of broadband and the development of national nuclear fusion technology.

Administrative reorganization

In order to reinforce overall responsibility and co-ordination of S&T innovation policies and relevant micro-economic policies, the consecutive Roh and Lee governments have proceeded with a series of administrative and organizational changes. We have already seen that the Science and Technology Minister was promoted to Deputy Prime Minister in 2004 and that the Minister also holds the post of Vice-Chair of the NSTC.

In order to ensure the planning and co-ordination of S&T policies, the Roh government introduced ministry-wide R&D programmes and established the ephemeral Office of Science and Technology Innovation (OSTI) within MoST. It consisted of specialists from the private sector (20%) and civil servants from both relevant ministries (40%) and from MoST (40%). OSTI was responsible for addressing specialized S&T issues and for ensuring fairness and neutrality in the formulation and implementation of S&T innovation policy until it was abolished by the incoming Lee government.

In addition, the Law on the Presidential Advisory Council on Science and Technology (enacted in 1991) was amended to reinforce the council's status in 2004. A Presidential Advisor for Information and Science and Technology was appointed to assist the president in managing an enlarged council. The law was subsequently revised in 2008 and renamed the Law on the Presidential Advisory Council on Education, Science and Technology.

Since the advent of the Lee government in February 2008, not only has OSTI been abolished but MoST and the Ministry of Education have also been merged to form the Ministry of Education, Science and Technology (MEST)[3], while the Ministry of Commerce, Industry and Energy and the Ministry of Communication have been merged to create the Ministry of the Knowledge Economy (MKE). This consolidation has been initiated by the new Korean President within an overall drive to reduce the size of government and cut the number of ministries in the executive branch (OECD, 2009).

S&T innovation policy integration, co-ordination, evaluation and management

By introducing various administrative and organizational changes to promote innovation, both the Roh and Lee governments have reinforced the co-ordination, evaluation and management function of S&T policy. This includes giving authority to the NSTC to co-ordinate and evaluate national R&D programmes. Up until 2008, it was also responsible for distributing the budget for national R&D programmes. Since 2008, NSTC has been responsible for setting national R&D priorities, co-ordinating national R&D programmes and so on. Responsibility for evaluating national R&D programmes and distributing their resource budget has fallen to the Ministry of Strategy and Finance. Also, a Special Committee on National Defence R&D was set up in 2007 to discuss and co-ordinate S&T policy-related issues, including the allocation of the national defence R&D budget among the relevant ministries (Figure 1).

Greater co-ordination of current S&T policy can be seen in the growing number of joint agendas submitted by more than two ministries; these now exceed 40% of all submitted agendas. For instance, various ministries are collaborating on the new drug development programme (MEST, MKE and Ministry of Welfare) and on the agriculture and forestry R&D programme (Ministry of Agriculture and Forestry, Rural Development Administration and the Forest Service).

Greater support for government-funded research institutions

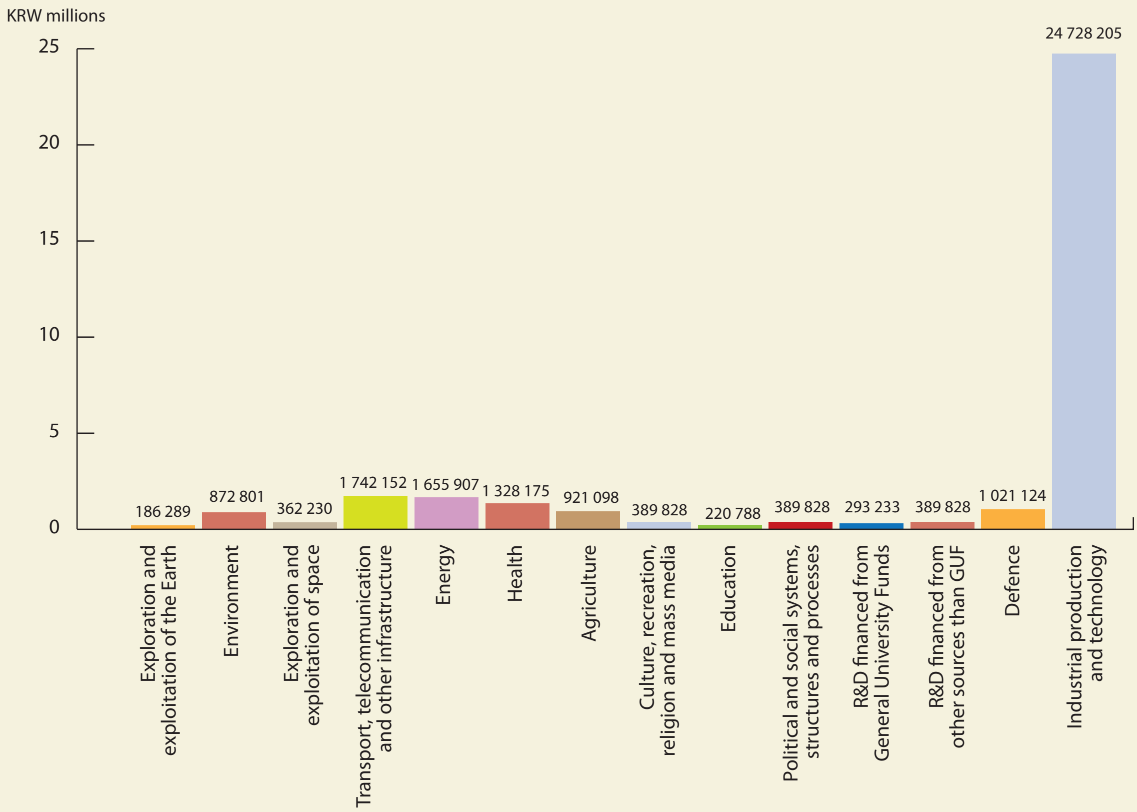
The government is also promoting R&D activities of government-funded research institutes, which are key performers of national R&D in Korea. The Roh government enacted the Law on the Establishment, Management and Development of Government-funded Research Institutions in the Areas of Science and Technology (2004) and transferred authority over research institutions to the NSTC to develop closer ties between STI policy and R&D activities. However, starting with the Lee administration, the government-funded Research Institute was reorganized within the government's administrative reform in 2008 and authority over research institutions was transferred to MEST and MKE.[4]

Furthermore, the Lee government has introduced measures to promote specialized research programmes and

3. MEST continues to assume the role of NSTC Secretariat.

4. There are now two research councils in Korea, the Research Council of Basic Science and Technology under MEST and the Research Council of Industrial Science and Technology under MKE.

Figure 1: GERD in the Republic of Korea by socio-economic objective, 2008



Source: MEST/KISTEP (2009) *Survey of Research and Development in Korea*

established a mid-term strategy to ensure that R&D resources and the capabilities of government-funded research institutions are utilized efficiently.

A performance-based evaluation and management system for R&D

In 2005, the government enacted the Law on the Evaluation and Management of the Performance of National R&D Programmes to enhance the efficiency of these programmes. A year later, it implemented the *Basic Plan for Performance Evaluation* (2006–2010), leading to the establishment of a performance-based evaluation and management system. Three years earlier, the Ministry of Information and Communication – now part of MKE – had implemented the Project Manager System to deal with specialization issues in R&D management, such as improving efficiency in R&D using the Six Sigma[5] method. The same year, it had established the National Science and Technology Information System (2007–2009) for the integrated management of S&T information.

R&D INPUT

Greater government investment in R&D

Government investment in R&D has increased steadily in Korea since 1993. In addition, diverse policies were pursued from 2003 to 2009 to enhance the efficiency of R&D investment. Over this period, the government share of the annual budget dedicated to R&D reached a total of KRW 42.4 trillion (US$ 31.9 billion), or some KRW 10 trillion (US$ 7.5 billion). From 2005 to 2009, total government investment in R&D increased by 12.2 %, a considerably higher rate than the increase in total government expenditure of about 8.0%.

5. Originally developed by Motorola (USA) in the early 1980s for manufacturing, this method of quality management has since been extended to other business processes. It relies on analysis, statistical methods and other means to achieve targets such as improved product quality, better safety, greater profits or a faster delivery time.

Table 2: Trends in GERD in the Republic of Korea, 2003–2008

		2003	2004	2005	2006	2007	2008
Government investment in R&D	in KRW trillions	6.5	7.1	7.8	8.9	9.8	11.1
	in US$ billions	4.9	5.3	5.9	6.7	7.4	8.3
	as a share of the total government budget (%)	4.0	4.1	4.2	4.3	4.6	4.9
Total investment in R&D	in KRW trillions	19.1	22.2	24.2	27.3	31.3	34.5
	in US$ billions	14.3	16.7	18.2	20.5	23.5	25.9
	as a share of GDP (%)	2.5	2.78	2.8	3.0	3.2	3.4*

** provisional*

Note. Government investment in R&D includes the R&D-related government budget (general accounting plus special accounting).

Source: PACST/KISTEP (2007) *Analysis of the Performance of Science and Technology Policy of the Government from 2003 to 2007;* MEST/KISTEP (2009) *Survey of Research and Development in Korea*

Furthermore, the government diversified financial resources for investment in R&D by issuing Government Science and Technology Bonds (2006) and by establishing the Daedeok Special Zone Fund, the Technology Commercialization Fund administered by MKE and the Small and Medium-Sized Enterprises Fund administered by the Small and Medium-Sized Business Administration. The government also incited the private sector to invest more in R&D via tax incentives and reductions, as we have seen earlier. As a result, private sector investment grew at an annual average rate of 12.3% from 2003 to 2008. GERD consequently increased rapidly from KRW 17.3 trillion in 2002 (2.53% of GDP) to KRW 34.5 trillion in 2008 (3.37% of GDP) [Table 2 and Figures 2 and 3].

Increasing the efficiency of R&D investment

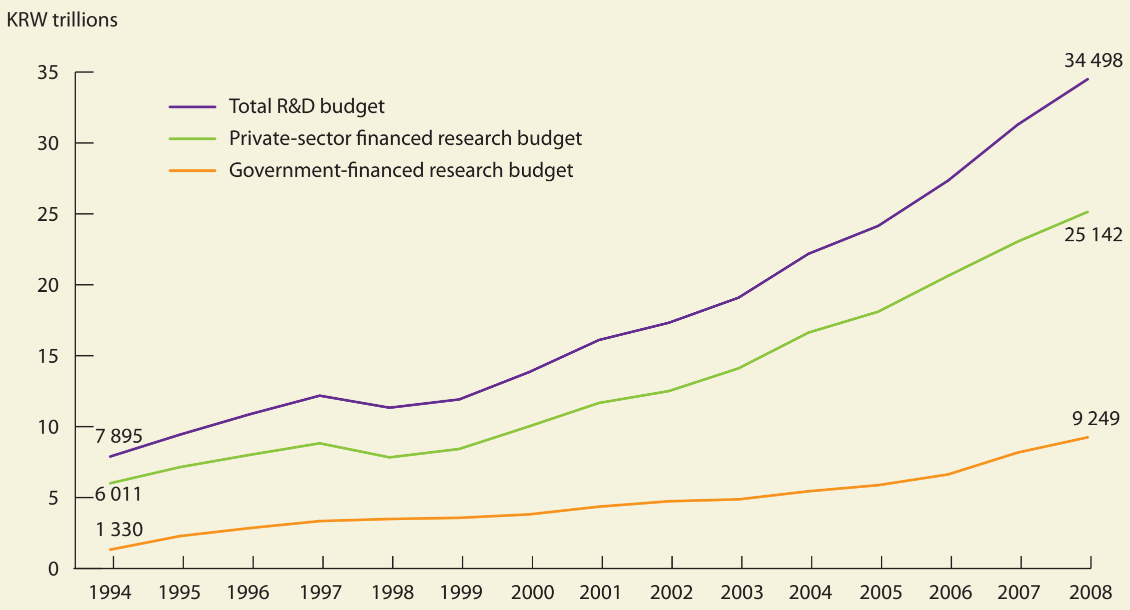
As investment in R&D grew, new policies were implemented to ensure that this investment would be used efficiently. Changes included a medium and long-term investment portfolio for the efficient use of limited R&D resources and a *Total Roadmap for National R&D Programmes*. These were presented in 2006. A year later, preliminary feasibility studies were introduced for large-scale R&D programmes requiring a budget of more than KRW 50 billion (US$ 37.6 million). In addition, the government implemented a comprehensive plan for the promotion of basic research (2005) and increased investment in basic and fusion research with the aim of developing independent fundamental technologies and intellectual property for Korea. The public R&D budget share for basic research increased from 19.0% in 2002 to 23.1% in 2006 and an estimated 29.3 % in 2009. At the same time, the government boosted support for small-scale basic research projects, from KRW 263.2 billion (US$ 198 million) in 2004 to KRW 380.4 billion (US$ 286.5 million) in 2008.

Incentives for the private sector to innovate

In 2006, the government amended the Law for the Transfer of Technology and secured adequate funding for corporate R&D, in order to encourage innovation. Corporations conduct about three-quarters of R&D in Korea, linking technology valuation with financing. At the same time, the government provided tax incentives to spur corporate R&D and innovation. These incentives include more time to apply for tax deductions on R&D, human resources development and investment in installations (from the end of 2006 to the end of 2009), an increase in tax deductions from 40% to 50% on outsourced research costs for large corporations and income and corporate tax reductions for research enterprises and cutting-edge technology companies in Daedeok Innopolis.[6] As a result of these measures, the number of innovation enterprises in Korea increased

6. Daedeok Innopolis is located near Daejeon. It has been designed to link researchers and developers with capital so that they can run businesses or take a share in a business. The main role of the organization is to translate the results of R&D into business profits.

Figure 2: Trends in R&D investment in the Republic of Korea, 1994–2008



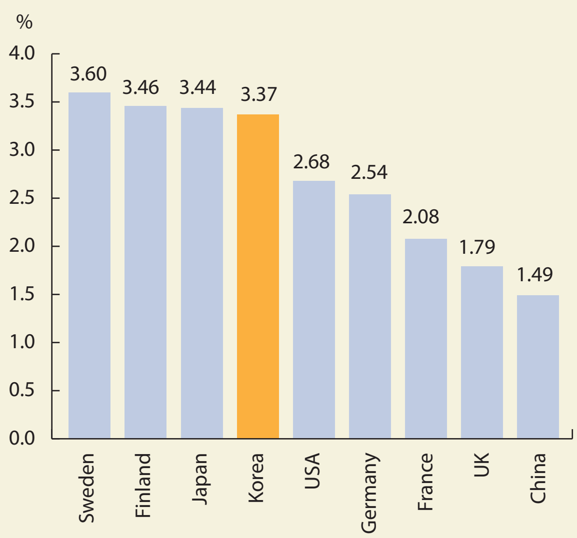
Source: MEST/ KISTEP (2009) *Survey of Research and Development in Korea*

substantially from 2002 to 2006: from 9 705 to 12 218 for subsidiary research centres of companies; from 1 856 to 7 183 for innovative small and medium sized enterprises; and from 8 778 to 12 218 for venture companies.

A greater effort to develop human resources

From 2003 to 2009, the government formulated and implemented major policies to support the development of basic science and human resources. The government is well aware that creativity is the foundation of innovation and will be essential if Korea's efforts to develop endogenous innovation capabilities in the midst of global competition are to succeed. These policies include the Strategy to Develop Human Resources in Science and Technology, the Medium and Long-term Supply and Demand Forecast for Human Resources in Science and Technology (2006–2010), the second Brain Korea 21 project (Box 2) and the Measures to Increase the Number of Civil Servants Specialized in Science and Engineering. Over the same period, the government introduced a number of programmes and raised the budget in all areas of S&T human resource development, including programmes for both young people and retired scientists and engineers (Table 4).

Figure 3: International comparison of R&D intensity in the Republic of Korea, 2008
Other countries are given for comparison



Source: MEST/ KISTEP (2009) *Survey of Research and Development in Korea*

Box 1: Preparing for the future with innovation

From 2003 to 2007, the government developed and supported 10 major next-generation growth engine programmes in S&T to prepare the national economy for the future. This research has resulted in a total of 136 achievements, including:

- The first wireless broadband (WiBro) technology in the world. WiBro was developed by the Korean telecommunications industry;
- An active-matrix organic light-emitting diode (AM-OLED) for large televisions;
- A digital multimedia broadcasting (DMB) transmission and reception system. DMB is a digital radio transmission technology developed by Korea as part of the national IT project to send multimedia, such as television, radio and datacasting, to mobile devices like mobile phones;
- 521M PRAM (Parameter RAM).

The government also launched large-scale national R&D programmes to support the commercialization of major research results, such as the magnetic levitation train, a treatment for encephalopathic dementia and digital actor and large-sized wing-in-ground-effect (WIG) craft.

In addition, the advancement of existing key industries has produced visible results. For example, thanks to support for the components and materials industry, including the establishment of the Korea Materials and Components Industry Agency in 2005, profits from international trade in this sector have skyrocketed: from US$ 2.9 billion in 2002 to US$ 34.7 billion in 2006. This said, the trading deficit with Japan in components and materials widened over the same period from US$ 1.8 billion to US$ 15.6 billion. However, the ratio of technology trade revenue to expenditure is improving. It rose from 0.23 % in 2002 to 0.42% in 2007, thanks to growth in technology exports. According to a report by the Ministry of Commerce, Industry and Energy (MoCIE), now MKE, Korea was 9th in the world for the export volume of cutting-edge technological products in 2003 but had climbed to 7th position by 2006. Korea is also making a greater number of the world's best-quality products than before, up from 122 in 2002 to 308 in 2006, according to MoCIE.

Source: MoCIE, January 2010

As a result of these efforts, the human resource base for research in Korea expanded during 2003–2008. The total number of researchers grew to 300 050 by the end of 2008, which is equivalent to 97 researchers for every 10 000 Koreans. Furthermore, in order to encourage research productivity, the remuneration system for researchers has improved, including an increase in remuneration to 50% of revenue generated from technology fees. A policy has also been introduced to raise KRW 200 billion (US$ 150 million) for the Korean Scientists and Engineers Mutual Aid Association by 2012. Another policy shortens the compulsory period of employment for specialized research staff – who are already exempted from military service – from four to three years, in order to promote a more stable and research-friendly environment.

Ensuring a better quality of life through S&T

From 2003 to 2009, the government also implemented R&D policies to promote a better quality of life, in a departure from the previous growth-oriented policies. It identified 22 priority areas and introduced policy documents entitled *Means of Technology-based Enhancement of the Quality of Life for the Realization of Vision 2030* (NSTC, 2007*a*) and *Comprehensive Means of Technology-based Improvement of the Quality of Life* (NSTC, 2007*b*). In addition, *Plans for the Pursuit of Transforming Transdepartmental R&D into Wonder Drugs* were adopted for a healthier life through the development of biotechnology and medical technology. In parallel, investment in these areas was expanded.

In order to improve health care and medical services, the government introduced the Law on the Development of Oriental Medicine and the Law on Cancer Management in 2003 and established the Korea Centre for Disease Control and Prevention. As implementation of all these policies and initiatives requires substantial funding, the government increased investment in areas related to technology-based life improvement to KRW 385.3 billion (US$ 290 million) in 2007, a 3.5 increase over 2003.

At the same time, different ministries began a concerted effort to tackle other societal issues. These measures included the enactment of the Basic Law on Low Birth Rates and an Ageing Society (2005). In addition, the government introduced measures to ensure safety

Box 2: Brain Korea 21

The first Brain Korea 21 project got under way in 1999. The aim was to prepare higher education in Korea for the realities of the 21st century. The government invested KRW 1.4 trillion (about US$ 1.2 billion) over seven years to develop world-class research universities and graduate schools. About three-quarters of this amount was earmarked for developing graduate schools in natural and applied sciences and in social and human sciences.

The second Brain Korea 21 project took over in 2006 and has pursued the goals of its predecessor with a budget of KRW 2.1 trillion (about US$ 1.8 billion) over seven years. In order to qualify for the programme and thereby receive government funding, universities are obliged to organize themselves into research consortia made up of university staff and to collaborate on specific projects. Extremely ambitious, the project has shifted the government focus from undergraduate to graduate education. Whereas some criticize this move for abandoning the principle of equal opportunity, others praise it for the focus on nurturing world-class research and for encouraging students to pursue graduate education.

The project is due to wind up in 2012.

Source: http://bnc.krf.or.kr/home/eng/bk21/aboutbk21.jsp

Table 3: Key achievements of Korean policy for S&T human resources, 2002–2008

Categories	Key policy	Key achievements (2002–2008)
Youth	■ Establishment of specific programmes for educating talented students in science, etc	■ Creation of school for gifted students in science (2003) ■ Increase in the number of educational institutions for gifted students in science: 15 (2002) to 25 (2007)
Undergraduate and graduate students in science and engineering	■ Pursue the New University for Regional Innovation and Brain Korea 21 (2nd stage) projects ■ Targets for employment of science and engineering majors by public institutions ■ More scholarships	■ Recipients (students) of government scholarships: 5 872 (2003) to 20 000 (2008) ■ Increase in labour costs : PhD course, KRW 1.2 million to KRW 2 million (US$ 900 to US$ 1 500) ■ Increase in research staff with exemption from military service: 1 674 (2003) to 2 500 (2008)
Female scientists and engineers	■ Systematic encouragement and support for female scientists and engineers	■ Increase in number of support centres for female scientists and engineers: 0 (2004) to 5 (2008) ■ Increase in percentage of females among working researchers: 18.2% (2003) to 24.6% (2007)
Retired engineers	■ Re-employment policy	■ Introduction of the techno-doctor programme, a rehiring programme for retired engineers: KRW 3.4 billion (2008) ■ Support ReSEAT programme: in-depth analysis of S&T information using retirees: KRW 2.5 billion (2008)

Source: KISTEP (2007); Analysis of PACST performance of Science and Technology policy of the Government from 2003 to 2007; NSTC (2008) *Science and Technology Basic Plan* of the *Lee Myung-Bak Government* (2008–2012) from atomic power and radioactive waste materials. For example, in 2005, the location of a radioactive waste treatment plant was chosen with the consent of the local community. The Atomic Energy Act (2005) was also amended to include a nuclear power plant safety examination system. Furthermore, the government set up a National Emergency Management Agency (2007) and Social Safety Network Research Institute (2006) to cope with disasters comprehensively .

The government has also strived to ensure safety and reliability in the construction and transportation sectors, as demonstrated by the development of the Korean tilting train (2001–2007) and bullet train (2002–2007). The government has also engaged in a variety of activities to secure eco-friendly resources, such as drilling for gas hydrates in 2007 in the East Sea, the fifth successful attempt in the world. It is also participating in a project within the International Partnership for the Hydrogen Economy[7] and developing core environmental technologies.

Under the new government, NSTC recommended to President Lee in January 2009 that investment in public welfare should be expanded to cope with social and global issues such as food safety, climate change, mad cow disease, avian influenza and so on.

Measures for ensuring more balanced regional development

Past policies designed to achieve rapid economic growth in Korea have led to imbalanced regional development and created widening gaps between sectors. The government is now assertively pursuing regional STI policies that are expected to help correct these inequalities and ensure balanced and sustainable regional development for the future. These policies include the first five-year Plan for Balanced Regional Development of the Nation (2004) and the third five-year Plan for Promotion of Regional Science and Technology, (2007) covering the period 2008–2012.

A noticeable effect of this shift towards S&T policy for regional development has been a substantial increase in investment in regional R&D. The share of the government budget for R&D (general accounting plus special accounting) allocated to regions – excluding the Seoul Metropolitan Area and the City of Daejeon – increased from 27% in 2003 to 40% in 2008. Local governments have also recognized the importance of S&T for the development of their regions and carried investment in this sector from 0.93% of their budget in 2002 to 2.3% in 2006.

This surge in funding of regional R&D has led to an increase in regional innovation. The number of technoparks in Korea, which totalled only eight in 2002, had doubled to 16 by 2006. In addition, the Special Law on Daedeok R&D Special Zone was enacted in July 2005 to spur regional innovation. This law established a comprehensive plan for the development of special R&D zones in November 2005 and promoted the Daedeok region as the site for research, development and commercialization of new innovative products. As a result, Daedok Innopolis has attracted foreign investment of US$ 13 million and 28 companies with an annual turnover of more than KRW 10 billion (US$ 7 million). It has become an important site for technology transfer (600 cases as of March 2010) and for bringing innovation to the marketplace (21 new innovative products).

More foreign R&D centres and stronger international co–operation in S&T

While pursuing balanced regional development at home, the government is also aiming to broaden the scope of Korea's S&T policy and to strengthen national competitiveness in the global economy. As part of this strategy, the government is attempting to attract overseas research centres to Korea. To this end, it implemented the Method of Consolidating Laws Related to Attracting Overseas R&D Centres in March 2006. As a result, 51 foreign R&D centres had been established in Korea by the end of June 2007.

Moreover, Korea is now playing a greater role in international S&T co-operation and participating in various international projects to tackle global issues. These projects include the International Thermonuclear Experimental Reactor (*see page* 158), the European Union's Galileo satellite navigation system and the Global Research Laboratory (Box 3). Korea is also seeking to participate in the EU's Seventh Framework Programme for Research and Technological Development (FP7).

7. This partnership also involves Australia, Brazil, Canada, China, European Commission, France, Germany, Iceland, India, Italy, Japan, New Zealand, Norway, Russian Federation, the UK and USA: www.iphe.net

The government is promoting the participation of companies in the EU Framework Programme and supporting public R&D funding (about KRW 20 million per company annually) for these companies. In 2009, the government was planning to spend a total of KRW 2.6 billion to support companies' participation in FP7.

Encouraging people to participate in S&T development

Fostering an ethical approach to research

For the government, social responsibility and ethical awareness are important issues for scientists and engineers. It has introduced the *Scientist and Engineer's Charter* (2004) and the *Scientist and Engineer's Code of Ethics* (2007). Furthermore, it has reinforced internal monitoring of how research funds are being used, set up the Cyber Report Centre for Execution of the Research Budget (2005) and introduced the Research Budget Management Certification System (2005) to foster greater transparency in the allocation and utilization of research budgets.

By October 2007, a total of 113 research organizations had implemented the government's *Guidelines for Securing Research Ethics* and supported the establishment of a self-examination system for verifying the truthfulness of research. Moreover, the government is analysing the effect of new technologies on society, culture, ethics and the environment. In order to be able to deal with these effects appropriately, it was conducting an *Evaluation of Technological Influence* resulting from the development of new technologies in 2010. These new technologies include nanotechnology, biotechnology, information technology (IT), convergence technologies and ubiquitous computing technologies that have substantial social ripple effects.

Developing an S&T culture

In building a society based on principle and trust, it is important to ensure that practices are ethical. This holds true for the S&T sector as well. That is why the government is attempting to increase people's understanding of, and support for, S&T and to promote popular participation in their development.

In 2003, the government implemented a five-year plan to bring S&T and culture closer together. It launched the Science Korea initiative in 2004 to build a national consensus on how S&T should develop and to integrate science into daily life. This includes stimulating interest in science and engineering among young people and popularizing scientific topics.

Box 3: The Global Research Laboratory

The Global Research Laboratory programme was launched by the Korea Foundation for International Cooperation in Science and Technology (KICOS) in 2006. It develops original core technologies to solve global problems through international collaborative research between Korean and foreign laboratories. One advantage of the programme is that it makes it possible to share research results from large-scale projects and pool resources, thereby reducing the cost of research.

In 2007, a total of 16 areas were being supported:

- Stem cell applications;
- Early diagnosis of cancer;
- Environmental conservation and restoration;
- Gene therapy;
- Nano-based materials;
- IT nanodevices;
- Bio-information application technology;
- Environmentally friendly nano-materials;
- Nano-level materials processing;
- New and renewable energy;
- Prevention of, and response to, natural disasters;
- Bio-immune protection and infectious diseases control;
- Nano-bio materials;
- Next-generation display technology;
- Biochip Sensor technology;
- Climate change projection and responsive technologies for environmental change.

The Global Research Laboratory programme is supported by MEST and managed by the National Research Foundation of Korea. Any Korean research centre, laboratory, research group, organization or institution may apply for the programme, in line with Article 7 of the Technology Development Promotion Law. Project proposals must be presented jointly by the Korean and foreign research laboratory to a review committee that includes foreign members.

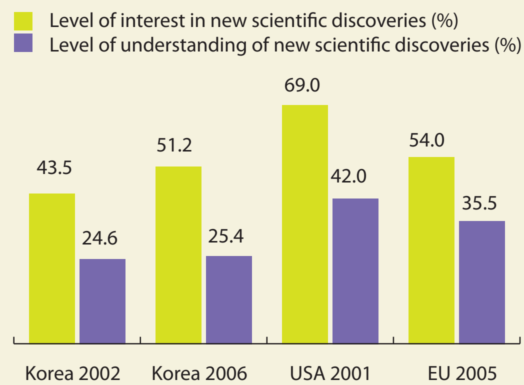
Source: MEST

for details: webmaster@mest.go.kr
or webmaster@nrf.re.kr

The government relies on the media and other means to build an S&T culture in Korea. For example, it provides science programmes like *Science Café*, broadcast by KBS, Korea's premier public broadcaster and the biggest Korean television network with an audience rating of more than 7%. Another science programme is *Science TV*, which was broadcast throughout the country in September 2007. A third example is *Brain Power Plant Q*, a programme aired by the Munhwa Broadcasting Corporation, one of the four major national Korean television and radio networks. On the Internet, the government has posted *Science All*, a scientific literary portal, since 2005 and has been publishing the science news bulletin *Science Times* regularly since 2003.

In addition, the government disseminates information on S&T policy through its *Science and Technology Innovation Newsletter* and provides an opportunity to share scientific knowledge through the weekly science lecture programme *Science Touch*. Research achievements are also disseminated through exhibitions like that on research performance and future economic growth. Other initiatives include the Science for Leaders and the Science and Technology Ambassador programmes to increase awareness among leaders from various sectors of society of the importance of S&T and to stimulate their interest. As a result of these efforts, the level of interest among Koreans of new scientific discoveries has improved considerably (Figure 4).

Figure 4: Level of interest in S&T among Koreans 2006 (%)
Other countries and regions are given for comparison



Source: Korea Foundation for Advancement of Science and Culture (2006) *Survey on level of understanding of people on science and technology*

POSITIVE TRENDS AND OUTCOMES

Rapid growth in private sector investment in S&T

One of the government's major achievements during 2003–2008 was the introduction of measures establishing a firm foundation for the enhancement of R&D and economic performance to drive future growth.

The government increased the share of the budget it allocated to R&D and encouraged the private sector to do likewise. From 2003 to 2008, the combined R&D budget of the government and private sector increased at an average annual rate of 12.6 %. Private sector investment alone grew by 12.3% during this period, a rate which far exceeds that of some very advanced countries: USA, Japan and Germany could all boast of growth of around 5%. In addition, the Korean GERD/GDP ratio, or R&D intensity, climbed from 2.63% in 2003 to 3.37% in 2008, placing Korea fourth among OECD countries for this indicator.

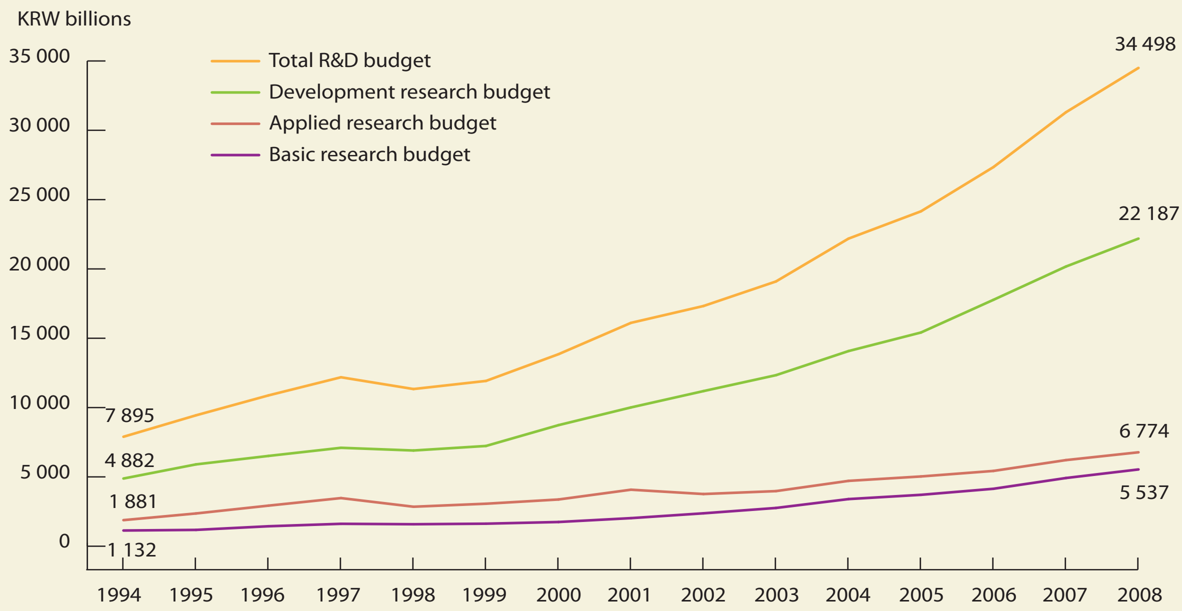
Greater support for basic research and innovation

With greater R&D invest;ment has come greater support for basic research in Korea, creating a better basis for independent innovation. Government investment in basic research increased from 19.5% of the budget in 2003 to 23.1% in 2006 then to 25.6% in 2008. In monetary terms, however, the budget for basic research almost doubled in five years, from KRW 2.76 trillion (US$ 2.1 billion) in 2003 to KRW 5.54 trillion (US$ 4.2 billion) in 2008, reflecting the determination of the government and private sector to develop basic research (Figure 5).

Greater R&D investment by small and medium-sized venture enterprises

During 2003–2009, the government continued to promote balanced growth for both large corporations and small and medium-sized venture enterprises, together with encouraging innovation in the private sector. This differs from past administrations which had tended to concentrate more on large corporations. As a result, investment in R&D by small and medium-sized venture enterprises has started to grow again after contracting in 2000 due to the collapse of the IT venture bubble (Figure 6). The manufacturing industry is also showing healthy growth: the ratio of R&D investment to sales has grown from 2.19% in 2002 to 2.76% in 2008 (Table 4).

Figure 5: GERD in the Republic of Korea by type of research, 1994–2008



Source: MEST/KISTEP (2009) *Survey of Research and Development in Korea*

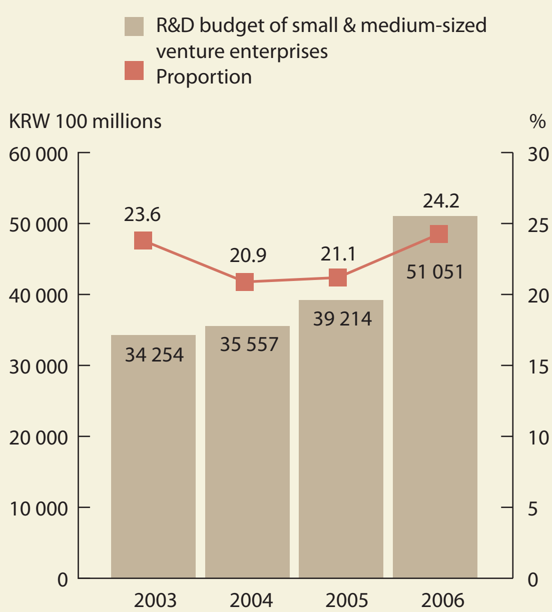
A steep climb in the number of researchers

Besides greater investment in R&D, another major trend in S&T has been the significant increase in the number of researchers. Their ranks grew at an annual average rate of 8.7% from 2003 to 2008. As a result, there are now 300 050 researchers in Korea, placing the country fifth worldwide. As for the number of researchers in relation to population size, there were 97 full-time equivalent (FTE) researchers per 10 000 population in 2008, compared to 66 in 2003. The number of FTE researchers relative to active researchers also increased substantially over the same period. However, Korea still trails the USA, China, Japan and Germany in terms of overall numbers (Figure 7).

A stronger patent performance and productivity

The number of registered patents is a key indicator of innovation. From 2003 to 2007, the volume of Korean patents increased substantially, largely due to greater and more effective investment in R&D over this period and government efforts to stimulate innovation. The number of patents registered by Korea in the USA increased by 99.4% from 3 786 in 2003 to 7 549 in 2008 – ranking Korea fourth worldwide for this indicator.

Figure 6: R&D budget of Korean small and medium-sized venture enterprises, 2003–2006



Source: MoST (2007) *White Paper on National Science and Technology Policy from 2003 to 2007*

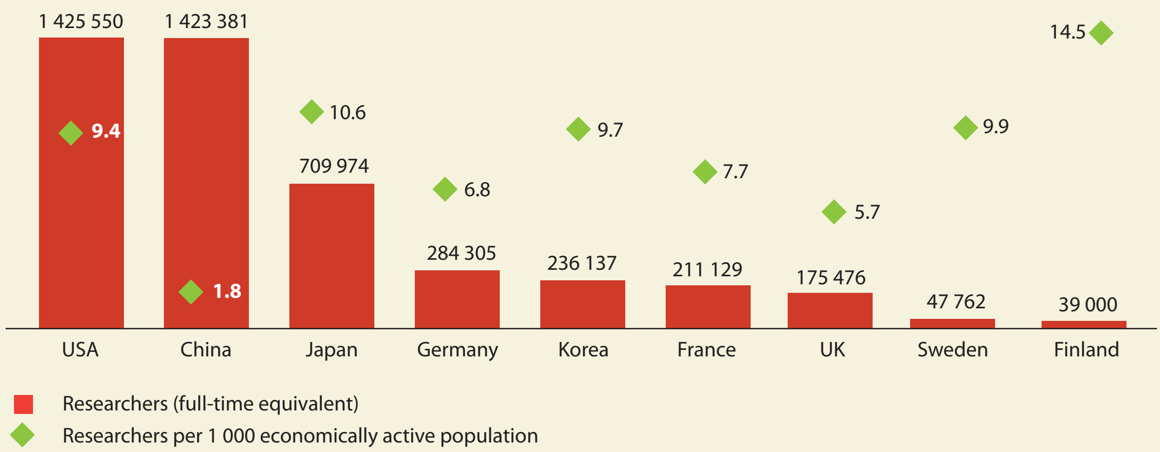
Table 4: R&D expenditure and industrial sales in the Republic of Korea, 2007 and 2008

Industry	2007				2008			
	Expenditure		R&D/sales ratio (%)		Expenditure		R&D/sales ratio (%)	
	Use	Invest	Use	Invest	Use	Invest	Use	Invest
All industries	23 864 893	25 132 297	2.43	2.56	26 000 069	27 341 718	2.13	2.24
Agriculture	11 874	11 666	9.05	8.89	21 955	21 563	2.78	2.73
Manufacturing	21 338 862	22 341 528	2.97	3.11	22 996 967	24 132 473	2.63	2.76
Beverages, food & tobacco	331 074	329 858	0.76	0.76	348 237	348 637	0.97	0.97
Textiles, clothing & leather	146 452	137 231	0.86	0.81	152 587	140 834	0.72	0.67
Chemicals & chemical products (excluding medical products)	1 277 484	1 236 842	1.72	1.67	1 302 447	1 240 279	1.56	1.48
Medicines & pharmaceuticals	596 779	589 838	5.85	5.78	634 493	668 492	5.24	5.52
Rubber & plastic	374 116	354 114	2.56	2.42	435 301	407 465	2.34	2.19
Non-metal products	141 864	139 864	1.20	1.18	143 713	143 401	1.04	1.03
Metal industry	415 824	483 822	0.63	0.74	511 686	635 367	0.58	0.72
Metal processing products (excluding machine & furniture)	171 614	149 564	1.92	1.68	233 781	224 243	2.04	1.96
Electronic components, computer Radio, TV & communication Equipment & apparatus	–	–	–	–	12 080 709	12 957 217	6.36	6.82
Semiconductors	6 407 130	6 340 185	7.80	7.72	7 478 411	8 360 027	8.14	9.10
Electronic components	1 216 549	1 118 251	3.17	2.91	1 369 978	1 335 408	3.22	3.14
Computers and peripherals	276 463	266 565	4.94	4.76	195 095	197 327	3.76	3.80
Communications & broadcasting equipment	2 610 091	2 497 438	6.99	6.69	2 742 083	2 764 020	6.32	6.37
Video & audio equipment	276 104	265 913	4.88	4.70	273 454	278 758	4.51	4.60
Medical, precision & optical Machinery and watches	369 089	314 984	7.50	6.40	688 545	550 908	7.29	5.83
Electrical devices	–	–	–	–	681 879	645 470	2.49	2.36
Other machines and equip.	–	–	–	–	1 568 276	1 440 400	3.15	2.90
Cars & trailers	3 831 826	4 372 820	3.42	3.90	3 442 680	3 967 551	2.83	3.26
Other transporting machines	493 754	486 923	1.07	1.06	545 341	520 445	0.89	0.85
Furniture	29 680	30 816	1.02	1.06	17 068	18 185	1.03	1.09
Other products	25 962	25 573	2.35	2.31	50 197	50 520	3.26	3.28
Electricity, gas & water services	241 486	224 062	0.45	0.42	258 755	143 991	0.39	0.21
Sewerage processing & recycling, Environmental remediation	–	–	–	–	22 703	19 130	2.53	2.13
Construction	544 369	853 259	0.49	0.77	644 940	951 250	0.50	0.74
Services sector	1 721 747	1 694 695	1.74	1.71	2 048 632	2 066 535	1.39	1.40
Transportation	55 791	42 962	0.27	0.35	55 081	65.100	0.32	0.38
Publications, video, broadcasting & information	–	–	–	–	1 292 208	1 328 318	2.00	2.06
Telecommunications	325 722	356 317	0.83	0.90	378 911	439 531	0.92	1.06
Expertise via S&T services	–	–	–	–	522 027	494 259	3.84	3.64

Note. The total amount of sub-categorized items is not consistent with the higher categorized items because this table only shows the result of analysis of major industries. As for some industries, data are not available for comparison with the previous year due to the revision of the KSIC-9, Korea's industrial classification code

Source: MEST/KISTEP (2009) *Survey of Research and Development in Korea*

Figure 7: Number of FTE researchers in the Republic of Korea, 2008
Other countries are given for comparison



Source: MEST/ KISTEP (2009) *Survey of Research and Development in Korea*

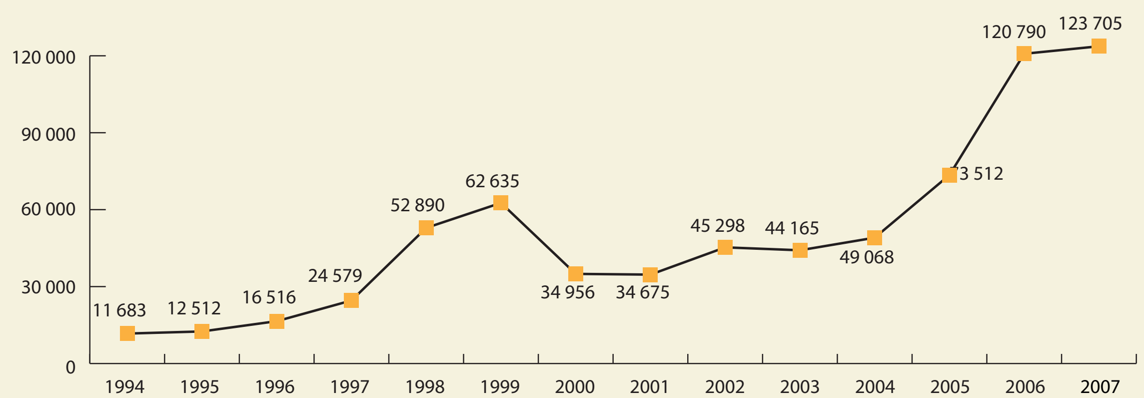
As for domestic patents, their number grew from 45 298 in 2002 to 123 705 in 2007 (Figure 8). These positive trends in patent performance suggest that increases in R&D investment from 2003 onwards started producing results as early as 2005.

Moreover, the number of Korean patents belonging to the Triadic patent families, which are registered in the patent offices of the USA, Japan and EU, grew approximatively by a factor of 2.3 from 2002 to 2005, increasing from 1 383 to 3 158 respectively. Also, the number of Triadic patent family patents per KRW 1 billion of research budget funding increased from 0.08 in 2002 to 0.13 in 2005 (Figure 9).

A healthier technology trade balance

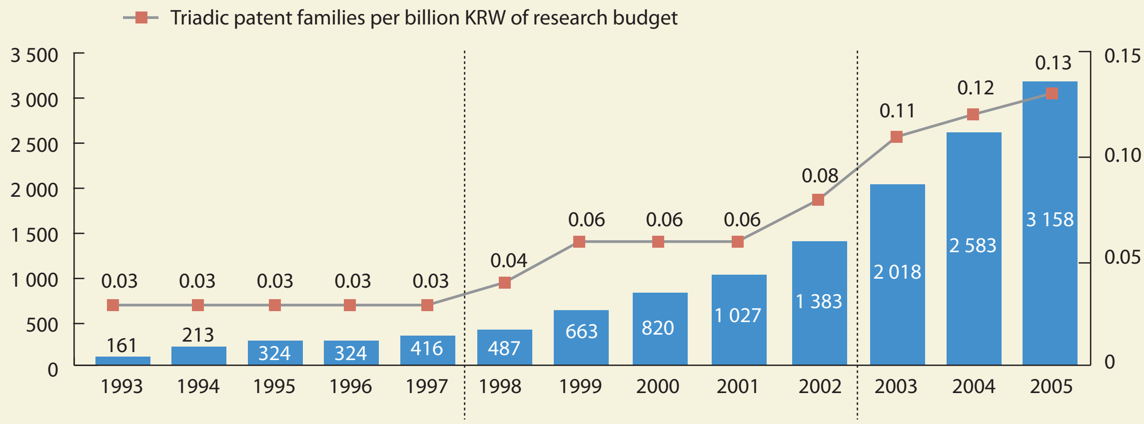
During 2003–2007, technology trade volumes increased markedly. This suggests that innovation has become more intensive in Korea in recent years and technology trade with other countries more active. The technology trade volume amounted to US$ 4.05 billion in 2003 and by 2007 had almost doubled (growing by 80%) to US$ 7.28 billion (Figure 10).

Figure 8: Trends in patent registrations for the Republic of Korea, 1994–2007



Source: MEST/KISTEP (2009) *Survey of Research and Development in Korea*

Figure 9: Triadic patent family registrations and patent productivity in the Republic of Korea, 1993–2005



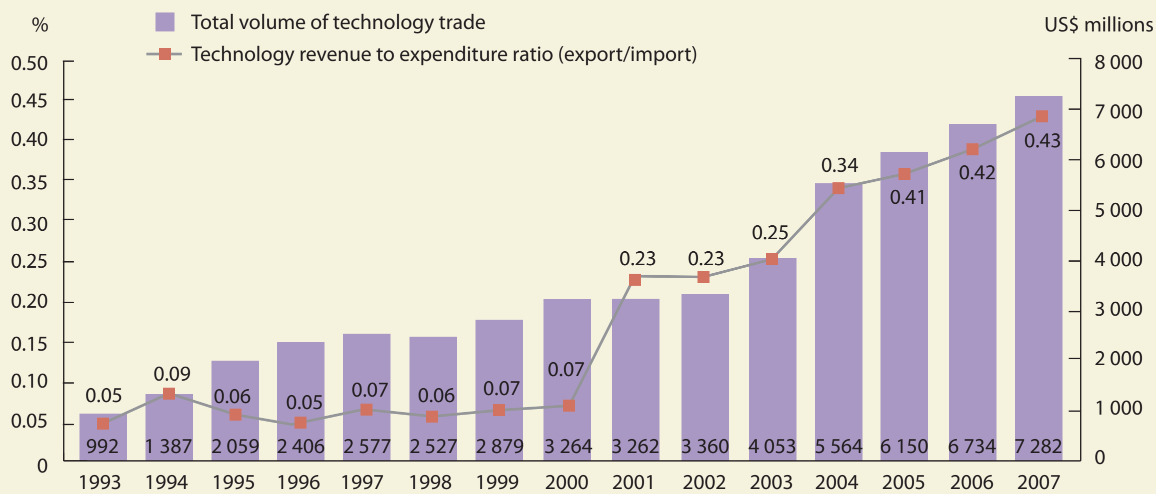
Source: MoST (2007) *White Paper on National Science & Technology Policy from 2003 to 2007*

In addition, the ratio of technology trade revenue to expenditure, calculated as the ratio of technology exports to technology imports, increased from 0.25% in 2003 to 0.43% in 2007, indicating that conditions for technology trade have improved substantially in Korea. However, judging from 2007 figures, this ratio is still very low compared to such advanced countries as Japan (3.49), UK (1.90), USA (1.75), Sweden (1.51), Finland (0.69) and Germany (1.11).

More articles in SCI journals

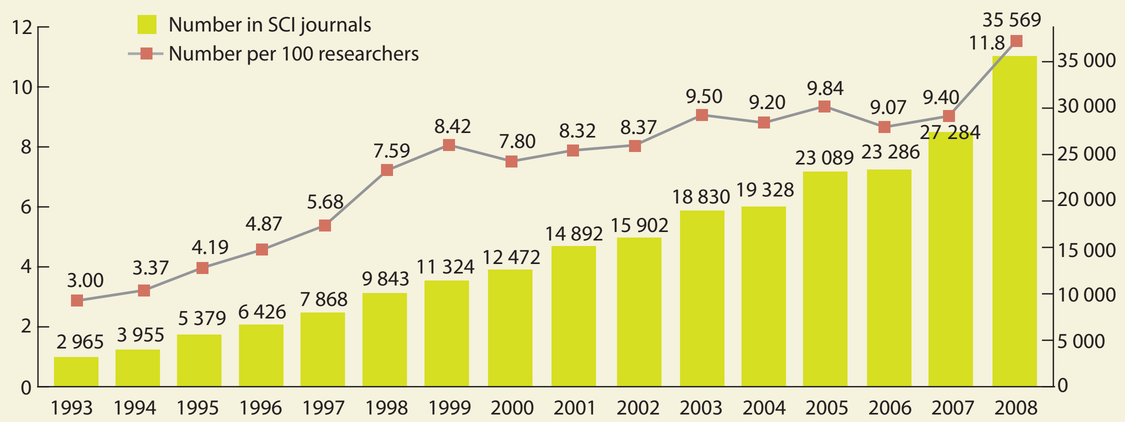
The number of articles in Science Citation Index (SCI) journals is a commonly used indicator to measure R&D performance at the national level. The number of Korean articles almost doubled between 2003 and 2008 from 18 830 to 35 569 (Figure 11). In addition, the number of Korean articles in SCI journals per 100 researchers has gone up to nine since 2003, indicating that research efficiency has improved overall.

Figure 10: Volume of Korean technology trade and revenue and expenditure ratio, 1993–2007



Source: MEST and KISTEP(2009) *Survey of Research and Development in Korea*

Figure 11: Korean scientific articles, 1993–2008



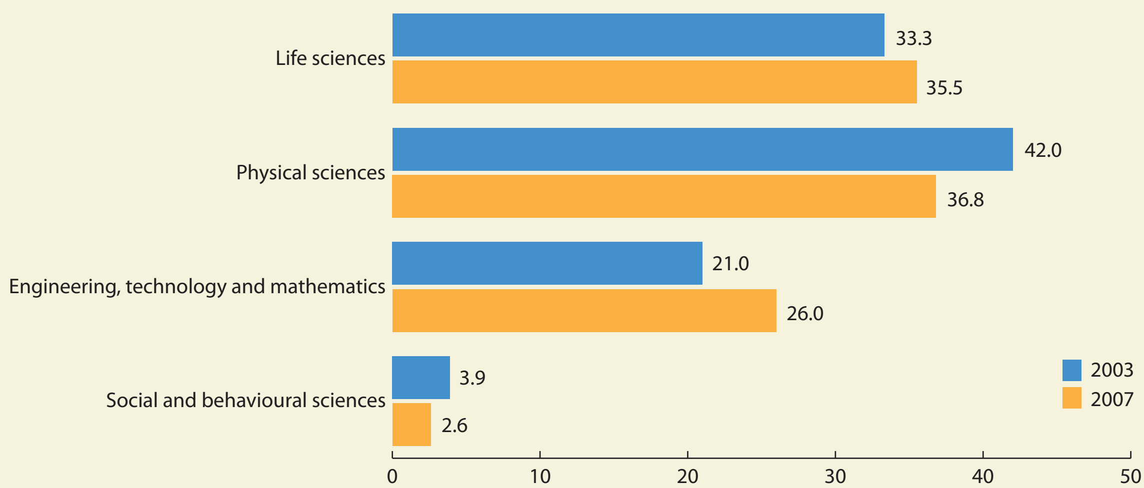
Source: MEST(2010) *Main Statistics on Science and Technology*

Furthermore, the distribution of Korean articles in SCI journals shows a heavy focus on the physical sciences and engineering, with far fewer publications in life sciences than in other dynamic countries for research (OECD, 2009). Figure 12 suggests this might be changing, albeit slowly. In terms of volume and world share, Korea performs best in clinical medicine and material sciences respectively (Figure 13).

Improved competitiveness in S&T

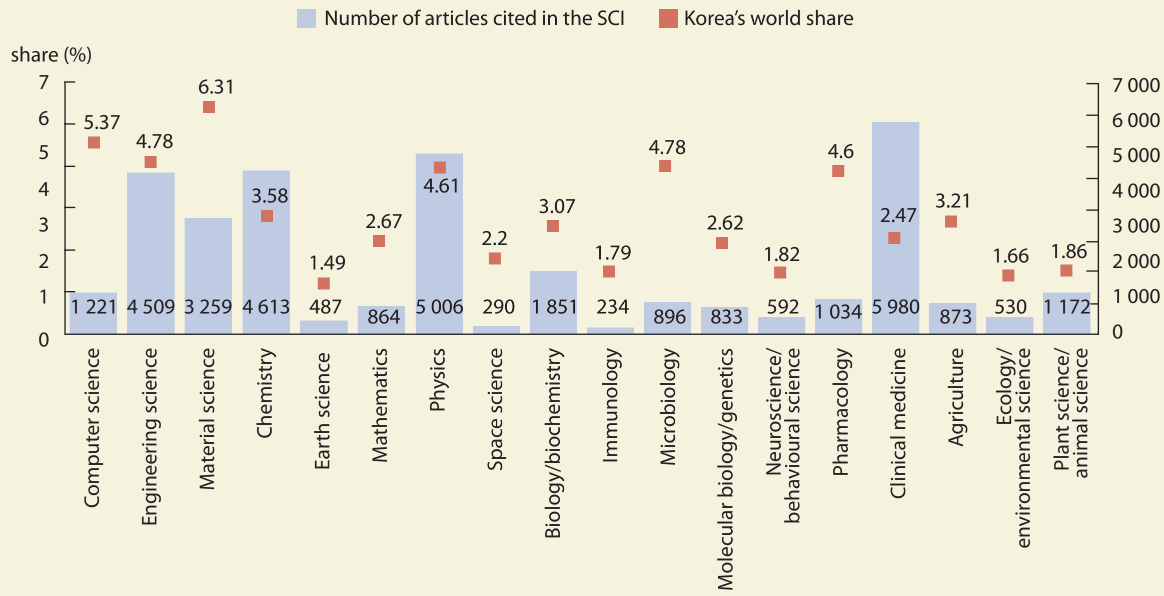
The results of a comprehensive evaluation carried out by the Institute of Management Development (IMD) in Switzerland of national competitiveness in S&T for various countries show that the competitiveness of Korea in S&T has taken off since 2003 (IMD, 2009). Korea's scientific competitiveness climbed from 13th place worldwide in 2005 to 3rd place in 2009.

Figure 12: Korean publications by major field of science, 2003 and 2007 (%)



Source: MEST(2010) *Main Statistics on Science and Technology*

Figure 13: Volume of Korean publications by major field of science, 2008



Note: Data are taken from Thomson Reuters, Science Citation Index Expanded.

Source: MEST (2010) *Main Statistics on Science and Technology*

Figure 14: Changes in the Republic of Korea's competitiveness ranking in S&T, 1994–2009
According to an IMD evaluation

Source: IMD (2009) *World Competitiveness Yearbook;* OECD (2009) *Country Review of Innovation Policy in Korea*

In terms of technological competitiveness, however, Korea has taken the opposite path, slipping from 2nd place overall (2005) to 14th (2009) [Figure 14]. This is due to a poor showing for some key indicators. For example, in terms of the extent to which the development and application of technology are supported by the legal environment, Korea ranks only 37th and for technological co-operation between companies 38th. It can only manage 36th place for the extent to which technological regulation supports business development and innovation and 34th for the funding of technological development. Other indicators taken into account in the overall evaluation include whether cyber security is being adequately addressed by corporations (38th) and the percentage of mobile telephone subscribers in the general population (38th) [IMD, 2009]. In Japan, scientific competitiveness may have managed to hold on to 3rd place since 2009 but the country's technological competitiveness has slipped from 9th place (2005) to 16th place (2009), owing to the recent economic recession in Japan.

CONCLUSION

The Republic of Korea has performed exceptionally well in the past few decades in its efforts to catch up to the world's leading economies, instigating waves of industrial upgrades to become a world leader in some of the most high-tech industries (OECD, 2009). More than 80% of GERD has gone on research applications and development. Of this share, 50% has fuelled economic development with a focus on industrial technology.

Despite the global economic recession caused by the US sub-prime mortgage crisis, the Korean economy expanded by 1.2% in 2009 and is projected to grow 4.4 % this year (OECD, 2009). Korea owes much of its success to high levels of both total expenditure on R&D and business expenditure on R&D, a highly educated labour force, strong infrastructure in ICTs and the development of substantial technological capabilities in a number of high-tech areas.[8]

However, Korea is now entering a critical phase in its development with few guarantees of continuing success. It is reaching the limits of its catch-up strategy due to the difficulties of creating a new growth engine, its continuing deficit in the technological balance of payments and a lack of national R&D investment in preparedness for natural and human-induced disasters and in global issues like climate change.

To overcome these limitations, Korea's STI strategy needs to shift from a 'catch-up' model to a 'post catch-up' model incorporating such features as a 'creative mode' and 'green growth mode', among others. Future investment in R&D should be expanded in the areas of basic research and green technology to enable research to focus more on frontier research and take a greener path, raise the innovative and absorptive capacities of small and medium-sized enterprises and link up researchers better to international sources of knowledge (OECD, 2009). Korea needs to expand R&D investment in socially responsible technology in such areas as disaster prevention, food safety and mitigation and adaptation to climate change.

It will also be necessary to boost R&D investment in the university sector. Universities are the key performers of basic research and concentrate high-quality human capital. Korean STI policy needs to nurture and utilize its world-class human resources and to strengthen global S&T co-operation.

8. Korean firms recently conquered the highest world market share in three areas: DRAM semiconductors, a memory product commonly used in personal computers; liquid crystal display (LCD) computer monitors and televisions to which thin-film transistors (TFT) are added; and CDMA cellular phones.

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National Science and Technology Information Service: http://rndgate.ntis.go.kr/

National Science and Technology Council: www.nstc.go.kr

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Since joining KISTEP in February 1999, he has been involved in evaluating national R&D programmes, co-ordinating R&D budgets and planning the mid- and long-term *National Science and Technology Plan* for NSTC in his capacity as Principle Investigator.

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A challenge for the future will be to ensure that innovation policy is not the sole driver of science policy and that the national science base can remain sufficiently comprehensive [to enable it to pursue] global scientific collaboration.

Tim Turpin, Richard Woolley, Patarapong Intarakumnerd and Wasantha Amaradasa

21 · Southeast Asia and Oceania

Tim Turpin, Richard Woolley, Patarapong Intarakumnerd
and Wasantha Amaradasa

INTRODUCTION

The present chapter covers a wide diversity of economies in Southeast Asia, Australia, New Zealand and the Pacific Islands.[1] Of the seven countries grouped under Southeast Asia, one is the world's fifth-largest exporter of merchandise, newly industrialized Singapore. At the other end of the scale, Cambodia ranks 111th for world merchandise exports, whereas Timor Leste does not even feature in the global statistics of the World Trade Organization (WTO).

The total population of the seven Southeast Asian countries plus Australia and New Zealand came to 549 million in 2009. The total GDP for this group in 2008 amounted to US$ 2 475 million, just over half that of China (US$ 4 327 million) and twice that of India (US$ 1 213 million). The developed industrial economies of Australia and New Zealand account for only 5% of the population but nearly half of the group's total GDP.

The present chapter also encompasses 22 Pacific Island countries and territories, although, in terms of science, these are dominated by 'the big four': Fiji, Papua New Guinea, New Caledonia and French Polynesia. These economies are nevertheless small in size and in terms of their contribution to world trade.

The global recession triggered by the US subprime crisis in 2008 has been experienced differently from one country to another. Australia, for example, was one of the few countries of the Organisation for Economic Co-operation and Development (OECD) that technically avoided a recession. This was largely because of the comparatively sound financial structures in the economy and the continued high demand for commodities from China and India. A strong economic stimulus programme was introduced by the Australian government in 2009 but this focused on infrastructure projects with little or no direct implications for science.

The earlier Asian financial crisis from 1997 to 1999 had reverberated around Southeast Asia, leading to a number of structural and institutional reforms in national financial systems. Indonesia, the Philippines, Thailand and Malaysia were all hard-hit by the Asian crisis but reforms set in motion as a consequence served to cushion many economies from the impact of the global recession a decade later, compared to what North America and Western Europe have been going through. Moreover, in most of the countries covered here, science remains a comparatively low priority in national strategic plans, as we shall see in the country profiles that follow for Cambodia, Thailand and Fiji in particular. As a consequence, the global recession has had very little direct impact on science.

Nevertheless, the impact can be observed through: (a) a reduction in high-tech exports; (b) more sharply defined science priorities aligned with local national priorities in Australia, New Zealand and Singapore; and in some cases (c) reduced spending on science and technology (S&T). This latter impact is not yet clearly documented because of the time lag in data availability on expenditure on research and development (R&D) but the issue has been foreshadowed in some national policy statements.

The stories that will unfold in the following pages are as diverse as the countries themselves. There is no one single story that epitomizes the region as a whole, or even sub-regions. There are, however, some common trends in terms of the general direction science policy is taking, the mobility of human resources and international collaboration.

Firstly, all countries are dependent to some degree on the science systems of the global scientific Triad: USA, Europe and Japan. This is evident in world output of scientific papers, patents and other related intellectual property, foreign investment and technological innovation and research training.

Secondly, the global mobility of, and competition for, scientists and engineers have intensified. All countries are seeking to train, attract and retain an increasing cohort of scientists and engineers.

Thirdly, international collaboration in S&T is growing rapidly, partly due to liberalized political arrangements and partly due to the growing cost of much scientific infrastructure.

Fourthly, science policy has shifted ground in terms of national development strategies. Science policy has been brought in from the cold to play a central role in innovation policies. This has quite significant long-term implications and carries with it policy management dilemmas.

A Thai Buddhist monk using a laptop

Photo: © Richard Stamper/ iStockphoto

1. The present chapter includes the seven Southeast Asian countries of Cambodia, Indonesia, Malaysia, Philippines, Singapore, Thailand and Viet Nam, as well as Australia and New Zealand, plus the 22 Pacific Island countries and territories dominated by Fiji, Papua New Guinea, New Caledonia and French Polynesia.

The responsibility for a science, technology and innovation (STI) system draws on a wider range of government portfolios than previously, whereas science has usually remained the responsibility of one, or perhaps two, ministries. With innovation touching on the responsibilities of a much wider range of portfolios, co-ordination becomes a key factor. An accompanying challenge is thus to maintain a strong, competitive basic science system in the context of the sometimes competing policy demands that emerge.

Last but not least, globalization offers both opportunities and challenges for some of the smaller economies. Global competition has drawn groups of countries into collaborating networks. Thus, regional structures[2] such as the Association of Southeast Asian Nations (ASEAN), the Asia-Pacific Economic Cooperation (APEC), the Pacific Islands Forum and the Greater Mekong Subregion offer new opportunities for coalescing scientific capacity.

2. See Annex I for the composition of ASEAN, APEC, the Pacific Islands Forum and Greater Mekong Region

These issues are discussed below in the context of five structural factors: (i) research and development (R&D) input (ii) R&D output and, in the country profiles (iii) institutional arrangements (iv) policies and priorities and (v) future trends and challenges.

R&D INPUT

Trends in R&D expenditure and personnel

The available data for all countries show rising national investment in R&D. Singapore and Australia more than doubled spending between 2000 and 2006. However, when gross domestic expenditure on R&D (GERD) is configured as a percentage of GDP, it becomes clear that, for Thailand, the Philippines and Indonesia, among others, these investments have barely kept pace with growth in GDP (Table 1).

Of all the countries covered in the present chapter, Singapore stands out as the most rapidly growing science investor. In Singapore, GERD doubled between 2000 and 2007, progressing from 1.9% to 2.5% of GDP.

Table 1: Socio-economic and R&D input indicators for Southeast Asia and Oceania, 2009 or most recent year available
Selected countries

				Researchers				GERD			
	Population 2009 (millions)	GDP per capita, 2008 (US$ thousands)	Year	Total FTE	Researchers per million population (FTE)	Women researchers (%)	Technicians per million population	As % of GDP	Per capita PPP$	Performed by business (%)	Funded by business (%)
Australia	22.1	48.3	2006	87 270	4 231	44.8*	993	2.17	720.7	57.3	57.2
Cambodia	14.8	0.8	2002	223	17	22.6	13	0.05	0.5	12.1	0
Indonesia	231.4	2.2	2005	35 564[h]	162[h]	–	–	0.05[a]	1.6[a]	3.7[a]	–
Malaysia	28.3	8.2	2006	9 694	372	38.8	44	0.64	79.9	84.9	84.7
New Zealand	4.4	29.9	2007	18 300	7 084[h]	0	894	1.26	330.5	42.7	40.1
Philippines	92.2	1.9	2005	6 896	81	50.7	10	0.12	3.4	68.0	62.6
Singapore	5.0	39.4	2007	27 301	6 088	0	529	2.52	1 341.8	66.8	59.8
Thailand	63.4	4.2	2005	20 506	311	49.9	160	0.23	18.1^{+1}	40.9^{+1}	48.7
Timor Leste	1.2	0.5*	–	–	–	–	–	–	–	–	–
Viet Nam	85.8	1.0	2002	9 328	115	42.8	–	0.19	3.1	14.5	18.1

-n/+n = data refer to *n* years before or after reference year a = partial data h = headcount * national estimation

Note: For Australia, women researchers are derived from 2006 census data.

Source: UNESCO Institute for Statistics, June 2010; United Nations Statistical Division, June 2010

Table 2: Knowledge Economy Index and Knowledge Index for Southeast Asia and Oceania, 2009
Selected countries

Country	Ranking for 145 countries (KEI)	Change in Rank from 1995	KEI	KI	Economic incentive regime	Innovation	Education	ICTs
Singapore	19	+2	8.44	8.03	9.68	9.58	5.29	9.22
Australia	11	-1	8.97	9.08	8.66	8.88	9.69	8.67
New Zealand	14	-6	8.92	8.97	8.79	8.66	9.78	8.46
Malaysia	48	–	6.07	6.06	6.11	6.82	4.21	7.14
Thailand	63	-9	5.52	5.66	5.12	5.76	5.58	5.64
Fiji	86	-4	4.20	4.47	3.4	5.03	4.25	4.12
Philippines	89	-16	4.12	4.03	4.37	3.8	4.69	3.60
Indonesia	103	-2	3.29	3.17	3.66	3.19	3.59	2.72
Viet Nam	106	+14	3.51	3.74	2.79	2.72	3.66	4.80
Cambodia	137	-8	1.56	1.54	1.63	2.07	1.93	0.62

Note: Developed by the World Bank, the Knowledge Eonomy Index (KEI) is based on the average of the normalised scores of a country for all four pillars of the knowledge economy: economic incentive and institutional regime; education; innovation and ICTs. The Knowledge Index (KI) measures a country's ability to generate, adopt and use knowledge. The KI index is based on key variables for the three knowledge pillars: education, innovation and ICTs. It should be noted that some data are missing for Viet Nam.

Source: World Bank database, accessed March 2010

GERD per capita also doubled to US$ 1 342, a figure considerably higher than that for Japan (US$ 1 159), the USA (US$ 1 195) or the UK (US$ 620). Singapore also stands out for the four groups of variables used by the World Bank to construct its Knowledge Economy Index (KEI): economic incentive, innovation, education and information and communication technologies (ICTs) [Table 2]. Yet, even Singapore has struggled to move up the ladder: in 2009, it ranked 19th out of 146 economies on the KEI, having climbed just two rungs since 1995. Nevertheless, the dynamic rise of Singapore is one of the outstanding developments of the past five years.

The number of S&T personnel has also grown considerably across the region. Again, Singapore leads in terms of growth. However, Singapore still has a comparatively small pool of technicians, suggesting future skills shortages if the current pace of scientific growth continues unabated. In Indonesia, numbers of S&T personnel appear to have declined, although it should be noted that the available data are not directly comparable. Meanwhile, data on investment in R&D and S&T personnel are few and far between for many of the Pacific countries and Timor Leste.

An important indicator of national capability in STI is the level of business sector investment in R&D. These data are highly variable across the countries covered here. For example, Malaysia and the Philippines both have comparatively high rates of business investment in R&D. However, this is largely because of the presence of large foreign firms operating in those countries. There is evidence that similar developments are underway in Thailand. The challenges for the STI systems of these countries will be to lever knowledge and technology from this foreign investment for their domestic economies.

Cambodia and Timor Leste have been undergoing considerable social and economic transformation. As a consequence, investment in S&T has focused primarily on institution-building and on developing human resources. The tragedy of Cambodia's turmoil throughout the 1970s is reflected in a miniscule human resource base compared to its neighbours. Also undergoing economic transition, Viet Nam has been developing from a low base but S&T institutional structures are comparatively well-developed and, although undergoing widespread reform, provide a strong historical foundation on which to build.

Two important observations can be made from these indicators. The first is that there is considerable diversity across the region in terms of human resources and expenditure on S&T. The second observation concerns the rapid, meteoric rise of Singapore's scientific capacity.

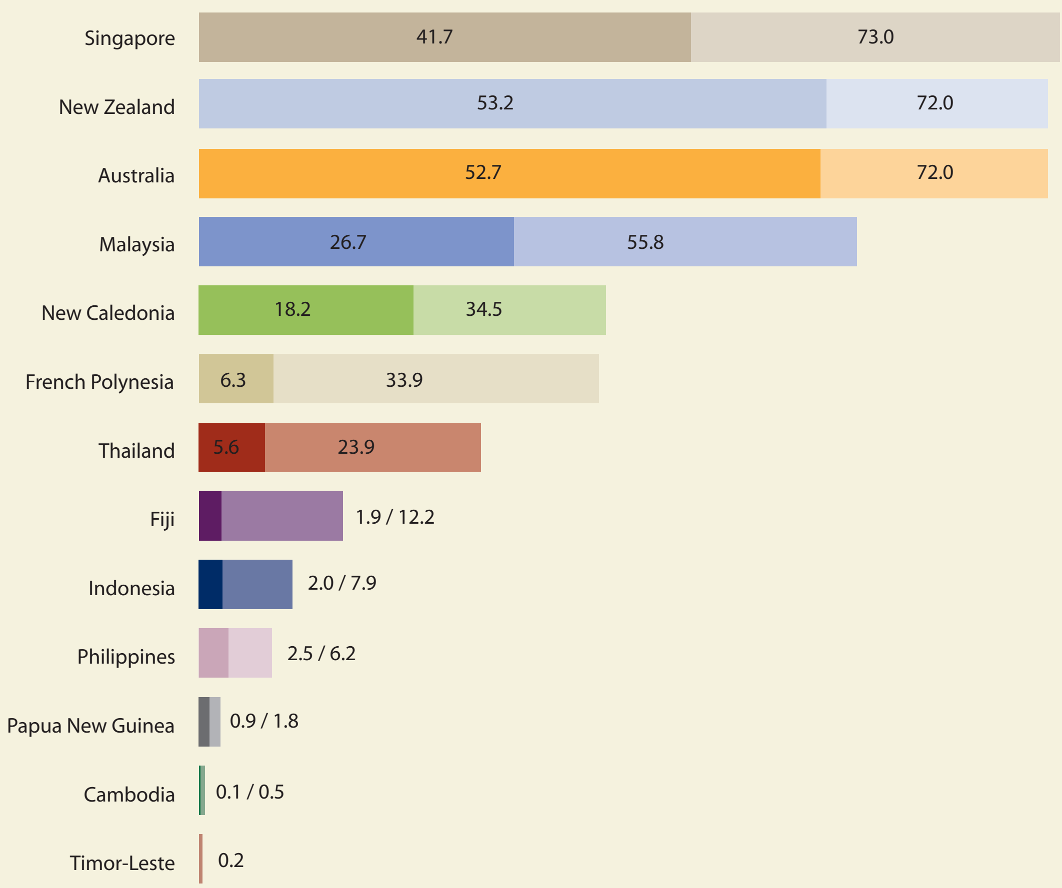
Singapore is one of the few countries in the region with a net inflow of scientific personnel, both from the region and from other scientifically advanced economies. There is growing evidence that Singapore is becoming central to global knowledge hubs in fields such as biomedical science and information technology (IT). A big challenge for Singapore will be to maintain the present inflow of human capital in order to underpin sustained knowledge-based development over the next decade, even as the rapid growth of the Indian and Chinese economies is stimulating demand for skilled personnel in these countries. However, it can be safely said that the growing presence of Singapore in global science is not simply a localized phenomenon but also carries wider implications for scientific collaboration across regional economies.

Information infrastructure: reaching the poor

One issue confronting most countries concerns their capacity to deliver benefits from science to the rural poor who live outside the major cities. According to the World Bank's ICT variable, Singapore performs best in Southeast Asia, no doubt due in part to being essentially an urban country.

Singapore, Australia and New Zealand have all massively expanded Internet access since 2001 (Figure 1). What is striking is the difficulty countries with a large, urban poor face in spreading access to the Internet, such as Cambodia, the Philippines and Timor Leste. Interestingly, the French-speaking Pacific territories have developed Internet usage quite rapidly since 2000, no doubt due to their ties to metropolitan France.

Figure 1: Internet users per 100 population in Southeast Asia and Oceania, 2001 and 2008
Selected countries and territories



Source: United Nations Statistical Division, Millennium Development Goals Indicators

Table 3: English-language scientific articles by authors from Southeast Asia and Oceania, 1998–2008
Selected countries

	Australia	Cambodia	Indonesia	Malaysia	New Zealand	Philippines	Singapore	Thailand	Viet Nam	Annual Total	Annual growth (%)
1998	16 432	8	305	658	3 519	263	2 264	855	198	**24 502**	
1999	16 766	12	354	830	3 597	292	2 729	965	239	**25 784**	5.2
2000	18 945	14	429	805	3 762	353	3 465	1 182	315	**29 270**	13.5
2001	19 155	14	449	906	3 772	317	3 781	1 344	353	**30 091**	2.8
2002	19 645	20	421	961	3 819	398	4 135	1 636	343	**31 378**	4.3
2003	20 920	23	428	1 123	3 935	418	4 621	1 940	458	**33 866**	7.9
2004	22 456	41	471	1 308	4 260	427	5 434	2 116	434	**36 947**	9.1
2005	23 376	50	526	1 520	4 590	467	5 971	2 409	540	**39 449**	6.8
2006	25 449	64	597	1 757	4 739	464	6 300	3 000	617	**42 987**	9.0
2007	26 619	80	582	2 151	4 974	535	6 249	3 582	698	**45 470**	5.8
2008	28 313	75	650	2 712	5 236	624	6 813	4 134	875	**49 432**	8.7
Total	**238 076**	**401**	**5 212**	**14 731**	**46 203**	**4 558**	**51 762**	**23 163**	**5070**	**389 176**	**7.3**
Growth 1998–2008 (%)	72.3	837.5	113.1	312.2	48.8	137.3	200.9	383.5	341.9		101.7

Source: Thomson Reuters' (Scientific) Inc. Web of Science (Science Citation Index Expanded), complied for UNESCO by the Canadian Observariore des sciences at des technologies

R&D OUTPUT

Scientific publications

The number of scientific publications has grown substantially in the region, increasing by around 70% from 1998 to 2008, with Australia, Singapore and New Zealand being the largest knowledge producers (Table 3). For many countries, publications grew from a very low starting point but some quickly overcame this handicap, including Thailand and Malaysia. In 2001, Singapore even overtook New Zealand, a country with a similar population, and has since consolidated its position.

'The big four' dominated the scientific output of the Pacific over the same ten-year period: New Caledonia, Papua New Guinea, Fiji and French Polynesia. These four accounted for 86% of articles published by scientists in the Pacific islands that were recorded in Thomson Reuters' Science Citation Index (Table 4). Overall, the Pacific countries and territories account for less than 1% of all the scientific articles produced by the countries covered in the present chapter.

These data raise the question of just how central the three major science publishing countries of Australia, Singapore and New Zealand are to scientific collaboration? Do regional knowledge hubs really pivot around these countries or is each of the three simply pursuing its own separate scientific endeavour? In the answer lies the key to understanding the dynamics of regional co-operation in S&T.

It is possible to explore this question by investigating patterns of co-authorship (Table 5). Co-authorship data tell an interesting story. *Firstly,* it is clear that international co-authorship of scientific papers is a commonplace practice for scientists right across the region. *Secondly,* the rate of international co-authorship is significantly higher among those countries that produce a modest amount of scientific papers. The level of international co-authorship for specific countries may thus provide an indicator of international scientific dependence. Cambodia, for example, has been almost entirely dependent on international co-authorship for its publication output for the past decade (94%). Scientists in Indonesia and the Philippines also have relatively high rates of co-publication with international colleagues. Singapore, Australia, New Zealand and Malaysia are, by contrast, far less dependent on co-authors abroad for their publication output and there is evidence of

Table 4: English-language scientific articles by authors from Pacific islands, 1998–2008
Selected countries and territories

	Fiji	French Polynesia	New Caledonia	Papua New Guinea	Other Pacific Islands	Total Pacific	Annual growth (%)
1998	24	44	66	61	27	**222**	
1999	29	35	51	76	37	**228**	2.7
2000	23	38	65	68	32	**226**	-0.9
2001	23	32	56	72	20	**203**	-10.2
2002	33	35	39	65	20	**192**	-5.4
2003	33	33	59	62	40	**227**	18.2
2004	41	40	62	53	46	**242**	6.6
2005	58	35	85	43	38	**259**	7.0
2006	62	44	115	50	57	**328**	26.6
2007	60	38	126	81	44	**349**	6.4
2008	59	41	107	79	30	**316**	-9.5
Total	**455**	**415**	**831**	**710**	**391**	**2 792**	**4.2**
Growth 1998–2008 (%)	145.8	-6.8	62.1	29.5	11.1	42.3	

Source: Thomson Reuters' (Scientific) Inc. Web of Science (Science Citation Index Expanded), complied for UNESCO by the Canadian Observariore des sciences at des technologies

considerable collaboration between countries in the region. International comparisons suggest that a figure of around 40–50% for international co-authorship represents a good balance between the national science base and global collaborative science.

Although scientists from the USA are the most prominent collaborators overall, there is some diversity in international co-authorship. Among the Pacific nations and territories, Australia and France are the dominant partners, with the French connection logically being strongest for the French-speaking territories. There is also co-operation among Pacific countries and territories. For example, over 10% of Fiji's international co-authored publications include at least one author from another Pacific country. The same is true for French Polynesia and New Caledonia. This is an important development for the smaller Pacific States and territories because co-authorship with the larger Pacific economies indicates not only co-operation in common areas of scientific endeavour but also potential knowledge conduits to major global science hubs elsewhere. The US scientific hub is the most frequent source of co-authors for most Southeast Asian countries, Australia and New Zealand. However, Indonesian and Vietnamese scientists co-author articles primarily with their Japanese counterparts and Malaysian authors with Chinese scientists. China is also an important collaborator for scientists from Singapore, the Philippines and Australia, an interesting addition to the scientific domination generally accorded to the USA, Japan and the European Union (EU).

National strengths in particular fields emerge when publications are counted by field of research (Figure 2). For the region as a whole, clinical medicine predominates (30% of all publications), followed by biological (15%), engineering (15%) and biomedical sciences (13%). In some countries, scientific output is concentrated in one or two fields. For example, nearly half of Cambodia's modest output is circumscribed to the medical sciences. Interestingly, Earth and space sciences also make up a sizeable share of its research output. By contrast, output from Singapore emanates firstly from engineering, followed by medicine and physics. Fiji, Indonesia, New Zealand, Papua New Guinea and the Philippines all have a high output in biological sciences. Malaysia stands apart, with its strong focus on chemistry.

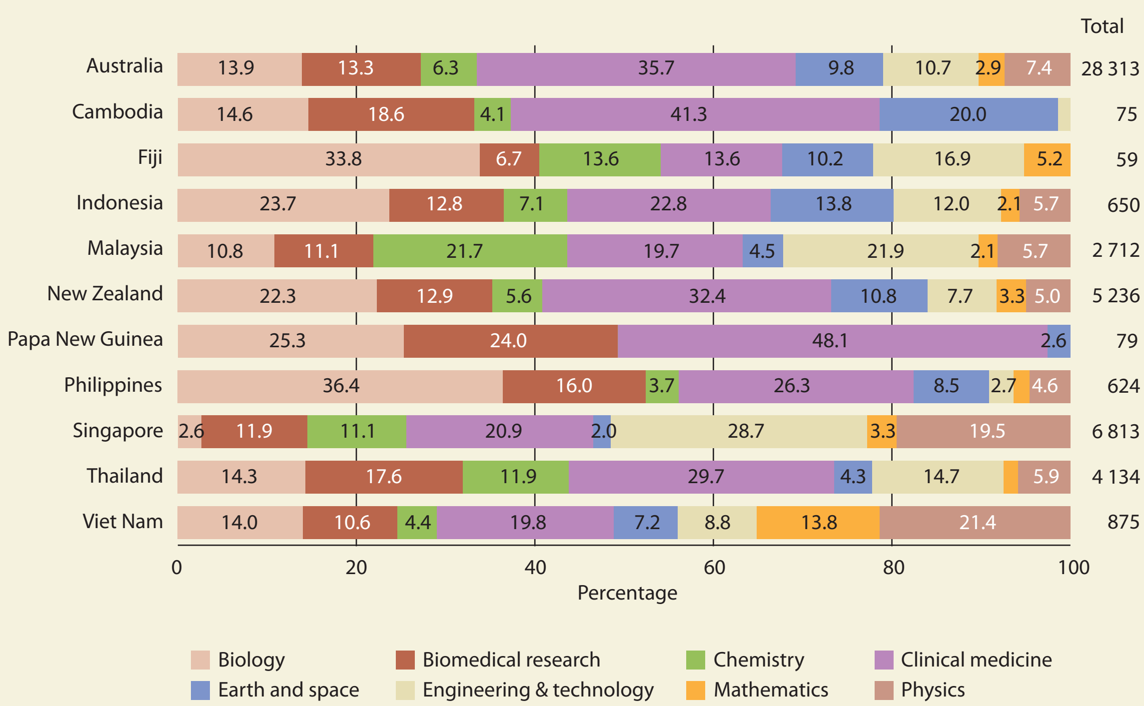
There is also evidence of the growing impact of the science produced in the region. One indicator of scientific

Table 5: Top three countries for international co-authorship with Southeast Asia and Oceania, 1998–2008

Selected countries and territories	SCI papers 1998–2008	International co-authors (%)	Country of origin of co-author (%)		
Australia	207 944	45.5	USA (14.7)	UK (7.7)	China (5.2)
Cambodia	396	93.9	USA (26.9)	France (19.9)	Japan (15.1)
Indonesia	4 750	88.8	Japan (28.1)	USA (22.1)	Australia (22.1)
Malaysia	13 576	48.4	China (18.0)	UK (12.8)	India (12.6)
New Zealand	42 491	48.5	USA (32.0)	Australia (24.9)	UK (17.9)
Philippines	4 079	71.9	USA (32.6)	Japan (25.0)	China (7.2)
Singapore	45 943	41.4	USA (30.2)	China (29.1)	Australia (10.8)
Thailand	21 001	56.6	USA (34.6)	Japan (22.7)	UK (12.1)
Viet Nam	4 569	62.1	Japan (19.1)	USA (15.3)	France (14.6)
Fiji	453	78.4	Australia (35.8)	USA (22.5)	India (13.0)
French Polynesia	415	88.4	France (70.0)	USA (21.3)	New Caledonia (8.7)
New Caledonia	831	83.9	France (59.8)	USA (16.5)	Australia (13.2)
Papua New Guinea	671	80.9	Australia (46.0)	USA (31.5)	UK (14.4)

Source: Thomson Reuters' (Scientific) Inc. Web of Science (Science Citation Index Expanded), complied for UNESCO by the Canadian Observariore des sciences at des technologies

Figure 2: Publications in Southeast Asia and Oceania by major field of science, 2008 (%)



Source: Thomson Reuters' (Scientific) Inc. Web of Science (Science Citation Index Expanded), complied for UNESCO by the Canadian Observariore des sciences at des techniques

Table 6: Scientific papers and citations of authors from Southeast Asia and Oceania, 1999–2009
Selected countries and territories

Country/territory	Papers	Citations	Citations per paper
Australia	284 272	3 304 072	11.62
Cambodia	566	4 197	7.42
Fiji	633	2 955	4.67
French Polynesia	456	3 805	8.34
Indonesia	5 885	45 156	7.67
Malaysia	17 980	79 098	4.40
New Caledonia	950	7 780	8.19
New Zealand	55 253	575 803	10.42
Papua New Guinea	741	7 318	9.88
Philippines	5 370	44 295	8.25
Singapore	58 731	498 782	8.49
Thailand	26 896	188 759	7.02
Viet Nam	5 878	41 043	6.98

Note: Data cover the period 1 January 1999 to 31 December 2009.

Source: ISI Web of Knowledge, Essential Science Indicators, March 2010

impact is the level of citation of scientific papers (Table 6). Most of the larger science systems in the region were achieving average citations per paper that were relatively close to the overall average number of citations for all papers from all countries (10.51 citations per paper). Citations per paper also appear to be on an upward trend for the developing economies in the region.

A higher than average citation rate for papers from a particular country in a given field can be considered an indicator of scientific impact. For example, Australian papers were more highly cited than the overall average in 16 out of 22 broad scientific field for the period 1999–2009, with New Zealand (10 fields) and Singapore (8 fields) also showing clear evidence of achieving above-average impact across a spectrum of sciences. However, some of the smaller science systems from the region also achieved above-average impact in specific fields, including: the Philippines (computer science, environment/ecology, pharmacology and toxicology, plant and animal science); Viet Nam (clinical medicine, microbiology, neuroscience); Indonesia (geosciences, social sciences); Papua New Guinea (biology, microbiology) and New Caledonia (geosciences). These apparent strengths are discussed in the country profiles that follow , along with, national priorities for science and national policy directions.

Patents

One regional feature is the trend towards integrating S&T policies with innovation and industry policies, notably through the registration of patents. Through the period 2000–2007, the number of patents held in the USA and registered by the Southeast Asian countries, Australia or New Zealand nearly doubled (Table 7). Australia and New Zealand were the two largest patent-registering countries and Malaysia was the fastest-growing patent producer, although from a smaller base. Malaysia registered less than half as many patents as New Zealand in 2001 but matched it by 2006 and moved ahead in 2007.

Table 7: USPTO registered patents from Southeast Asia and Oceania, 2000–2007
Selected countries

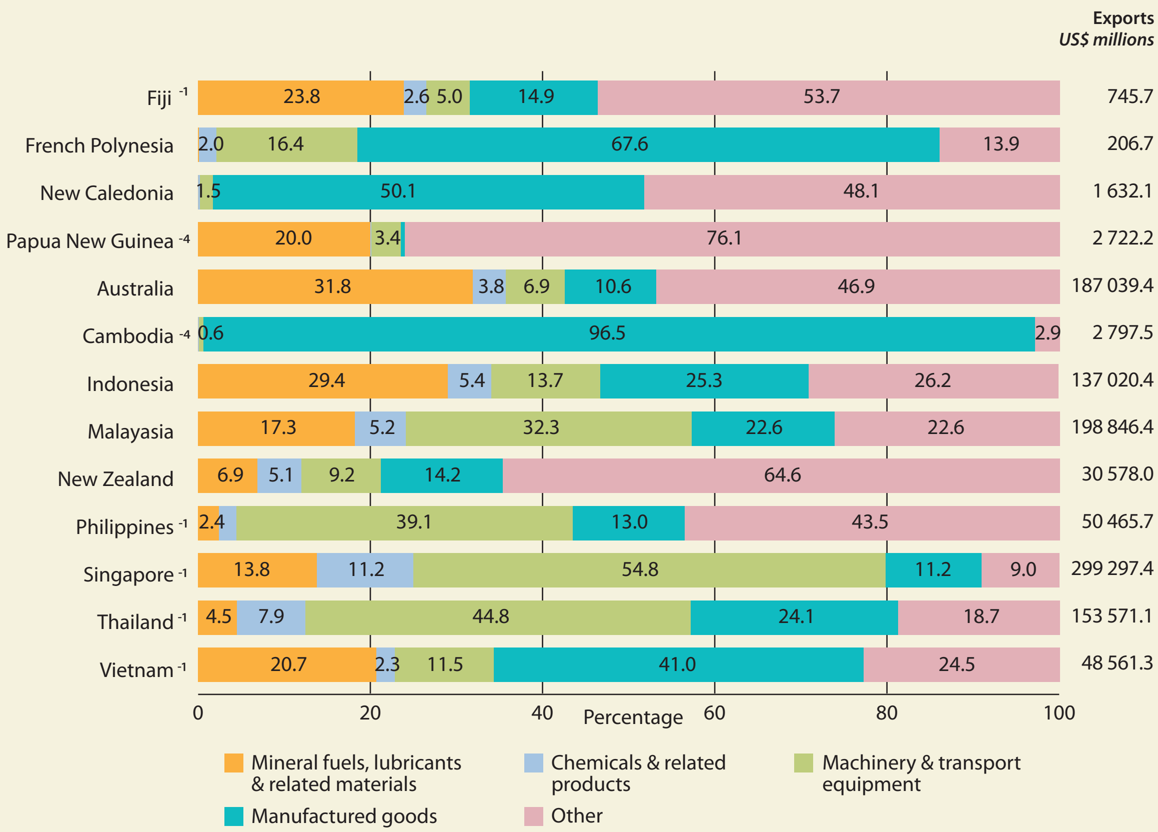
	2000	2001	2002	2003	2004	2005	2006	2007	increase, 2000–2007 (%)
Australia	802	981	964	1 023	1 068	1 002	1 476	1 382	72.3
Cambodia	–	–	–	–	1	–	1	–	–
Indonesia	11	13	9	13	11	12	7	9	-18.2
Malaysia	63	65	94	77	111	117	162	212	236.5
New Zealand	125	147	171	164	161	135	160	136	8.8
Philippines	17	22	30	45	39	26	44	33	94.1
Singapore	274	373	505	523	540	429	519	481	75.5
Thailand	25	39	60	37	37	28	56	28	12.0
Viet Nam	1	4		2	2	6	2	1	0.0
Total	**1 318**	**1 644**	**1 833**	**1 884**	**1 970**	**1 755**	**2 427**	**2 282**	**73.1**

Source: UNESCO Institute for Statistics

High-tech exports

Despite the global recession, a number of Southeast Asian economies have performed well in high-tech manufactured exports and commodities in particular (Figure 3). High-tech manufacturing is drawn mainly from Sections 5 and 7 of the Standard International Trade Classification. Within Section 7, the major high-tech products are electronics, electrical and related data equipment but also some power-generating equipment and medical devices. Section 5 includes medical and pharmaceutical products, optical equipment, aeronautics, photographic equipment and metrological devices (Lall, 2000). Where the available data are recent enough, growth in some of these high-tech exports appears to have slowed or even declined as a result of the global recession. However, a closer analysis shows that the decline has been progressing since 2000, suggesting a lead up to the recession rather than a direct consequence.

Figure 3: High-tech exports from Southeast Asia and Oceania, 2008 (%)
Selected countries and territories



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

Note: Exports are grouped according to the Standard International Trade Classification: Mineral fuels, lubricants and related materials (Section 3); Chemicals and related products (Section 5); Machinery and transport equipment (Section 7). The categories for Manufactured goods and Other do not include any high-tech exports.

Source: United Nations Comtrade database

Malaysia's exports of machinery and transport equipment (Section 7), the largest commodity group (33.2% of exports), actually dropped by 23.6% in 2007–2008, mainly due to a fall in exports of electronic integrated circuits. This sub-group collapsed by 75% from 2007 to 2008 but was generally flat through 2000–2008. Other major high-tech exports from Malaysia for 2007 include automatic data processing equipment (7.2% of total exports) and office and data processing machine parts (5.5%).

Major high-tech exports from the Philippines dropped 40% between 2006 and 2007. For the latter year, electronic integrated circuits comprised 11.0% of total exports and automatic data processing machines 7.8%.

Exports of machinery and transport equipment constituted the majority (54.8%) of Singapore's exports in 2007. High-tech manufacturing featured strongly in Singapore's export performance, including electronic integrated circuits (21.1% of total exports) and automatic data processing equipment (3.4%). Over the period 2003–2007, Section 7 exports averaged a growth rate of 13.8% but this fell to 4.7% for 2006–2007. Although exports of electronic circuits slowed, they still reflected a positive trend.

Like Malaysia, Thailand performed well in high-tech exports of automatic data processing equipment (8.2% of total exports in 2006–2007) and electronic integrated circuits (5.3%) over the same period. For Thailand, machinery and transport equipment represented nearly half (44.8%) of total exports. For this section, Thailand has maintained an annual growth rate of 18.3% for several years, with a slight dip in 2006–2007 to 17.9%.

It is likely that, when data emerge for 2009 and 2010, they will reveal evidence of a decline in high-tech exports but it is also likely that some countries in the region will fare worse than others. As recovery deepens, economies such as Singapore and Thailand will probably recover more quickly than others, given the current trend.

COUNTRY PROFILES: Australia and New Zealand

Australia

S&T and economic status

Although it maintains a comparatively small population, Australia ranks 23rd in terms of world trade merchandise exports. GDP per capita amounted to US$ 48 253 in 2008. Merchandise exports (US$ 187 million in 2009) were dominated by fuel and mining (60%), with manufacturing comprising just 16% and agriculture 14%.

Australia has been undergoing somewhat of an STI policy transition since 2005. Through the early 2000s, the economy lagged behind other OECD countries in terms of the level of investment in R&D. In 2000, GERD in Australia amounted to just 1.61% of GDP, with business contributing just under half (47.8%) of the total, according to the UNESCO Institute for Statistics. With the exception of mining, business expenditure on R&D remained well below the OECD average. Even though GERD rose to 2.17% by 2006, driven largely by the growing share (57.3%) invested by business in general and mining in particular, the Australian economy still slipped from 5th to 18th position in the World Economic Forum Index from 2000 to 2008 (Cutler, 2008). This apparent slide in global competitiveness in all but the natural resources sector spurred the new government to undertake a series of reforms in 2007. A number of reviews that directly or indirectly focused on the national science system were carried out between 2007 and 2010. These included reviews of: the Australian innovation system; the higher education system; the co-operative research centres programme; and a series of sectoral reviews covering automobile production, clothing and footwear, and pharmaceuticals. In all cases, the recommendations made and the policies that have resulted so far have sought to bring science more centrally into the Australian innovation and industrial systems and to overcome some of the structural weaknesses noted in recent years, such as a general decline in public investment in science. According to the Innovation Review, Australian government support for science and innovation as a share of GDP fell by approximately 25% from 1994 to 2007 (Cutler, 2008).

Structural arrangements, priorities and policies

As a consequence of the recent reviews cited above and an apparent commitment to strengthening the science base underpinning the country's innovation performance, seven priorities for innovation were identified in 2009 to complement existing national research priorities. These are not sectoral priorities but rather are directed towards systemic reform of the innovation system. These priorities are:

- improving research funding;
- producing skilled researchers to undertake the national research effort;
- securing value from commercialization and development of 'industries for the future';
- disseminating new technologies, processes and ideas;
- enhancing collaboration within the research sector and between researchers and industry;
- stimulating international collaboration in R&D;
- involving the public and communities to work with others in the innovation system to improve policy development and service delivery.

Within the university research system, there remains a set of four overarching research priorities dating from 2002. These are:

- an environmentally sustainable Australia;
- promoting and maintaining good health;
- frontier technologies for building and transforming Australian industries;
- safeguarding Australia.

These research priorities are not directly attributable to specific fields of scientific enquiry but rather set out generic targets for socio-economic development. Under each broad heading, there are lists of more specific research targets.

Australia's business sector investment in R&D has traditionally been weak and dominated by a small number of large firms, particularly in mining. The recent growth in business sector R&D shows promise but this has largely been led by mining and energy, which accounted for 17.4% of the total national R&D effort in 2007, up from 12.8% two years earlier. The public sector remains the major performer across most fields of research; it is responsible for nearly 100% of pure basic research and 94% of strategic basic research. Around 94% of business sector investment is either experimental development or applied research.

Apart from universities, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) is by far the biggest public sector performer of research. In 2009, it employed 6500 people at 50 sites across the country. CSIRO research priorities are driven by a set of flagship programmes adopted in 2000:

- energy transformed;
- food futures;
- climate adaptation;
- future manufacturing;
- preventative health;
- wealth from oceans;
- minerals down under and;
- sustainable agriculture.

These flagship priorities reflect the growing regional concern with climate change and sustainable production. Expenditure on the Commonwealth socio-economic objective of the environment has been rising slowly over the past decade, reaching 2.4% of all Commonwealth research investment for 2007.

Future trends and challenges for Australia

The Australian government increased the science budget by 5% over the previous year's budget in 2008 and a further increase of 25% was foreshadowed for the 2010 science and innovation budget. Among major initiatives, the government has announced a 'super science initiative'. This AU$ 1 100 million initiative is directed towards key enabling technologies: biotechnology, nanotechnology and ICTs, as well as two other key areas: space science and astronomy; and marine and climate science. This investment is likely to direct the overall national R&D effort further towards the development of environmental technologies and management practices.

The Australian Cooperative Research Centres Programme has been a key feature of the national science system for nearly two decades. Over AU$ 150 million of Commonwealth funds are invested in the programme. Recent changes announced by the government include a refocus on public good research, which should again add further impetus to environmental technologies and their management, including alternative energy and water management.

There are three key challenges confronting the Australian system. The first concerns the comparatively weak and narrowly focused business sector involvement in the system. The challenge will be to draw smaller and potentially innovative firms into the broader national science and innovation system. Public sector investment is critical for building a strong national basic science capability but the recent trend toward contestable funding in a *common arena* for the academic and public sector system has blurred the boundaries for the missions of different science institutions. The Australian Institute of Marine Science (AIMS), the Australian Nuclear Science and Technology Organisation (ANSTO), the CSIRO and universities are now in competition across many common sources of funds. This is a product of the integration of S&T policy with innovation policy. The challenge, however, will be to ensure that the basic science base can remain as broad as possible in order to sustain a strong, diverse and sustainable science culture. Managing the sometimes competing demands of science and the much broader demands of innovation and industry policy will remain a major structural challenge for policy advisors and governments.

New Zealand

S&T and economic status

New Zealand ranks 63rd on the World Trade Organization (WTO) world trade merchandise index. GDP per capita is lower than in neighbouring Australia, at US$ 29 870. New Zealand's trade remains dominated by agricultural exports (59%) and scientific output is strongly concentrated in the biological and medical sciences (Figure 2).

New Zealand, like Australia, has lagged behind most other OECD countries in terms of the level of investment in R&D. It was not until 2002 that the GERD/GDP ratio reached 1.2%. Moreover, the level of private sector R&D is lower than for almost all other OECD countries.

Structural arrangements, priorities and policies

In early 1990, New Zealand introduced a major restructuring of its science system which is still valid today. The new arrangement separated science policy development, science funding and the production of scientific output. A longer-term strategic view directed towards 'benefit' to New Zealand was adopted and a rather unique structure put in place establishing the government as a 'science purchaser' (Cleland and Manly, 2007). The Ministry of Research, Science and Technology (MoRST) is still the main driver of science policy and the Foundation for Research, Science and Technology is the major purchaser of public-funded science. The Health Research Council is the major purchaser of medical research.

Although science policy is aligned with innovation policy, administration remains more discrete than in Australia. However, there is a strong emphasis on 'Transformational Research, Science and Technology' and on establishing roadmaps for S&T investment. There are currently four strategic priorities:

- sharpening the agenda;
- engaging the population with S&T;
- improving business performance; and
- building a world-class science system.

Existing priorities in biological and medical research have been maintained, with new sectoral areas targeted for development through national roadmaps, including food research, energy and biotechnology. Through 2008–2009, transformational research focused on building a high-tech platform for renewable energy. The Health Research Council received a considerable increase in funding in the 2009 budget.

Established in 1992, Crown Research Institutes (CRIs) are a major feature of the New Zealand system. By 2004, investment in CRIs had reached US$ 395 million, making them the biggest national investment programme. Although their structural arrangements are quite different from the Cooperative Research Centres in Australia, they represent a similar structural feature in the New Zealand science system and provide a similar level of policy input.

International linkages are a strategic priority for New Zealand. These are enshrined in a number of agreements, including the Energy Development in Island Nations partnership with the USA and Iceland, and the Science and Technology Cooperative Agreement with the EU.

Future trends and challenges for New Zealand

New Zealand ranks just below Australia on the Knowledge Economy Index (KEI) overall but higher for the variable of economic incentive regime. Both countries have policies in place to build closer alliances between the research and business sectors. Both are also placing greater emphasis on public good research, much of which comes in response to environmental concerns. For New Zealand, this is described as 'eco-innovation' that will draw together government, industry and science (MoRST, 2009: 3)

A key challenge identified by the New Zealand government is to 'refocus' the CRIs in order to deliver a greater impact in tackling challenges New Zealand faces for the future. This includes, building high-tech platforms for renewable energy, food research and biotechnology.

COUNTRY PROFILES: Southeast Asia

Cambodia

S&T and economic status

Cambodia is still recovering from the trauma of the international and civil wars that decimated the country's scientific capacity in the 1970s. The economy has grown rapidly in the first decade of the 21st century, albeit from a very low base. GDP per capita stood at US$ 769 in 2009, placing Cambodia just ahead of Timor Leste for this indicator. The country currently ranks 111th on the world trade merchandise export index. Merchandise exports are concentrated in manufacturing, primarily clothing.

Although Cambodia has been progressing rapidly both economically and socially, the country does not compare well in terms of knowledge-based development. On the World Bank Knowledge for Development Index for 2009, the Cambodian economy still lags well behind all other East Asian and Pacific countries. The country has fallen further behind on the knowledge index with a 'normalised regional score' of 2.8 in 1996 declining to 1.15 in 2009. This is in spite of the presence of many other positive social and economic indicators.

There is currently no competitive funding programme to support scientific research, although proposals are in place to establish a National Research Commission for Education. Consequently, there are, as yet, no clearly defined research priorities but, with renewed efforts to establish a national science funding system, these are in the process of being developed. Publications are growing from a small base with output almost totally dependent on international co-authorship. The USA, France and Japan are the three main partner countries contributing to this output. Output is almost entirely concentrated in the life sciences, with three-quarters of publications relating to the biological, biomedical or medical sciences (Figure 2). Internet usage is in its infancy with just 0.5% of the population having access (Figure 1).

Structural arrangements, priorities and policies

There is currently no overt national strategy for S&T. As a consequence, S&T policy remains fragmented and dispersed across the various ministries responsible for social and economic management and development. There are, however, some nascent structures emerging that could provide the basis for a national strategy.

The supply of scientists and engineers has been growing and there is potential for further development. Their number remains limited, however, because of a comparatively weak institutional capacity and a higher education system that has grown faster than its capacity to deliver quality control across a highly diverse range of institutions proposing higher education. Responsibility for university-based professional training rests with the Ministry of Education, Youth and Sport and technical training with the Ministry of Labour. As the higher education system continues to grow, the country faces an immediate, pressing challenge to co-ordinate institutional strengths in order to entrench national quality and achieve policy objectives across the entire higher education system. As yet, there are no defined priorities for scientific research.

Cambodia's private sector remains weak and very much dependent on both foreign direct investment (FDI) and overseas development aid (ODA). Consequently, it is the public sector which shoulders most of the burden for national investment in knowledge-based development, including R&D. As the private sector becomes stronger and more innovative, the policy challenge will be to find ways to stimulate the development of R&D and innovation in the private sector. While S&T is not specifically mentioned in the country's development plans, S&T issues are directed to an *ad hoc* committee composed of representatives from eight ministries and co-ordinated by the Ministry of Industry, Mines and Energy.

Future trends and challenges for Cambodia

The future challenges for Cambodia are immense, with institutional and human resource-building a major priority. At present, there are a number of internationally supported initiatives underway to help the country overcome institutional barriers. For example, the World Bank is supporting an initiative with the Ministry of Education, Youth and Sport to enhance the research capacity of the higher education system, and the Asian Development Bank is supporting the elaboration of a 'technology adoption framework' with the Ministry of Industry, Mines and Energy. There are also plans to develop the nation's research funding system and reviews are underway to revitalize science and engineering education.

The country is at an early stage of developing an industrial private sector. FDI is being sought and will probably by located in one or more of the 21 special economic zones that have been proposed by the government.

The growth areas at the moment are the garment, tourism, construction and property development industries. The growth in garment manufacturing is related to the influx of FDI due to low labour costs.

As S&T policy becomes more national in focus and is directed towards the development of a national innovation system, it will be necessary to monitor and review national progress. At present, no single agency has the mandate or the resources to evaluate S&T policy or develop indicators for monitoring S&T and innovation. A critical challenge will be to build some institutional capacity to carry out this work and to resource periodic data collection and analysis.

The global economic recession since 2008 threatens to staunch the flow of international support. However, there are promising signs for Cambodia in terms of natural oil reserves. At present, agriculture and fuel comprise just 5% of the country's merchandise exports. The discovery of potentially lucrative oil reserves in recent years may lead to growth in raw production but the capacity to process the raw product onshore will depend upon the availability of skilled personnel and funding for industrial development.

Indonesia

S&T and economic status

Indonesia is the most populous country in Southeast Asia; it also comprises 45% of the total population of the countries studied here. Since the Asian financial crisis in the late 1990s, the economy has struggled to recover. The Indonesian economy is now well down on the World Bank Knowledge Index scale, above only Cambodia. However, due to the overall size of the economy, it ranks 31st in the world merchandise trade value index. Manufacturing and fuel (36%) and mining (38%) comprise the main merchandise export category groups. GDP per capita in 2008 came to US$ 2 247. The GERD/GDP ratio has languished, recording only 0.05% in 2005. It fares only better than Cambodia and Viet Nam for the share of GERD contributed by the private sector.

In previous decades, Indonesia placed great emphasis on building S&T institutions. Apart from the university sector and departmental R&D organizations, there are currently seven national R&D agencies (*see next section*). In 2005, these seven agencies were working on a series of priority programmes: food and agriculture, energy, defence, transportation, ICTs, health and pharmaceuticals.
With the onset of the global recession, the policy effort has been directed toward sharpening the S&T investment focus on those areas that have potential for economic 'transformation'. Consequently, there is a determined effort to establish intermediate agencies, such as business innovation centres, business technology centres and incubators. In the university system, there has been a strong focus has on improving quality.

Structural arrangements, priorities and policies

The Ministry of Research and Technology (MoRT) is responsible for driving S&T policy. In 2005, it announced a 20-year vision statement. In this vision statement, S&T is portrayed as a 'main force' for sustainable prosperity. Seven R&D agencies come under the direct authority of MoRT. These are: the National Institute for Scientific Research (LIPI), the Agency for the Assessment and Application of Technology (BPPT); the National Institute of Aeronautics and Space (LAPAN); the National Co-ordinating Agency of Survey and Mapping (BAKOSURTANAL); the National Standardisation Agency (BSN); the National Nuclear Energy Agency (BATAN) and the National Nuclear Energy Control Board (BAPETEN).
A set of additional institutes and centres reside under the jurisdiction of various ministries.

Four key science programmes were identified for development in 2005–2009: (1) R&D; (2) diffusion and utilization of S&T; (3) institutional capacity-building and; (4) increasing the industrial capacity of S&T. For 2009, a set of thematic programmes were also identified (Firdausy, 2006):

- tsunami early warning system;
- open source (software development);
- agro-technology;
- marine science;
- defence from bioterrorism;
- bio-ethics;
- DNA forensic technology;
- natural resource accounting.

Since 2002, a number of presidential decrees have driven the development of the science system, for example: the 2005 decree for Technology Transfer of Property Rights and Outputs of R&D and the 2006 Decree of Permission for International Researchers, Bodies and Institutions to Conduct Research Activities in Indonesia. The latter reflects an overall strategy to develop international collaboration.

The numbers of researchers in the system appeared to slip back around the mid-2000s but there has since been a concerted effort to build up numbers of research personnel in national S&T institutions. Publication output has only progressed modestly, thanks to a high level of international co-authorship. Japan is the primary country of origin for collaborators, followed by the USA and Australia (Table 5). Output has been dominated by biological, biomedical and medical sciences, presenting a pattern somewhat similar to that of Cambodia and New Zealand.

In 2009, there were 2 600 institutions providing higher education, including universities, academies and institutes. The emphasis has been on strengthening the research capacity and quality of just a fraction of the top universities.

Indonesian patenting activity has remained limited throughout the first decade of the century, with essentially no growth in the patent system. Developing IPR centres and technology transfer institutions are part of the national strategy to stimulate patenting activity.

Future trends and challenges for Indonesia

MoRT has identified three key challenges: overcoming the mismatch between public sector research output and the demands of industry; enhancing R&D capacity in the private sector; and overcoming the structural barriers between the public and private sectors.

Science networks have been identified as a mechanism for responding to these challenges. Current policies focus on fostering national co-operation in the key areas noted above, in order to share resources, utilize economies of scale and build both virtual and actual centres of excellence. International networking is being encouraged to increase the quality and quantity of researchers engaged in international research.

Like many other countries in the region, Indonesia has also identified the need to broaden community acceptance and understanding of how S&T serve to enhance development.

Human resources are likely to remain a major challenge. Balancing efforts to augment the pool of researchers against budget constraints from the global recession will make the task of network-building all the more imperative.

Malaysia

S&T and economic status

Malaysia has made rapid progress in science, technology and economic development, recovering rapidly from the Asian financial crisis of the late 1990s. The economy is dominated by a high ratio of manufacturing (65%) among exports, ranking 21st in the world merchandise export value index. As with the Philippines, much of this is a product of foreign firms located in the country. GDP per capita in 2008 amounted to US$ 8 197. The GERD/GDP ratio has grown from 0.49% in 2000 to 0.64% in 2006 (Table 1).

Growth in business expenditure on R&D as a proportion of GERD has been a major contributor to this expansion, rising from 58% in 2000 to 85% in 2006. For the immediate future, this may be a double-edged sword, as contractions in R&D investment by many multinational firms following the global recession may leave a vacuum that might not easily be covered by the increase in public expenditure. In terms of the Knowledge Index, Malaysia has remained stationary in 48th position. The economy ranks comparatively highly on the ICT and innovation variables, with education remaining the key challenge. Internet usage has grown dramatically, with 56% of the population enjoying access in 2008 (Figure 1).

Publication output has risen rapidly over the past decade, very much led by domestic capacity. The international co-authorship rate for Malaysian scientists was of the same order as for Australia and New Zealand. Interestingly, China was the primary contributor to international co-authorship. In contrast to most other countries in the region, chemistry dominated Malaysia's scientific output.

Numbers of S&T personnel have continued to climb. So too has the number of patents. Malaysia has recorded the fastest growth in patenting activity of all countries in the region, from only 63 USTPO registered patents in 2000 to over 200 in 2007. Consistent with these data is the good national performance in high-tech exports *(see page 445)*.

Structural arrangements, priorities and policies

The Ministry of Science, Technology and Innovation is the leading national institution, drawing STI policies towards a common goal. The second *National Plan for Science and Technology Policy 2002-2020,* adopted in 2003, set out a clear strategy of developing institutions and partnerships to enhance Malaysia's economic position. Underpinning this strategy are four specific capacity-building targets:

S&T institutional capacity, commercialization of R&D output, human resource development, and generating a culture of techno-entrepreneurship.

The *National Plan* presented a vision for 2020 centred on those areas that could yield the highest economic pay-off. This included policy considerations of: demonstrated need, availability of national advantage, relevance and the capacity to achieve objectives. This approach to strategic planning is common across many of the industrially advanced economies, such as Singapore, Australia and New Zealand. However, Malaysia has been more explicit than many other countries in identifying industrial targets for the science base.
These include:

- advanced manufacturing and materials;
- micro-electronics;
- biotechnology;
- ICTs and multimedia;
- energy;
- aerospace;
- nanotechnology;
- photonics;
- pharmaceuticals.

In addition, Malaysia has announced plans to engage in roadmapping-type exercises in key industrial sectors.

Future trends and challenges for Malaysia

Over the past decade, there has been a clear shift towards demand-driven R&D. However, a shortage of skills is likely to hamper development efforts. In spite of considerable growth in human resources in S&T overall, there is some evidence of a net loss of scientific personnel across many fields, with the notable exception of agricultural science and chemistry.

Another major challenge for Malaysian S&T will be to maintain and nurture growth in public sector investment in basic science through the current period of global economic downturn.

The Philippines

S&T and economic status

The Philippines has struggled to maintain and develop its science system since the Asian financial crisis. For many indicators, it has barely kept pace with regional S&T development. GERD as a proportion of GDP has actually fallen, as has GERD per capita. Only Indonesia and Cambodia record lower GERD/GDP ratios (Table 1). With the second-largest population in the region, the economy ranks 56th in terms of merchandise exports. GDP per capita amounted to US$ 1 856 in 2009. Manufactured goods comprised 83% of merchandise exports in 2008 but this was largely because of the dominance of foreign firms operating in the economy. The activity of many of these is concentrated in electronics manufacturing and assembly. The *National Science and Technology Plan, 2002–2020* describes the economy as 'sluggish or slow moving with uncontrolled urbanisation'.

Although the business sector share of GERD is high, this is misleading. As in Malaysia, it is due to a high level of foreign manufacturing. A clear challenge for S&T policy will be to seek ways to leverage technological capacity into local firms and into sectors other than the assembly of electrical components.

Structural arrangements, priorities and policies

The Department of Science and Technology is the key agency in the Philippines, with policy development co-ordinated by a series of sectoral councils. The *National Science and Technology Plan, 2002–2020* sets out the short- and long-term strategy for deriving greater benefits from investment in science. Strategic emphasis is placed on raising GERD to 2% of GDP by 2020 and doubling the share of business R&D investment. Strategic emphasis is also placed on promoting technology transfer, improving human development indices, promoting S&T advocacy and expanding science networks.

The Philippines is also seeking to identify key areas for innovation-led growth. Biotechnology and ICTs get a particular mention. There is an expectation that, by 2020, the economy will have developed a wide range of globally competitive products with high-tech content. Strategies for achieving these goals included clustering – an approach successfully adopted by Singapore *(see overleaf)* – and targeting human resource development in S&T. The *Plan* targets small and medium-sized enterprises as loci for stimulating local S&T spill-overs. The Philippines has also been pursuing a strategy for communicating science to the broader population through various media-based strategies. This vision for the future foreshadows the Philippines as carving out niches in selected S&T areas that could be described as world-class. Specific longer-term sectoral priorities defined in the 2002–2020 plan are farther-ranging and broader than, for example, in Singapore.

They include:
- agriculture and forestry;
- health and medicine;
- biotechnology;
- ICTs;
- micro-electronics;
- materials science;
- the environment;
- natural disaster mitigation;
- energy;
- manufacturing and process engineering.

Future trends and challenges for the Philippines
High-tech manufacturing exports are tied to a small number of very large multinational corporations. A key challenge will be to maintain the broad range of desired priorities within the financial constraints presented by the global recession.

Many ambitious targets are set out in the national plan for 2002–2020. Although these targets are very clear, the institutional and economic capacity to deliver them has not been forthcoming. In particular, the goal to raise the Philippines' global ranking in key areas is challenged by the high achievements of many other countries in the Asian region. For example, the Philippines has actually fallen 16 places on the World Knowledge Economy Index, from 65th to 89th position. Although still ranking above Indonesia, the economy is well behind those of Malaysia and Thailand.

Singapore
S&T and economic status
Singapore is one of the smaller countries in the region with a population only slightly larger than that of New Zealand. Despite its small geographical size and population, it has demonstrated considerable success in developing a globally competitive science system. In 2008, Singapore's economy recorded GDP per capita of US$ 39 423, the second-highest of the countries covered in the present chapter after Australia. It ranks 14th in terms of world merchandise export value. According to the World Bank, Singapore is one of only two countries in the region (Viet Nam being the other) that improved their world ranking in the Knowledge Index between 1995 and 2008. Singapore outranked all countries covered in the present chapter for the related variables of 'economic incentive regime, ICTs' and 'innovation'. The country's growth in publications may not have not been as dramatic as some of the countries starting from a smaller base but, significantly, growth has been strongly driven by Singapore-based scientists.

Structural arrangements, priorities and policies
Singapore's five-year *National Science and Technology Plan* published in 2000 noted the need to increase the number and quality of human resources in S&T substantially. The Plan for 2005–2010 reinforced this strategy, emphasizing the need to build on three areas to achieve 'translational competency': nurturing local talent; recruiting global talent and working with industry to promote technology development and transfer (MTIS, 2006). Co-ordination for implementing the plan is divided between the Agency for Science, Technology and Research (A*STAR) for public sector activities and the Economic Development Board for private sector activities. Throughout the decade, Singapore has remained focused on recruiting key world-renowned scientists, offering them globally competitive salaries and conditions. The success of this recruitment campaign is reflected in a considerable level of growth (nearly 50%) in the number of researchers per million in the total population between 2000 and 2007.

Although the global recession has led to a tighter focus on the development of S&T, growth since 2000 has been remarkable. The national approach has been to cluster key research agencies geographically to provide a national knowledge hub with ties to institutes abroad that are world-renowned for scientific endeavour in two key areas: ICTs and biomedical research. To achieve this, the Science and Engineering Council has drawn together seven research institutions concerned with ICT to create *Fusionopolis* and the Biomedical Research Council has created a cluster of five key biomedical research institutes to form *Biopolis*. These two clusters are at the heart of Singapore's drive to create global centres of excellence in these two niche areas.

The Singaporean approach is very much policy-driven. For example, ministerial-level steering committees have been established to drive development in key areas, including environment and water technologies, and interactive digital media. While the general approach is to build close links between public-funded science and business, there is still a strong focus on basic research.

Future trends and challenges for Singapore
The government fixed a target in 2006 of achieving a GERD/GDP ratio of 3% by 2010. A challenge for Singapore will be to consolidate the significant scientific growth that has occurred throughout the decade and maintain the

comparatively high levels of investment in the wake of the global recession. The business sector was a major contributor to GERD even before the turn of the century and has increased its share over the past decade. Maintaining the momentum in the wake of the global recession will thus remain a challenge for the next few years.

Singapore has been highly successful in attracting foreign scientists and technicians to its well-funded laboratories and institutions. Another key challenge will be maintain this level of human capital and further develop the country's training system to meet technical demands in the longer term.

Thailand

S&T and economic status

Thailand ranks 26th in terms of world merchandise exports and, like Malaysia and the Philippines, these exports are dominated by manufactured exports. GDP per capita in 2008 came to US$ 4 187. The GERD/GDP ratio for Thailand is low and actually fell marginally from 0.26% in 2001 to 0.25% in 2007. On the World Bank's Knowledge Economy Index, Thailand ranks 63rd, well behind Malaysia and Singapore but well ahead of Viet Nam.

Objectives in three key areas have been identified for national development and improving overall economic performance. The first goal is to increase the total number of firms undertaking innovation. The second is to improve management skills and the third is to raise the country's competitiveness in S&T against international benchmarks.

The targets for development cover three main sectors:

- ***the industrial sector,*** comprising industries selected by the government and those possessing future potential, including the food, automotive, software, microchip and textile industies, tourism, health-related services and the bio-industry;
- ***the community economy,*** focusing on quality upgrades of the One-Village-One-Product programme . This programme has now been in place for two decades. It is directed towards improving communities' access to finance and management skills;
- ***the social sector***, covering environmental development, support for children and the underprivileged and so forth. An additional focus after the present Abisit Goverment came to power in 2009 was to make Thailand a 'creative economy' based on the creativity, talent and unique culture of the Thai people.

The main strength of the Thai system can be found in private firms. More intense competition in the global market and the Asian financial crisis of 1997 have, to some degree, led to a behaviour change among Thai firms. After the 1997 crisis, they abandoned their long-standing attitude of relying on off-the-shelf foreign technologies in favour of developing in-house R&D capabilities. Several large conglomerates recently expanded their R&D activities and a number of smaller companies have begun collaborating with university R&D groups to develop technology. Another new phenomenon is that multinational corporations are now engaging in more technologically sophisticated activities than before, such as product design. In the automotive industry, for example, several Japanese car-makers, such as Toyota, Honda, Isuzu and Nissan, have set up technical centres in Thailand. Toyota's technical centre employs 600 R&D engineers.

Structural arrangements, priorities and policies

The main objectives of the current *National Science and Technology Strategic Plan* (2004–2013) are to enhance Thailand's capability to adapt to rapid change in the globalization era and strengthen the country's long-term competitiveness. The vision statement in the *Plan* is consistent with the government's development goals of sustainable competitiveness, a strong community economy, a knowledge society, healthy environment and better quality of life. The *Plan* emphasizes four fundamental development factors for achieving these goals: a strong national innovation system, robust human resources, an enabling environment for development and capacity in four core future technologies: ICTs, biotechnology, materials science and nanotechnology.

The cluster concept has been the main policy for industrial collaboration at the local, national and regional levels ever since the Thaksin Government (2001–2006) and remains so. The government declared five strategic clusters for Thailand to pursue: automotive industry, food industry, tourism, fashion and software. These are not conceived simply as geographical clusters but rather as virtual clusters with innovation links that can be supported through policy. Visions for these five clusters have been defined as: Kitchen of the World (food cluster), Detroit of Asia (automotive cluster), Asia Tropical Fashion (fashion cluster) , World Graphic Design and Animation Centre (software cluster), and Asia Tourism Capital. At the regional level, Thailand has been divided into 19 geographical areas. Each area has had to plan and implement its own cluster strategy, focusing on a few strategic products or services. Each has been supervised by the so-called Chief Executive Officer (CEO) Governors, who have been given authority by the central government to act like provincial CEOs. The cluster concept has also been applied at the local level to build the capacity of the grassroot economy in the name of 'community-based clusters', especially to help the One-Village-One Product programme succeed.

An 'innovative nation with wisdom and a learning base' was one of Thailand's Dreams projected by the Thaksin Government within attempts to make this dream (one of seven) come true, several strategies were devised. These include: continual investment in R&D, an environment conducive to attracting and stimulating innovation, high accessibility to knowledge and information across the nation, fluent English as a second language, possessing a stronglearning basis, such as a passion for reading and greater access to cheap but good books (Phasukavanich, 2003). The issue of 'competitiveness' has also been made a high priority, as illustrated by the establishment of a National Competitiveness Committee in 2003 chaired by the prime minister.

The ten-year *Science and Technology Action Plan (2004–2013)* placed the concepts of a national innovation system and industrial clusters at its heart by highlighting concrete measures to stimulate their development. This plan marks the country's 'official' transition from an S&T policy to an STI policy. However, to date, neither the *National Science and Technology Strategic Plan* nor the Basic Law on Science, Technology and Innovation has adopted, in practice, the innovation system approach as the main policy content (Intarakumnerd, 2006).

Future trends and challenges for Thailand

Several key weaknesses in the Thai policy-making process have been identified by local analysts. These include: ineffective supra-ministerial cross-cutting policy processes and a lack of inter-ministerial co-ordinating mechanisms; an imbalance in the STI policy-making process between the key science ministry, the Ministry of Science and Technology (MoST), and other ministries with an economic mission; and the limited participation of the private sector in the policy-making process.

In Thailand, there is no structured mechanism for co-ordination between ministries. The national plan for 2004–2013 creates the position of Chief Science Officer in every relevant ministry to co-ordinate S&T activities and interact with the National Competitiveness Committee. However, these posts still exist only on paper today. MoST plays a more central role in STI policy planning and implementation than economic agencies like the Ministry of Industry. This imbalance contrasts with the situation in Chinese Taipei, the Republic of Korea and Japan, where economic agencies like the Japanese Ministry of International Trade and Industry, the Korean Economic Planning Board (EPB) and the Taiwanese Ministry of Economic Affairs play significant roles in this area.

A further challenge is to overcome inconsistencies in the amount of resources allocated to different strategies for S&T development. For example, initiatives directed towards enhancing S&T training capacity in the private sector are dwarfed by the level of resources directed towards new initiatives in the public research sector. Systemic failures also need to be overcome, such as by providing grants where they are needed or direct subsidies, as in the East Asian newly industrialized economies, to help private firms develop their technological capabilities.

Timor Leste

Timor Leste has the smallest population and economy of all the countries discussed in the present chapter, with the exception of some of the Pacific Island nations. It has been defined as the poorest Asian nation. The country is still in the early stages of recovery from socio-political turmoil since gaining independence in 1999. Few data are available on economic development and even fewer on S&T. However, it is known that FDI accounts for over 40% of GDP, an indicator of the economy's high level of dependence on international funding. Unemployment is estimated to be around 70%. Over 80% of the population is dependent on agriculture, forestry or fisheries. Consequently, environmental issues are of prime concern.

There is no designated agency with overall responsibility for S&T but the Ministry of Education is the biggest source of funding. After the turmoil of the late 1990s, the country's only university, the Universidade Nacional de Timor-Leste, re-opened in 2000. There are currently five faculties that reflect the country's development needs: agriculture, political science, economics, education and engineering.

The National Research Centre and the Institute of Linguistics opened in July 2001 to support the work of the faculties. Longer-term planning foreshadows the development of tertiary studies in health, law, communications, accounting, fisheries, architecture, physics and chemistry.

Broader institutional development for S&T is only now just under way, with US$ 500 000 having been allocated in 2009 towards the establishment and maintenance of national laboratories. National parks have recently been established, including some marine parks. Their development will rely on international knowledge-based linkages.

According to the president, the economy is faring well, with more than 10% real growth at the end of 2008, in spite of the global recession. Nevertheless, it will be a big challenge to overcome the lack of educated or skilled personnel. Weak public institutions and inadequate infrastructure compound these difficulties. Significant oil reserves offer a glimmer of hope for future economic development but the technical resources required to manage these in order to obtain maximum benefit remain, as with Cambodia, a major challenge for the country's nascent technical capacity.

Viet Nam

S&T and economic status

The Vietnamese economy has been undergoing considerable restructuring and transformation. This has carried through into the area of STI. Viet Nam is one of the few countries covered in the present chapter that has been gaining ground in the World Bank Knowledge for Development index; it currently ranks 51st on the world merchandise trade index. However, GDP per capita of US$ 1 041 reflects the considerable disparities in income across the country. Investment in S&T in Viet Nam remains low, at just US$ 5 per capita in 2007, compared to US$ 20 for China in 2004 and US $1 000 in the Republic of Korea in 2007.

S&T policies in Viet Nam have been described as comprising two distinct types: explicit and implicit. Explicit policies emerged in 1987 with the government's decision to remove the state monopoly on S&T. This was followed by decrees on foreign technology transfer (1988), organizational and individual rights to enter into contracts or to co-operate in S&T (1992) and on external grants in support of S&T (1994). A foreign investment law was adopted in 1995 that governs S&T activities in economic projects.

To cope with the demands of fulfilling the requirements for joining WTO, Viet Nam has enacted the Intellectual Property Law (2005) and Technology Transfer Law (2006). The aim of these two laws is to protect the rights and responsibilities of people and organizations who own intellectual property or invest in technology transfer, according to international standards. Further decrees and resolutions have been issued by the government give greater autonomy to R&D organizations and provide firms with financial incentives. These measures are a radical departure from the situation prevailing just a decade ago when all S&T activity fell under the exclusive jurisdiction of the state.

Tangible achievements of R&D in recent years include Vietnamese script identification and processing software, kits for virus-related disease testing, the construction of a 53 000 tonne ship, the first satellite Vinasat and advancements in agriculture. In December 2009, these success stories and others were celebrated by a gathering of nearly 500 representatives of S&T organizations.

Structural arrangements, priorities and policies

As in Thailand, Vietnamese policies are evolving from S&T policy to STI policy. A growing number of features of the national innovation system concept have been incorporated into the policy-making process. Six important STI policy areas were identified by the prime minister in September 2004:

- improve the process of formulating the R&D projects funded by state budget;
- reform the state management on public R&D institutions;
- reform S&T financing;
- reform human resource management in S&T;
- develop technological markets;
- improve the state management of S&T.

At this stage, these have been defined as general areas for future policy action. As yet, there is little evidence as to how these areas might be addressed across different agencies. Nevertheless, they do suggest a shift towards a more systemic, networked approach to STI.

Those national institutes for research which do not come directly under an individual government ministry or agency were designed in Viet Nam to act as national networks of S&T and placed under the Office of the Prime Minister. They are not instruments for implementing policies laid down by ministries but rather focus on R&D. The most influential of these institutes is the National Centre of Natural Science and Technology, which performs advanced basic research primarily in mathematics and theoretical physics. This particularity of Viet Nam finds a parallel in the Advanced Institute of Science and Technology under the Ministry of Economy, Trade and Industry in Japan and the Industrial Technology Research Institute under the Ministry of Economic Affairs in Chinese Taipei.

Innovation has emerged centre stage in many initiatives. For example, there was a national forum on innovation strategy in 2006. The Ministry of Science and Technology is also trying to establish collaboration with global players like IBM to promote innovation. Firms, as the centre of innovation, are obtaining a more crucial role in the learning process.

A new actor has also emerged in the national innovation system, namely, quasi-governmental, quasi-private organizations. These provide mainly technical, information gathering and technology consulting services. They throw bridges between universities, government research and technology organizations and firms. This type of organization has been permitted since the early 1990s as a result of economic reform policy. Scientists and researchers who were formerly, or are currently, employed at government institutes or universities have established many of these organizations. It is estimated that over 500 such organizations, often called 'centres', are in operation (Sinh, 2009).

Future trends and challenges for Viet Nam

Industry collaboration policy is a major area of weakness in Viet Nam, with some notable exceptions like Nong Lam University. Its administration and research centres contribute strongly to the agriculture sector: designing efficient agriculture machines and providing technical assistances to farmers. Weak linkages between government research institutes and private firms have been acknowledged by the government. However, research institutes were recently allowed to set up their own companies. This is an attempt to reduce the dichotomy between production (done by firms) and technology development activities (done by research institutes).

Another future challenge for the government is the fact that the major source of investment in S&T is the state budget. Trying to build linkages between universities, public research institutes and private firms entirely via state investment presents a real difficulty. Increasing the level of private investment in S&T will not be easy, particularly in the years following the global recession when all other countries in the region will be seeking to create incentives to attract much-needed private investment.

COUNTRY PROFILES: The Pacific Island states

Science and R&D in the Pacific

The Pacific Island states are diverse, yet each is in many ways unique. Although science is a comparatively low priority among policy-makers, there is an emerging regional presence in S&T. This is largely due to the common concerns confronting many of the smaller low-lying Pacific nations, such as sea-level rise, saltwater intrusion and the growing frequency of destructive storms. Regional organizations increasingly play an important role in providing member countries with specialized expertise and assistance in conducting research in priority areas that they would otherwise be unable to afford. A number of regional bodies are involved in conducting R&D studies on environmental and economic issues, renewable energy, health care and social and cultural issues facing the region. Many of these are based in Fiji. Organizations include the Asia Pacific Regional Environment Network (APRENET), the University of the South Pacific (USP), the Secretariat of the Pacific Community (SPC) with its head office in New Caledonia, the Pacific Islands Forum Secretariat (PIFS), Pacific Island Geosciences; the Pacific Island Association of Non-Governmental Organisations (PIANGO), the Ecumenical Centre for Research, Education and Advocacy (ECREA), the International Council for the Study of the Pacific Islands (ICSPI) and the Pacific Operations Centre (EPOC) of the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP).

These regional institutions and initiatives have been successful in generating high-quality information on research. Among these, the Secretariat of the Pacific

Box 1: The Secretariat of the Pacific Community

The Secretariat of the Pacific Community (SPC) was the first regional organization in the Pacific. It was established in 1947 as the South Pacific Commission. The SPC now acts as an international body. It delivers priority work programmes to member countries and territories to develop professional, scientific, technical, research and management capacity with a focus on:

- land resources, including forestry and agriculture;
- marine resources, including coastal and oceanic fisheries, as well as related broader environmental issues;
- social resources, with a focus on women, youth and culture.

Most SPC programmes are funded by the EU, the Australian Centre for International Agricultural Research (ACIAR), AUSAID, NZAID, the German Co-operation Agency (GTZ) and Chinese Taipei.

The Pacific Agricultural Plant Genetic Resources Network (PAPGREN) was set up in 2004, in order to ensure the survival of Pacific food crops by maintaining a diversity of plant stocks. It has been one of the key achievements of the SPC programmes. Financial support for PAPGREN is provided by ACIAR and NZAID. The 'seeds' of PAPGREN were sown in 1998 when the SPC created a regional genebank that is now known as the Centre for Pacific Crops and Trees (CePaCT).

The Pacific Regional Information SysteM (PRISM) is the brainchild of the region's National Statistical Offices (NSOs). It was adopted by the SPC in 2002 with support from the UK Department for International Development. The aim is to give National Statistical Offices the tools and skills necessary to develop, publish and maintain statistical indicators, summaries, reports and so on for the region. As of 2010, no data were yet available on R&D in the region.

The four founding members of the SPC remain members: Australia, France, New Zealand and the USA. For a complete list of the 22 Pacific Island states and territories which are members, see Annex I.

Source: authors

Community (SPC) plays a key role in developing S&T competencies in the region (Box 1).

The past few years have seen an improvement in R&D capacity in the higher education sector in particular, in the midst of continuing high turnover in S&T personnel. Much of the credit for the emergence of a vibrant, if fledgling research culture can go to institutions like the USP and the Fiji School of Medicine, founded in 1979, as well as other more recent institutions like the University of Fiji (UoF) and the Fiji National University (FNU).

Established in 2006, UoF has lost no time in laying the groundwork for research on matters of national interest. It has already established two centres: the Centre for Energy, Environment and Sustainable Development and the Centre for Indigenous Studies. In 2010, it was planning to promote a rural electrification programme using photovoltaic battery systems which it plans to adapt with the assistance of the Tata Energy Research Institute in New Delhi, India (personal submission).

Of even more recent vintage is the FNU[3], dating from January 2010. The FNU has yet to articulate its strategic approach to serving national priorities using its own S&T capabilities.

The oldest university in the region, the USP[4] focuses heavily on the concerns of the Pacific Islands. The university concentrates research on sustainable development in the broad sense of the word, as R&D covers environmental economics, S&T and social and cultural issues. Capitalizing on current scholarship programmes with Australia, New Zealand, Chinese Taipei and France, the university plans to enhance international and regional research partnerships, according to the *USP Strategic Plan 2010–2012*.

3. The FNU was formed by bringing six existing organizations under one umbrella: Fiji College of Agriculture, Fiji Institute of Advanced Education, Fiji School of Medicine, Fiji School of Nursing, Fiji Teacher Training School and Fiji Institute of Technology.

4. The main campus of the USP is in Suva, Fiji. Founded in 1968, the university is supported by 12 Pacific Island countries: Cook Islands, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu and Vanuatu.

Intergovernmental organizations such as the United Nations Development Programme (UNDP) and the United Nations International Children's Emergency Fund (UNICEF) also play an important role by way of targeted research and project assistance with soft technologies in their respective areas of expertise. Private-sector industrial R&D in the region is almost non-existent, as firms' technological requirements can be adequately satisfied through technology transfer from beyond the region. The government established the Papua New Guinea Research, Science and Technology Council in 2008 to embark upon research and innovation, and to pave the way for industrialization in the light of major development projects in mining, oil and gas.

There is only limited information available for some Pacific Island states on priority areas for science. In the section that follows, these countries are therefore discussed as a group rather than individually.

Trends and challenges in the Pacific Islands

Food and energy security

The region is heavily dependent on imported foodstuffs. This is due to a decline in per capita food production and an imbalance in demand for local foodstuffs within island nations[5]. In line with this observation, the *Pacific Islands Forum Action Plan 2009* emphasized the need to sustain momentum to ensure better food and energy security, maximize the sustainable economic returns for fisheries and design an appropriate disaster-risk management programme to minimize any adverse impact of natural disasters on agriculture.

ICTs

Pacific Island countries are experiencing a wave of liberalization and development of their telecommunications markets. At present, integration of ICTs into development efforts is not uniform across the region. Papua New Guinea has a relatively advanced telecom network but teledensity and mobile and Internet penetration remain extremely low, at less than 2%. Fiji also has a fairly reliable and efficient telecom system but low Internet penetration (12% in 2008).

The Pacific ICT Ministerial Forum held in February 2009 agreed to a set of priorities and actions to spur ICT development in the Pacific. Among the agreed priorities were: regional connectivity initiatives, the building of human capacity, shared regulatory resources and the use of ICTs for early warning and response systems. The Pacific Region Headquarters of the US National Oceanic and Atmospheric Administration (NOAA), situated in Honolulu, serves as the key source of early warning bulletins for natural disasters. Regional connectivity needs improving rapidly, however, and staff will need advanced training if the response system is to be effective.

Climate change

Climate change is a great challenge for Pacific Island states. It threatens not only livelihoods and living standards but the very viability of communities. Although Pacific Island states play a small role in causing climate change, the impact on them is great. Many Pacific Islands face new challenges like ensuring access to freshwater in the wake of contamination of groundwater with seawater as a result of sea-level rise and the greater frequency of violent storms. These phenomena place the security and health of communities in greater jeopardy than before. Some habitats and island states even face obliteration, such as Tuvalu, which lies on average just 1.5 m above sea level.

For the SPC, scientific research is required to model the future impact of climate change on agriculture and forestry in particular and devise means of adaptation, in order to maintain these sectors. In this regard, the *Tsukuba Declaration* outlines a strategy for adapting agriculture to climate change in the Pacific (Tsukuba, 2008). It advocates the development of 'climate ready'[6] collections of crop varieties, for example, at the region's Centre for Pacific Crops and Trees (Box 1).

Education

Policies for developing better education systems are a priority in the region. With the technology boom in Asia–Pacific, the need to integrate modern technology into classroom instruction is on everyone's lips. The following measures have been proposed to achieve 21st century competencies and skills in Asia–Pacific. All are of high relevance to the Pacific Islands: evidence-based learning approaches, cognitive research, enhancement of the professional development of science teachers, inclusion, and usage of modern ICT facilities so that

5. This phenomenon has also been observed in the Caribbean, see page 133.

6. Crop varieties able to tolerate more extreme drought, heat-stress and saline conditions in future

schools can access Internet for classroom activities. Taking this point a step further, Papua New Guinea's *National Higher Education Plan 2030* (forthcoming) aims to make research and S&T the fundamental priority of the higher education sector, as these twin engines will drive the *National Vision 2050*.

Health

A better delivery of health services is considered a high priority in the region, in order to minimize child mortality, maternal mortality and obesity, and tackle HIV/AIDS issues. Obesity seems to be a key health problem among Pacific Islanders, consuming a very large proportion of the health budget. As the key health research school in the region, the Fiji School of Medicine has taken it upon itself to establish the Pacific STI & HIV Research Centre[7] and the Centre for Health Information, Policy and Systems, launched in 2009 and 2010 respectively.

Towards an S&T policy for the Pacific

The features common to Pacific Islands suggest that there may well be some advantage in promoting science policy at the regional level. Such an approach would serve to foster collaboration across the region. In an attempt to ascertain whether it would be feasible to draw up a regional policy on S&T, the Australian National University and UNESCO collaborated with SPC on a review of existing literature on formal science policy in the Pacific Islands covering agriculture, health, environment and education. The review noted the advantages of having a science policy at a regional level, at least for environmental and biosecurity matters (Perera and Lamberts, 2006). The review stressed that, in order to develop S&T that is appropriate and applicable to the socio-economic climate of the Pacific, provisions would need to be made for wide consultations with governments and other key stakeholders in the region, in order to obtain a clear indication of the perceived needs and interests of each Pacific Island nation. In this regard, the absence of basic statistics on S&T needs to be rectified to make the Pacific Islands more visible in global science. These two issues — the consultation process and the generation of statistics in the region — become fundamental requirements for moving towards an S&T policy for the region.

7. STI is the acronym for sexually transmitted infections.

CONCLUSION

The country reviews presented in the present chapter reflect considerable economic, industrial and social diversity across Southeast Asia and Oceania. The region is home to some of the world's wealthiest industrially developed economies and some of the world's poorest. The status of science in terms of capacity, priorities and output consequently varies accordingly. Behind these structural differences, there are some common features in terms of the way in which science is progressing.

Firstly, sustained growth over the past decade in both the Chinese and Indian economies has been dramatic and is already having a marked impact on regional S&T capacity. Although this manifests itself in different ways, the influence of the Indian and Chinese growth affects almost all countries. For example, the commodities boom through the 2000s, driven to a large extent by India and China, has led to considerable rise in mining-related R&D in Australia and a consequent growth in business-sector R&D investment. The growth in scientific publications from India and China has also had the effect of limiting comparative gain for all countries in terms of their contribution to global output in scientific publications. Furthermore, in co-authored publications from the region, China and India are already among the top three co-authoring countries for five of the countries covered here.

Secondly, in most countries, science policy has become integrated with innovation policies. This has been a global trend, as countries seek to use science to drive economic competitiveness and, among the less developed countries, development. A challenge for the future will be to ensure that innovation policy is not the sole driver of science policy and that the national science base can remain sufficiently comprehensive to enable global scientific collaboration to continue.

Thirdly, with the move from S&T to STI, there has been a growing focus on policies to promote and manage cross-sector R&D. Across the region, a range of strategies for achieving this purpose is evident. Many countries have introduced collaborative project-funding schemes. Others have introduced major initiatives like the Australian Cooperative Research Centres programme. This program has been in place in Australia since 1991 and has served as a model for similar policy initiatives in other countries (e.g. Thailand). Singapore has approached the issue by making large, strategic investments to establish cross-sector clusters like Biopolis. All countries that have introduced such programmes have tied them in one way or another to broad national strategic priorities.

There is also evidence of new knowledge hubs emerging in some fields linked to those already anchored in North America and Western Europe and, in some ways, moving beyond these hubs in the Northern Hemisphere. There is evidence, for example, that Singapore is an emerging hub for biomedical and engineering technologies, both in the region and globally.

Another common thread running through the region is the growing attention being paid to climate change and sustainable development. The role of science in improving understanding of issues associated with climate change and in mitigating or adapting to the impact of climate change are reflected in the national plans of most countries in Southeast Asia and Oceania. In many cases, these issues are embedded in general priority statements, even if the specifics of tackling the challenge are left to public research institutes. One example is the Thai Biotechnology Center under the National Science and Technology Development Agency. It has been conducting research over the past five years on biogas from casava, corn, sugar cane and pig's waste. However, except for some pilot projects, most are still in the early stages of research and thus a long way from attracting markets or becoming a future source of energy.

In Fiji and elsewhere, foreign donor funds are being directed towards sustainable agriculture and forestry. In the Philippines, priorities for sustainable agriculture are strategically linked to regional science networks like ACIAR. In other countries, there are localised responses. In Indonesia for example, national priorities for renewable energy focus on geothermal production and bioethanol, among others. Australia has identified 'environmentally sustainable Australia' as a research priority. Furthermore, Australia's Commonwealth Scientific and Industrial Research Organisation has a programme called Flagship for Energy Transformed which focuses on developing clean, affordable energy and transport technologies for a sustainable future. The environment is also a key feature in the country's Sustainable Agriculture programme, which addresses productivity and food security 'in a carbon constrained world'. In Australia, however, the main driver of alternative energy R&D are incentives like the introduction of levies to support household production of solar electricity for regional grid systems. In many parts of the country, householders who have installed solar energy collectors and inverters are paid a kilowatt hour rate for production at more than twice the scheduled peak purchase rate for electricity delivered through the grid. Singapore's Thematic Strategic Research Programme noted that its 2005 five-year plan includes Carbon Capture and Utilization and Sustainable Materials which are directed towards key environmental issues but with a market focus.

In sum, the scientific response to climate change and the quest for alternative energy sources in the region is being driven by market demand, on the one hand, and public debates and expectations, on the other hand, coupled with local natural advantage. Even among those countries with defined 'green' research priorities, the level of investment is driven by a combination of scientific quality and market demand. The critical issue for most countries will be to ensure they have a sufficient scientific base to serve these consumer demands as they emerge.

Lastly, one of the clear trends across the region is the greater level of international engagement and co-operation. This is evident in the growing co-publication rates but also in the trend which sees researchers spending time abroad as part of their training and on-going collaboration throughout their careers. This is a promising trend for many of the smaller countries because only through international scientific engagement will many local problems be resolved. Only time will tell whether such an engagement will serve the interests of the smaller economies or simply those more deeply embedded in the core of global scientific networks.

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Australian Science Portal : http://www.science.gov.au/

Ministry of Higher Education of Papua New Guinea: www.ohe.gov.pg

New Zealand Science Portal: http://sciencenewzealand.org/

Pacific Islands Forum Secretariat: www.forumsec.org

Pacific Institute of Public Policy: www.pacificpolicy.org

Samoa Science, Research Organization: www.sros.org.ws

Secretariat of the Pacific Community: www.spc.int/

University of New Caledonia: www.univ-nc.nc

University of South Pacific: www.usp.ac.fj

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In 2008, Dr Amaradasa served on the Expert Committee mandated by the National Science and Technology Commission to prepare a Draft National Science and Technology Policy for Sri Lanka. In 2007–2008, he acted as convenor for the National Science Foundation of the Draft National Policy on University, Industry and Institute Partnerships in Research.

The Tax Office buildings in Port-au-Prince after the earthquake that hit Haiti on 12 January 2010

Photo:
Fernando Brugman/*UNESCO*

While actively concerned with the immediate post-disaster needs of recently affected populations in Haiti and Pakistan, UNESCO is engaged in efforts to enhance the scientific and technical capacities of competent institutions in these countries to cope with the risk of similar occurrences in the future.

Extract from the message from
Irina Bokova, Director-General of UNESCO, on the occasion of the International Day for Disaster Reduction, 13 October 2010

Annexes

Annex I: Composition of regions and sub-regions

Groupings mentioned in Chapter 1

DEVELOPED COUNTRIES	North America; Europe; Japan; Australia and New Zealand
DEVELOPING COUNTRIES	Africa; Latin America and the Caribbean; Asia excluding Japan; Oceania excluding Australia and New Zealand
LEAST DEVELOPED COUNTRIES	Afghanistan; Angola; Bangladesh; Benin; Bhutan; Burkina Faso; Burundi; Cambodia; Cape Verde; Central African Republic; Chad; Comoros; Democratic Republic of the Congo; Djibouti; Equatorial Guinea; Eritrea; Ethiopia; Gambia; Guinea; Guinea-Bissau; Haiti; Kiribati; Lao People's Democratic Republic; Lesotho; Liberia; Madagascar; Malawi; Maldives; Mali; Mauritania; Mozambique; Myanmar; Nepal; Niger; Rwanda; Samoa; São Tome and Principe; Senegal; Sierra Leone; Solomon Islands; Somalia; Sudan; Timor-Leste; Togo; Tuvalu; Uganda; United Republic of Tanzania; Vanuatu; Yemen; Zambia
AMERICAS	Anguilla; Antigua and Barbuda; Argentina; Aruba; Bahamas; Barbados; Belize; Bermuda; Bolivia; Brazil; British Virgin Islands; Canada; Cayman Islands; Chile; Colombia; Costa Rica; Cuba; Dominica; Dominican Republic; Ecuador; El Salvador; Falkland Islands (Malvinas); French Guiana; Grenada; Guadeloupe; Guatemala; Guyana; Haiti; Honduras; Jamaica; Martinique; Mexico; Montserrat; Netherlands Antilles; Nicaragua; Panama; Paraguay; Peru; Saint Kitts and Nevis; Saint Lucia; Saint Pierre and Miquelon; Saint Vincent and the Grenadines; Suriname; Trinidad and Tobago; Turks and Caicos Islands; United States of America; United States Virgin Islands; Uruguay; Venezuela **North America** Canada; United States of America **Latin America and the Caribbean** America excluding Canada and the United States of America
EUROPE	Åland Islands; Albania; Andorra; Austria; Belarus; Belgium; Bosnia and Herzegovina; Bulgaria; Channel Islands; Croatia; Cyprus; Czech Republic; Denmark; Estonia; Faeroe Islands; Finland; France; Germany; Gibraltar; Greece; Greenland; Guernsey; Holy See; Hungary; Iceland; Ireland; Isle of Man; Italy; ; Jersey; Latvia; Liechtenstein; Lithuania; Luxembourg; Malta; Monaco; Montenegro; Netherlands; Norway; Poland; Portugal; Republic of Moldova; Romania; Russian Federation; San Marino; Serbia; Slovakia; Slovenia; Spain; Svalbard and Jan Mayen Islands; Sweden; Switzerland; The former Yugoslav Republic of Macedonia; Turkey; Ukraine; United Kingdom of Great Britain and Northern Ireland **European Union** Austria; Belgium; Bulgaria; Cyprus; Czech Republic; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Luxembourg; Malta;

Netherlands; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Sweden; United Kingdom of Great Britain and Northern Ireland

Commonwealth of Independent States in Europe
Belarus; Republic of Moldova; Russian Federation; Ukraine

Central, Eastern and Other Europe
Europe excluding European Union and Commonwealth of Independent States in Europe

AFRICA

Algeria; Angola; Benin; Botswana; Burkina Faso; Burundi; Cameroon; Cape Verde; Central African Republic; Chad; Comoros; Congo; Côte d'Ivoire; Democratic Republic of the Congo; Djibouti; Egypt; Equatorial Guinea; Eritrea; Ethiopia; Gabon; Gambia; Ghana; Guinea; Guinea-Bissau; Kenya; Lesotho; Liberia; Libyan Arab Jamahiriya; Madagascar; Malawi; Mali; Mauritania; Mauritius; Mayotte; Morocco; Mozambique; Namibia; Niger; Nigeria; Rwanda; Saint Helena; São Tome and Principe; Senegal; Seychelles; Sierra Leone; Somalia; South Africa; Sudan; Swaziland; Togo; Tunisia; Uganda; United Republic of Tanzania; Zambia; Zimbabwe

Sub-Saharan countries in Africa
Africa excluding African Arab states

Arab States in Africa
Algeria; Djibouti; Egypt; Libyan Arab Jamahiriya; Mauritania; Morocco; Sudan; Tunisia

ASIA

Afghanistan; Armenia; Azerbaijan; Bahrain; Bangladesh; Bhutan; Brunei Darussalam; Cambodia; China; Democratic People's Republic of Korea; Georgia; Hong Kong Special Administrative Region of China; India; Indonesia; Iran; Iraq; Israel; Japan; Jordan; Kazakhstan; Kuwait; Kyrgyzstan; Lao People's Democratic Republic; Lebanon; Macao; China; Malaysia; Maldives; Mongolia; Myanmar; Nepal; Oman; Pakistan; Palestinian Autonomous Territories; Philippines; Qatar; Republic of Korea; Saudi Arabia; Singapore; Sri Lanka; Syrian Arab Republic; Tajikistan; Thailand; Timor-Leste; Turkmenistan; United Arab Emirates; Uzbekistan; Viet Nam; Yemen

Commonwealth of Independent States in Asia
Armenia; Azerbaijan; Kazakhstan; Kyrgyzstan; Tajikistan; Turkmenistan; Uzbekistan

Newly Industrialized Economies in Asia
Hong Kong Special Administrative Region of China; Indonesia; Malaysia; Philippines; Republic of Korea; Singapore

Arab States in Asia
Bahrain; Iraq; Jordan; Kuwait; Lebanon; Oman; Palestinian Autonomous Territories; Qatar; Saudi Arabia; Syrian Arab Republic; United Arab Emirates; Yemen

Other in Asia
Asia excluding Commonwealth of Independent States in Asia; Newly Industrialized Economies in Asia and Asian Arab States

OCEANIA

American Samoa; Australia; Cook Islands; Fiji; French Polynesia; Guam; Kiribati; Marshall Islands; Micronesia (Federated States of); Nauru; New Caledonia; New Zealand; Niue; Norfolk Island; Northern Mariana Islands; Palau; Papua New Guinea; Pitcairn; Samoa; Solomon Islands; Tokelau; Tonga; Tuvalu; Vanuatu; Wallis and Futuna Islands

Arab States all

African Arab States and Asian Arab States

Commonwealth of Independent States all

Commonwealth of Independent States in Asia plus Commonwealth of Independent States in Europe

Organisation for Economic Co-operation and Development (OECD)

Australia; Austria; Belgium; Canada; Czech Republic; Denmark; Finland; France; Germany; Greece; Hungary; Iceland; Ireland; Italy; Japan; Luxembourg; Mexico; Netherlands; New Zealand; Norway; Poland; Portugal; Republic of Korea; Slovakia; Spain; Sweden; Switzerland; Turkey; United Kingdom of Great Britain and Northern Ireland; United States of America

European Free Trade Association

Iceland; Liechtenstein; Norway; Switzerland

Groupings mentioned elsewhere in the report

African Union

Africa excluding Mayotte and Saint Helena

Asia–Pacific Economic Cooperation (APEC)

Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong (China); Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; The Philippines; Russian Federation; Singapore; Chinese Taipei; Thailand; United States of America; Viet Nam

Association of Southeast Asian Nations (ASEAN)

Brunei Darussalam; Cambodia; Indonesia; Lao PDR; Malaysia; Myanmar; Philippines; Singapore; Thailand; Viet Nam

Caribbean Common Market (CARICOM)

Antigua and Barbuda; Bahamas; Barbados; Belize; Dominica; Dominican Republic; Grenada; Guyana; Haiti; Jamaica; Montserrat; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Suriname; Trinidad and Tobago

Economic Community of West African States

Benin; Burkina Faso; Cape Verde; Côte d'Ivoire; Gambia; Ghana; Guinea; Guinea-Bissau; Liberia; Mali; Niger; Nigeria; Senegal; Sierra Leone; Togo

Economic Cooperation Organization

Afghanistan; Azerbaijan; Iran; Kazakhstan; Kyrgyzstan; Pakistan; Tajikistan; Turkey; Turkmenistan; Uzbekistan

Economic and Monetary Community of Central Africa
Cameroon; Central African Republic; Chad; Republic of Congo; Equatorial Guinea; Gabon

Eurasian Economic Community
Belarus, Kazakhstan, Kyrgyzstan, Russian Federation, Tajikistan

Greater Mekong Subregion
Cambodia; People's Republic of China; Lao People's Democratic Republic; Myanmar; Thailand; Viet Nam

Indian Ocean Rim Association for Regional Cooperation
Australia, Bangladesh, India, Indonesia, Iran, Kenya, Madagascar, Malaysia, Mauritius, Mozambique, Oman, Singapore, South Africa, Sri Lanka, Tanzania, Thailand, United Arab Emirates, Yemen

Mercado Commún del Sur (MERCOSUR)
Argentina; Brazil; Paraguay; Uruguay; Venezuela

Organization of American States
Antigua and Barbuda; Argentina; Bahamas; Barbados; Belize; Bolivia; Brazil; Canada; Chile; Colombia; Costa Rica; Cuba; Dominica; Dominican Republic; Ecuador; El Salvador; Grenada; Guatemala; Guyana; Haiti; Honduras; Jamaica; Mexico; Nicaragua; Panama; Paraguay; Peru; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Suriname; Trinidad and Tobago; United States of America; Uruguay; Venezuela

Organisation of the Islamic Conference
Afghanistan; Albania; Algeria; Azerbaijan; Bahrain; Bangladesh; Benin; Brunei Darussalam; Burkina Faso; Cameroon; Chad; Comoros; Côte d'Ivoire; Djibouti; Egypt; Gabon; Gambia; Guinea; Guinea Bissau; Guyana; Indonesia; Iran; Iraq; Kazakhstan; Kuwait; Oman; Jordan; Kazakhstan; Lebanon; Libyan Arab Jamahiriya; Maldives; Malaysia; Mali; Mauritania; Morocco; Mozambique; Niger; Nigeria; Palestinian Autonomous Territories; Pakistan; Qatar; Saudi Arabia; Senegal; Sierra Leone; Somalia; Sudan; Suriname; Syrian Arab Republic; Tajikistan; Togo; Turkey; Turkmenistan; Tunisia; Uganda; United Arab Emirates; Uzbekistan; Yemen

Pacific Islands Forum
Australia; Cook Islands; Federated States of Micronesia; Fiji; Kiribati; Nauru; New Zealand; Niue; Palau; Papua New Guinea; Republic of Marshall Islands; Samoa; Solomon Islands; Tonga; Tuvalu; Vanuatu

Secretariat of the Pacific Community
American Samoa ; Cook Islands; Federated States of Micronesia; Fiji; French Polynesia; Guam; Kribati; Marshall Islands; Nauru; New Caledonia; Niue; Northern Mariana Islands ; Palau; Papua New Guinea ; Pitcairn Islands; Samoa; Solomon Islands; Tokelau; Tonga ; Tuvalu; Vanuatu; Wallis and Futuna

Southern African Development Community
Angola; Botswana; Democratic Republic of the Congo; Lesotho; Madagascar; Malawi; Mauritius; Mozambique; Namibia; Seychelles; South Africa; Swaziland; United Republic of Tanzania; Zambia; Zimbabwe

South Asian Association for Regional Cooperation
Afghanistan; Bangladesh; Bhutan; India; Maldives; Nepal; Pakistan; Sri Lanka

Mathematics class at Mahe Primary School in Beijing

Photo: UNESCO

The Millennium Development Goals (MDGs) are eight goals to be achieved by 2015 that respond to the world's main development challenges. The MDGs are drawn from the actions and targets contained in the Millennium Declaration *adopted by 189 nations and signed by 147 heads of State and government during the United Nations' Millennium Summit in September 2000.*

The eight MDGs break down into 21 quantifiable targets that are measured by 60 indicators. The specific indicators can be found at: ***www.un.org/millenniumgoals***

Annex II: Millennium Development Goals

Goal 1: Eradicate extreme poverty and hunger

Target 1a: Reduce by half the proportion of people living on less than a dollar a day

Target 1b: Achieve full and productive employment and decent work for all, including women and young people

Target 1c: Reduce by half the proportion of people who suffer from hunger

Goal 2: Achieve universal primary education

Target 2a: Ensure that all boys and girls complete a full course of primary schooling

Goal 3: Promote gender equality and empower women

Target 3a: Eliminate gender disparity in primary and secondary education, preferably by 2005 and at all levels by 2015

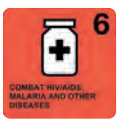
Goal 4: Reduce child mortality

Target 4a: Reduce by two-thirds the mortality rate among children under five

Goal 5: Improve maternal health

Target 5a: Reduce by three-quarters the maternal mortality ratio

Target 5b: Achieve, by 2015, universal access to reproductive health



Goal 6: Combat HIV/AIDS, malaria and other diseases

Target 6a: Halt and begin to reverse the spread of HIV/AIDS

Target 6b: Achieve, by 2010, universal access to treatment for HIV/AIDS for all those who need it

Target 6c: Halt and begin to reverse the incidence of malaria and other major diseases

Goal 7: Ensure environmental sustainability

Target 7a: Integrate the principles of sustainable development into country policies and programmes; reverse loss of environmental resources

Target 7b: Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss

Target 7c: Reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation

Target 7d: Achieve significant improvement in lives of at least 100 million slum dwellers, by 2020

Goal 8: Develop a global partnership for development

Target 8a: Develop further an open, rule-based, predictable, non-discriminatory trading and financial system

Target 8b: Address the special needs of the least developed countries

Target 8c: Address the special needs of landlocked developing countries and small island developing States

Target 8d: Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term

Target 8e: In cooperation with pharmaceutical companies, provide access to affordable essential drugs in developing countries

Target 8f: In co-operation with the private sector, make available the benefits of new technologies, especially information and communications

Crop scientist in the United States of America

Photo: © United States Department of Agriculture

National STI policies clearly face a radically new global landscape today, one in which the territorial policy focus is coming under severe pressure… the steep drop in the marginal cost of reproduction and diffusion of information has led to a world in which geographical borders are less and less relevant for research and innovation. Knowledge accumulation and knowledge diffusion are able to take place at a faster pace, involving a growing number of new entrants and providing a threat to established institutions and positions.

Hugo Hollanders and Luc Soete (see page26)

Statistical annex

Table 1: GERD as a percentage of GDP, 2000–2008

Country/Territory	2000	2001	2002	2003	2004	2005	2006	2007	2008
North America									
Canada	1.91	2.09	2.04	2.04	2.07	2.05	1.97	1.90	1.84
United States of America	2.75[c]	2.76[c]	2.66[c]	2.66[c]	2.58[c]	2.61[c]	2.65[c]	2.72[c]	2.82[c]
Latin America									
Argentina	0.44	0.42	0.39	0.41	0.44	0.46	0.49	0.51	–
Belize									
Bolivia	0.29	0.29	0.28	–	–	–	–	–	–
Brazil	1.02	1.04	0.98	0.96	0.90	0.97	1.00	1.10	–
Chile	0.53	0.53	0.68	0.67	0.68	–	–	–	–
Colombia	0.12[b]	0.12	0.13	0.15	0.16	0.16	0.16	0.16	–
Costa Rica	0.39	–	–	0.36	0.37	–	0.39	0.32	–
Ecuador	0.08[-2]	0.06	0.06	0.06	–	–	0.14[b]	0.15	–
El Salvador	0.08[-2]	–	–	–	–	–	–	0.09	–
Guatemala	–	–	–	–	–	0.03[g]	0.05[g]	0.06[g]	–
Guyana	–	–	–	–	–	–	–	–	–
Honduras	0.04	0.04	0.04	0.04	0.04	–	–	–	–
Mexico	0.37	0.39	0.44	0.40	0.40[b]	0.41	0.39	0.37	–
Nicaragua	0.08[-3]	–	0.05	–	–	–	–	–	–
Panama	0.38[b]	0.38	0.36	0.34	0.24	0.25	0.25	0.20	0.21
Paraguay	–	0.09	0.11	0.09	0.08	0.09	–	–	–
Peru	0.11	0.11	0.10	0.10	0.15	–	–	–	–
Suriname	–	–	–	–	–	–	–	–	–
Uruguay	0.21	–	0.24	–	–	–	0.35	0.42	0.64
Venezuela	–	–	–	–	–	–	–	–	–
Caribbean									
Antigua and Barbuda	–	–	–	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–	–	–	–
Barbados	–	–	–	–	–	–	–	–	–
Cuba	0.45	0.53	0.53	0.54	0.56	0.51[e]	0.41[e]	0.44	0.49
Dominica	–	–	–	–	–	–	–	–	–
Dominican Republic	–	–	–	–	–	–	–	–	–
Grenada	–	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–	–
Jamaica	–	0.05	0.06	–	–	–	–	–	–
Saint Kitts and Nevis	–	–	–	–	–	–	–	–	–
Saint Lucia	0.36[-1, h]	–	–	–	–	–	–	–	–
Saint Vincent and the Grenadines	–	0.05	0.15	–	–	–	–	–	–
Trinidad and Tobago	0.11	0.10	0.14	0.12	0.12	0.12	0.10	0.06	–
European Union									
Austria	1.94[e]	2.07[e]	2.14	2.26[e]	2.26	2.44[e]	2.46	2.54	2.66[e]
Belgium	1.97	2.08	1.94	1.88	1.87	1.84	1.86	1.90	1.92
Bulgaria	0.52	0.47	0.49	0.50	0.50	0.49	0.48	0.48	0.49
Cyprus	0.24	0.25	0.30	0.35	0.37	0.40	0.43	0.45	0.47
Czech Republic	1.21	1.20	1.20	1.25	1.25	1.41	1.55	1.54	1.47
Denmark	2.18[-1]	2.39	2.51	2.58	2.48	2.46	2.48	2.56[b]	2.72[e]
Estonia	0.60	0.70	0.72	0.77	0.85	0.93	1.14	1.11	1.29
Finland	3.35	3.30	3.36	3.43	3.45	3.48	3.45	3.47	3.46[e]
France	2.15[b]	2.20	2.23	2.17	2.15[b]	2.10	2.10	2.04	2.02
Germany	2.45	2.46	2.49	2.52	2.49	2.48	2.53	2.54	–
Greece	0.60[-1]	0.58	–	0.57	0.55[e]	0.58	0.57[e]	0.57[e]	–
Hungary	0.78[d]	0.92[d]	1.00[d]	0.93[d]	0.88[b]	0.94	1.00	0.96	–
Ireland	1.12[e]	1.10	1.10	1.17	1.24	1.25	1.25	1.28	1.42
Italy	1.05	1.09	1.13	1.11	1.10	1.09	1.13	1.18	1.18
Latvia	0.44[b]	0.40	0.42	0.38	0.42	0.56	0.70	0.59	0.61
Lithuania	0.59	0.67	0.66	0.67	0.75	0.75	0.79	0.82	0.80
Luxembourg	1.65	–	–	1.65	1.63	1.56	1.66	1.62[e]	1.74

Country/Territory	2000	2001	2002	2003	2004	2005	2006	2007	2008
European Union *continued*									
Malta	–	–	0.26[e]	0.26[e]	0.53[b, e]	0.57[e]	0.62[e]	0.59[e]	–
Netherlands	1.82	1.80	1.72	1.76	1.81[b]	1.79	1.78	1.72	1.63
Poland	0.64	0.62	0.56	0.54	0.56	0.57	0.56	0.57	0.61
Portugal	0.76[e]	0.80	0.76[e]	0.74	0.77[e]	0.81	1.02[e]	1.21	1.51[b]
Romania	0.37	0.39	0.38	0.39	0.39	0.41	0.45	0.53	0.59
Slovakia	0.65	0.63	0.57	0.57	0.51	0.51	0.49	0.46	0.47
Slovenia	1.39	1.50	1.47	1.27	1.40	1.44	1.56	1.45	1.66
Spain	0.91	0.91	0.99	1.05	1.06	1.12	1.20	1.27	1.34
Sweden	3.61[-1, g]	4.17[g]	–	3.85[g]	3.62[g]	3.60[b]	3.74[h]	3.61	3.75[e]
United Kingdom	1.81	1.79	1.79	1.75	1.69	1.73	1.76	1.82	1.88
Southeast Europe									
Albania	–	–	–	–	–	–	–	–	–
Bosnia and Herzegovina	–	–	–	0.02[g]	0.02[g]	0.03[g]	0.02[g]	0.03[g]	–
Croatia	1.07	0.93	0.96	0.97	1.05	0.87	0.76	0.81	0.90
Montenegro	–	–	–	0.80	1.02	0.92	1.24	1.10	–
Republic of Moldova	0.81[-3]	–	–	0.32[b]	0.35	0.40	0.41	0.55	–
Serbia	0.93	0.34	0.69	0.54	0.31	0.42	0.47	0.35	–
FYR Macedonia	0.44	0.32	0.26	0.23	0.25	0.25	0.21	–	–
Other Europe									
Andorra	–	–	–	–	–	–	–	–	–
Belarus	0.72	0.71	0.62	0.61	0.63	0.68	0.66	0.96	–
Iceland	2.67[e]	2.95	2.95[e]	2.82	–	2.77	2.99	2.70	2.67
Liechtenstein	–	–	–	–	–	–	–	–	–
Monaco	–	–	–	–	–	–	–	–	–
Norway	1.64[-1]	1.59	1.66	1.71	1.59	1.52	1.52	1.64	1.62
Russian Federation	1.05	1.18	1.25	1.28	1.15	1.07	1.07	1.12	1.03
San Marino	–	–	–	–	–	–	–	–	–
Switzerland	2.53	–	–	–	2.90	–	–	–	–
Turkey	0.48	0.54	0.53	0.48	0.52	0.59	0.58	0.72	–
Ukraine	0.96	1.02	1.00	1.11	1.08	1.03	0.95	0.85	–
Sub-Saharan Africa									
Angola	–	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–	–
Botswana	–	–	–	–	–	0.50	–	–	–
Burkina Faso	0.18[-3, g]	0.19[g]	0.33[g]	0.27[g]	0.23[g]	0.17[g]	–	0.11[b, g]	–
Burundi	–	–	–	–	–	–	–	–	–
Cameroon	–	–	–	–	–	–	–	–	–
Cape Verde	–	–	–	–	–	–	–	–	–
Central African Republic	–	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–	–
Democratic Rep. of the Congo	–	–	–	–	0.42[h]	0.48[h]	–	–	–
Equatorial Guinea	–	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–	–
Ethiopia	–	–	–	–	–	0.18[g]	–	0.17[g]	–
Gabon	–	–	–	–	–	–	–	–	–
Gambia	–	–	–	–	–	–	–	–	–
Ghana	–	–	–	–	–	–	–	–	–
Guinea	–	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–	–
Kenya	–	–	–	–	–	–	–	–	–
Lesotho	–	–	0.05[g]	0.05[g]	0.06[g]	–	–	–	–
Liberia	–	–	–	–	–	–	–	–	–

Table 1: GERD as a percentage of GDP, 2000–2008

Country/Territory	2000	2001	2002	2003	2004	2005	2006	2007	2008
Sub-Saharan Africa *continued*									
Madagascar	0.12[g]	0.22[b,g]	0.25[g]	0.34[b,g]	0.22[g]	0.18[g]	0.16[g]	0.14[g]	–
Malawi	–	–	–	–	–	–	–	–	–
Mali	–	–	–	–	–	–	–	–	–
Mauritius	0.29[h]	0.37[h]	0.37[h]	0.34[h]	0.38[h]	0.37[h]	–	–	–
Mozambique	–	–	0.50[h]	–	–	–	0.53	–	–
Namibia	–	–	–	–	–	–	–	–	–
Niger	–	–	–	–	–	–	–	–	–
Nigeria	–	–	–	–	–	–	–	–	–
Rwanda	–	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–	–
Senegal	–	–	–	–	–	0.09[e,g]	–	–	–
Seychelles	–	0.43	0.41	0.41	0.42	0.31	–	–	–
Sierra Leone	–	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–	–
South Africa	0.60[-3]	0.73	–	0.80	0.86	0.92	0.95	0.93	–
Swaziland	–	–	–	–	–	–	–	–	–
Togo	–	–	–	–	–	–	–	–	–
Uganda	–	–	0.37	0.26	0.26	0.22	0.30	0.39	–
United Republic of Tanzania	–	–	–	–	–	–	–	–	–
Zambia	0.01[-3,g]	–	0.01[b,g]	0.01[g]	0.03[g]	0.03[g]	–	–	–
Zimbabwe	–	–	–	–	–	–	–	–	–
Arab states									
Algeria	–	0.23[g]	0.36[g]	0.20[g]	0.16[g]	0.07[g]	–	–	–
Bahrain	–	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–	–
Egypt	0.19[g]	–	–	–	0.27[b,g]	0.25[g]	0.26[g]	0.23[g]	–
Iraq	–	–	–	–	–	–	–	–	–
Jordan	–	–	0.34	–	–	–	–	–	–
Kuwait	0.13[g]	0.18[g]	0.18[g]	0.14[g]	0.13[g]	0.10[g]	0.08[g]	0.09[g]	–
Lebanon	–	–	–	–	–	–	–	–	–
Libyan Arab Jamahiriya	–	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	–	–	–
Morocco	0.29[-2]	0.63	0.55	0.66	–	–	0.64	–	–
Oman	–	–	–	–	–	–	–	–	–
Palestinian Autonomous Territories	–	–	–	–	–	–	–	–	–
Qatar	–	–	–	–	–	–	–	–	–
Saudi Arabia	–	–	–	0.06[g]	0.05[g]	0.04[g]	0.04[g]	0.05[g]	–
Sudan	0.47[e]	0.44[e]	0.39[e]	0.34[e]	0.29[e]	0.29[e]	–	–	–
Syrian Arab Republic	–	–	–	–	–	–	–	–	–
Tunisia	0.46	0.53	0.63	0.73	1.00	1.02[e]	–	–	–
United Arab Emirates	–	–	–	–	–	–	–	–	–
Yemen	–	–	–	–	–	–	–	–	–
Central and West Asia									
Armenia	0.18	0.28	0.25	0.24	0.21	0.21	0.24	0.21	–
Azerbaijan	0.34	0.34	0.30	0.32	0.30	0.22	0.17	0.17	–
Georgia	0.22	0.24	0.19[b]	0.22[b]	0.24	0.18	–	–	–
Israel	4.32[d]	4.60[d]	4.59[d]	4.32[d]	4.26[d]	4.37[d]	4.41[d]	4.76[d]	4.86[d]
Kazakhstan	0.18	0.22	0.26	0.25	0.25	0.28	0.24	0.21	0.22
Kyrgyzstan	0.16	0.17	0.20	0.22	0.20	0.20	0.23	0.23	–
Mongolia	0.20[g]	0.29[b,g]	0.28[g]	0.28[g]	0.29[g]	0.26[g]	0.21[g]	0.23[g]	–
Tajikistan	–	0.09	0.07	0.07	0.07	0.10	0.10	0.06	–
Turkmenistan	–	–	–	–	–	–	–	–	–
Uzbekistan	–	–	–	–	–	–	–	–	–

Country/Territory	2000	2001	2002	2003	2004	2005	2006	2007	2008
South Asia									
Afghanistan	–	–	–	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–	–	–	–
India	0.77	0.75	0.74	0.73	0.77	0.80	0.80[e]	0.80[e]	–
Iran (Islamic Republic of)	–	0.55	0.55	0.67	0.59	0.73	0.67	–	–
Maldives	–	–	–	–	–	–	–	–	–
Nepal	–	–	–	–	–	–	–	–	–
Pakistan	0.13[g]	0.17[g]	0.22[e, g]	–	–	0.44	–	0.67	–
Sri Lanka	0.14[b, e, g]	–	–	–	0.18[b]	–	0.17	–	–
Southeast Asia									
Brunei Darussalam	–	–	0.02[g]	0.02[g]	0.04[b, g]	–	–	–	–
Cambodia	–	–	0.05[e, g]	–	–	–	–	–	–
China	0.90[b]	0.95	1.07	1.13	1.23	1.34	1.42	1.44	–
Democratic People's Rep. of Korea	–	–	–	–	–	–	–	–	–
Hong Kong SAR of China	0.47	0.55	0.59	0.69	0.74	0.79	0.81	–	–
Indonesia	0.07[g]	0.05[g]	–	–	–	0.05[b, g]	–	–	–
Japan	3.04	3.12	3.17	3.20	3.17	3.32	3.40	3.44	–
Lao PDR	–	–	0.04[g]	–	–	–	–	–	–
Macao, China	–	0.07[e, g]	0.08[e, g]	0.06[e, g]	0.06[e, g]	0.11[e, g]	–	–	–
Malaysia	0.47	–	0.65	–	0.60	–	0.64	–	–
Myanmar	0.11[g]	0.07[g]	0.16[g]	–	–	–	–	–	–
Philippines	–	–	0.15	0.14	–	0.12	–	–	–
Republic of Korea	2.30	2.47	2.40	2.49	2.68	2.79	3.01	3.21[b]	–
Singapore	1.88	2.11	2.15	2.11	2.19	2.28	2.27	2.52	–
Thailand	0.25[e]	0.26	0.24[e]	0.26	0.26[e]	0.23	0.25[e]	–	–
Timor–Leste	–	–	–	–	–	–	–	–	–
Viet Nam	–	–	0.19	–	–	–	–	–	–
Oceania									
Australia	1.51	–	1.69	–	1.78	–	2.06	–	–
Cook Islands	–	–	–	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–	–	–	–
Micronesia (Federated States of)	–	–	–	–	–	–	–	–	–
Nauru	–	–	–	–	–	–	–	–	–
New Zealand	1.00[-1]	1.14[b]	–	1.19	–	1.16	–	1.21	–
Niue	–	–	–	–	–	–	–	–	–
Palau –		–	–	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–	–

b = break in series with previous year for which data are available; c = excluding most or all capital expenditures; d = excluding defence (all or mostly); e = estimation; g = underestimated or partial data; h = overestimated or based on overestimated data

Source: UNESCO Institute for Statistics, July 2010

Table 2: GERD in purchasing power parity dollars, 2002 and 2007

Country/Territory	GERD in PPP$ thousands		GERD per capita (PPP$)		GERD per researcher full-time equivalent PPP$ thousands		GERD per researcher headcount PPP$ thousands	
	2002	2007	2002	2007	2002	2007	2002	2007
North America								
Canada	19 145 334	23 961 471^{+1}	611.4	720.4^{+1}	165.0	170.7$^{-1, e}$		
United States of America	277 066 000^{c}	398 086 000$^{+1, c}$	942.4^{c}	1 277.3$^{+1, c}$	206.4$^{c, e}$	243.9$^{-1, c, e}$	–	–
Latin America								
Argentina	1 159 295	2 658 754	30.8	67.3	44.4	68.7	28.0	45.0
Belize	–	–	–	–	–	–	–	–
Bolivia	75 132	–	8.7	–	72.2	–	61.2$^{-1, b}$	–
Brazil	13 022 456	20 237 663	72.7	106.4	181.4	162.1	106.1	101.5
Chile	1 070 584	1 228 578^{-3}	67.8	76.2^{-3}	154.2	91.5$^{-3, b}$	125.8	66.9$^{-3, b}$
Colombia	319 762	600 639	7.8	13.5	61.9	107.8	31.1	50.0
Costa Rica	118 551^{+1}	154 875	28.4^{+1}	34.7	216.3^{+1}	289.7^{-3}	101.2^{+1}	44.0^{b}
Ecuador	43 400	145 947^{b}	3.4	10.9^{b}	78.9	158.0^{b}	62.4	90.4^{b}
El Salvador	19 986^{-4}	35 108	3.4^{-4}	5.7	103.6^{-4}	–	42.8^{-4}	128.1
Guatemala	18 077$^{+3, g}$	35 311^{g}	1.4$^{+3, g}$	2.6^{g}	46.6$^{+3, g}$	90.8^{g}	29.4$^{+3, g}$	55.7^{g}
Guyana	–	–	–	–	–	–	–	–
Honduras	7 375	8 553^{-3}	1.1	1.3^{-3}	–	–	14.3	14.7^{-4}
Mexico	4 171 249	5 598 448^{b}	40.9	52.1^{b}	130.9^{+1}	147.6	98.6^{+1}	–
Nicaragua	4 680	–	0.9	–	19.6^{-5}	–	18.3	–
Panama	82 541	87 817^{+1}	26.9	25.8^{+1}	277.9	157.6^{b}	198.4^{b}	132.2
Paraguay	20 370	20 133^{-2}	3.7	3.4^{-2}	44.8	48.0^{-2}	25.7	25.6^{-2}
Peru	142 461	238 147^{-3}	5.3	8.7^{-3}	–	–	–	48.0^{-3}
Suriname	–	–	–	–	–	–	–	–
Uruguay	57 684	272 194^{+1}	17.3	81.3^{+1}	46.4	235.1^{+1}	15.0	126.4^{+1}
Venezuela	–	–	–	–	–	–	–	–
Caribbean								
Antigua and Barbuda	–	–	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–	–	–
Barbados	–	–	–	–	–	–	–	–
Cuba	–	–	–	–	–	–	–	–
Dominica	–	–	–	–	–	–	–	–
Dominican Republic	–	–	–	–	–	–	–	–
Grenada	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–
Jamaica	9 769	–	3.7	–	–	–	–	–
Saint Kitts and Nevis	–	–	–	–	–	–	–	–
Saint Lucia	4 074$^{-3, h}$	–	26.2$^{-3, h}$	–	–	–	55.1$^{-3, h}$	–
Saint Vincent and the Grenadines	947	–	8.8	–	–	–	45.1–	
Trinidad and Tobago	23 962	18 736	18.4	14.1	–	–	46.4^{+1}	29.6
European Union								
Austria	5 229 773	8 416 155$^{+1, e}$	647.0	1 009.5$^{+1, e}$	216.8	244.8$^{+1, e}$	132.2	144.7
Belgium	6 010 857	7 259 100^{+1}	585.4	685.4^{+1}	196.0	199.5^{+1}	136.2	136.3
Bulgaria	296 118	438 976^{+1}	37.5	57.8^{+1}	32.1	38.6^{+1}	28.4	29.7
Cyprus	47 809	99 974^{+1}	66.9^{e}	115.9^{+1}	109.9	113.0^{+1}	47.1	58.9
Czech Republic	2 063 863	3 767 938^{+1}	202.5	365.1^{+1}	137.8	126.5$^{+1, b}$	67.4	85.2^{+1}
Denmark	4 147 211	5 498 242$^{+1, b, e}$	772.1	1 007.3$^{+1, b, e}$	162.3^{b}	177.7$^{+1, e, b}$	109.5^{b}	117.8^{b}
Estonia	116 674	358 349^{+1}	86.0	267.1^{+1}	38.1	90.1^{+1}	22.9	51.6$^{+1, e}$
Finland	4 814 673	6 659 038$^{+1, e}$	926.1	1 255.4$^{+1, e}$	131.4^{+2}	162.9$^{+1, e}$	105.2^{+2}	121.6
France	38 152 962	42 892 759^{+1}	637.7	691.4^{+1}	204.7	196.1	164.6^{b}	154.7
Germany	56 657 086	72 241 917	689.0	877.3	213.1^{e}	248.4	149.6^{+1}	165.0
Greece	1 418 898^{+1}	1 801 628^{e}	128.7^{+1}	162.1^{e}	90.8^{+1}	86.5^{e}	50.6^{+1}	48.4^{-2}
Hungary	1 492 605^{d}	1 824 527	146.9^{d}	181.9	99.7^{d}	104.9	50.1^{d}	55.2
Ireland	1 430 225	2 636 267^{+1}	362.9	594.2^{+1}	152.5	192.3^{+1}	92.2	128.0
Italy	17 268 878	22 127 747^{+1}	299.9	371.2^{+1}	242.4	229.8^{+1}	158.6	143.7^{-1}
Latvia	100 643	227 050^{+1}	43.1	100.5^{+1}	29.2	52.0^{+1}	16.5	26.9
Lithuania	252 566	475 929^{+1}	72.8	143.3^{+1}	39.9	56.3^{+1}	26.5	33.9

Country/Territory	GERD in PPP$ thousands 2002	GERD in PPP$ thousands 2007	GERD per capita (PPP$) 2002	GERD per capita (PPP$) 2007	GERD per researcher full-time equivalent PPP$ thousands 2002	GERD per researcher full-time equivalent PPP$ thousands 2007	GERD per researcher headcount PPP$ thousands 2002	GERD per researcher headcount PPP$ thousands 2007
European Union *continued*								
Luxembourg	451 827[+1]	671 116[+1]	996.9[+1]	1 396.4[+1]	231.8[+1]	294.1[+1]	223.3[+1]	253.0[e]
Malta	20 739[e]	48 606[+1, b, e]	52.6[e]	119.3[+1, b, e]	76.2[e]	92.8[+1, b, e]	30.1[e]	51.1[b, e]
Netherlands	8 890 819	10 973 542[+1]	552.8	664.0[+1]	233.0[b]	214.9[+1, b]	190.3	198.2[-4]
Poland	2 472 248	3 990 922[+1]	64.5	104.7[+1]	43.6	64.5[+1]	27.2	36.2
Portugal	1 453 206[e]	3 734 873[+1, b]	140.4[e]	349.8[+1, b]	76.6[e]	92.1[+1, b]	43.4[e]	56.5
Romania	603 468	1 711 354[+1]	27.5	80.1[+1]	29.7	88.2[+1]	24.5	42.6
Slovakia	398 306	563 470[+1]	74.0	104.4[+1]	43.4	44.8[+1]	25.9	28.4[+1]
Slovenia	577 595	935 992[+1]	290.1	464.5[+1]	124.4	133.1[+1]	82.2	88.8
Spain	9 808 500	19 369 879[+1]	237.7	435.4[+1]	117.7	147.9[+1]	65.3	86.8
Sweden	10 360 405[+1, g]	12 781 239[+1, e]	1 155.1[+1, g]	1 388.6[+1, e]	215.0[+1, g]	265.1[+1, b, e]	127.4[+3, a]	166.0[b]
United Kingdom	30 635 691	41 043 072[+1]	515.8	670.3[+1]	154.6[e]	157.0[+1, e]	93.4[+3, e]	102.3[e]
South–East Europe								
Albania	–	–	–	–	–	–	–	–
Bosnia and Herzegovina	3 467[+1, g]	7 086[g]	0.9[+1, g]	1.9[g]	15.0[+1, g]	9.5[b, g]	5.2[+1, g]	2.4[b, g]
Croatia	558 183	703 629[+1]	125.0	159.1[+1]	65.1	105.1[+1]	50.1	54.5
Montenegro	33 463[+1]	80 474	52.3[+1]	129.6	–	–	55.6[+1]	119.9
Republic of Moldova	22 434[+1, b]	52 997	6.2[+1, b, e]	14.8[e]	8.2[+1, b, h]	20.4[h]	8.2[+1, b, h]	20.4[h]
Serbia	333 439	245 276	44.5[e]	33.3[e]	–	27.9	30.7[g]	23.2[b]
FYR Macedonia	32 944	32 885[-1]	16.3	16.1[-1]	28.3	31.0[-1]	12.5	14.8[-1]
Other Europe								
Andorra	–	–	–	–	–	–	–	–
Belarus	365 964	1 017 440	36.8	104.6	–	–	19.7	53.6
Iceland	263 812[e]	313 181[+1]	923.5[e]	992.8[+1]	130.9[+1]	135.7[+1]	71.3[+1]	75.3[+1]
Liechtenstein	–	–	–	–	–	–	–	–
Monaco	–	–	–	–	–	–	–	–
Norway	2 792 174	4 522 390[+1]	615.3	948.8[+1]	142.7[+1]	173.5[+1, e]	83.9[+1]	99.6
Russian Federation	15 941 227	23 382 745[+1]	109.7	165.4[+1]	32.4	51.8[+1]	38.4[h]	62.2[+1, h]
San Marino	–	–	–	–	–	–	–	–
Switzerland	5 765 769[-2]	7 470 175[-3]	802.6[-2]	1 010.4[-3]	220.9[-2]	294.1[-3]	130.4[-2]	172.8[-3]
Turkey	3 008 863	6 781 532	44.0	92.9	125.4	136.5	42.2	66.5
Ukraine	1 921 261	2 753 653	40.0	59.5	40.2[+4, h]	40.8[h]	22.5	34.9
Sub–Saharan Africa								
Angola	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–
Botswana	–	111 714[-2]	–	60.7[-2]	–	–	–	64.5[-2, h]
Burkina Faso	36 171[g]	18 335[b, g]	2.9[g]	1.2[b, g]	–	–	153.3[g]	98.0[b, g]
Burundi	–	–	–	–	–	–	–	–
Cameroon	–	–	–	–	–	–	–	–
Cape Verde	–	–	–	–	–	–	–	–
Central African Republic	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–
Democratic Rep. of the Congo	60 515[+2, h]	75 217[-2, h]	1.1[+2, h]	1.3[-2, h]	–	–	6.7[+2, h]	7.2[-2, h]
Equatorial Guinea	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–
Ethiopia	85 282[+3, g]	106 300[g]	1.1[+3, g]	1.4[g]	53.0[+3, g]	65.8[g]	39.0[+3, g]	44.7[g]
Gabon	–	–	–	–	–	–	–	–
Gambia	–	–	–	–	–	–	–	–
Ghana	–	–	–	–	–	–	–	–
Guinea	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–
Kenya	–	–	–	–	–	–	–	–

Table 2: GERD in purchasing power parity dollars, 2002 and 2007

Country/Territory	GERD in PPP$ thousands		GERD per capita (PPP$)		GERD per researcher full-time equivalent PPP$ thousands		GERD per researcher headcounts PPP$ thousands	
	2002	2007	2002	2007	2002	2007	2002	2007
Sub-Saharan Africa *continued*								
Lesotho	1 024[g]	1 563[-3, g]	0.5[g]	0.8[-3, g]	85.3[g]	78.1[-3, g]	20.9[g]	23.0[-3, g]
Liberia	–	–	–	–	–	–	–	–
Madagascar	29 088[g]	25 790[g]	1.8[g]	1.4[g]	36.9[g]	27.5[b, g]	21.9[g]	13.9[b, g]
Malawi	–	–	–	–	–	–	–	–
Mali	–	–	–	–	–	–	–	–
Mauritius	39 204[h]	47 014[-2, h]	32.2[h]	37.5[-2, h]	–	–	93.3[-5, h]	–
Mozambique	52 128[h]	83 158[-1]	2.7[h]	3.9[-1]	–	246.8[-1, b, h]	111.4[h]	246.8[-1, b, h]
Namibia	–	–	–	–	–	–	–	–
Niger	–	–	–	–	–	–	–	–
Nigeria	–	–	–	–	–	–	–	–
Rwanda	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–
Senegal	–	16 252[-2, e, g]	–	1.4[-2, e, g]	–	–	–	–
Seychelles	5 493	4 519[-2]	68.0[e]	54.5[-2, e]	–	347.6[-2, h]	–	322.8[-2, h]
Sierra Leone	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–
South Africa	2 727 421[+1]	4 358 460	58.2[+1]	88.6	193.0[+1]	225.6	88.8[+1]	108.7
Swaziland	–	–	–	–	–	–	–	–
Togo	–	–	–	–	–	–	–	–
Uganda	72 461	128 134	2.8	4.2	–	–	115.0	143.8
United Republic of Tanzania	–	–	–	–	–	–	–	–
Zambia	638[b, g]	3 840[-2, g]	0.1[b, g]	0.3[-2, g]	1.4–5[, g]	–	2.4[g]	4.8[-2, g]
Zimbabwe	–	–	–	–	–	–	–	–
Arab states								
Algeria	670 180[g]	157 008[-2, g]	21.3[g]	4.8[-2, g]	–	28.1[-2, g]	–	11.4[-2, g]
Bahrain	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–
Egypt	833 714[+2, b, g]	911 473[g]	11.0[+2, b, g]	11.4[g]	–	18.5[g]	–	9.5[g]
Iraq	–	–	–	–	–	–	–	–
Jordan	59 740	–	11.7	–	–	–	–	–
Kuwait	128 156[g]	110 335[g]	52.5[g]	38.7[g]	370.4[g]	233.8[g]	370.4[g]	233.8[g]
Lebanon	–	–	–	–	–	–	–	–
Libyan Arab Jamahiriya	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	–	–
Morocco	477 528	764 824[-1]	16.2	24.8[-1]	–	38.3[-1, h]	18.5[h]	27.2[-1, h]
Oman	–	–	–	–	–	–	–	–
Palestinian Autonomous Territories	–	–	–	–	–	–	–	–
Qatar	–	–	–	–	–	–	–	–
Saudi Arabia	260 541[+1, g]	271 332[g]	11.6[+1, g]	11.0[g]	–	–	–	265.0[g]
Sudan	186 236[e]	179 085[-2, e]	5.1[e]	4.6[-2, e]	–	–	20.5[e]	16.0[-2, e]
Syrian Arab Republic	–	–	–	–	–	–	–	–
Tunisia	321 589	660 607[-2, e]	33.4	66.9[-2, e]	32.5[g]	45.1[-2, e, g]	18.1[g]	26.0[-2, e, g]
United Arab Emirates	–	–	–	–	–	–	–	–
Yemen	–	–	–	–	–	–	–	–
Central and West Asia								
Armenia	20 376	36 164	6.7	11.8	–	–	4.1[h]	8.8[h]
Azerbaijan	67 705	114 387	8.6[e]	13.8[e]	–	–	6.6	10.1
Georgia	20 922[b]	27 805[-2, b]	4.5[b]	6.2[-2, b]	–	–	1.7[b]	3.4[-2, b]
Israel	7 102 887[d]	9 921 036[+1, d]	1 121.4[d]	1 407.0[+1, d]	–	–	–	–
Kazakhstan	235 752	384 342[+1]	15.8	24.8[+1]	–	–	25.2	35.7[+1]
Kyrgyzstan	14 190	24 337	2.8	4.6	–	–	6.9	12.0
Mongolia	13 361[g]	19 123[g]	5.5[g]	7.3[g]	–	–	6.8[g]	11.0[g]
Tajikistan	4 847	7 612	0.8	1.1	–	–	2.8	5.9
Turkmenistan	–	–	–	–	–	–	–	–
Uzbekistan	–	–	–	–	–	–	–	–

Country/Territory	GERD in PPP$ thousands		GERD per capita (PPP$)		GERD per researcher Full-time equivalent PPP$ thousands		GERD per researcher headcount PPP$ thousands	
	2002	2007	2002	2007	2002	2007	2002	2007
South Asia								
Afghanistan	–	–	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–	–	–
India	12 943 392	24 792 602[e]	12.0	21.3[e]	102.6[-2]	126.7[-2, e]	–	–
Iran (Islamic Republic of)	2 757 714	4 699 412[-1]	40.3	65.6[-1]	–	93.0[-1]	67.4[+2]	69.3[-1]
Maldives	–	–	–	–	–	–	–	–
Nepal	–	–	–	–	–	–	–	–
Pakistan	1 486 576[+3]	2 726 960	9.0[+3]	15.7	117.2[+3]	103.5[b]	48.0[+3]	50.8
Sri Lanka	115 761[+2, b]	135 013[-1]	6.0[+2, b]	6.9[-1]	43.2[+2, b]	73.7[-1]	25.2[+2, b]	29.9[-1]
Southeast Asia								
Brunei Darussalam	2 483[g]	6 272[-3, b, g]	7.1[g]	17.3[-3, b, g]	25.1[g]	61.6[-3, b, g]	8.4[g]	25.7[-3, b, g]
Cambodia	6 819[e, g]	–	0.5[e, g]	–	30.6[e, g]	–	9.2[e, g]	–
China	39 200 833	102 428 349	30.5	77.1	48.4	72.0	–	–
Dem. People's Rep. of Korea	–	–	–	–	–	–	–	–
Hong Kong SAR of China	1 105 994	2 174 326[-1]	163.2	314.4[-1]	104.0	118.6[-1]	87.7	105.4[-1]
Indonesia	249 957[-1, g]	347 237[-2, b, g]	1.2[-1, g]	1.6[-2, b, g]	5.9[-1, g]	–	2.7[-1, g]	9.8[-2, b, g]
Japan	108 166 135	147 938 883	851.0	1 161.3	167.3[b]	208.4	136.7	167.5
Lao PDR	2 638[g]	–	0.5[g]	–	30.3[g]	–	12.6[g]	–
Macao, China	7 798[e, g]	18 569[-2, e, g]	17.1[e, g]	38.1[-2, e, g]	74.3[e, g]	62.2[-2, e, g]	39.6[e, g]	33.1[-2, e, g]
Malaysia	1 523 027	2 090 896[-1]	62.8	80.1[-1]	212.8	215.7[-1]	85.6	109.9[-1]
Myanmar	–	–	–	–	–	–	–	–
Philippines	286 596	290 819[-2]	3.5	3.4[-2]	49.3[+1]	42.2[-2]	39.8	27.2[-2]
Republic of Korea	22 506 800	41 339 086[b]	479.4	861.9[b]	158.6	186.3[b]	118.5	143.0[b]
Singapore	3 043 455	5 819 930	738.6	1 297.8	168.0	213.2	141.4	183.8
Thailand	840 232[e]	1 2003 204[-1, e]	13.2[e]	18.1[-1, e]	54.5[+1]	51.0[-2]	33.1[+1]	30.7[-2]
Timor–Leste	–	–	–	–	–	–	–	–
Viet Nam	252 159	–	3.1	–	27.0	–	6.1	–
Oceania								
Australia	9 885 298	15 284 418[-1]	503.0	741.0[-1]	135.1	175.4[-1]	–	–
Cook Islands	–	–	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–	–	–
Micronesia (Federated States of)	–	–	–	–	–	–	–	–
Nauru	–	–	–	–	–	–	–	–
New Zealand	1 106 484[+1]	1 389 264	275.7[+1]	331.3	69.9[+1]	75.9	43.4[+1]	46.8
Niue	–	–	–	–	–	–	–	–
Palau –		–	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–

-n/+n = data refer to *n* years before or after reference year; b = break in series with previous year for which data are available; c = excluding most or all capital expenditures; d = excluding defence (all or mostly); e = estimation; g = underestimated or partial data; h = overestimated or based on overestimated data

Source: for GERD and researchers: UNESCO Institute for Statistics, July 2010. for GDP and PPP conversion factor (local currency per international $): World Bank; World Development Indicators, as of May 2010. Population: United Nations Department of Economic and Social Affairs, (2009); *World Population Prospects: the 2008 Revision*

Table 3: GERD by performing sector and source of funds, 2002 and 2007 (%)

Country/Territory	GERD by performing sector (%) 2002					2007				
	Business enterprise	Government	Higher education	Private non-profit	Not specified	Business enterprise	Government	Higher education	Private non-profit	Not specified
North America										
Canada	57.6	10.5	31.7	0.3		54.2[+1]	10.2[+1]	35.0[+1]	0.6[+1]	
United States of America	70.0[c]	12.1	13.4[c]	4.5[c]		72.6[+1,c]	10.6[+1]	12.9[+1,c]	3.9[+1,c]	
Latin America										
Argentina	26.1	37.2	33.9	2.8		30.3	38.9	28.8	1.9	
Belize	–	–	–	–	–	–	–	–	–	–
Bolivia	25.0	21.0	41.0	13.0						
Brazil	40.4	20.6	38.9	0.1		40.2[-3]	21.3[-3]	38.4[-3]	0.1[-3]	
Chile	35.8[b]	11.0[b]	38.8[b]	14.3[b]		46.2[-3]	10.2[-3]	32.0[-3]	11.6[-3]	
Colombia	25.8	3.0	53.1	18.0		22.7	5.7	52.4	19.3	
Costa Rica	32.0[+1,f]	11.0[+1,f]	38.0[+1,f]	19.0[+1,f]		33.0[b,f]	16.0[b,f]	45.3[b,f]	5.8[b,f]	
Ecuador	11.4	33.5	11.4	43.7		21.5[b]	58.1[b]	3.9[b]	3.3[b]	13.2[b]
El Salvador								99.6		0.4
Guatemala	2.9[+3,g]	33.7[+3,g]	63.3[+3,g]	0.1[+3,g]		1.0[g]	18.9[g]	74.2[g]	5.9[g]	
Guyana	–	–	–	–	–	–	–	–	–	–
Honduras	–	–	–	–	–	–	–	–	–	–
Mexico	34.1	25.1	39.5	1.3		47.4[b]	25.2	26.1[b]	1.3	
Nicaragua	–	–	–	–	–	–	–	–	–	–
Panama		49.3[f]	7.2[f]	43.6[f]		[-2]	37.1[-2]	8.6[-2]	54.2[-2]	
Paraguay		35.9	40.7[b]	23.4[b]			27.0[-2,b]	61.7[-2,b]	11.2[-2,b]	
Peru	10.7[f]	31.7[f]	47.7[f]	11.4[f]	[f]	29.2[-3]	25.6[-3]	38.1[-3]	7.1[-3]	
Suriname	–	–	–	–	–	–	–	–	–	–
Uruguay	49.0[b]	19.4[b]	31.6[b]			18.1[+1,b]	64.3[+1,b]	17.5[+1,b]		
Venezuela	–	–	–	–	–	–	–	–	–	–
Caribbean										
Antigua and Barbuda	–	–	–	–	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–	–	–	–	–
Barbados	–	–	–	–	–	–	–	–	–	–
Cuba	–	–	–	–	–	–	–	–	–	–
Dominica	–	–	–	–	–	–	–	–	–	–
Dominican Republic	–	–	–	–	–	–	–	–	–	–
Grenada	–	–	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–	–	–
Jamaica	–	–	–	–	–	–	–	–	–	–
Saint Kitts and Nevis	–	–	–	–	–	–	–	–	–	–
Saint Lucia	6.3[-3]	58.1[-3]			35.6[-3]	–	–	–	–	–
Saint Vincent and the Grenadines	86.7	13.3								
Trinidad and Tobago	10.5	71.3	18.2			25.1[-1,b]	51.1[-1,b]	23.8[-1,b]		
European Union										
Austria	66.8	5.7	27.0	0.4		70.6	5.3	23.8	0.3	
Belgium	70.4	7.2	21.2	1.3		68.9[+1]	8.6[+1]	21.2[+1]	1.3[+1]	
Bulgaria	18.5	71.4	10.0			31.0[+1]	58.3[+1]	9.6[+1]	1.0[+1]	
Cyprus	20.3	40.8	29.5	9.5		22.7[+1]	22.3[+1]	46.4[+1]	8.6[+1]	
Czech Republic	61.1	23.0	15.6	0.3		61.9[+1]	20.9[+1]	16.8[+1]	0.4[+1]	
Denmark	69.0	7.4[b]	23.0[b]	0.6		70.1[+1,e]	3.2[+1,e]	26.2[+1,e]	0.5[+1,e]	
Estonia	30.7	17.0	47.9	4.5		43.2[+1]	11.8[+1]	42.9[+1]	2.1[+1]	
Finland	69.9	10.4	19.2	0.6		72.3[+1,e]	8.7[+1,b,e]	19.0[+1,e]	[+1,n]	
France	63.3	16.5	18.9	1.4		63.0[+1]	16.1[+1]	19.7[+1]	1.2[+1]	
Germany	69.2	13.7[j]	17.0	[n]		70.0	13.9[j]	16.1	[n]	
Greece	32.1[+1]	20.3[+1]	46.7[+1]	0.9[+1]		26.9[e]	21.4[e]	50.4[e]	1.3[e]	
Hungary	35.5[f]	32.9[d,f]	25.2[f]		6.5[e]	50.3[f]	24.2[f]	23.3[f]		2.2[e]
Ireland	68.8	8.7	22.4			64.9[+1]	7.7[+1]	27.4[+1]		
Italy	48.3	17.6	32.8	1.3		50.9[+1]	13.2[+1]	32.6[+1]	3.3[+1]	
Latvia	40.9	19.0	40.1			25.0[+1]	27.5[+1]	47.4[+1]		
Lithuania	16.9	33.4	49.8			23.8[+1]	23.1[+1]	53.1[+1]		

GERD by source of funds (%)

2002						2007					
Business enterprise	Government	Higher education	Private non-profit	Abroad	Not specified	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not specified
51.5	31.6[e]	6.1[e]	2.7	8.2		47.6[+1]	33.0[+1, e]	6.7[+1, e]	3.3[+1]	9.3[+1]	
65.2[c]	29.1[c]	2.7[c]	3.0[c]	[m]		67.3[+1, c]	27.0[+1, c]	2.7[+1, c]	3.0[+1, c]	–[+1, m]	
24.3	70.2	2.3	1.9	1.2		29.3	67.6	1.4	1.1	0.6	
–	–	–	–	–	–	–	–	–	–	–	–
16.0	20.0	31.0	19.0	14.0							
45.0	53.3	1.7				44.7	52.9	2.4			
33.2	54.6	0.4	0.3	11.3		45.8[-3]	44.4[-3]	0.8[-3]	0.3[-3]	8.7[-3]	
29.1	22.5	39.3	1.9	7.2		27.2	37.7	25.6	5.4	4.1	
–	–	–	–	–	–	–	–	–	–	–	–
17.4[+4, b]	69.3[+4, b]	4.0[+4, b]	1.2[+4, b]	4.2[+4, b]	4.0[+4, b]	21.5	58.1	3.9	3.3	7.0	6.2
1.2[-4]	51.9[-4]	13.2[-4]	10.4[-4]	23.4[-4]		1.8	50.4	39.4	0.9	7.4	
	36.5[+4, b, g]	23.7[+4, b, g]		39.8[+4, b, g]			27.9[g]	21.7[g]		50.5[g]	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
34.7	55.5	8.2	0.8	0.8		45.1[b]	50.2[b]	3.2[b]	0.1[b]	1.4[b]	
–	–	–	–	–	–	–	–	–	–	–	–
0.6[b]	26.2	2.1	0.2	70.8	0.1	0.4[-2]	38.5[-2]	1.4[-2]	0.7[-2]	58.9[-2]	–
	63.2	12.7	2.3	21.8		0.3[-2, b]	74.9[-2, b]	8.6[-2, b]	2.0[-2, b]	14.2[-2, b]	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
46.7	17.1	31.4	0.1	4.7		24.6[+1, b]	60.2[+1, b]	12.9[+1, b]		2.3[+1, b]	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
35.0	60.0			5.0		18.0[+1, b]	69.0[+1, b]			13.0[+1, b]	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
44.6	33.6		0.4	21.4		46.3[+1, e]	37.2[+1, e]		0.4[+1, e]	16.1[+1, e]	
59.4	23.2	2.6	0.5	14.3		61.4	22.2	2.8	0.7	13.0	
24.8	69.8	0.2	0.2	5.0		34.2	56.7	1.0	0.5	7.6	
17.4	61.6	3.8	2.0	15.1		16.4	64.6	2.8	1.7	14.5	
53.7	42.1	0.5	1.0	2.7		52.2[+1]	41.3[+1]	1.2[+1]	[+1]	5.3[+1]	
59.9[+1]	27.1[+1]	[n]	2.7[+1]	10.3[+1]		61.1[+1, b, e]	25.3[+1, b, e]	0.3[+1, b, e]	3.6[+1, b, e]	9.7[+1, b, e]	
29.1	53.9	2.4	0.3	14.3		33.6[+1]	50.0[+1]	0.5[+1]	0.3[+1]	15.5[+1]	
69.5	26.1	0.2	1.0	3.1		68.2	24.1	0.3	1.0	6.5	
52.1	38.3	0.7	0.9	8.0		50.5[+1]	39.4[+1]	1.3[+1]	0.8[+1]	8.0[+1]	
65.5[e]	31.6[e]		0.5[e]	2.4[e]		67.9	27.7		0.4	4.0	
28.2[+1]	46.4[+1]	2.6[+1]	1.2[+1]	21.6[+1]		31.1[-2]	46.8[-2]	1.7[-2]	1.5[-2]	19.0[-2]	
29.7[f]	58.5[d, f]		0.3[f]	10.4[f]	1.2[e]	43.9	44.4[b]		0.6	11.1	
63.4	27.5	1.9		7.1		49.6	32.2	0.4	1.9	15.9	
39.7[+3]	50.7[+3]	0.1[+3]	1.6[+3]	8.0[+3]		42.0	44.3	1.3	2.9	9.5	
21.7	42.7			35.6		27.0[+1]	47.3[+1]	2.5[+1]		23.1[+1]	
27.9	65.1			7.1		21.4[+1]	55.6[+1]	7.2[+1]	0.3[+1]	15.5[+1]	

Annex

Table 3: GERD by performing sector and source of funds, 2002 and 2007 (%)

Country/Territory	GERD by performing sector (%) 2002 Business enterprise	Government	Higher education	Private non-profit	Not specified	2007 Business enterprise	Government	Higher education	Private non-profit	Not specified
European Union *continued*										
Luxembourg	89.1[+1]	10.5[+1]	0.4[+1, e]			81.5[+1]	15.5[+1]	3.0[+1]		
Malta	24.7	16.5	58.8			65.3[+1, b]	2.4[+1]	32.2[+1, b]		
Netherlands	56.7	13.8	28.8	0.7		55.0[+1]	13.0[+1, j]	32.1[+1]	[+1, n]	
Poland	20.3	45.5	33.9	0.3		30.9[+1]	35.3[+1]	33.6[+1]	0.1[+1]	
Portugal	32.5[e]	18.8[e]	37.5[e]	11.2[e]		50.0[+1]	7.7[+1]	33.6[+1, b]	8.6[+1]	
Romania	60.3	24.2	15.6			30.0[+1]	41.0[+1]	28.9[+1]	0.2[+1]	
Slovakia	64.3	26.6[d]	9.1			42.9[+1]	32.8[+1, d]	24.3[+1]	0.1[+1]	
Slovenia	59.7	23.1	15.5	1.7		64.6[+1]	21.9[+1]	13.4[+1]	0.1[+1]	
Spain	54.6[b]	15.4	29.8	0.2[b]		54.9[+1, b]	18.2[+1]	26.7[+1]	0.2[+1]	
Sweden	74.4[+1, g]	3.5[+1]	21.8[+1]	0.4[+1]		74.1[+1, e]	4.4[+1, e]	21.3[+1, e]	0.2[+1, e]	
United Kingdom	64.8	9.2	24.0	1.9		64.2[+1]	8.3[+1]	25.2[+1]	2.3[+1]	
Southeast Europe										
Albania	–	–	–	–	–	–	–	–	–	–
Bosnia and Herzegovina		2.6[+1, g]	78.8[+1, g]		18.6[+1, g]		12.6[g]	68.7[g]	1.1[g]	17.6[g]
Croatia	42.7	22.2	35.1			44.3[+1]	25.2[+1]	30.3[+1]	0.1[+1]	
Montenegro	8.4[+1]	14.9[+1]	76.7[+1]			5.2	14.9	80.0		
Republic of Moldova	17.9[+3]	72.8[+3]	9.3[+3]	[+3]		15.5	73.4	11.1		
Serbia	5.4	42.7	52.0			2.5	54.2	43.3		
FYR Macedonia	2.6	56.5	40.9			12.3[-1]	47.9[-1]	39.8[-1]	[-1]	
Other Europe										
Andorra	–	–	–	–	–	–	–	–	–	–
Belarus	51.0	32.6	16.4			61.4[b]	27.1[b]	11.5		
Iceland	57.2[e]	24.5[e]	16.1[e]	2.2[e]		54.6[+1]	17.8[+1]	25.1[+1]	2.5[+1]	
Liechtenstein	–	–	–	–	–	–	–	–	–	–
Monaco		100.0[+2, g]					100.0[-2, g]			
Norway	57.4	15.8	26.8			53.8[+1]	14.6[+1]	31.5[+1]		
Russian Federation	69.9	24.5	5.4	0.2		62.9[+1]	30.1[+1]	6.7[+1]	0.3[+1]	
San Marino	–	–	–	–	–	–	–	–	–	–
Switzerland	73.9[-2]	1.3[-2, b]	22.9[-2]	1.9[-2]		73.7[-3]	1.1[-3]	22.9[-3]	2.3[-3]	
Turkey	28.7	7.0	64.3			41.3	10.6	48.2		
Ukraine	51.9	42.1	6.0			55.4	37.7	6.9		
Sub-Saharan Africa										
Angola	–	–	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–	–	–
Botswana						15.6[-2]	79.4[-2]	1.2[-2]	3.8[-2]	
Burkina Faso		100.0[g]					72.2[b, g]		21.1[b, g]	6.7[b, g]
Burundi	–	–	–	–	–	–	–	–	–	–
Cameroon	–	–	–	–	–	–	–	–	–	–
Cape Verde	–	–	–	–	–	–	–	–	–	–
Central African Republic	–	–	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–	–	–
Democratic Republic of the Congo		100.0[+2, h]					100.0[-2, h]			
Equatorial Guinea	–	–	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–	–	–
Ethiopia		85.6[+3, g]	14.3[+3, g]	0.1[+3, g]			84.4[g]	14.6[g]	1.0[g]	
Gabon	–	–	–	–	–	–	–	–	–	–
Gambia	–	–	–	–	–	–	–	–	–	–
Ghana	–	–	–	–	–	–	–	–	–	–
Guinea	–	–	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–	–	–
Kenya	–	–	–	–	–	–	–	–	–	–

GERD by source of funds (%)

2002						2007					
Business enterprise	Government	Higher education	Private non-profit	Abroad	Not specified	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not specified
80.4[+1]	11.2[+1]	[+1]	0.1[+1]	8.3[+1]		76.0	18.2	[e]	0.1	5.7	
18.6	59.8			21.6		50.8[+1, b]	28.1[+1, b]		0.1[+1]	21.0[+1]	
50.0	37.1	0.1	1.1	11.6		51.1[-4]	36.2[-4]	0.1[-4]	1.3[-4]	11.3[-4]	
30.1	61.9	2.9	0.3	4.8		30.5[+1]	59.8[+1]	4.1[+1]	0.2[+1]	5.4[+1]	
31.6[e]	60.5[e]	1.1[e]	1.8[e]	5.0[e]		47.0	44.6	0.7	2.3	5.4	
41.6	48.4	3.0		7.0		23.3[+1]	70.1[+1]	2.6[+1]	[+1]	4.0[+1]	
53.6	44.1[g]	0.1	0.2	2.1		34.7[+1]	52.3[+1, g]	0.3[+1]	0.4[+1]	12.3[+1]	
60.0	35.6	0.6		3.7		62.8[+1]	31.3[+1]	0.3[+1]	[+1]	5.6[+1]	
48.9	39.1	4.5	0.7	6.8		45.5	43.7	3.3	0.5	7.0	
65.1[+1, g]	24.3[+1, g]	0.1[+1, g]	3.1[+1, g]	7.3[+1, g]		64.0[b]	22.2[b]	0.7[b]	3.8[b]	9.3[b]	
43.5	28.9	1.1	5.0	21.5		47.2[+1]	29.5[+1]	1.2[+1]	4.5[+1]	17.6[+1]	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
45.7	46.4	6.4		1.5		40.8[+1]	49.3[+1]	1.9[+1]	0.2[+1]	7.9[+1]	
–	–	–	–	–	–	–	–	–	–	–	–
				1.9[+1, b]	98.1[+1, b]					2.7	97.3
–	–	–	–	–	–	–	–	–	–	–	–
7.8[e]	76.3[e]	7.3[e]	[e]	8.6[e]		–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
24.4	63.4	2.2		10.1		45.1[b]	49.2[b]	0.3	0.1	5.3	
43.9[+1]	40.1[+1]	[+1]	1.5[+1]	14.5[+1]		50.4[+1]	38.8[+1]	[+1]	0.8[+1]	10.0[+1]	
–	–	–	–	–	–	–	–	–	–	–	–
	97.0[+2, g]				3.0[+2, g]		98.8[-2, g]				1.2[-2, g]
49.2[+1]	41.9[+1]	0.6[+1]	0.8[+1]	7.4[+1]		45.3	44.9	0.6	0.9	8.3	
33.1	58.4	0.3	0.1	8.0		28.7[+1]	64.7[+1]	0.5[+1]	0.2[+1]	5.9[+1]	
–	–	–	–	–	–	–	–	–	–	–	–
69.1[-2]	23.2[-2]	2.1[-2]	1.4[-2]	4.3[-2]		69.7[-3]	22.7[-3]	1.5[-3]	0.8[-3]	5.2[-3]	
41.3	50.6	[n]	6.9[i]	1.3		48.4	47.1	4.0[i]	0.5		
33.4[e]	36.3[e]	0.4[e]	0.4[e]	26.2[e]	3.4[e]	30.2[b]	52.2[b]	0.2[b]	0.1[b]	15.9[b]	1.3[b]
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
	100.0[g]						72.3[b, g]			24.5[b, g]	3.2[b, g]
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
	100.0[+2, h]						100.0[-2, h]				
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
	69.2[+3, g]	[+3, n]	0.1[+3, g]	30.8[+3, g]			71.7[g]	[n]	0.7[g]	27.0[g]	0.5[g]
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–

Table 3: GERD by performing sector and source of funds, 2002 and 2007 (%)

Country/Territory	GERD by performing sector (%) 2002					2007				
	Business enterprise	Government	Higher education	Private non-profit	Not specified	Business enterprise	Government	Higher education	Private non-profit	Not specified
Sub-Saharan Africa *conitued*										
Lesotho	–	–	–	–	–	–	–	–	–	–
Liberia	–	–	–	–	–	–	–	–	–	–
Madagascar		60.5$^{+1, b, g}$	39.5$^{+1, b, g}$				40.4^{g}	59.6^{g}		
Malawi	–	–	–	–	–	–	–	–	–	–
Mali	–	–	–	–	–	–	–	–	–	–
Mauritius	–	–	–	–	–	–	–	–	–	–
Mozambique							100.0^{-1}			
Namibia	–	–	–	–	–	–	–	–	–	–
Niger	–	–	–	–	–	–	–	–	–	–
Nigeria	–	–	–	–	–	–	–	–	–	–
Rwanda	–	–	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–	–	–
Senegal	–	–	–	–	–		33.3$^{-2, e, g}$	66.7$^{-2, e, g}$		
Seychelles		98.1		1.9			97.1^{-2}		2.9^{-2}	
Sierra Leone	–	–	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–	–	–
South Africa	55.5^{+1}	21.9^{+1}	20.5^{+1}	2.1^{+1}		57.7	21.7	19.4	1.2	
Swaziland	–	–	–	–	–	–	–	–	–	–
Togo	–	–	–	–	–	–	–	–	–	–
Uganda	1.3	97.4	1.3			7.5	67.5		25.0	
United Rep. of Tanzania	–	–	–	–	–	–	–	–	–	–
Zambia	4.0^{g}	71.0^{g}	12.0^{g}	13.0^{g}		13.8$^{-2, g}$	49.3$^{-2, g}$	24.6$^{-2, g}$	12.3$^{-2, g}$	
Zimbabwe	–	–	–	–	–	–	–	–	–	–
Arab states										
Algeria	–	–	–	–	–	–	–	–	–	–
Bahrain	–	–	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–	–	–
Egypt	–	–	–	–	–	–	–	–	–	–
Iraq	–	–	–	–	–	–	–	–	–	–
Jordan	–	–	–	–	–	–	–	–	–	–
Kuwait		100.0^{g}					100.0^{g}			
Lebanon	–	–	–	–	–	–	–	–	–	–
Libyan Arab Jamahiriya	–	–	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	–	–	–	–
Morocco						22.0^{-1}	25.6^{-1}	52.4^{-1}		
Oman	–	–	–	–	–	–	–	–	–	–
Palestinian Autonomous Territories	–	–	–	–	–	–	–	–	–	–
Qatar	–	–	–	–	–	–	–	–	–	–
Saudi Arabia	–	–	–	–	–	–	–	–	–	–
Sudan	31.8^{e}	39.0^{e}	29.2^{e}			33.7$^{-2, e}$	39.2$^{-2, e}$	27.1$^{-2, e}$		
Syrian Arab Republic	–	–	–	–	–	–	–	–	–	–
Tunisia	8.2	43.1	37.0		11.7	14.5$^{-2, e}$	50.8$^{-2, e}$	34.8$^{-2, e}$	$^{-2, e}$	
United Arab Emirates	–	–	–	–	–	–	–	–	–	–
Yemen	–	–	–	–	–	–	–	–	–	–
Central and West Asia										
Armenia		99.6^{+1}	0.4^{+1}				93.6	6.4		
Azerbaijan	21.1	54.4	24.5			20.4	69.5	10.1		
Georgia		92.1^{b}	7.9^{b}				73.2$^{-2, b}$	26.8$^{-2, b}$		
Israel	75.3^{d}	5.5^{d}	15.5	3.7		80.8$^{+1, d}$	4.4$^{+1, d}$	11.9^{+1}	2.8^{+1}	
Kazakhstan	28.9^{+1}	61.5^{+1}	9.1^{+1}	0.6^{+1}		50.8^{+1}	32.2^{+1}	14.9^{+1}	2.2^{+1}	
Kyrgyzstan	50.9	42.3	6.8			28.4	59.6	12.0		
Mongolia		78.3^{g}	21.7^{g}			3.1^{g}	84.2^{g}	12.7^{g}		
Tajikistan		96.5	3.5				93.1^{-2}	6.9^{-2}		
Turkmenistan	–	–	–	–	–	–	–	–	–	–
Uzbekistan	–	–	–	–	–	–	–	–	–	–

GERD by source of funds (%)

2002						2007					
Business enterprise	Government	Higher education	Private non-profit	Abroad	Not specified	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not specified
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
	$22.3^{+1, b, g}$	$39.5^{+1, b, g}$		$38.2^{+1, b, g}$			32.0^{g}	59.6^{g}		8.4^{g}	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
	100.0						100.0^{-2}				
	34.7			65.3							
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–		$100.0^{-2, e, g}$				
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
54.8^{+1}	34.0^{+1}	0.1^{+1}	0.2^{+1}	10.9^{+1}		44.8^{-1}	40.4^{-1}	3.3^{-1}	1.0^{-1}	10.6^{-1}	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
1.3	33.8	1.3		63.6		7.5	41.7			50.7	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
$4.4^{+1, b, g}$	$94.7^{+1, b, g}$	$^{+1, b, g}$		$0.9^{+1, b, g}$		2.4^{g}	97.6^{g}				
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
21.6	37.1	41.2				22.7^{-1}	74.7^{-1}			2.6^{-1}	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
8.0	41.5	33.0		5.9	11.7	$14.1^{-2, e}$	$45.1^{-2, e}$	$30.5^{-2, e}$	$^{-2, e}$	$10.4^{-2, e}$	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
	55.2			11.2	33.6		50.3			11.3	38.5
21.3	73.7		4.9			20.8	76.5	^{n}	2.6	0.1	
–	–	–	–	–	–	–	–	–	–	–	–
70.8^{d}	22.8^{d}	2.5	0.6	3.2^{d}		$77.2^{-1, d}$	$15.9^{-1, d}$	2.2^{-1}	1.7^{-1}	$3.0^{-1, d}$	
$25.5^{+1, b}$	$59.5^{+1, b}$	$8.8^{+1, b}$	$0.6^{+1, b}$	$5.6^{+1, b}$		50.7^{+1}	31.4^{+1}	14.7^{+1}	2.2^{+1}	1.0^{+1}	
52.7	45.9	0.1		1.2		36.4^{-2}	63.6^{-2}	$^{-2}$	$^{-2}$	$^{-2}$	
4.8^{+1}	$90.5^{+1, g}$	$2.2^{+1, g}$	$^{+1, g}$	$0.9^{+1, g}$	$1.6^{+1, g}$	3.1	82.4^{g}	0.5^{g}	^{g}	1.6^{g}	12.4^{g}
2.3	91.8				5.9	2.2^{-2}	91.9^{-2}	0.3^{-2}			5.5^{-2}
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–

Annex

Table 3: GERD by performing sector and source of funds, 2002 and 2007 (%)

Country/Territory	GERD by performing sector (%) 2002					2007				
	Business enterprise	Government	Higher education	Private non-profit	Not specified	Business enterprise	Government	Higher education	Private non-profit	Not specified
South Asia										
Afghanistan	–	–	–	–	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–	–	–	–	–
India	19.3[j]	76.5	4.1	[m]		29.6[e, j]	66.0[e]	4.4[e]	[m]	
Iran (Islamic Republic of)	18.6	57.5	23.9			14.2[-1]	55.3[-1]	30.5[-1]		
Maldives	–	–	–	–	–	–	–	–	–	–
Nepal	–	–	–	–	–	–	–	–	–	–
Pakistan	–	67.6[+3]	32.4[+3]	–	–	–	73.3	26.7	–	–
Sri Lanka	5.5[+2, b, j]	61.0[+2, b]	33.6[+2, b]	[+2, m]		19.1[-1, j]	51.3[-1]	29.6[-1]	[-1, m]	
Southeast Asia										
Brunei Darussalam	0.6[g]	68.5[g]	30.8[g]				91.6[-3, b, g]	8.4[-3, b, g]	[-3, b, g]	
Cambodia	12.1[e, g]	25.3[e, g]	11.8[e, g]	50.8[e, g]						
China	61.2	28.7	10.1			72.3	19.2	8.5		
Democratic People's Rep. of Korea	–	–	–	–	–	–	–	–	–	–
Hong Kong SAR of China	33.2[j]	3.1	63.6	[m]		52.6[-1, j]	2.1[-1]	45.3[-1]	[-1, m]	
Indonesia	14.3[-1, g]	81.1[-1]	4.6[-1]			3.7[-2, b, g]	96.2[-2, b, g]	[-2, b, g]	[-2, b, g]	
Japan	74.4	9.5	13.9	2.1		77.9	7.8	12.6	1.7	
Lao PDR	36.9[g]	50.9[g]	12.2[g]							
Macao, China	–	–	–	–	–	–	–	–	–	–
Malaysia	65.3	20.3	14.4			84.9[-1]	5.2[-1]	9.9[-1]	[-1]	
Myanmar	–	–	–	–	–	–	–	–	–	–
Philippines	67.8	16.9	13.2	2.1		58.6[-2]	18.6[-2]	21.3[-2]	1.5[-2]	
Republic of Korea	74.9	13.4	10.4	1.3		76.2[b]	11.7[b]	10.7[b]	1.5[b]	
Singapore	61.4	13.2	25.4			66.8	12.2	21.0		
Thailand	43.9[+1]	22.5[+1]	31.0[+1]	2.6[+1]		43.6[-2]	17.2[-2]	38.3[-2]	1.0[-2]	
Timor–Leste	–	–	–	–	–	–	–	–	–	–
Viet Nam	14.5	66.4	17.9	1.1						
Oceania										
Australia	52.5	18.8	26.0	2.7		58.3[-1]	13.7[-1]	25.1[-1]	2.8[-1]	
Cook Islands	–	–	–	–	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–	–	–	–	–
Micronesia (Federated States of)	–	–	–	–	–	–	–	–	–	–
Nauru	–	–	–	–	–	–	–	–	–	–
New Zealand	40.8[+1]	27.8[+1]	31.4[+1]			42.7	27.3	30.0		
Niue	–	–	–	–	–	–	–	–	–	–
Palau –		–	–	–	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–	–	–

-n/+n = data refer to *n* years before or after reference year; b = break in series with previous year for which data are show; c = excluding most or all capital expenditures; d = excluding defense (all or mostly); e = estimation; f = the sum of the breakdown does not add to the total; g = underestimated or partial data; h = overestimated or based on overestimated data; i = including higher education; j = including private non-profit; k = included in government; l = included in higher education; m = included in business enterprise; n = included elsewhere; o = including government

Source: GERD data: UNESCO Institute for Statistics, July 2010

GERD by source of funds (%)

2002						2007					
Business enterprise	Government	Higher education	Private non-profit	Abroad	Not specified	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not specified
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
$19.3^{h, j}$	76.5^{h}	4.1^{h}	^{m}	^{n}		$29.6^{e, h, j}$	$66.0^{e, h}$	$4.4^{e, h}$	^{m}	^{n}	
18.6	74.7	6.7				14.2^{-1}	74.6^{-1}	11.2^{-1}			
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
	87.0^{+3}	11.9^{+3}		0.3^{+3}	0.8^{+3}		82.9	12.9	1.8	1.0	1.5
$0.6^{+2, b, j}$	$67.5^{+2, b, i}$	$^{+2, k}$	$^{+2, m}$	$22.6^{+2, b}$	$9.3^{+2, b}$	$19.0^{-1, j}$	$65.2^{-1, i}$	$^{-1, k}$	$^{-1, m}$	4.8^{-1}	10.9^{-1}
8.8^{g}	91.2^{g}	^{g}	^{g}			$1.6^{-3, b, g}$	$91.0^{-3, b, g}$	$7.4^{-3, b, g}$	$^{-3, b, g}$	$^{-3, b, g}$	
	$17.9^{e, g}$		$43.0^{e, g}$	$28.4^{e, g}$	$10.6^{e, g}$						
$60.1^{+1, f}$	$29.9^{+1, f}$			$1.9^{+1, f}$	$8.0^{+1, e}$	70.4^{f}	24.6^{f}			1.3^{f}	3.7^{e}
–	–	–	–	–	–	–	–	–	–	–	–
35.3^{j}	62.8	0.2	^{m}	1.7		$52.8^{-1, j}$	43.1^{-1}	0.2^{-1}	$^{-1, m}$	3.9^{-1}	
$14.7^{-1, b, j}$	84.5^{-1}	0.2^{-1}	$^{-1, m}$		0.7^{-1}						
74.1	18.4^{e}	6.5^{e}	0.7	0.4		77.7	15.6^{e}	5.6^{e}	0.7	0.3	
36.0^{g}	8.0^{g}	2.0^{g}	^{n}	54.0^{g}							
–	–	–	–	–	–	–	–	–	–	–	–
51.5	32.1	4.9		11.5		84.7^{-1}	5.0^{-1}	9.7^{-1}	$^{-1}$	0.2^{-1}	0.4^{-1}
–	–	–	–	–	–	–	–	–	–	–	–
68.6	19.1	5.9	0.2	5.5	0.7	62.6^{-2}	25.6^{-2}	6.0^{-2}	0.7^{-2}	4.8^{-2}	0.3^{-2}
72.2	25.4	1.6	0.4	0.4		73.7^{b}	24.8^{b}	1.0^{b}	0.3^{b}	0.2^{b}	
49.9	42.3	0.7		7.2		59.8	34.9	0.9		4.3	
41.8^{+1}	38.6^{+1}	15.1^{+1}	0.6^{+1}	2.6^{+1}	1.3^{+1}	48.7^{-2}	31.5^{-2}	14.9^{-2}	0.7^{-2}	1.8^{-2}	2.4^{-2}
–	–	–	–	–	–	–	–	–	–	–	–
18.1	74.1	0.7^{j}	^{l}	6.3	0.8						
50.7^{f}	41.2^{f}	0.2^{f}	1.7^{f}	3.6^{f}	2.7^{e}	58.3^{-1}	37.3^{-1}	0.1^{-1}	1.8^{-1}	2.4^{-1}	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
38.2^{+1}	43.8^{+1}	8.8^{+1}	2.1^{+1}	7.1^{+1}		40.1	42.7	8.7	3.7	4.8	
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–

Table 4: Total researchers and per million inhabitants, 2002 and 2007

Country/Territory	2002 Total researchers	2002 Female researchers (%)*	2002 per million inhabitants	2007 Total researchers	2007 Female researchers (%)*	2007 per million inhabitants
	Researchers in full-time equivalents					
North America						
Canada	116 032	–	3 705	139 011[-1,e]	–	4 260[-1,e]
United States of America	1 342 450[e]	–	4 566[e]	1 425 550[-1,e]	–	4 663[-1,e]
Latin America						
Argentina	26 083	48.3	692	38 681	52.8[e]	980
Belize	–	–	–	–	–	–
Bolivia	1 040	–	120	–	–	–
Brazil	71 806	–	401	133 266[+1]	48.0	694[+1]
Chile	6 943	–	440	13 427[-3,b]	30.2[-3]	–
Colombia	5 167	–	126	5 570	36.6	126
Costa Rica	548[+1]	–	131[+1]	527[-2]	40.9[-2]	122[-2]
Ecuador	550	–	44	924[b]	–	69
El Salvador	293[-2]	–	49[-2]	–	–	–
Guatemala	388[+3,g]	32.1[+4,g]	31[+3,g]	389[g]	33.1[g]	29[g]
Guyana	–	–	–	–	–	–
Honduras	–	–	–	–	–	–
Mexico	31 132[e]	–	305[e]	37 930	–	353
Nicaragua	340[-5]	–	70[-5]	–	–	–
Panama	297	25.2[-6]	97	480[b]	27.7	144[b]
Paraguay	455	–	82	419[-2]	–	71[-2]
Peru	–	–	–	–	–	–
Suriname	–	–	–	–	–	–
Uruguay	1 242	–	373	1 158[+1]	45.9[+1]	346[+1]
Venezuela	1 761[g]	–	70[g]	5 261[+1,g]	52.8[+1,g]	187[+1,g]
Caribbean						
Antigua and Barbuda	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–
Barbados	–	–	–	–	–	–
Cuba	–	–	–	–	–	–
Dominica	–	–	–	–	–	–
Dominican Republic	–	–	–	–	–	–
Grenada	–	–	–	–	–	–
Haiti	–	–	–	–	–	–
Jamaica	–	–	–	–	–	–
Saint Kitts and Nevis	–	–	–	–	–	–
Saint Lucia	–	–	–	–	–	–
Saint Vincent and the Grenadines	–	–	–	–	–	–
Trinidad and Tobago	–	–	–	–	–	–
European Union						
Austria	24 124	15.8	2 984	34 377[+1]	20.6	4 123[+1]
Belgium	30 668	27.1	2 987	36 382[+1]	30.7	3 435[+1]
Bulgaria	9 223	47.2	1 169	11 384[+1]	47.8	1 499[+1]
Cyprus	435	31.5	608[e]	885[+1]	34.0	1 026[+1]
Czech Republic	14 974	26.2	1 469	29 785[+1,b]	25.4[+1,b]	2 886[+1]
Denmark	25 547[b]	26.6[b]	4 756[b]	30 945[+1,b,e]	29.3[b]	5 670[+1,e]
Estonia	3 059	41.3	2 254	3 979[+1]	41.5	2 966[+1]
Finland	38 630[a]	–	7 431[a]	40 879[+1]	–	7 707[+1]
France	186 420	–	3 116	215 755	–	3 496
Germany	265 812[e]	16.3[+1]	3 232[e]	290 853	17.7[-2]	3 532
Greece	15 631[+1]	33.3[+1]	1 418[+1]	20 817[e]	31.7[-2]	1 873[e]
Hungary	14 965[d]	31.4[+4]	1 473[d]	17 391[b]	31.7	1 733
Ireland	9 376	27.8	2 379	13 709[+1]	30.4	3 090[+1]
Italy	71 242	28.6[+1]	1 237	96 303[+1]	32.9[-1]	1 616[+1]
Latvia	3 451	53.2	1 477	4 370[+1]	48.9	1 935[+1]

Researchers in headcounts						
2002			2007			
Total researchers	Female researchers (%)*	per million inhabitants	Total researchers	Female researchers (%)*	per million inhabitants	Country/Territory
						North America
–	–	–	–	–	–	Canada
–	–	–	–	–	–	United States of America
						Latin America
41 356	50.5	1 098	59 052	51.5	1 495	Argentina
–	–	–	–	–	–	Belize
1 250$^{-1,b}$	39.6$^{-1,b}$	147$^{-1,b}$	–	–	–	Bolivia
122 699	46.0^{e}	685	210 716^{+1}	48.0	1 098^{+1}	Brazil
8 507	32.7	539	18 365$^{-3,b}$	30.0$^{-3,b}$	1 139^{-3}	Chile
10 292	34.4	250	12 017	36.4	271	Colombia
1 193	38.0	291	3 521^{b}	40.0^{b}	790	Costa Rica
696	23.0	55	1 615^{b}	44.9^{b}	121	Ecuador
252$^{+1,b}$	31.0$^{+1,b}$	42$^{+1,b}$	401^{+1}	32.9^{+1}	65^{+1}	El Salvador
615$^{+3,g}$	42.6$^{+3,g}$	48$^{+3,g}$	634^{g}	31.7^{g}	47^{g}	Guatemala
–	–	–	–	–	–	Guyana
516	28.9	80	539^{-4}	26.5^{-4}	81^{-4}	Honduras
44 577^{+1}	31.6$^{+1,e}$	432^{+1}	–	–	–	Mexico
256	42.5^{g}	49	326^{-3}	–	61^{-3}	Nicaragua
416^{b}	37.0	136^{b}	572	32.7	171	Panama
794	50.1	143	787^{-2}	46.8^{-2}	133^{-2}	Paraguay
–	–	–	4 965^{-3}	–	81^{-3}	Peru
–	–	–	–	–	–	Suriname
3 839	47.2	1 154	2 153^{+1}	52.3^{+1}	643^{+1}	Uruguay
2 077^{g}	44.4^{g}	82^{g}	6 038$^{+1,g}$	53.1$^{+1,g}$	215$^{+1,g}$	Venezuela
						Caribbean
–	–	–	–	–	–	Antigua and Barbuda
–	–	–	–	–	–	Bahamas
–	–	–	–	–	–	Barbados
6 057	48.9^{+3}	544	5 525^{+1}	48.5^{+1}	493^{+1}	Cuba
–	–	–	–	–	–	Dominica
–	–	–	–	–	–	Dominican Republic
–	–	–	–	–	–	Grenada
–	–	–	–	–	–	Haiti
–	–	–	–	–	–	Jamaica
–	–	–	–	–	–	Saint Kitts and Nevis
74^{-3}	33.3$^{-3,g}$	477^{-3}	–	–	–	Saint Lucia
21	–	194	–	–	–	Saint Vincent and the Grenadines
518^{+1}	40.2^{+1}	396^{+1}	634	38.0	477	Trinidad and Tobago
						European Union
39 557	20.7	4 893	53 590	26.4	6 451	Austria
44 133	27.7	4 298	51 278	31.1	4 869	Belgium
10 445	46.3	1 323	13 090	46.8	1 713	Bulgaria
1 014	29.4	1 418^{e}	1 532	32.6	1 941^{e}	Cyprus
30 635	29.5	3 006	44 240^{+1}	28.5^{+1}	4 287^{+1}	Czech Republic
37 883^{b}	26.2^{b}	7 053^{b}	42 992^{b}	30.2^{b}	7 895^{b}	Denmark
5 089	42.6	3 750	6 940$^{+1,e}$	44.3	5 174^{+1}	Estonia
50 215^{a}	29.9^{a}	9 659^{a}	53 420	31.5^{b}	10 111	Finland
231 816^{b}	27.8^{b}	3 874^{b}	273 542	27.4^{-1}	4 432	France
397 130^{+1}	19.5^{+1}	4 824^{+1}	437 780	23.2	5 317	Germany
28 058^{+1}	37.1^{+1}	2 546^{+1}	33 396^{-2}	36.4^{-2}	3 019^{-2}	Greece
29 764^{d}	33.7^{d}	2 930^{d}	33 059	33.5	3 295	Hungary
15 512	30.2	3 936	19 380	32.0	4 450	Ireland
108 882	28.7	1 891	137 163^{-1}	33.3^{-1}	2 326^{-1}	Italy
6 101	51.8	2 611	7 823	52.4	3 448	Latvia

Table 4: Total researchers and per million inhabitants, 2002 and 2007

Country/Territory	Researchers in full-time equivalents					
	2002			2007		
	Total researchers	Female researchers (%)*	per million inhabitants	Total researchers	Female researchers (%)*	per million inhabitants
Sub-Saharan Africa *continued*						
Lithuania	6 326	47.2	1 824	8 458^{+1}	48.5	2 547^{+1}
Luxembourg	1 949^{+1}	–	4 300^{+1}	2 282^{+1}	17.6^{-2}	4 748^{+1}
Malta	272	25.0$^{+2, b}$	690	524$^{+1, b}$	25.7	1 286^{+1}
Netherlands	38 159^{b}	–	2 373^{b}	51 052$^{+1, b}$	–	3 089^{+1}
Poland	56 725	37.5^{+1}	1 480	61 831^{+1}	39.4	1 623^{+1}
Portugal	18 984^{e}	45.0^{e}	1 834^{e}	40 563$^{+1, b}$	43.9	3 799$^{+1, b}$
Romania	20 286	45.3	925	19 394^{+1}	43.8	908^{+1}
Slovakia	9 181	40.8	1 706	12 587^{+1}	42.3^{+1}	2 331^{+1}
Slovenia	4 642	34.6	2 331	7 032^{+1}	33.7	3 490^{+1}
Spain	83 318	35.7	2 019	130 986^{+1}	37.9	2 944^{+1}
Sweden	48 186^{+1}	29.0$^{+3, a}$	5 372^{+1}	48 220$^{+1, b, e}$	28.8$^{b, g}$	5 239$^{+1, e}$
United Kingdom	198 163^{e}	–	3 337^{e}	261 406$^{+1, e}$	–	4 269^{+1}
Southeast Europe						
Albania	–	–	–	–	–	–
Bosnia and Herzegovina	232$^{+1, g}$	–	61$^{+1, g}$	745$^{b, g}$	–	197^{g}
Croatia	8 572	42.6	1 919	6 697^{+1}	47.2	1 514^{+1}
Montenegro	–	–	–	–	–	–
Republic of Moldova	2 737$^{+1, g}$	45.4^{+1}	759$^{+1, e, g}$	2 592^{g}	45.1	726$^{e, g}$
Serbia	–	–	–	8 806	47.2	1 196^{e}
FYR Macedonia	1 164	49.1	575	1 062^{-1}	51.5^{-1}	521^{-1}
Other Europe						
Andorra	–	–	–	–	–	–
Belarus	–	–	–	–	–	–
Iceland	1 917^{+1}	36.0^{+1}	6 653^{+1}	2 308^{+1}	36.4^{+1}	7 315^{+1}
Liechtenstein	–	–	–	–	–	–
Monaco	9$^{+2, g}$	44.4$^{+2, g}$	278$^{+2, e, g}$	10$^{-2, g}$	50.0$^{-2, g}$	308$^{-2, e, g}$
Norway	20 989^{+1}	–	4 596^{+1}	26 062$^{+1, e}$	–	5 468$^{+1, e}$
Russian Federation	491 944	–	3 385	451 213^{+1}	–	3 191^{+1}
San Marino	–	–	–	–	–	–
Switzerland	26 105^{-2}	–	3 634^{-2}	25 400^{-3}	–	–
Turkey	23 995	34.2	351	49 668	34.1	680
Ukraine	68 764$^{+4, g}$	–	1 476$^{+4, g}$	67 493^{g}	43.9	1 458^{g}
Sub-Saharan Africa						
Angola	–	–	–	–	–	–
Benin	–	–	–	–	–	–
Botswana	–	–	–	–	–	–
Burkina Faso	–	–	–	–	–	–
Burundi	–	–	–	–	–	–
Cameroon	–	–	–	–	–	–
Cape Verde	60	–	132	–	–	–
Central African Republic	–	–	–	–	–	–
Chad	–	–	–	–	–	–
Comoros	–	–	–	–	–	–
Congo	102$^{-2, g}$	12.8$^{-2, g}$	34$^{-2, g}$	–	–	–
Côte d'Ivoire	–	–	–	1 269$^{-2, g}$	16.5$^{-2, g}$	66$^{-2, g}$
Democratic Rep. of the Congo	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–
Ethiopia	1 608^{+3}	6.9^{+3}	22^{+3}	1 615	7.7	21
Gabon	–	–	–	–	–	–
Gambia	–	–	–	–	–	–
Ghana	–	–	–	–	–	–
Guinea	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–

Researchers in headcounts

2002			2007			
Total researchers	**Female researchers (%)***	**per million inhabitants**	**Total researchers**	**Female researchers (%)***	**per million inhabitants**	**Country/Territory**
						Sub-Saharan Africa *continued*
9 517	47.7	2 745	13 393	50.4	3 991	Lithuania
2 023[+1]	17.4[+1, e]	4 463[+1]	2 470[e]	24.1[e]	5 200[e]	Luxembourg
689	23.6[+2, b]	1 747	997	25.5	2 455	Malta
46 730	–	2 905	45 554[-4]	17.2[-4]	2 818[-4]	Netherlands
90 842	39.3[+1]	2 370	97 289	39.9	2 551	Poland
33 501[e]	44.0[e]	3 236[e]	51 443	43.4	4 834	Portugal
24 636	44.2	1 123	30 740	44.7	1 433	Romania
15 385	39.6	2 859	19 814[+1]	42.3[+1]	3 669[+1]	Slovakia
7 027	35.1	3 529	8 742	34.9	4 349	Slovenia
150 098	35.2	3 638	206 190	37.0	4 681	Spain
82 496[+3, a, b]	35.8[+3, a, b]	9 099[+3, a, b]	73 112[b]	34.5[b]	7 982[b]	Sweden
364 807[+3, e]	35.7[+3, e]	6 054[+3, e]	378 710[e]	36.6[e]	6 219[e]	United Kingdom
						South–East Europe
–	–	–	–	–	–	Albania
662[+1, g]	–	175[+1, g]	2 953[b, g]	–	782[g]	Bosnia and Herzegovina
11 136	41.7	2 494	11 109	44.6	2 508	Croatia
602[+1]	39.0[+1]	940[+1]	671	41.3	1 081	Montenegro
2 737[+1, g]	45.4[+1]	759[+1, e, g]	2 592[g]	45.1	726[e, g]	Republic of Moldova
10 855[h]	43.0[h]	1 449[e, h]	10 580[b]	47.0[b]	1 436[b, e]	Serbia
2 636	47.4	1 302	2 218[-1]	50.1[-1]	1 088[-1]	FYR Macedonia
						Other Europe
–	–	–	–	–	–	Andorra
18 557	45.1	1 864	18 995	43.3	1 953	Belarus
3 517[+1]	39.4[+1]	12 207[+1]	4 158[+1]	37.8[+1]	13 181[+1]	Iceland
–	–	–	–	–	–	Liechtenstein
9[+2, g]	44.4[+2, g]	278[+2, g]	10[-2, g]	50.0[-2, g]	308[-2, e, g]	Monaco
35 700[+1]	29.4[+1]	7 817[+1]	41 752	33.3	8 845	Norway
414 676[g]	43.2[g]	2 853[g]	375 804[+1, g]	41.8[+1, g]	2 658[+1g]	Russian Federation
–	–	–	–	–	–	San Marino
44 230[-2]	20.3[-2]	6 157[-2, a]	43 220[-3]	26.7[-3]	5 846[-3]	Switzerland
71 288	35.6	1 042	101 961	36.7	1 397	Turkey
85 211	42.9	1 774	78 832	43.9	1 703	Ukraine
						Sub–Saharan Africa
–	–	–	–	–	–	Angola
–	–	–	1 000[e]	–	119[e]	Benin
–	–	–	1 732[-2, g]	30.8[-2, g]	942[-2, g]	Botswana
236[g]	14.4[g]	19[g]	187[b, g]	13.4[b, g]	13[b, g]	Burkina Faso
–	–	–	–	–	–	Burundi
–	–	–	462[-2, g]	19.0[-2, g]	26[-2, g]	Cameroon
107	52.3	235	–	–	–	Cape Verde
11[+3, g]	–	3[+3, g]	41[g]	41.5[g]	10[g]	Central African Republic
–	–	–	–	–	–	Chad
–	–	–	–	–	–	Comoros
–	–	–	–	–	–	Congo
–	–	–	2 397[-2, g]	16.5[-2, g]	125[-2, g]	Côte d'Ivoire
9 072[+2, h]	–	158[+2, h]	10 411[-2, h]	–	176[-2, g]	Democratic Rep. of the Congo
–	–	–	–	–	–	Equatorial Guinea
–	–	–	–	–	–	Eritrea
2 187[+3]	6.3[+3]	29[+3]	2 377	7.4	30	Ethiopia
80[+2, g]	31.3[+2, g]	60[+2, g]	150[-1, g]	24.7[-1, g]	107[-1, g]	Gabon
40[g]	–[g]	29[g]	46[-2, g]	8.7[-2, g]	30[-2, g]	Gambia
–	–	–	–	–	–	Ghana
2 117[-2, g]	5.8[-2, g]	253[-2, g]	–	–	–	Guinea
–	–	–	–	–	–	Guinea–Bissau

Table 4: Total researchers and per million inhabitants, 2002 and 2007

Country/Territory	Researchers in full-time equivalents: 2002 Total researchers	2002 Female researchers (%)*	2002 per million inhabitants	2007 Total researchers	2007 Female researchers (%)*	2007 per million inhabitants
Sub-Saharan Africa *continued*						
Kenya	–	–	–	–	–	–
Lesotho	12[g]	62.5[h]	6[g]	20[-3, g]	58.8[-3, h]	10[-3]
Liberia	–	–	–	–	–	–
Madagascar	788[g]	30.6[g]	49[g]	937[g]	34.2[g]	50[g]
Malawi	–	–	–	–	–	–
Mali	–	–	–	513[-1, g]	13.3[-1, g]	42[-1, g]
Mauritius	–	–	–	–	–	–
Mozambique	–	–	–	337[-1, b, g]	33.5	16[-1, b, g]
Namibia	–	–	–	–	–	–
Niger	104[g]	–	9[g]	101[-2, g]	–	8[-2, g]
Nigeria	–	–	–	–	–	–
Rwanda	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–
Senegal	3 011[+4, e, g]	10.0[+4, e, g]	260[+4, e, g]	3 277[e, g]	10.0[e, g]	276[e, g]
Seychelles	–	–	–	13[-2, g]	30.8[-2, g]	157[+2, e, g]
Sierra Leone	–	–	–	–	–	–
Somalia	–	–	–	–	–	–
South Africa	14 131[+1]	35.8[+1]	302[+1]	19 320	38.3[-1]	393
Swaziland	–	–	–	–	–	–
Togo	142[+1]	–	25[+1]	216[b]	12.2[g]	34[b]
Uganda	–	–	–	–	–	–
United Republic of Tanzania	–	–	–	–	–	–
Zambia	536[-3, g]	14.2[-4, g]	53[-3, g]	–	–	–
Zimbabwe	–	–	–	–	–	–
Arab states						
Algeria	–	–	–	5 593[-2, g]	36.5[-2, g]	170[-2, g]
Bahrain	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–
Egypt	–	–	–	49 363[g]	–	617[g]
Iraq	–	–	–	–	–	–
Jordan	9 090[-4]	17.9[-4]	1 952[-4]	–	–	–
Kuwait	346[g]	–	142[g]	472[g]	35.2[g]	166[g]
Lebanon	–	–	–	–	–	–
Libyan Arab Jamahiriya	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–
Morocco	–	–	–	19 972[-1, g]	29.8[-1, g]	647[-1, g]
Oman	–	–	–	–	–	–
Palestinian Autonomous Territories	–	–	–	–	–	–
Qatar	–	–	–	–	–	–
Saudi Arabia	–	–	–	–	–	–
Sudan	–	–	–	–	–	–
Syrian Arab Republic	–	–	–	–	–	–
Tunisia	9 910[h]	48.6[+1]	1 030[h]	15 833[-1, h]	47.7[-2]	1 588[-1, h]
United Arab Emirates	–	–	–	–	–	–
Yemen	–	–	–	–	–	–
Central and West Asia						
Armenia	–	–	–	–	–	–
Azerbaijan	–	–	–	–	–	–
Georgia	–	–	–	–	–	–
Israel	–	–	–	–	–	–
Kazakhstan	–	–	–	–	–	–
Kyrgyzstan	–	–	–	–	–	–
Mongolia	–	–	–	–	–	–
Tajikistan	–	–	–	–	–	–
Turkmenistan	–	–	–	–	–	–
Uzbekistan	–	–	–	–	–	–

Researchers in headcounts						
2002			2007			
Total researchers	Female researchers (%)*	per million inhabitants	Total researchers	Female researchers (%)*	per million inhabitants	Country/Territory
						Sub-Saharan Africa *continued*
–	–	–	–	–	–	Kenya
49[g]	75.6[h]	25[g]	68[-3, g]	55.7[-3, h]	34[-3, g]	Lesotho
–	–	–	–	–	–	Liberia
1 329[g]	31.2[g]	82[g]	1 852[g]	35.2[g]	100[g]	Madagascar
–	–	–	–	–	–	Malawi
–	–	–	1 236[-1, g]	12.1[-1, g]	102[-1, g]	Mali
231[-5]	19.9[-5]	200[-5]	–	–	–	Mauritius
468[g]	–	24[g]	337[-1, b, g]	33.5[-1, b, g]	16[-1, b, g]	Mozambique
–	–	–	–	–	–	Namibia
128[g]	–	11[g]	129[-2, g]	–	10[-2, g]	Niger
18 973[g]	18.3[g]	145[g]	28 533[-2, g]	17.0[-2, g]	203[-2, g]	Nigeria
–	–	–	–	–	–	Rwanda
–	–	–	–	–	–	Sao Tome and Principe
8 043[+4, e, g]	9.9[+4, e, g]	694[e, g]	8 709[e, g]	9.9[e, g]	732[e, g]	Senegal
–	–	–	14[-2, g]	35.7[-2, g]	169[-2, g]	Seychelles
–	–	–	–	–	–	Sierra Leone
–	–	–	–	–	–	Somalia
30 707[+1]	38.0[+1]	655[+1]	40 084	40.3[e]	815	South Africa
–	–	–	–	–	–	Swaziland
428[+1]	–	75[+1]	834[b]	12.0[g]	132[b]	Togo
630	37.5	24	891	41.0	29	Uganda
–	–	–	–	–	–	United Republic of Tanzania
268[b, g]	12.4[b, g]	24[b, g]	792[-2, g]	27.4[-2, g]	67[-2, g]	Zambia
–	–	–	–	–	–	Zimbabwe
						Arab states
–	–	–	13 805[-2, g]	34.8[-2, g]	420[-2, g]	Algeria
–	–	–	–	–	–	Bahrain
–	–	–	–	–	–	Djibouti
–	–	–	95 947[g]	36.2[e, g]	1 198[g]	Egypt
–	–	–	–	–	–	Iraq
15 891[+1, b]	21.3[+1, b]	3 030[+1, b]	–	–	–	Jordan
346[g]	–	142[g]	472[g]	35.2[g]	166[g]	Kuwait
–	–	–	–	–	–	Lebanon
215[+2]	–	37[+2]	373	–	60	Libyan Arab Jamahiriya
–	–	–	–	–	–	Mauritania
25 790[g]	26.4[g]	874[g]	28 089[-1, g]	28.2[-1, g]	910[-1, g]	Morocco
–	–	–	–	–	–	Oman
–	–	–	–	–	–	Palestinian Autonomous Territories
–	–	–	–	–	–	Qatar
1 513[g]	17.4[g]	69[g]	1 024[b, g]	–	41[b, g]	Saudi Arabia
9 100[e]	30.3[e]	250[e]	11 208[-2, e]	40.0[-2, e]	290[-2, e]	Sudan
–	–	–	–	–	–	Syrian Arab Republic
17 725[h]	44.9[+1]	1 842[h]	27 529[-1, h]	44.6[-2]	2 761[-1, h]	Tunisia
–	–	–	–	–	–	United Arab Emirates
–	–	–	–	–	–	Yemen
						Central and West Asia
4 927[g]	47.0[g]	1 610[g]	4 114[g]	44.7[g]	1 339[g]	Armenia
10 195	51.4	1 293[e]	11 280	52.0	1 358[e]	Azerbaijan
11 997	51.4	2 592	8 112[-2]	52.7[-2]	1 817[-2]	Georgia
–	–	–	–	–	–	Israel
9 366	48.7	627	10 780[+1]	51.3[+1]	695[+1]	Kazakhstan
2 065	49.3	407	2 034	43.7	380	Kyrgyzstan
1 973[g]	46.8[g]	805[g]	1 740[g]	48.1[g]	666[g]	Mongolia
1 752	40.0	278	1 286	38.8[-1]	191	Tajikistan
–	–	–	–	–	–	Turkmenistan
–	–	–	–	–	–	Uzbekistan

Table 4: Total researchers and per million inhabitants, 2002 and 2007

Country/Territory	Researchers in full-time equivalents 2002 Total researchers	2002 Female researchers (%)*	2002 per million inhabitants	2007 Total researchers	2007 Female researchers (%)*	2007 per million inhabitants
South Asia						
Afghanistan	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–
India	115 936[-2]	12.0[-2, g]	111[-2]	154 827[-2, e]	14.8[-2, e, g]	137[-2, e]
Iran (Islamic Republic of)	–	–	–	50 546[-1]	24.0[-1]	706[-1]
Maldives	–	–	–	–	–	–
Nepal	1 500[e]	–	59[e]	–	–	–
Pakistan	12 689[+3]	16.2[+3]	77[+3]	26 338[b]	23.4[b]	152[b]
Sri Lanka	2 679[+2, b]	32.1[+2, b]	138[+2, b]	1 833[-1]	41.1[-1]	93[-1]
Southeast Asia						
Brunei Darussalam	99[g]	–	284[g]	102[-3, b, g]	–	281[-3, b, g]
Cambodia	223[e, g]	22.6[e, g]	17[e, g]	–	–	–
China	810 525	–	630	1 423 380	–	1 071
Democratic People's Rep. of Korea	–	–	–	–	–	–
Hong Kong SAR of China	10 639	–	1 570	18 326[-1]	–	2 650[-1]
Indonesia	42 722[-1]	–	205[-1]	–	–	–
Japan	646 547[b]	–	5 087[b]	709 974	–	5 573
Lao PDR	87	–	16	–	–	–
Macao, China	105[e, g]	15.4[e, g]	230[e, g]	298[-2, e, g]	20.8[-2, e, g]	612[-2, e, g]
Malaysia	7 157	34.2	295	9 694[-1]	38.8[-1]	372[-1]
Myanmar	837[g]	–	18[g]	–	–	–
Philippines	5 860[+1]	52.7[+1, e]	71[+1]	6 896[-2]	50.7[-2]	81[-2]
Republic of Korea	141 917	6.5[-4]	3 023	221 928[b]	–	4 627[b]
Singapore	18 120	–	4 398	27 301	–	6 088
Thailand	18 114[+1]	–	281[+1]	20 506[-2]	49.9[-2]	311[-2]
Timor–Leste	–	–	–	–	–	–
Viet Nam	9 328	–	115	–	–	–
Oceania						
Australia	73 173	–	3 723	87 140[-1]	–	4 224[-1]
Cook Islands	–	–	–	–	–	–
Fiji	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–
Micronesia (Federated States of)	–	–	–	–	–	–
Nauru	–	–	–	–	–	–
New Zealand	15 822[+1]	–	3 943[+1]	18 300	–	4 365
Niue	–	–	–	–	–	–
Palau –		–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–
Samoa	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–
Tonga	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–

Researchers in headcounts

2002			2007			
Total researchers	Female researchers (%)*	per million inhabitants	Total researchers	Female researchers (%)*	per million inhabitants	Country/Territory
						South Asia
–	–	–	–	–	–	Afghanistan
6 097^{-5}	14.0^{-5}	46^{-5}	–	–	–	Bangladesh
–	–	–	–	–	–	Bhutan
–	–	–	–	–	–	India
51 899^{+2}	19.8^{+2}	742^{+2}	67 795^{-1}	23.0^{-1}	947^{-1}	Iran (Islamic Republic of)
–	–	–	–	–	–	Maldives
3 000^{e}	15.0^{e}	117^{e}	–	–	–	Nepal
30 982^{+3}	23.4^{+3}	187^{+3}	53 729^{b}	27.3^{b}	310^{b}	Pakistan
4 602$^{+2, b}$	35.4$^{+2, b}$	238$^{+2, b}$	4 520^{-1}	41.5^{-1}	229^{-1}	Sri Lanka
						Southeast Asia
294^{g}	26.9^{g}	844^{g}	244$^{-3, b, g}$	40.6$^{-3, b, g}$	673$^{-3, b, g}$	Brunei Darussalam
744$^{e, g}$	20.7$^{e, g}$	56$^{e, g}$	–	–	–	Cambodia
–	–	–	–	–	–	China
–	–	–	–	–	–	Democratic People's Rep. of Korea
12 611	–	1 861	20 634^{-1}	–	2 984^{-1}	Hong Kong SAR of China
92 817^{-1}	–	446^{-1}	35 564$^{-2, b, g}$	30.6^{-2}	162$^{-2, b, g}$	Indonesia
791 224	11.2	6 225	883 386	13.0	6 934	Japan
209	23.0^{e}	37	–	–	–	Lao PDR
197$^{e, g}$	18.8$^{e, g}$	431$^{e, g}$	561$^{-2, e, g}$	21.6$^{-2, e, g}$	1 150$^{-2, e, g}$	Macao, China
17 790	35.8^{+2}	734	19 021^{-1}	37.7^{-1}	729^{-1}	Malaysia
4 725^{g}	85.5^{h}	100^{g}	–	–	–	Myanmar
7 203	54.0	89	10 690^{-2}	52.0^{-2}	125^{-2}	Philippines
189 888	11.6	4 045	289 098^{b}	14.9^{b}	6 028^{b}	Republic of Korea
21 531	25.6	5 225	31 657	27.4	7 059	Singapore
29 850^{+1}	45.6^{+1}	463^{+1}	34 084^{-2}	50.3^{-2}	517^{-2}	Thailand
–	–	–	–	–	–	Timor–Leste
41 117	42.8	508	–	–	–	Viet Nam
						Oceania
–	–	–	–	–	–	Australia
–	–	–	–	–	–	Cook Islands
–	–	–	–	–	–	Fiji
–	–	–	–	–	–	Kiribati
–	–	–	–	–	–	Marshall Islands
–	–	–	–	–	–	Micronesia (Federated States of)
19$^{+1, g}$	15.8$^{+1, g}$	1 925$^{+1, e, g}$	–	–	–	Nauru
25 486^{+1}	39.3^{-1}	5 635^{-1}	29 700	–	7 084	New Zealand
–	–	–	–	–	–	Niue
–	–	–	–	–	–	Palau –
–	–	–	–	–	–	Papua New Guinea
–	–	–	–	–	–	Samoa
–	–	–	–	–	–	Solomon Islands
–	–	–	–	–	–	Tonga
–	–	–	–	–	–	Tuvalu
–	–	–	–	–	–	Vanuatu

-n/+n = data refer to *n* years before or after reference year; a = university graduates instead of researchers; b = break in series with previous year for which data are show; e = estimation; g = underestimated or partial data; h = overestimated or based on overestimated data

Note: The year for the share of female researchers may not be the same as the year for total researchers for some countries.

Source: UNESCO Institute for Statistics

Table 5: Scientific publications by country, 2000–2008

Country/Territory	Scientific publications								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
North America									
Canada	29 813	29 211	30 310	32 813	34 574	37 844	40 343	41 179	43 539
United States of America	224 643	223 085	226 894	237 139	247 301	256 956	264 079	267 488	272 879
Latin America									
Argentina	4 297	4 394	4 719	4 613	4 755	4 959	5 317	5 630	6 197
Belize	2	4	5	8	6	12	12	6	6
Bolivia	59	76	85	107	105	118	120	175	175
Brazil	10 521	11 201	12 573	13 331	15 436	16 503	18 473	22 289	26 482
Chile	1 817	1 990	2 271	2 484	2 600	2 847	3 042	3 335	3 646
Colombia	627	602	698	682	767	834	1 005	1 265	1 856
Costa Rica	192	253	235	253	276	292	283	306	375
Ecuador	115	96	135	151	149	192	188	241	266
El Salvador	11	11	12	6	20	19	14	16	17
Guatemala	32	49	46	43	53	57	50	61	55
Guyana	10	12	13	7	8	20	11	21	17
Honduras	19	17	20	25	18	25	28	23	22
Mexico	4 610	4 966	5 239	5 798	6 409	6 742	6 860	7 697	8 262
Nicaragua	25	18	14	23	26	37	50	35	50
Panama	78	121	120	129	154	145	178	203	235
Paraguay	24	24	23	26	38	28	29	37	34
Peru	179	222	220	302	279	317	365	439	453
Suriname	4	7	6	7	10	12	6	6	7
Uruguay	311	307	317	353	386	416	419	447	559
Venezuela	976	974	1 051	1 083	980	1 081	1 109	1 097	1 263
Caribbean									
Antigua and Barbuda	–	2	2	3	–	5	4	6	8
Bahamas	6	6	6	3	6	7	9	16	9
Barbados	31	37	30	45	55	42	38	39	50
Cuba	610	674	583	669	617	652	709	708	775
Dominica	1	5	1	3	3	4	5	5	2
Dominican Republic	35	20	14	17	23	18	18	24	35
Grenada	4	2	2	13	6	7	23	44	53
Haiti	11	7	11	11	8	12	21	11	20
Jamaica	106	142	138	126	143	130	124	132	160
Saint Kitts and Nevis	4	2	3	4	1	3	6	5	8
Saint Lucia	2	3	4	1	–	2	1	2	1
Saint Vincent and the Grenadines	2	1	1	–	1	1	2	1	–
Trinidad and Tobago	94	110	111	111	113	136	106	134	127
European Union									
Austria	6 915	7 370	7 460	7 925	8 233	8 439	8 607	9 218	9 656
Belgium	9 436	9 706	10 217	10 918	11 370	12 157	12 357	13 087	13 773
Bulgaria	1 519	1 450	1 528	1 512	1 602	1 742	1 682	2 215	2 227
Cyprus	152	149	186	169	223	250	286	320	370
Czech Republic	4 176	4 399	4 700	5 036	5 549	5 663	6 390	6 980	7 565
Denmark	7 445	7 536	7 469	7 856	8 145	8 435	8 761	9 011	9 316
Estonia	519	566	543	582	662	724	758	896	918
Finland	7 007	7 128	7 161	7 319	7 612	7 689	8 152	8 161	8 328
France	47 068	46 717	47 219	48 341	49 132	51 447	53 444	53 757	57 133
Germany	64 745	64 675	65 500	66 319	68 599	71 709	73 319	74 481	76 368
Greece	4 808	5 170	5 588	5 944	6 723	7 337	8 429	8 998	9 296
Hungary	4 103	4 129	4 140	4 458	4 352	4 765	4 919	4 921	5 399
Ireland	2 431	2 493	2 656	2 852	3 325	3 750	4 147	4 356	4 824
Italy	31 020	32 246	33 221	35 867	37 615	39 293	41 247	43 474	45 273
Latvia	323	339	349	309	336	306	293	357	408
Lithuania	466	501	602	650	806	864	1 098	1 635	1 672
Luxembourg	93	99	103	107	157	166	192	211	302

Country/Territory	Scientific publications								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
European Union *continued*									
Malta	28	32	41	57	40	60	52	67	98
Netherlands	17 383	17 250	18 037	18 880	19 757	21 182	21 783	22 128	22 945
Poland	9 890	10 913	11 340	12 591	13 702	13 615	14 795	15 850	17 916
Portugal	3 117	3 450	3 847	4 318	4 907	5 123	6 336	6 056	7 106
Romania	1 918	1 934	2 127	2 166	2 290	2 492	2 856	3 865	4 975
Slovakia	1 799	1 838	1 840	1 841	2 091	1 898	2 206	2 433	2 632
Slovenia	1 550	1 497	1 609	1 778	1 735	1 996	2 065	2 359	2 766
Spain	21 537	22 663	24 105	25 154	27 045	29 108	31 446	33 498	35 739
Sweden	14 242	14 568	14 686	14 593	15 130	15 719	16 094	16 244	16 068
United Kingdom	62 478	60 738	61 073	62 645	64 646	66 390	69 047	71 001	71 302
Southeast Europe									
Albania	30	26	35	33	28	35	24	39	52
Bosnia and Herzegovina	24	42	35	52	51	90	89	249	287
Croatia	1 151	1 155	1 254	1 352	1 481	1 596	1 672	2 040	2 348
Montenegro	–	–	–	–	–	1	7	61	93
Republic of Moldova	173	156	160	199	162	211	219	180	223
Serbia	1 041	988	1 003	1 160	1 397	1 604	1 755	2 264	2 729
FYR Macedonia	123	132	104	100	111	105	124	171	197
Other Europe									
Andorra	1	3	3	2	1	3	8	8	1
Belarus	1 079	954	975	980	927	961	931	908	1 021
Iceland	266	318	328	363	374	402	428	467	531
Liechtenstein	27	13	12	26	26	30	35	36	44
Monaco	32	45	42	52	62	61	58	55	56
Norway	4 462	4 702	4 592	4 812	5 263	5 782	6 358	6 619	6 958
Russian Federation	26 939	25 168	25 493	24 930	24 774	24 365	23 730	25 266	27 083
San Marino	1	–	–	–	1	1	1	4	3
Switzerland	13 583	13 065	13 403	14 300	15 311	15 777	17 083	17 535	18 156
Turkey	5 159	6 351	8 608	10 182	12 764	13 573	14 460	16 863	17 787
Ukraine	4 137	4 173	3 990	3 807	3 868	3 967	3 900	4 131	4 979
Sub–Saharan Africa									
Angola	12	13	11	5	9	17	13	15	12
Benin	64	52	70	66	86	84	113	126	153
Botswana	92	82	97	101	105	106	133	141	138
Burkina Faso	64	80	87	110	117	105	149	137	179
Burundi	4	7	2	11	6	7	5	14	6
Cameroon	172	180	227	261	282	293	386	405	463
Cape Verde	–	1	–	3	1	1	6	1	3
Central African Republic	13	11	10	12	16	20	19	19	16
Chad	6	9	11	12	7	21	24	11	12
Comoros	1	1	1	2	3	4	1	6	3
Congo	26	20	37	36	41	48	75	76	61
Côte d'Ivoire	129	112	111	140	119	106	122	151	171
Democratic Rep. of the Congo	23	10	11	16	14	21	12	24	30
Equatorial Guinea	1	3	2	4	4	1	2	2	1
Eritrea	11	18	22	16	18	23	29	21	14
Ethiopia	208	191	239	246	267	259	275	362	364
Gabon	45	56	56	57	56	57	70	70	76
Gambia	53	66	59	67	68	65	86	64	77
Ghana	153	143	158	159	172	195	214	255	267
Guinea	5	19	13	11	12	13	27	21	14
Guinea –Bissau	11	11	21	19	19	19	15	25	16
Kenya	465	471	507	558	541	533	642	699	763
Lesotho	5	5	5	4	3	3	11	7	11
Liberia	–	3	5	1	3	4	3	–	6

Table 5: Scientific publications by country, 2000–2008

Country/Territory	Scientific publications								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
Sub-Saharan Africa *continued*									
Madagascar	69	70	51	96	80	104	131	146	141
Malawi	103	96	105	107	103	106	121	155	161
Mali	30	46	52	52	67	68	95	74	88
Mauritius	38	43	53	33	44	42	46	36	39
Mozambique	24	40	27	31	38	51	57	72	76
Namibia	24	58	41	46	45	76	73	61	59
Niger	39	37	40	44	30	65	60	63	77
Nigeria	723	623	694	681	737	940	1 097	1 537	1 869
Rwanda	5	8	7	5	14	11	23	32	23
Sao Tome and Principe	2	1	3	5	1	–	2	1	1
Senegal	165	152	148	197	178	201	180	210	211
Seychelles	13	6	7	13	6	11	20	24	19
Sierra Leone	7	11	5	3	4	4	4	7	10
Somalia	1	–	1	–	1	–	2	–	1
South Africa	3 241	3 435	3 538	3 546	3 782	4 026	4 539	4 885	5 248
Swaziland	5	11	11	14	6	19	8	13	19
Togo	32	22	17	33	36	32	35	36	43
Uganda	142	146	133	174	231	221	271	377	354
United Republic of Tanzania	201	190	207	252	256	298	359	395	376
Zambia	61	77	64	68	71	91	111	122	121
Zimbabwe	188	184	199	199	153	159	170	204	194
Arab states									
Algeria	410	445	483	582	703	770	948	1 157	1 289
Bahrain	49	59	43	68	83	91	112	116	98
Djibouti	–	1	1	1	3	2	2	3	2
Egypt	2 304	2 407	2 569	2 850	2 809	2 828	3 139	3 506	3 963
Iraq	55	73	63	81	52	84	122	167	184
Jordan	459	454	511	549	594	624	646	792	928
Kuwait	469	481	448	449	492	494	518	545	607
Lebanon	256	312	312	348	385	453	531	520	591
Libyan Arab Jamahiriya	41	48	42	65	56	67	90	96	100
Mauritania	16	13	14	20	11	25	20	19	13
Morocco	1 041	1 082	1 071	991	969	970	977	1 064	1 167
Oman	185	210	237	262	251	268	269	309	315
Palestinian Autonomous Territories	–	1	–	–	–	–	–	–	–
Qatar	38	47	47	69	106	106	121	159	195
Saudi Arabia	1 321	1 252	1 329	1 340	1 336	1 277	1 348	1 483	1 745
Sudan	76	69	92	98	100	115	108	142	146
Syrian Arab Republic	106	117	102	129	143	160	149	186	198
Tunisia	540	667	747	876	933	1 199	1 485	1 727	2 026
United Arab Emirates	270	302	327	400	441	506	562	595	660
Yemen	35	40	31	26	41	41	51	53	56
Central and West Asia									
Armenia	313	317	363	389	400	377	395	414	544
Azerbaijan	160	137	183	227	210	234	233	224	292
Georgia	246	224	271	231	290	300	355	319	328
Israel	8 880	8 752	9 136	9 498	9 624	9 619	10 077	9 962	10 069
Kazakhstan	184	190	211	244	230	189	206	253	218
Kyrgyzstan	36	47	38	24	30	43	46	50	54
Mongolia	40	41	43	57	62	65	69	94	115
Tajikistan	29	34	44	29	31	32	30	44	45
Turkmenistan	13	7	10	6	3	4	6	8	3
Uzbekistan	329	289	299	292	302	291	282	331	301

Country/Territory	Scientific publications								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
South Asia									
Afghanistan	–	–	–	3	8	7	7	6	16
Bangladesh	335	377	385	430	446	474	554	614	729
Bhutan	3	2	7	5	11	8	22	5	6
India	16 650	17 635	18 911	20 772	22 375	24 422	27 418	32 041	36 261
Iran (Islamic Republic of)	1 296	1 571	2 102	2 869	3 534	4 610	6 000	8 770	10 894
Maldives	1	2	1	2	–	1	3	5	3
Nepal	103	113	117	134	148	148	196	193	223
Pakistan	553	535	703	808	885	1 104	1 525	2 303	2 994
Sri Lanka	158	159	185	256	226	266	265	305	400
Southeast Asia									
Brunei Darussalam	31	26	25	32	34	27	26	35	40
Cambodia	14	14	20	23	41	50	64	80	75
China	28 916	33 996	38 206	46 428	56 815	69 175	83 419	92 380	104 968
Democratic People's Rep. of Korea	1	–	4	5	15	11	10	21	35
Hong Kong SAR of China	334	52	1	–	–	–	–	–	–
Indonesia	429	449	421	428	471	526	597	582	650
Japan	72 681	72 213	73 429	75 779	76 156	75 608	76 039	74 468	74 618
Lao PDR	9	12	16	24	27	34	49	44	52
Macao, China	9	7	9	11	14	–	–	–	–
Malaysia	805	906	961	1 123	1 308	1 520	1 757	2 151	2 712
Myanmar	19	21	12	21	30	38	42	40	37
Philippines	353	317	398	418	427	467	464	535	624
Republic of Korea	13 374	15 507	17 072	20 076	23 571	25 576	27 828	28 305	32 781
Singapore	3 465	3 781	4 135	4 621	5 434	5 971	6 300	6 249	6 813
Thailand	1 182	1 344	1 636	1 940	2 116	2 409	3 000	3 582	4 134
Timor –Leste	–	–	–	–	–	–	–	–	–
Viet Nam	315	353	343	458	434	540	617	698	875
Oceania									
Australia	18 945	19 155	19 645	20 920	22 456	23 376	25 449	26 619	28 313
Cook Islands	2	–	1	–	–	1	1	3	–
Fiji	23	23	33	33	41	58	62	60	59
Kiribati	–	–	–	–	–	–	1	2	–
Marshall Islands	1	–	2	3	4	1	5	–	1
Micronesia (Federated States of)	5	1	–	6	6	4	5	6	3
Nauru	–	–	–	–	–	–	–	–	–
New Zealand	3 762	3 772	3 819	3 935	4 260	4 590	4 739	4 974	5 236
Niue	–	–	–	–	–	–	–	1	–
Palau 2		7	2	3	6	7	8	10	3
Papua New Guinea	68	72	65	62	53	43	50	81	79
Samoa	2	2	7	1	5	3	6	1	–
Solomon Islands	11	4	4	9	5	5	7	8	4
Tonga	2	2	1	5	4	–	3	4	4
Tuvalu	1	–	–	1	–	–	1	–	–
Vanuatu	7	3	5	8	9	12	9	6	9

Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

Table 6: Publications by major field of science, 2002 and 2008

Country/Territory	Biology 2002	Biology 2008	Biomedical research 2002	Biomedical research 2008	Chemistry 2002	Chemistry 2008	Clinical medicine 2002	Clinical medicine 2008
North America								
Canada	3 351	4 571	4 779	6 018	2 306	3 022	9 761	14 683
United States of America	17 349	21 234	41 135	45 125	17 334	18 984	81 871	103 835
Latin America								
Argentina	826	1 287	664	883	536	669	1 078	1 316
Belize	3	3	–	–	–	–	1	2
Bolivia	33	75	6	19	2	8	28	42
Brazil	1 572	5 526	1 583	3 467	1 656	2 390	3 243	8 799
Chile	322	633	249	430	271	303	494	778
Colombia	141	329	79	129	83	168	184	543
Costa Rica	108	175	28	54	21	11	44	89
Ecuador	34	82	14	32	3	3	37	50
El Salvador	2	3	2	5	–	–	5	4
Guatemala	13	14	13	8	–	–	17	28
Guyana	7	6	–	–	3	4	1	6
Honduras	6	5	4	1	–	–	8	14
Mexico	874	1 669	558	911	474	716	994	1 749
Nicaragua	2	8	–	8	–	1	7	15
Panama	73	140	27	47	–	4	10	26
Paraguay	5	8	3	5	2	–	12	20
Peru	50	102	25	53	4	9	87	189
Suriname	3	3	–	–	–	–	3	3
Uruguay	71	125	60	105	22	55	78	148
Venezuela	125	241	142	162	150	136	289	334
Caribbean								
Antigua and Barbuda	–	1	–	2	–	–	2	5
Bahamas	–	5	–	2	–	–	4	2
Barbados	6	8	3	11	1	3	7	18
Cuba	129	156	65	81	71	96	151	214
Dominica	–	1	–	–	–	–	1	–
Dominican Republic	4	12	2	1	–	1	6	17
Grenada	–	2	–	21	–	–	1	30
Haiti	–	–	1	3	–	2	9	13
Jamaica	18	23	13	10	16	10	71	92
Saint Kitts and Nevis	–	–	–	–	–	–	2	8
Saint Lucia	2	–	–	1	–	–	2	–
Saint Vincent and the Grenadines	–	–	–	–	–	–	–	–
Trinidad and Tobago	28	25	8	11	9	5	50	54
European Union								
Austria	490	682	982	1 273	647	765	2 955	3 515
Belgium	809	1 278	1 441	1 740	1 079	1 197	3 512	5 030
Bulgaria	88	477	152	209	336	409	183	292
Cyprus	12	21	11	28	22	34	34	55
Czech Republic	519	1 040	632	986	871	1 102	726	1 473
Denmark	881	1 015	1 302	1 569	504	558	2 612	3 674
Estonia	62	153	70	135	56	76	101	174
Finland	755	871	1 057	1 189	562	591	2 562	2 835
France	2 975	3 865	6 563	7 169	5 401	6 090	13 069	16 034
Germany	3 838	5 155	8 742	10 006	7 399	8 344	20 781	24 708
Greece	476	760	472	793	575	720	1 617	3 513
Hungary	319	743	574	712	741	715	1 030	1 385
Ireland	349	486	359	753	231	380	898	1 626
Italy	1 711	2 941	3 912	5 179	3 413	3 805	11 280	16 673
Latvia	18	28	36	32	82	65	38	59
Lithuania	33	146	65	94	99	123	67	301
Luxembourg	11	29	17	36	5	21	48	99

Earth and space		Engineering and technology		Mathematics		Physics		Total	
2002	2008	2002	2008	2002	2008	2002	2008	2002	2008
2 620	3 877	3 763	5 971	1 102	1 763	2 628	3 634	30 310	43 539
15 206	19 819	23 939	28 572	6 724	9 356	23 336	25 954	226 894	272 879
407	631	362	487	118	229	728	695	4 719	6 197
1	1	–	–	–	–	–	–	5	6
12	23	2	3	–	–	2	5	85	175
657	1 028	1 259	2 209	398	708	2 205	2 355	12 573	26 482
440	650	163	346	114	208	218	298	2 271	3 646
36	67	62	345	19	56	94	219	698	1 856
14	20	10	10	2	7	8	9	235	375
21	41	5	5	–	2	21	51	135	266
2	4	1	–	–	–	–	1	12	17
2	3	1	1	–	–	–	1	46	55
2	–	–	1	–	–	–	–	13	17
–	–	1	1	–	–	1	1	20	22
484	739	610	996	219	322	1 026	1 160	5 239	8 262
5	17	–	–	–	–	–	1	14	50
8	18	2	–	–	–	–	–	120	235
–	–	1	1	–	–	–	–	23	34
31	62	4	20	2	6	17	12	220	453
–	1	–	–	–	–	–	–	6	7
19	34	17	34	14	18	36	40	317	559
40	58	137	162	51	63	117	107	1 051	1 263
–	–	–	–	–	–	–	–	2	8
1	–	1	–	–	–	–	–	6	9
1	3	4	3	3	1	5	3	30	50
18	33	57	90	14	26	78	79	583	775
–	–	–	–	–	–	–	1	1	2
1	2	1	2	–	–	–	–	14	35
1	–	–	–	–	–	–	–	2	53
1	1	–	1	–	–	–	–	11	20
17	12	2	9	1	4	–	–	138	160
1	–	–	–	–	–	–	–	3	8
–	–	–	–	–	–	–	–	4	1
1	–	–	–	–	–	–	–	1	–
4	19	9	12	1	1	2	–	111	127
420	748	764	1 070	241	444	961	1 159	7 460	9 656
605	951	1 040	1 483	310	531	1 421	1 563	10 217	13 773
100	146	236	264	74	97	359	333	1 528	2 227
7	21	43	109	12	41	45	61	186	370
262	510	542	969	214	413	934	1 072	4 700	7 565
644	757	526	724	149	180	851	839	7 469	9 316
78	125	69	103	15	27	92	125	543	918
501	709	808	955	157	226	759	952	7 161	8 328
3 457	4 899	5 260	7 123	2 399	3 113	8 095	8 840	47 219	57 133
4 256	5 978	7 059	7 746	1 903	2 725	11 522	11 706	65 500	76 368
441	639	1 010	1 556	220	359	777	956	5 588	9 296
169	262	352	462	241	373	714	747	4 140	5 399
136	317	314	528	86	167	283	567	2 656	4 824
2 268	3 721	3 663	4 996	1 342	2 002	5 632	5 956	33 221	45 273
6	17	70	95	3	18	96	94	349	408
42	88	122	545	38	85	136	290	602	1 672
6	19	11	53	–	20	5	25	103	302

Table 6: Publications by major field of science, 2002 and 2008

Country/Territory	Biology		Biomedical research		Chemistry		Clinical medicine	
	2002	2008	2002	2008	2002	2008	2002	2008
European Union *continued*								
Malta	3	15	3	8	4	1	16	37
Netherlands	1 369	1 654	2 729	3 273	1 421	1 378	7 127	10 374
Poland	775	1 627	1 086	1 734	2 296	2 690	1 855	3 543
Portugal	427	908	497	874	607	1 067	564	1 279
Romania	32	115	67	332	518	661	91	451
Slovakia	267	314	258	338	288	346	220	417
Slovenia	87	231	175	242	252	341	281	692
Spain	2 576	4 306	2 956	4 293	3 918	4 510	6 423	9 744
Sweden	1 124	1 268	2 407	2 453	1 161	1 143	5 492	6 263
United Kingdom	4 515	4 975	9 586	10 789	5 469	5 352	22 007	26 754
Southeast Europe								
Albania	3	12	1	1	10	–	8	14
Bosnia and Herzegovina	3	25	2	14	3	3	13	170
Croatia	121	413	153	229	191	254	373	648
Montenegro	–	12	–	7	–	1	–	17
Republic of Moldova	8	7	5	10	40	87	5	7
Serbia	65	199	73	283	191	299	205	791
FYR Macedonia	7	16	10	26	32	35	21	52
Other Europe								
Andorra	–	–	–	–	–	–	2	1
Belarus	29	26	89	61	226	253	51	60
Iceland	57	70	34	66	11	18	121	181
Liechtenstein	1	–	–	3	2	7	2	15
Monaco	7	10	3	4	4	1	13	21
Norway	715	917	596	837	253	364	1 602	2 499
Russian Federation	1 050	1 317	1 851	1 835	5 240	5 308	1 599	1 914
San Marino	–	–	–	–	–	–	–	1
Switzerland	757	1 305	2 147	2 475	1 359	1 640	4 646	6 491
Turkey	546	1 435	532	1 155	844	1 639	4 243	7 978
Ukraine	75	113	151	175	712	820	129	168
Sub–Saharan Africa								
Angola	2	1	1	1	2	–	3	9
Benin	30	70	5	21	1	2	19	39
Botswana	30	29	8	17	14	20	15	24
Burkina Faso	15	57	15	26	3	5	49	74
Burundi	–	1	–	–	–	1	1	3
Cameroon	71	119	25	56	11	32	74	109
Cape Verde	–	1	–	1	–	–	–	–
Central African Republic	1	1	1	4	–	–	8	9
Chad	1	3	3	–	–	–	4	6
Comoros	1	–	–	–	–	–	–	3
Congo	9	21	–	5	1	2	24	27
Côte d'Ivoire	30	36	12	20	10	15	56	73
Democratic Rep. of the Congo	3	5	2	7	1	–	4	16
Equatorial Guinea	1	–	–	–	–	–	1	1
Eritrea	7	4	2	3	–	–	4	4
Ethiopia	70	108	18	44	9	11	114	125
Gabon	8	17	14	18	–	–	31	34
Gambia	2	1	11	23	–	–	45	52
Ghana	49	74	14	48	3	6	73	95
Guinea	1	6	1	1	–	1	8	6
Guinea–Bissau	1	–	1	3	–	–	19	13
Kenya	232	283	53	138	7	8	170	288
Lesotho	2	1	–	2	1	2	1	2
Liberia	1	1	–	2	–	–	4	1
Madagascar	22	57	12	20	2	3	12	41

	Earth and space		Engineering and technology		Mathematics		Physics		Total	
	2002	2008	2002	2008	2002	2008	2002	2008	2002	2008
	7	10	5	13	1	4	2	10	41	98
	1 346	1 764	1 687	2 051	360	507	1 998	1 944	18 037	22 945
	615	1 400	1 476	2 938	512	889	2 725	3 095	11 340	17 916
	243	599	738	1 147	161	316	610	916	3 847	7 106
	67	268	517	1 263	220	555	615	1 330	2 127	4 975
	94	198	237	415	71	133	405	471	1 840	2 632
	42	124	401	588	112	158	259	390	1 609	2 766
	1 481	2 811	2 716	4 428	1 018	1 661	3 017	3 986	24 105	35 739
	859	1 228	1 496	1 614	275	404	1 872	1 695	14 686	16 068
	4 678	6 079	6 715	7 612	1 383	2 197	6 720	7 544	61 073	71 302
	7	21	4	2	2	1	–	1	35	52
	–	9	3	41	1	9	10	16	35	287
	52	129	143	361	46	112	175	202	1 254	2 348
	–	4	–	33	–	2	–	17	–	93
	–	3	19	20	3	8	80	81	160	223
	35	109	174	479	69	208	191	361	1 003	2 729
	1	15	6	18	8	9	19	26	104	197
	1	–	–	–	–	–	–	–	3	1
	14	24	157	184	62	85	347	328	975	1 021
	60	113	17	26	6	22	22	35	328	531
	–	1	6	13	–	–	1	5	12	44
	14	20	–	–	–	–	1	–	42	56
	589	957	416	688	111	212	310	484	4 592	6 958
	2 468	2 981	3 144	3 329	1 251	1 584	8 890	8 815	25 493	27 083
	–	–	–	2	–	–	–	–	–	3
	870	1 591	1 116	1 816	270	423	2 238	2 415	13 403	18 156
	450	1 025	1 223	2 910	162	559	608	1 086	8 608	17 787
	217	260	860	1 339	167	401	1 679	1 703	3 990	4 979
	1	–	2	1	–	–	–	–	11	12
	2	9	5	–	3	4	5	8	70	153
	10	25	4	10	8	5	8	8	97	138
	1	8	1	3	2	2	1	4	87	179
	–	1	–	–	–	–	1	–	2	6
	13	45	7	26	4	19	22	57	227	463
	–	–	–	1	–	–	–	–	–	3
	–	2	–	–	–	–	–	–	10	16
	3	3	–	–	–	–	–	–	11	12
	–	–	–	–	–	–	–	–	1	3
	–	3	1	–	–	3	2	–	37	61
	1	10	–	3	1	10	1	4	111	171
	–	2	1	–	–	–	–	–	11	30
	–	–	–	–	–	–	–	–	2	1
	8	1	–	–	–	1	1	1	22	14
	22	45	2	7	–	9	4	15	239	364
	2	3	–	1	1	1	–	2	56	76
	1	–	–	1	–	–	–	–	59	77
	11	31	6	8	–	3	2	2	158	267
	3	–	–	–	–	–	–	–	13	14
	–	–	–	–	–	–	–	–	21	16
	25	33	13	9	1	1	6	3	507	763
	–	2	–	1	–	–	1	1	5	11
	–	–	–	1	–	–	–	1	5	6
	1	9	–	1	–	7	2	3	51	141

Table 6: Publications by major field of science, 2002 and 2008

Country/Territory	Biology 2002	Biology 2008	Biomedical research 2002	Biomedical research 2008	Chemistry 2002	Chemistry 2008	Clinical medicine 2002	Clinical medicine 2008
Sub-Saharan Africa *continued*								
Malawi	17	27	10	28	–	–	70	94
Mali	16	36	7	16	–	1	26	30
Mauritius	18	10	2	4	5	5	4	5
Mozambique	7	11	3	9	–	1	14	42
Namibia	21	22	4	2	–	–	5	3
Niger	21	24	3	11	–	–	11	20
Nigeria	243	367	80	492	36	52	204	701
Rwanda	–	4	–	2	1	–	6	15
Sao Tome and Principe	1	1	1	–	–	–	1	–
Senegal	36	36	19	35	5	13	65	79
Seychelles	4	11	–	3	–	–	3	5
Sierra Leone	4	1	–	5	–	–	1	2
Somalia	–	–	–	1	–	–	1	–
South Africa	828	1 163	481	690	307	410	841	1 453
Swaziland	2	8	–	2	1	3	2	5
Togo	4	13	2	2	1	1	6	20
Uganda	30	69	21	43	1	3	76	218
United Rep. of Tanzania	49	98	26	41	3	1	107	193
Zambia	13	16	5	10	–	–	39	88
Zimbabwe	65	59	26	27	1	1	72	74
Arab states								
Algeria	32	78	12	51	103	206	21	74
Bahrain	3	8	2	8	6	3	17	38
Djibouti	–	1	–	–	–	1	1	–
Egypt	192	259	146	295	672	861	478	992
Iraq	7	12	–	10	11	24	24	73
Jordan	46	100	39	51	61	126	130	211
Kuwait	15	22	63	55	37	57	165	259
Lebanon	16	34	30	57	16	37	150	285
Libyan Arab Jamahiriya	3	6	5	3	7	19	12	22
Mauritania	2	4	1	1	2	6	5	–
Morocco	99	107	49	62	220	155	232	292
Oman	22	30	10	16	21	24	72	79
Palestinian Autonomous Territories	–	–	–	–	–	–	–	–
Qatar	3	3	2	19	4	10	18	70
Saudi Arabia	43	44	62	134	137	157	627	723
Sudan	19	25	7	22	4	5	47	73
Syrian Arab Republic	30	75	4	19	13	14	16	39
Tunisia	63	283	63	230	115	196	160	512
United Arab Emirates	14	32	33	91	25	29	97	213
Yemen	4	3	3	3	1	6	13	21
Central and West Asia								
Armenia	9	6	23	26	32	66	20	44
Azerbaijan	2	4	5	4	43	81	10	11
Georgia	3	12	14	22	31	36	32	26
Israel	643	662	1 264	1 411	694	706	3 134	3 357
Kazakhstan	9	16	14	15	69	63	11	10
Kyrgyzstan	3	3	1	5	3	3	3	9
Mongolia	2	24	3	12	7	13	12	20
Tajikistan	3	1	1	3	8	14	2	3
Turkmenistan	2	–	–	–	1	–	2	–
Uzbekistan	12	18	8	21	92	61	15	22

	Earth and space		Engineering and technology		Mathematics		Physics		Total	
	2002	2008	2002	2008	2002	2008	2002	2008	2002	2008
	5	8	2	3	–	–	1	1	105	161
	2	4	1	–	–	–	–	1	52	88
	14	4	6	3	3	6	1	2	53	39
	3	13	–	–	–	–	–	–	27	76
	7	28	–	1	–	–	4	3	41	59
	2	16	1	3	–	2	2	1	40	77
	50	96	50	109	12	26	19	26	694	1 869
	–	2	–	–	–	–	–	–	7	23
	–	–	–	–	–	–	–	–	3	1
	8	19	7	8	2	12	6	9	148	211
	–	–	–	–	–	–	–	–	7	19
	–	2	–	–	–	–	–	–	5	10
	–	–	–	–	–	–	–	–	1	1
	434	520	294	467	127	227	226	318	3 538	5 248
	1	1	1	–	2	–	2	–	11	19
	2	2	–	3	1	1	1	1	17	43
	2	11	1	6	1	3	1	1	133	354
	14	30	4	11	–	–	4	2	207	376
	3	4	1	1	–	–	3	2	64	121
	27	23	5	3	1	4	2	3	199	194
	25	75	117	415	37	131	136	259	483	1 289
	3	4	6	16	3	5	3	16	43	98
	–	–	–	–	–	–	–	–	1	2
	111	205	510	714	121	167	339	470	2 569	3 963
	–	9	15	27	1	5	5	24	63	184
	34	75	115	222	20	64	66	79	511	928
	14	27	114	137	25	30	15	20	448	607
	19	33	38	86	9	19	34	40	312	591
	5	9	6	31	–	2	4	8	42	100
	1	1	1	–	2	1	–	–	14	13
	93	133	111	151	85	127	182	140	1 071	1 167
	16	35	60	75	17	19	19	37	237	315
	–	–	–	–	–	–	–	–	–	–
	2	5	14	45	1	10	3	33	47	195
	28	63	280	329	52	151	100	144	1 329	1 745
	1	5	6	10	–	1	8	5	92	146
	9	13	14	20	3	5	13	13	102	198
	30	106	143	377	80	138	93	184	747	2 026
	20	46	88	175	28	30	22	44	327	660
	1	5	6	8	2	2	1	8	31	56
	57	67	19	33	24	51	179	251	363	544
	10	13	20	34	19	36	74	109	183	292
	34	31	20	29	42	70	95	102	271	328
	372	506	1 011	1 143	524	754	1 494	1 530	9 136	10 069
	17	20	30	38	9	18	52	38	211	218
	10	17	1	6	–	2	17	9	38	54
	10	23	5	5	1	2	3	16	43	115
	7	5	9	3	11	4	3	12	44	45
	1	–	1	1	–	1	3	1	10	3
	12	16	30	28	20	22	110	113	299	301

Table 6: Publications by major field of science, 2002 and 2008

Country/Territory	Biology		Biomedical research		Chemistry		Clinical medicine	
	2002	2008	2002	2008	2002	2008	2002	2008
South Asia								
Afghanistan	–	–	–	3	–	–	–	12
Bangladesh	66	136	41	70	38	64	93	210
Bhutan	1	4	–	–	–	–	1	–
India	1 579	3 339	1 901	3 821	4 552	7 163	3 367	7 514
Iran (Islamic Republic of)	150	772	129	681	645	2 198	369	2 626
Maldives	1	–	–	–	–	–	–	–
Nepal	26	29	11	15	2	3	54	137
Pakistan	135	628	60	230	179	542	131	685
Sri Lanka	48	76	23	73	11	21	57	135
Southeast Asia								
Brunei Darussalam	3	7	1	2	3	1	1	19
Cambodia	3	11	2	14	–	3	14	31
China	1 716	5 672	2 682	9 098	9 499	23 032	3 863	13 595
Democratic People's Rep. of Korea	–	2	–	2	–	4	–	6
Hong Kong SAR of China	–	–	–	–	–	–	–	–
Indonesia	106	154	74	83	25	46	91	148
Japan	4 682	5 479	9 723	9 771	9 908	9 809	21 426	21 729
Lao PDR	7	9	–	9	–	2	7	27
Macao China	1	–	–	–	1	–	–	–
Malaysia	145	293	82	300	240	588	148	535
Myanmar	1	11	–	4	–	1	8	15
Philippines	206	227	40	100	9	23	72	164
Republic of Korea	617	1 755	1 893	3 824	2 545	4 006	3 017	7 610
Singapore	133	173	346	811	426	756	729	1 427
Thailand	261	591	202	730	216	491	580	1 227
Timor–Leste	–	–	–	–	–	–	–	–
Viet Nam	62	123	29	93	14	39	83	173
Oceania								
Australia	3 092	3 944	2 722	3 750	1 314	1 780	6 483	10 119
Cook Islands	–	–	–	–	–	–	1	–
Fiji	13	20	3	4	3	8	4	8
Kiribati	–	–	–	–	–	–	–	–
Marshall Islands	1	1	–	–	–	–	–	–
Micronesia (Federated States of)	–	2	–	1	–	–	–	–
Nauru	–	–	–	–	–	–	–	–
New Zealand	936	1 167	431	676	258	293	1 125	1 698
Niue	–	–	–	–	–	–	–	–
Palau 1		1	–	–	–	–	1	–
Papua New Guinea	20	20	9	19	1	–	27	38
Samoa	3	–	–	–	–	–	3	–
Solomon Islands	1	–	–	1	–	–	2	3
Tonga	1	–	–	–	–	–	–	4
Tuvalu	–	–	–	–	–	–	–	–
Vanuatu	2	6	–	–	–	–	3	2

Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

Earth and space 2002	Earth and space 2008	Engineering and technology 2002	Engineering and technology 2008	Mathematics 2002	Mathematics 2008	Physics 2002	Physics 2008	Total 2002	Total 2008
–	1	–	–	–	–	–	–	–	16
28	64	60	100	13	9	46	76	385	729
3	1	–	1	–	–	2	–	7	6
1 160	2 306	2 980	6 108	506	974	2 866	5 036	18 911	36 261
57	433	390	2 484	97	554	265	1 146	2 102	10 894
–	2	–	–	–	–	–	1	1	3
17	33	2	4	1	–	4	2	117	223
38	102	61	293	12	141	87	373	703	2 994
11	48	12	31	1	3	22	13	185	400
6	3	4	2	7	4	–	2	25	40
1	15	–	1	–	–	–	–	20	75
2 036	5 746	8 734	22 800	1 850	5 384	7 826	19 641	38 206	104 968
–	3	2	13	–	2	2	3	4	35
–	–	–	–	1	–	–	–	1	–
45	90	46	78	8	14	26	37	421	650
2 505	3 552	10 633	10 194	1 300	1 661	13 252	12 423	73 429	74 618
1	2	–	1	–	–	1	2	16	52
1	–	4	–	2	–	–	–	9	–
58	121	189	594	14	58	85	223	961	2 712
2	6	–	–	–	–	1	–	12	37
14	53	15	17	14	11	28	29	398	624
539	1 160	4 526	8 004	497	895	3 438	5 527	17 072	32 781
80	136	1 421	1 953	214	227	786	1 330	4 135	6 813
80	178	229	607	18	65	50	245	1 636	4 134
–	–	–	–	–	–	–	–	–	–
20	62	20	77	50	121	65	187	343	875
1 731	2 789	2 199	3 021	578	824	1 526	2 086	19 645	28 313
–	–	–	–	–	–	–	–	1	–
4	6	4	10	2	3	–	–	33	59
–	–	–	–	–	–	–	–	–	–
1	–	–	–	–	–	–	–	2	1
–	–	–	–	–	–	–	–	–	3
–	–	–	–	–	–	–	–	–	–
434	567	310	404	146	168	179	263	3 819	5 236
–	–	–	–	–	–	–	–	–	–
–	2	–	–	–	–	–	–	2	3
6	2	1	–	–	–	1	–	65	79
1	–	–	–	–	–	–	–	7	–
–	–	1	–	–	–	–	–	4	4
–	–	–	–	–	–	–	–	1	4
–	–	–	–	–	–	–	–	–	–
–	1	–	–	–	–	–	–	5	9

Table 7: Scientific publications in international collaboration, 2000–2008

Country/Territory	Scientific publications								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
North America									
Canada	10 821	11 240	12 144	13 338	14 617	16 165	17 492	18 446	20 030
United States of America	51 272	53 719	57 161	61 524	66 021	70 250	74 448	79 388	83 854
Latin America									
Argentina	1 540	1 660	1 778	1 889	2 129	2 182	2 304	2 497	2 766
Belize	2	4	5	7	6	10	12	6	5
Bolivia	52	69	78	94	98	109	107	160	165
Brazil	3 555	3 631	4 141	4 180	4 770	4 986	5 487	5 998	6 837
Chile	888	1 026	1 175	1 332	1 393	1 604	1 758	1 965	2 058
Colombia	398	392	446	448	516	560	663	743	1 017
Costa Rica	126	147	160	186	170	221	204	234	278
Ecuador	82	66	99	114	120	160	147	198	229
El Salvador	9	5	7	6	17	15	14	14	16
Guatemala	27	44	34	37	45	48	41	56	50
Guyana	6	8	7	4	4	8	8	17	13
Honduras	16	14	18	22	18	25	27	20	21
Mexico	1 964	2 212	2 279	2 413	2 755	2 901	3 049	3 241	3 589
Nicaragua	21	16	14	21	24	37	49	35	48
Panama	67	95	105	108	134	127	161	179	214
Paraguay	21	22	18	25	30	25	28	30	30
Peru	147	179	174	260	231	271	318	374	398
Suriname	2	7	5	5	7	11	4	5	6
Uruguay	204	202	197	231	254	265	280	293	381
Venezuela	398	477	468	505	516	590	579	551	639
Caribbean									
Antigua and Barbuda	–	1	–	3	–	5	4	5	5
Bahamas	3	4	5	2	6	6	5	11	9
Barbados	19	21	17	22	32	29	23	26	31
Cuba	312	371	309	384	369	388	437	462	506
Dominica	1	2	–	1	1	4	5	5	1
Dominican Republic	35	18	13	16	23	18	17	22	32
Grenada	4	1	1	11	4	6	23	43	53
Haiti	8	6	10	10	7	12	20	11	20
Jamaica	39	54	47	56	56	63	63	64	73
Saint Kitts and Nevis	2	2	3	3	1	2	6	5	8
Saint Lucia	2	3	2	1	–	2	1	2	1
Saint Vincent and the Grenadines	2	–	1	–	1	1	2	1	–
Trinidad and Tobago	38	52	50	50	59	55	49	70	76
European Union									
Austria	3 197	3 576	3 662	3 939	4 330	4 633	4 802	5 315	5 850
Belgium	4 728	5 007	5 461	5 808	6 161	6 732	6 962	7 560	8 135
Bulgaria	736	786	833	871	969	1 002	1 048	1 211	1 152
Cyprus	106	97	132	111	151	180	209	239	261
Czech Republic	1 917	2 117	2 210	2 371	2 640	2 798	3 103	3 350	3 587
Denmark	3 648	3 747	3 805	3 948	4 228	4 541	4 855	5 161	5 478
Estonia	279	301	286	304	366	380	393	464	507
Finland	2 978	3 005	3 099	3 300	3 429	3 574	3 835	4 106	4 305
France	18 374	18 998	19 782	21 037	22 167	23 835	25 121	26 130	28 046
Germany	23 905	25 259	26 930	28 020	30 065	31 966	33 628	35 391	36 668
Greece	1 800	1 915	2 000	2 236	2 474	2 703	3 118	3 442	3 531
Hungary	2 097	2 107	2 146	2 339	2 351	2 519	2 491	2 677	2 712
Ireland	1 050	1 077	1 218	1 360	1 604	1 860	2 107	2 262	2 635
Italy	11 155	11 885	12 553	13 401	14 605	15 656	16 376	17 845	19 027
Latvia	171	190	181	183	207	198	203	192	237
Lithuania	267	281	292	303	363	392	453	514	528
Luxembourg	65	75	78	86	112	130	161	177	243

Country/Territory	Scientific publications								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
European Union *continued*									
Malta	11	20	18	17	23	45	42	43	48
Netherlands	7 666	7 792	8 322	9 000	9 632	10 285	11 059	11 523	12 207
Poland	3 962	4 316	4 477	4 908	5 413	5 386	5 843	5 676	5 854
Portugal	1 517	1 727	1 930	2 184	2 498	2 646	3 262	3 177	3 746
Romania	919	954	1 093	1 169	1 250	1 299	1 475	1 745	1 888
Slovakia	854	918	955	990	1 199	1 043	1 262	1 313	1 440
Slovenia	568	569	632	720	730	885	886	1 026	1 196
Spain	7 253	7 874	8 630	9 160	10 264	11 402	12 580	13 613	15 193
Sweden	6 379	6 711	7 048	7 106	7 495	7 880	8 394	9 023	9 114
United Kingdom	21 903	22 602	23 898	25 400	27 506	29 207	31 373	33 808	35 663
Southeast Europe									
Albania	17	19	25	28	26	30	21	31	36
Bosnia and Herzegovina	14	31	28	39	41	80	68	115	124
Croatia	363	422	448	517	574	624	648	738	789
Montenegro	–	–	–	–	–	–	7	49	69
Republic of Moldova	100	112	121	151	129	155	171	131	151
Serbia	318	340	386	429	484	582	670	808	954
FYR Macedonia	62	67	53	50	68	69	77	87	123
Other Europe									
Andorra	1	3	2	2	1	3	7	7	1
Belarus	430	445	465	466	445	481	466	468	486
Iceland	172	219	201	245	240	282	293	338	390
Liechtenstein	17	9	6	17	17	23	25	28	37
Monaco	28	33	29	31	47	49	47	48	47
Norway	1 986	2 240	2 277	2 497	2 833	3 034	3 374	3 710	3 962
Russian Federation	8 301	8 524	8 884	8 658	9 043	9 162	8 792	8 823	8 778
San Marino	–	–	–	–	1	–	1	2	2
Switzerland	6 832	6 802	7 487	7 996	8 794	9 099	10 129	10 871	11 600
Turkey	1 011	1 166	1 499	1 737	2 103	2 081	2 306	2 583	2 860
Ukraine	1 610	1 871	1 814	1 855	1 931	1 856	1 918	2 080	2 079
Sub –Saharan Africa									
Angola	10	11	8	5	9	16	13	15	12
Benin	44	42	56	56	75	73	94	114	131
Botswana	35	29	58	40	53	75	84	97	96
Burkina Faso	44	54	66	102	110	98	141	128	165
Burundi	4	6	2	10	5	6	5	14	6
Cameroon	118	132	165	196	222	215	303	308	373
Cape Verde	–	1	–	3	1	1	6	1	3
Central African Republic	11	9	9	10	14	13	17	19	13
Chad	5	9	10	12	5	20	23	11	12
Comoros	1	1	1	2	2	2	–	5	3
Congo	20	13	27	30	33	38	67	68	55
Côte d'Ivoire	103	72	84	116	97	88	109	116	115
Democratic Rep. of the Congo	19	7	10	15	11	20	12	21	24
Equatorial Guinea	1	3	2	4	4	1	2	2	1
Eritrea	8	13	18	14	17	20	25	19	11
Ethiopia	110	108	132	165	177	181	219	269	251
Gabon	38	46	53	52	56	54	68	69	74
Gambia	42	58	56	65	63	62	75	57	74
Ghana	98	104	95	105	128	151	168	184	200
Guinea	5	11	12	10	11	12	24	20	14
Guinea –Bissau	11	11	21	18	18	19	15	23	16
Kenya	290	336	377	453	447	434	544	576	638
Lesotho	3	3	2	4	2	3	9	5	9
Liberia	–	3	5	1	3	4	3	–	6

Table 7: Scientific publications in international collaboration, 2000–2008

Country/Territory	Scientific publications								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
Sub-Saharan Africa *continued*									
Madagascar	53	51	46	80	68	89	118	127	123
Malawi	74	76	83	85	76	87	105	128	141
Mali	30	36	43	48	62	64	87	70	81
Mauritius	22	27	27	19	26	24	24	22	18
Mozambique	21	29	24	31	33	38	52	65	73
Namibia	16	26	24	29	34	60	66	54	50
Niger	27	22	26	32	22	50	48	49	71
Nigeria	193	183	229	220	229	271	305	378	460
Rwanda	5	7	6	5	14	10	21	30	20
Sao Tome and Principe	2	1	3	5	1	–	2	1	1
Senegal	117	115	121	150	152	163	147	161	167
Seychelles	12	4	6	7	4	9	16	23	18
Sierra Leone	5	10	5	2	3	4	3	4	8
Somalia	1	–	1	–	1	–	2	–	1
South Africa	1 161	1 315	1 414	1 576	1 767	1 885	2 170	2 410	2 629
Swaziland	5	8	4	10	2	11	5	9	13
Togo	17	9	12	28	33	23	27	27	30
Uganda	89	105	96	148	179	191	245	290	296
United Republic of Tanzania	135	146	160	212	208	252	309	330	324
Zambia	48	63	51	52	57	75	97	115	111
Zimbabwe	108	116	135	145	112	128	124	153	162
Arab states									
Algeria	256	273	278	333	412	440	562	642	711
Bahrain	10	19	18	31	37	36	54	55	53
Djibouti	–	1	1	1	3	2	2	3	2
Egypt	683	640	761	869	913	971	1 065	1 208	1 421
Iraq	15	16	12	20	20	27	47	57	82
Jordan	153	151	181	200	207	247	270	345	420
Kuwait	149	142	157	168	211	192	195	193	248
Lebanon	108	144	154	159	217	237	290	292	329
Libyan Arab Jamahiriya	19	24	21	36	37	38	57	54	74
Mauritania	15	12	13	18	10	22	17	17	12
Morocco	605	624	604	574	579	599	574	618	688
Oman	78	80	103	126	117	125	145	166	184
Palestinian Autonomous Territories	–	1	–	–	–	–	–	–	–
Qatar	13	17	19	37	46	48	70	115	152
Saudi Arabia	304	314	353	434	418	427	490	578	720
Sudan	46	38	63	67	69	69	82	91	97
Syrian Arab Republic	55	63	56	74	70	92	94	101	114
Tunisia	264	319	378	436	467	592	708	793	967
United Arab Emirates	144	139	172	226	238	283	348	404	434
Yemen	25	22	15	18	22	25	34	38	40
Central and West Asia									
Armenia	158	192	203	224	214	219	233	240	252
Azerbaijan	45	40	67	97	93	99	108	97	123
Georgia	126	141	157	140	171	176	206	191	196
Israel	3 484	3 575	3 706	3 916	4 011	4 060	4 236	4 274	4 443
Kazakhstan	65	76	101	117	126	105	117	158	113
Kyrgyzstan	22	26	26	15	17	29	29	37	35
Mongolia	33	35	40	55	55	60	65	91	109
Tajikistan	11	9	18	9	10	19	13	27	32
Turkmenistan	11	7	9	4	2	4	6	6	2
Uzbekistan	102	110	114	148	149	160	165	205	178

Country/Territory	Scientific publications								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
South Asia									
Afghanistan	–	–	–	2	6	6	6	6	14
Bangladesh	179	199	219	245	290	338	395	397	481
Bhutan	3	1	6	1	10	8	19	4	5
India	2 626	3 022	3 341	3 738	4 183	4 644	5 376	5 954	6 541
Iran (Islamic Republic of)	313	372	501	700	820	1 088	1 326	1 818	2 208
Maldives	1	2	1	2	–	–	1	5	3
Nepal	77	88	80	99	104	111	141	144	145
Pakistan	208	220	268	312	326	369	564	806	1 027
Sri Lanka	90	97	89	153	140	154	188	220	239
Southeast Asia									
Brunei Darussalam	14	21	13	17	24	17	21	22	22
Cambodia	10	9	16	20	38	46	59	77	74
China	6 535	7 606	8 778	10 609	12 665	14 788	17 637	19 518	23 043
Democratic People's Rep. of Korea	–	–	4	4	13	9	8	18	31
Hong Kong SAR of China	143	32	1	–	–	–	–	–	–
Indonesia	361	369	348	368	424	462	515	502	565
Japan	12 717	13 333	14 213	15 476	16 375	16 509	17 667	17 572	18 162
Lao PDR	7	12	14	22	26	32	44	44	50
Macao, China	7	6	6	8	12	–	–	–	–
Malaysia	360	402	443	544	595	715	842	1 011	1 121
Myanmar	17	18	10	19	29	37	39	38	36
Philippines	265	193	241	286	295	323	344	372	396
Republic of Korea	2 957	3 658	4 203	5 057	5 833	6 420	7 184	7 498	8 527
Singapore	1 079	1 242	1 374	1 672	2 031	2 361	2 691	2 906	3 294
Thailand	618	743	946	1 092	1 223	1 407	1 660	1 919	2 106
Timor –Leste	–	–	–	–	–	–	–	–	–
Viet Nam	238	270	256	359	368	446	509	557	680
Oceania									
Australia	6 298	6 887	7 435	8 088	9 090	9 642	10 662	11 729	13 139
Cook Islands	2	–	1	–	–	1	1	3	–
Fiji	15	15	20	25	28	39	38	48	48
Kiribati	–	–	–	–	–	–	1	2	–
Marshall Islands	1	–	2	3	4	1	5	–	1
Micronesia (Federated States of)	4	1	–	6	6	4	5	4	2
Nauru	–	–	–	–	–	–	–	–	–
New Zealand	1 418	1 435	1 600	1 732	1 918	2 199	2 346	2 592	2 790
Niue	–	–	–	–	–	–	–	1	–
Palau 2		7	2	3	5	5	8	10	3
Papua New Guinea	50	47	47	50	44	37	46	61	72
Samoa	–	–	3	–	1	2	–	1	–
Solomon Islands	11	3	4	8	4	5	6	8	4
Tonga	2	2	1	5	4	–	3	3	4
Tuvalu	–	–	–	1	–	–	1	–	–
Vanuatu	7	1	2	6	7	10	9	6	8

Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

Annex

Table 8: International trade in high-tech products, 2002 and 2007 (in US$ millions)

	Aerospace							
	Imports		World share of imports (%)		Exports		World share of exports (%)	
	2002	2007	2002	2007	2002	2007	2002	2007
World	**89 627**	**145 247**	**100.0**	**100.0**	**114 940**	**184 219**	**100.0**	**100.0**
Developed countries	73 949	103 541	82.5	71.3	109 573	172 549	95.3	93.7
Developing countries	15 610	40 976	17.4	28.2	5 362	11 638	4.7	6.3
Least developed countries	68	730	0.1	0.5	5	32	0.0	0.0
Americas	**29 091**	**39 300**	**32.5**	**27.1**	**52 120**	**90 105**	**45.3**	**48.9**
North America	26 567	34 204	29.6	23.5	48 411	83 407	42.1	45.3
Latin America and the Caribbean	2 524	5 096	2.8	3.5	3 708	6 699	3.2	3.6
Europe	**39 653**	**58 973**	**44.2**	**40.6**	**59 730**	**87 678**	**52.0**	**47.6**
European Union	36 782	53 728	41.0	37.0	54 186	82 609	47.1	44.8
Commonwealth of Independent States in Europe	354	373	0.4	0.3	2 754	1 500	2.4	0.8
Central, Eastern and Other Europe	2 518	4 872	2.8	3.4	2 789	3 569	2.4	1.9
Africa	**1 768**	**3 448**	**2.0**	**2.4**	**118**	**738**	**0.1**	**0.4**
South Africa	818	1 565	0.9	1.1	67	483	0.1	0.3
Other Sub–Saharan countries (excl. South Africa)	323	852	0.4	0.6	37	245	0.0	0.1
Arab States in Africa	626	1 031	0.7	0.7	15	9	0.0	0.0
Asia	**16 149**	**40 512**	**18.0**	**27.9**	**2 239**	**5 409**	**1.9**	**2.9**
Japan	5 327	8 472	5.9	5.8	877	1 830	0.8	1.0
China	3 488	10 704	3.9	7.4	134	732	0.1	0.4
Israel	559	956	0.6	0.7	15	28	0.0	0.0
India	157	2 304	0.2	1.6	4	13	0.0	0.0
Commonwealth of Independent States in Asia	160	771	0.2	0.5	100	487	0.1	0.3
Newly Industrialised Economies in Asia	5 882	14 115	6.6	9.7	1 074	2 198	0.9	1.2
Arab States in Asia	194	1 255	0.2	0.9	1	1	0.0	0.0
Other in Asia (excl. Japan, China, India, Israel)	382	1 934	0.4	1.3	35	120	0.0	0.1
Oceania	**2 967**	**3 014**	**3.3**	**2.1**	**734**	**289**	**0.6**	**0.2**
Other groupings								
Arab States all	820	2 286	0.9	1.6	16	10	0.0	0.0
Commonwealth of Independent States all	513	1 144	0.6	0.8	2 854	1 987	2.5	1.1
OECD	74 792	106 998	83.4	73.7	107 983	173 047	93.9	93.9
European Free Trade Association	2 256	3 706	2.5	2.6	2 610	2 879	2.3	1.6
Sub–Saharan Africa (incl. South Africa)	1 142	2 417	1.3	1.7	103	728	0.1	0.4
Other in Asia (incl. Japan, China, India, Israel)	9 913	24 371	11.1	16.8	1 064	2 723	0.9	1.5
Selected countries								
Argentina	189	809	0.2	0.6	83	341	0.1	0.2
Brazil	732	2 228	0.8	1.5	2 768	4 942	2.4	2.7
Canada	8 312	10 640	7.2	5.8	4 401	7 123	4.9	4.9
Cuba	55	62	0.1	0.0	10	91	0.0	0.0
Egypt	0	0	0.0	0.0	–	–	–	–
France	6 773	10 997	7.6	7.6	18 277	33 554	15.9	18.2
Germany	11 599	16 186	12.9	11.1	17 430	24 461	15.2	13.3
Iran (Islamic Republic of)	62	1	0.1	0.0	1	0	0.0	0.0
Mexico	355	962	0.4	0.7	790	1 250	0.7	0.7
Republic of Korea	738	2 648	0.8	1.8	326	393	0.3	0.2
Russian Federation	317	225	0.4	0.2	2 565	1 071	2.2	0.6
Turkey	249	1 058	0.3	0.7	163	650	0.1	0.4
United Kingdom	5 142	7 234	5.7	5.0	9 503	12 995	8.3	7.1
United States of America	22 166	27 082	24.7	18.6	40 099	72 766	34.9	39.5

Armament								Chemistry							
Imports		World share of imports (%)		Exports		World share of exports (%)		Imports		World share of imports (%)		Exports		World share of exports (%)	
2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007
4 846	**9 064**	**100.0**	**100.0**	**5 712**	**9 466**	**100.0**	**100.0**	**34 574**	**70 325**	**100.0**	**100.0**	**30 580**	**63 053**	**100.0**	**100.0**
3 329	6 714	68.7	74.1	5 280	8 437	92.4	89.1	24 796	50 251	71.7	71.5	23 319	43 956	76.3	69.7
1 470	2 172	30.3	24.0	429	1 026	7.5	10.8	9 496	19 508	27.5	27.7	7 247	19 080	23.7	30.3
47	178	1.0	2.0	3	2	0.0	0.0	282	565	0.8	0.8	14	17	0.0	0.0
1 840	**3 923**	**38.0**	**43.3**	**3 306**	**5 004**	**57.9**	**52.9**	**8 501**	**16 463**	**24.6**	**23.4**	**6 859**	**14 767**	**22.4**	**23.4**
1 681	3 633	34.7	40.1	3 072	4 764	53.8	50.3	5 548	11 201	16.0	15.9	5 511	11 850	18.0	18.8
159	290	3.3	3.2	235	240	4.1	2.5	2 953	5 263	8.5	7.5	1 349	2 917	4.4	4.6
1 624	**2 471**	**33.5**	**27.3**	**2 075**	**3 618**	**36.3**	**38.2**	**16 680**	**33 670**	**48.2**	**47.9**	**16 646**	**29 713**	**54.4**	**47.1**
1 110	2 003	22.9	22.1	1 283	2 680	22.5	28.3	14 322	28 898	41.4	41.1	14 433	26 509	47.2	42.0
3	25	0.1	0.3	378	42	6.6	0.4	949	2 214	2.7	3.1	287	568	0.9	0.9
510	443	10.5	4.9	414	896	7.3	9.5	1 409	2 557	4.1	3.6	1 926	2 636	6.3	4.2
112	**442**	**2.3**	**4.9**	**20**	**324**	**0.4**	**3.4**	**1 054**	**1 903**	**3.0**	**2.7**	**276**	**669**	**0.9**	**1.1**
0	–	0.0	–	7	–	0.1	–	209	336	0.6	0.5	224	529	0.7	0.8
99	400	2.0	4.4	13	324	0.2	3.4	572	994	1.7	1.4	46	131	0.2	0.2
13	42	0.3	0.5	0	0	0.0	0.0	273	574	0.8	0.8	5	10	0.0	0.0
1 041	**1 725**	**21.5**	**19.0**	**281**	**419**	**4.9**	**4.4**	**7 861**	**17 546**	**22.7**	**25.0**	**6 579**	**17 653**	**21.5**	**28.0**
217	160	4.5	1.8	155	92	2.7	1.0	2 562	5 608	7.4	8.0	1 007	2 282	3.3	3.6
4	2	0.1	0.0	18	59	0.3	0.6	978	3 399	2.8	4.8	2 569	7 831	8.4	12.4
–	–	–	–	–	20	–	0.2	112	225	0.3	0.3	228	16	0.7	0.0
1	6	0.0	0.1	3	4	0.0	0.0	173	545	0.5	0.8	818	2 007	2.7	3.2
0	70	0.0	0.8	0	7	0.0	0.1	81	328	0.2	0.5	37	966	0.1	1.5
291	556	6.0	6.1	70	209	1.2	2.2	2 472	4 283	7.2	6.1	1 598	3 239	5.2	5.1
307	848	6.3	9.4	0	16	0.0	0.2	296	892	0.9	1.3	41	123	0.1	0.2
220	83	4.5	0.9	36	11	0.6	0.1	1 188	2 266	3.4	3.2	281	1 188	0.9	1.9
229	**503**	**4.7**	**5.6**	**30**	**100**	**0.5**	**1.1**	**478**	**742**	**1.4**	**1.1**	**221**	**251**	**0.7**	**0.4**
320	890	6.6	9.8	1	16	0.0	0.2	569	1 466	1.6	2.1	46	133	0.2	0.2
4	95	0.1	1.0	378	50	6.6	0.5	1 029	2 542	3.0	3.6	324	1 534	1.1	2.4
3 732	7 108	77.0	78.4	5 005	8 603	87.6	90.9	25 258	50 567	73.1	71.9	23 989	45 264	78.4	71.8
306	387	6.3	4.3	345	665	6.0	7.0	825	1 255	2.4	1.8	1 852	2 438	6.1	3.9
99	400	2.0	4.4	20	324	0.4	3.4	781	1 330	2.3	1.9	270	660	0.9	1.0
443	251	9.1	2.8	211	186	3.7	2.0	5 013	12 043	14.5	17.1	4 902	13 324	16.0	21.1
2	9	0.0	0.1	7	17	0.1	0.2	212	635	0.6	0.9	230	389	0.8	0.6
13	9	0.3	0.1	205	200	3.6	2.1	650	1 378	1.9	2.0	457	910	1.5	1.4
382	668	6.7	7.1	431	572	8.9	6.3	1 060	3 332	3.5	5.3	1 131	2 072	3.3	2.9
0	0	0.0	0.0	0	0	0.0	0.0	53	46	0.2	0.1	1	0	0.0	0.0
1	1	0.0	0.0	0	–	0.0	–	67	127	0.2	0.2	1	2	0.0	0.0
86	187	1.8	2.1	252	441	4.4	4.7	2 850	5 308	8.2	7.5	3 267	6 041	10.7	9.6
105	161	2.2	1.8	226	458	4.0	4.8	2 355	5 719	6.8	8.1	4 450	7 074	14.6	11.2
179	0	3.7	0.0	27	0	0.5	0.0	210	87	0.6	0.1	16	335	0.1	0.5
30	47	0.6	0.5	18	18	0.3	0.2	663	873	1.9	1.2	271	820	0.9	1.3
225	417	4.6	4.6	56	167	1.0	1.8	852	1 953	2.5	2.8	690	1 737	2.3	2.8
3	25	0.1	0.3	378	42	6.6	0.4	695	1 290	2.0	1.8	234	366	0.8	0.6
192	36	4.0	0.4	49	134	0.9	1.4	438	929	1.3	1.3	64	139	0.2	0.2
118	249	2.4	2.8	82	145	1.4	1.5	1 428	2 490	4.1	3.5	1 857	2 100	6.1	3.3
1 250	3 060	25.8	33.8	2 689	4 097	47.1	43.3	4 417	9 129	12.8	13.0	4 451	8 518	14.6	13.5

Table 8: International trade in high-tech products, 2002 and 2007 (in US$ millions)

	Computers-office machines							
	Imports		World share of imports (%)		Exports		World share of exports (%)	
	2002	2007	2002	2007	2002	2007	2002	2007
World	**297 979**	**398 047**	**100.0**	**100.0**	**255 982**	**362 381**	**100.0**	**100.0**
Developed countries	219 553	275 588	73.7	69.2	137 746	132 122	53.8	36.5
Developing countries	78 115	121 865	26.2	30.6	118 235	230 253	46.2	63.5
Least developed countries	312	593	0.1	0.1	1	6	0.0	0.0
Americas	**90 020**	**111 423**	**30.2**	**28.0**	**38 988**	**34 627**	**15.2**	**9.6**
North America	78 360	92 611	26.3	23.3	26 937	23 792	10.5	6.6
Latin America and the Caribbean	11 660	18 812	3.9	4.7	12 051	10 836	4.7	3.0
Europe	**118 708**	**160 506**	**39.8**	**40.3**	**87 081**	**99 873**	**34.0**	**27.6**
European Union	111 936	147 419	37.6	37.0	86 217	98 709	33.7	27.2
Commonwealth of Independent States in Europe	790	4 214	0.3	1.1	52	145	0.0	0.0
Central, Eastern and Other Europe	5 981	8 873	2.0	2.2	813	1 019	0.3	0.3
Africa	**2 012**	**4 100**	**0.7**	**1.0**	**101**	**201**	**0.0**	**0.1**
South Africa	853	1 901	0.3	0.5	79	158	0.0	0.0
Other Sub–Saharan countries (excl. South Africa)	504	1 023	0.2	0.3	13	20	0.0	0.0
Arab States in Africa	655	1 176	0.2	0.3	9	23	0.0	0.0
Asia	**82 891**	**115 026**	**27.8**	**28.9**	**129 076**	**226 913**	**50.4**	**62.6**
Japan	19 076	17 992	6.4	4.5	23 026	7 791	9.0	2.1
China	12 402	24 194	4.2	6.1	32 931	139 858	12.9	38.6
Israel	872	1 295	0.3	0.3	237	418	0.1	0.1
India	1 227	3 782	0.4	1.0	163	277	0.1	0.1
Commonwealth of Independent States in Asia	147	445	0.0	0.1	4	6	0.0	0.0
Newly Industrialised Economies in Asia	44 259	55 503	14.9	13.9	64 984	62 794	25.4	17.3
Arab States in Asia	896	4 210	0.3	1.1	12	23	0.0	0.0
Other in Asia (excl. Japan, China, India, Israel)	4 012	7 604	1.3	1.9	7 720	15 747	3.0	4.3
Oceania	**4 348**	**6 992**	**1.5**	**1.8**	**735**	**766**	**0.3**	**0.2**
Other groupings								
Arab States all	1 552	5 386	0.5	1.4	21	46	0.0	0.0
Commonwealth of Independent States all	937	4 659	0.3	1.2	56	151	0.0	0.0
OECD	230 923	286 660	77.5	72.0	164 713	158 663	64.3	43.8
European Free Trade Association	4 665	5 537	1.6	1.4	756	775	0.3	0.2
Sub–Saharan Africa (incl. South Africa)	1 357	2 924	0.5	0.7	92	178	0.0	0.0
Other in Asia (incl. Japan, China, India, Israel)	37 589	54 868	12.6	13.8	64 077	164 090	25.0	45.3
Selected countries								
Argentina	155	1 011	0.1	0.3	33	23	0.0	0.0
Brazil	1 097	2 289	0.4	0.6	154	219	0.1	0.1
Canada	2 377	2 170	0.9	0.6	7 860	9 543	2.6	2.4
Cuba	55	70	0.0	0.0	1	5	0.0	0.0
Egypt	165	180	0.1	0.0	1	1	0.0	0.0
France	11 034	13 019	3.7	3.3	6 005	4 451	2.3	1.2
Germany	24 993	28 461	8.4	7.2	14 590	20 569	5.7	5.7
Iran (Islamic Republic of)	282	66	0.1	0.0	1	1	0.0	0.0
Mexico	7 880	9 642	2.6	2.4	10 919	9 411	4.3	2.6
Republic of Korea	5 131	7 104	1.7	1.8	16 191	17 956	6.3	5.0
Russian Federation	638	3 829	0.2	1.0	36	104	0.0	0.0
Turkey	781	2 305	0.3	0.6	32	99	0.0	0.0
United Kingdom	19 069	21 260	6.4	5.3	14 738	9 911	5.8	2.7
United States of America	70 500	83 068	23.7	20.9	24 560	21 622	9.6	6.0

Electrical machinery								Electronics-telecommunications							
Imports		World share of imports (%)		Exports		World share of exports (%)		Imports		World share of imports (%)		Exports		World share of exports (%)	
2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007
32 023	55 724	100.0	100.0	27 530	46 771	100.0	100.0	461 776	808 595	100.0	100.0	406 510	621 558	100.0	100.0
19 224	28 126	60.0	50.5	20 220	29 054	73.4	62.1	245 998	331 393	53.3	41.0	243 508	275 363	59.9	44.3
12 781	27 555	39.9	49.4	7 308	17 714	26.5	37.9	215 102	473 686	46.6	58.6	162 994	346 089	40.1	55.7
18	42	0.1	0.1	2	4	0.0	0.0	676	3 516	0.1	0.4	8	105	0.0	0.0
7 159	10 227	22.4	18.4	6 175	8 393	22.4	17.9	109 441	133 348	23.7	16.5	72 298	71 721	17.8	11.5
5 324	7 837	16.6	14.1	4 241	5 718	15.4	12.2	87 134	101 605	18.9	12.6	58 415	52 906	14.4	8.5
1 835	2 390	5.7	4.3	1 934	2 675	7.0	5.7	22 307	31 743	4.8	3.9	13 884	18 814	3.4	3.0
11 602	18 332	36.2	32.9	10 379	14 643	37.7	31.3	133 358	194 659	28.9	24.1	136 876	156 116	33.7	25.1
10 941	15 501	34.2	27.8	9 698	13 774	35.2	29.4	124 205	173 432	26.9	21.4	133 798	151 183	32.9	24.3
102	460	0.3	0.8	256	141	0.9	0.3	2 203	10 066	0.5	1.2	491	1 200	0.1	0.2
558	2 372	1.7	4.3	425	729	1.5	1.6	6 950	11 161	1.5	1.4	2 587	3 733	0.6	0.6
237	510	0.7	0.9	59	195	0.2	0.4	4 295	10 047	0.9	1.2	932	1 715	0.2	0.3
70	163	0.2	0.3	29	53	0.1	0.1	1 743	2 681	0.4	0.3	245	391	0.1	0.1
37	115	0.1	0.2	2	3	0.0	0.0	1 045	2 871	0.2	0.4	37	205	0.0	0.0
129	232	0.4	0.4	28	139	0.1	0.3	1 507	4 495	0.3	0.6	650	1 120	0.2	0.2
12 693	25 994	39.6	46.6	10 768	23 330	39.1	49.9	210 329	464 350	45.5	57.4	195 660	391 000	48.1	62.9
2 115	2 891	6.6	5.2	5 460	8 522	19.8	18.2	22 776	33 170	4.9	4.1	47 617	65 702	11.7	10.6
2 887	7 646	9.0	13.7	1 939	6 682	7.0	14.3	41 801	145 475	9.1	18.0	26 875	114 674	6.6	18.4
920	280	2.9	0.5	485	435	1.8	0.9	1 809	2 110	0.4	0.3	3 592	346	0.9	0.1
139	470	0.4	0.8	12	47	0.0	0.1	2 140	10 856	0.5	1.3	403	1 023	0.1	0.2
14	67	0.0	0.1	0	1	0.0	0.0	368	1 462	0.1	0.2	14	22	0.0	0.0
5 756	12 404	18.0	22.3	2 411	6 425	8.8	13.7	128 884	241 242	27.9	29.8	109 623	195 017	27.0	31.4
101	607	0.3	1.1	2	2	0.0	0.0	1 624	9 107	0.4	1.1	28	56	0.0	0.0
760	1 628	2.4	2.9	460	1 216	1.7	2.6	10 928	20 928	2.4	2.6	7 509	14 160	1.8	2.3
332	660	1.0	1.2	149	210	0.5	0.4	4 353	6 192	0.9	0.8	743	1 006	0.2	0.2
230	839	0.7	1.5	31	142	0.1	0.3	3 131	13 602	0.7	1.7	678	1 176	0.2	0.2
116	527	0.4	0.9	256	142	0.9	0.3	2 570	11 528	0.6	1.4	506	1 222	0.1	0.2
22 039	33 940	68.8	60.9	22 134	32 613	80.4	69.7	276 881	369 244	60.0	45.7	280 965	341 818	69.1	55.0
314	601	1.0	1.1	353	588	1.3	1.3	4 667	5 943	1.0	0.7	2 286	3 190	0.6	0.5
108	278	0.3	0.5	31	56	0.1	0.1	2 788	5 552	0.6	0.7	282	595	0.1	0.1
6 822	12 916	21.3	23.2	8 355	16 902	30.3	36.1	79 454	212 538	17.2	26.3	85 995	195 905	21.2	31.5
24	150	0.1	0.3	7	9	0.0	0.0	143	2 095	0.0	0.3	51	47	0.0	0.0
205	313	0.6	0.6	52	75	0.2	0.2	2 663	2 075	0.6	0.3	1 485	2 279	0.4	0.4
564	827	2.0	1.8	497	827	1.6	1.5	6 824	4 586	1.7	0.7	9 668	10 654	2.1	1.3
4	9	0.0	0.0	0	0	0.0	0.0	88	125	0.0	0.0	3	15	0.0	0.0
29	23	0.1	0.0	0	0	0.0	0.0	254	809	0.1	0.1	1	1	0.0	0.0
994	1 483	3.1	2.7	648	763	2.4	1.6	12 789	16 569	2.8	2.0	14 227	13 911	3.5	2.2
3 238	3 813	10.1	6.8	2 912	4 854	10.6	10.4	27 040	41 823	5.9	5.2	30 549	42 572	7.5	6.8
22	18	0.1	0.0	3	1	0.0	0.0	512	410	0.1	0.1	11	42	0.0	0.0
1 420	1 547	4.4	2.8	1 671	2 371	6.1	5.1	14 514	17 095	3.1	2.1	12 071	14 922	3.0	2.4
1 748	3 742	5.5	6.7	611	1 598	2.2	3.4	20 898	33 669	4.5	4.2	27 726	55 317	6.8	8.9
72	304	0.2	0.5	218	96	0.8	0.2	1 733	8 603	0.4	1.1	338	697	0.1	0.1
135	1 579	0.4	2.8	9	39	0.0	0.1	1 422	3 933	0.3	0.5	140	299	0.0	0.0
1 641	1 820	5.1	3.3	2 250	2 012	8.2	4.3	19 862	20 169	4.3	2.5	28 517	11 900	7.0	1.9
4 827	7 011	15.1	12.6	3 677	4 892	13.4	10.5	77 466	90 951	16.8	11.2	51 591	48 320	12.7	7.8

Table 8: International trade in high-tech products, 2002 and 2007 (in US$ millions)

	Non-electrical machinery							
	Imports		World share of imports (%)		Exports		World share of exports (%)	
	2002	2007	2002	2007	2002	2007	2002	2007
World	**30 778**	**52 355**	**100.0**	**100.0**	**33 549**	**59 434**	**100.0**	**100.0**
Developed countries	21 416	33 743	69.6	64.4	31 821	53 921	94.8	90.7
Developing countries	9 314	18 408	30.3	35.2	1 725	5 467	5.1	9.2
Least developed countries	48	204	0.2	0.4	3	46	0.0	0.1
Americas	**7 940**	**10 833**	**25.8**	**20.7**	**8 803**	**12 230**	**26.2**	**20.6**
North America	5 982	7 653	19.4	14.6	8 366	11 310	24.9	19.0
Latin America and the Caribbean	1 957	3 180	6.4	6.1	437	920	1.3	1.5
Europe	**14 305**	**24 337**	**46.5**	**46.5**	**19 177**	**35 402**	**57.2**	**59.6**
European Union	12 350	20 027	40.1	38.3	15 737	29 229	46.9	49.2
Commonwealth of Independent States in Europe	587	1 708	1.9	3.3	844	1 272	2.5	2.1
Central, Eastern and Other Europe	1 369	2 602	4.4	5.0	2 596	4 901	7.7	8.2
Africa	**418**	**1 066**	**1.4**	**2.0**	**22**	**44**	**0.1**	**0.1**
South Africa	104	267	0.3	0.5	9	20	0.0	0.0
Other Sub–Saharan countries (excl. South Africa)	66	278	0.2	0.5	10	12	0.0	0.0
Arab States in Africa	248	520	0.8	1.0	2	12	0.0	0.0
Asia	**7 791**	**15 475**	**25.3**	**29.6**	**5 479**	**11 662**	**16.3**	**19.6**
Japan	1 196	1 777	3.9	3.4	4 246	7 286	12.7	12.3
China	2 101	4 551	6.8	8.7	226	1 206	0.7	2.0
Israel	97	169	0.3	0.3	147	336	0.4	0.6
India	133	601	0.4	1.1	85	184	0.3	0.3
Commonwealth of Independent States in Asia	106	177	0.3	0.3	3	3	0.0	0.0
Newly Industrialised Economies in Asia	2 403	3 813	7.8	7.3	699	2 319	2.1	3.9
Arab States in Asia	579	2 981	1.9	5.7	1	6	0.0	0.0
Other in Asia (excl. Japan, China, India, Israel)	1 176	1 407	3.8	2.7	73	322	0.2	0.5
Oceania	**324**	**645**	**1.1**	**1.2**	**68**	**96**	**0.2**	**0.2**
Other groupings								
Arab States all	827	3 501	2.7	6.7	3	18	0.0	0.0
Commonwealth of Independent States all	693	1 884	2.3	3.6	846	1 275	2.5	2.1
OECD	22 828	34 813	74.2	66.5	31 551	54 346	94.0	91.4
European Free Trade Association	953	1 783	3.1	3.4	2 532	4 625	7.5	7.8
Sub–Saharan Africa (incl. South Africa)	171	545	0.6	1.0	20	32	0.1	0.1
Other in Asia (incl. Japan, China, India, Israel)	4 703	8 505	15.3	16.2	4 776	9 334	14.2	15.7
Selected countries								
Argentina	78	223	0.3	0.4	15	24	0.0	0.0
Brazil	463	573	1.5	1.1	28	70	0.1	0.1
Canada	1 134	687	3.4	1.2	1 287	1 536	4.2	2.9
Cuba	3	16	0.0	0.0	1	4	0.0	0.0
Egypt	3	17	0.0	0.0	0	0	0.0	0.0
France	1 737	2 677	5.6	5.1	1 988	2 729	5.9	4.6
Germany	3 091	5 167	10.0	9.9	4 752	9 028	14.2	15.2
Iran (Islamic Republic of)	514	20	1.7	0.0	0	2	0.0	0.0
Mexico	1 090	1 767	3.5	3.4	362	789	1.1	1.3
Republic of Korea	895	1 178	2.9	2.3	303	1 164	0.9	2.0
Russian Federation	301	966	1.0	1.8	713	1 079	2.1	1.8
Turkey	381	632	1.2	1.2	36	172	0.1	0.3
United Kingdom	2 127	2 475	6.9	4.7	2 581	3 338	7.7	5.6
United States of America	4 695	6 117	15.3	11.7	7 232	10 623	21.6	17.9

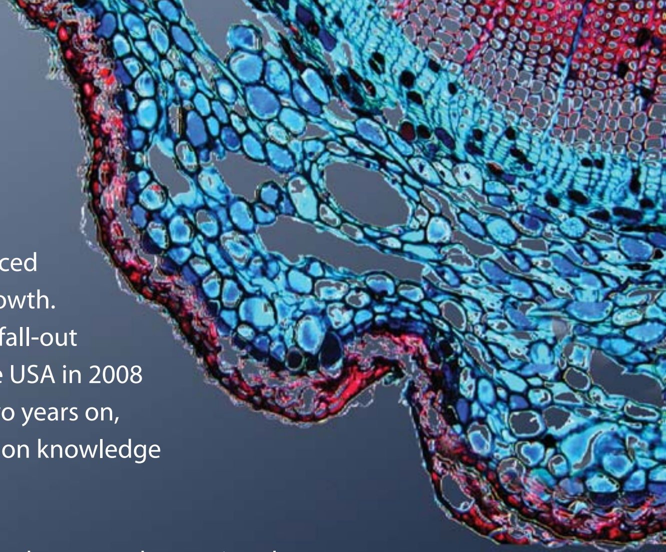
Pharmacy								Scientific instruments							
Imports		World share of imports (%)		Exports		World share of exports (%)		Imports		World share of imports (%)		Exports		World share of exports (%)	
2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007
53 106	**120 519**	**100.0**	**100.0**	**50 805**	**111 292**	**100.0**	**100.0**	**102 420**	**239 160**	**100.0**	**100.0**	**97 187**	**224 953**	**100.0**	**100.0**
44 048	99 065	82.9	82.2	47 200	102 756	92.9	92.3	71 531	131 486	69.8	55.0	84 229	157 513	86.7	70.0
8 726	20 203	16.4	16.8	3 600	8 518	7.1	7.7	30 684	107 015	30.0	44.7	12 953	67 423	13.3	30.0
332	1 251	0.6	1.0	5	18	0.0	0.0	206	659	0.2	0.3	5	18	0.0	0.0
11 606	**25 930**	**21.9**	**21.5**	**8 295**	**17 888**	**16.3**	**16.1**	**29 219**	**54 144**	**28.5**	**22.6**	**28 046**	**43 388**	**28.9**	**19.3**
8 662	18 177	16.3	15.1	7 534	16 839	14.8	15.1	24 088	37 587	23.5	15.7	25 205	38 736	25.9	17.2
2 944	7 753	5.5	6.4	762	1 049	1.5	0.9	5 130	16 557	5.0	6.9	2 841	4 652	2.9	2.1
33 042	**77 179**	**62.2**	**64.0**	**38 520**	**84 328**	**75.8**	**75.8**	**39 396**	**79 979**	**38.5**	**33.4**	**45 895**	**94 935**	**47.2**	**42.2**
26 649	64 192	50.2	53.3	30 558	67 585	60.1	60.7	35 394	68 634	34.6	28.7	40 694	84 922	41.9	37.8
652	2 689	1.2	2.2	92	172	0.2	0.2	1 056	4 896	1.0	2.0	701	825	0.7	0.4
5 741	10 298	10.8	8.5	7 869	16 571	15.5	14.9	2 945	6 449	2.9	2.7	4 501	9 188	4.6	4.1
1 123	**2 518**	**2.1**	**2.1**	**51**	**84**	**0.1**	**0.1**	**1 331**	**2 971**	**1.3**	**1.2**	**166**	**318**	**0.2**	**0.1**
171	375	0.3	0.3	21	28	0.0	0.0	450	1 084	0.4	0.5	68	172	0.1	0.1
348	713	0.7	0.6	13	33	0.0	0.0	279	716	0.3	0.3	23	38	0.0	0.0
603	1 430	1.1	1.2	17	23	0.0	0.0	602	1 172	0.6	0.5	76	108	0.1	0.0
6 659	**13 169**	**12.5**	**10.9**	**3 731**	**8 513**	**7.3**	**7.6**	**30 865**	**98 717**	**30.1**	**41.3**	**22 565**	**85 529**	**23.2**	**38.0**
2 442	3 506	4.6	2.9	991	1 236	2.0	1.1	7 103	12 368	6.9	5.2	12 659	23 209	13.0	10.3
681	1 677	1.3	1.4	1 235	3 168	2.4	2.8	9 440	52 765	9.2	22.1	3 318	28 622	3.4	12.7
104	154	0.2	0.1	38	157	0.1	0.1	686	1 032	0.7	0.4	892	1 328	0.9	0.6
383	1 090	0.7	0.9	610	1 880	1.2	1.7	775	2 402	0.8	1.0	260	566	0.3	0.3
99	249	0.2	0.2	1	15	0.0	0.0	163	706	0.2	0.3	25	30	0.0	0.0
1 244	2 644	2.3	2.2	771	1 866	1.5	1.7	10 313	23 683	10.1	9.9	5 209	31 027	5.4	13.8
817	2 531	1.5	2.1	37	97	0.1	0.1	1 073	3 009	1.0	1.3	17	11	0.0	0.0
889	1 316	1.7	1.1	46	94	0.1	0.1	1 313	2 752	1.3	1.2	187	735	0.2	0.3
676	**1 723**	**1.3**	**1.4**	**208**	**479**	**0.4**	**0.4**	**1 609**	**3 349**			**514**	**783**	**0.5**	**0.3**
1 420	3 962	2.7	3.3	54	120	0.1	0.1	1 675	4 181	1.6	1.7	93	119	0.1	0.1
751	2 938	1.4	2.4	93	187	0.2	0.2	1 219	5 602	1.2	2.3	725	855	0.7	0.4
44 725	98 541	84.2	81.8	47 276	102 651	93.1	92.2	76 599	143 934	74.8	60.2	86 746	181 812	89.3	80.8
4 797	8 370	9.0	6.9	7 655	16 308	15.1	14.7	2 088	4 194	2.0	1.8	4 401	8 891	4.5	4.0
520	1 088	1.0	0.9	34	60	0.1	0.1	729	1 800	0.7	0.8	91	210	0.1	0.1
4 500	7 744	8.5	6.4	2 921	6 536	5.8	5.9	19 316	71 319	18.9	29.8	17 315	54 460	17.8	24.2
193	529	0.4	0.4	138	203	0.3	0.2	116	578	0.1	0.2	43	104	0.0	0.0
943	1 940	1.8	1.6	97	197	0.2	0.2	1 174	3 300	1.1	1.4	183	385	0.2	0.2
361	1 245	0.7	1.1	1 141	2 684	2.1	2.2	1 905	2 956	2.0	1.3	4 334	5 815	4.2	2.4
21	23	0.0	0.0	44	99	0.1	0.1	46	99	0.0	0.0	6	33	0.0	0.0
194	125	0.4	0.1	9	1	0.0	0.0	86	154	0.1	0.1	0	1	0.0	0.0
4 006	6 522	7.5	5.4	4 115	7 345	8.1	6.6	4 840	9 078	4.7	3.8	4 751	10 026	4.9	4.5
5 090	13 981	9.6	11.6	4 219	13 633	8.3	12.2	7 856	15 411	7.7	6.4	14 675	31 227	15.1	13.9
304	174	0.6	0.1	5	16	0.0	0.0	401	178	0.4	0.1	1	5	0.0	0.0
777	1 454	1.5	1.2	319	355	0.6	0.3	2 760	9 533	2.7	4.0	2 535	3 563	2.6	1.6
479	1 005	0.9	0.8	206	420	0.4	0.4	3 659	8 251	3.6	3.5	882	22 448	0.9	10.0
480	2 050	0.9	1.7	75	119	0.1	0.1	844	4 001	0.8	1.7	485	577	0.5	0.3
714	1 408	1.3	1.2	51	97	0.1	0.1	597	1 680	0.6	0.7	42	149	0.0	0.1
2 995	7 170	5.6	5.9	4 016	8 427	7.9	7.6	5 410	8 209	5.3	3.4	6 430	10 466	6.6	4.7
7 522	15 493	14.2	12.9	7 173	15 594	14.1	14.0	19 755	31 772	19.3	13.3	23 301	35 780	24.0	15.9

Table 8: International trade in high-tech products, 2002 and 2007 (in US$ millions)

	Total							
	Imports		World share of imports (%)		Exports		World share of exports (%)	
	2002	2007	2002	2007	2002	2007	2002	2007
World	**1 107 129**	**1 899 035**	**100.0**	**100.0**	**1 022 794**	**1 683 127**	**100.0**	**100.0**
Developed countries	723 843	1 059 908	65.4	55.8	702 895	975 671	68.7	58.0
Developing countries	381 297	831 389	34.4	43.8	319 853	707 209	31.3	42.0
Least developed countries	1 988	7 739	0.2	0.4	46	247	0.0	0.0
Americas	**294 816**	**405 591**	**26.6**	**21.4**	**224 890**	**298 124**	**22.0**	**17.7**
North America	243 346	314 507	22.0	16.6	187 691	249 323	18.4	14.8
Latin America and the Caribbean	51 470	91 084	4.6	4.8	37 199	48 801	3.6	2.9
Europe	**408 367**	**650 104**	**36.9**	**34.2**	**416 379**	**606 308**	**40.7**	**36.0**
European Union	373 689	573 833	33.8	30.2	386 604	557 201	37.8	33.1
Commonwealth of Independent States in Europe	6 696	26 646	0.6	1.4	5 854	5 865	0.6	0.3
Central, Eastern and Other Europe	27 981	49 625	2.5	2.6	23 921	43 242	2.3	2.6
Africa	**12 350**	**27 006**	**1.1**	**1.4**	**1 746**	**4 288**	**0.2**	**0.3**
South Africa	4 419	8 370	0.4	0.4	749	1 833	0.1	0.1
Other Sub–Saharan countries (excl. South Africa)	3 274	7 963	0.3	0.4	193	1 010	0.0	0.1
Arab States in Africa	4 657	10 673	0.4	0.6	803	1 445	0.1	0.1
Asia	**376 280**	**792 514**	**34.0**	**41.7**	**376 378**	**770 429**	**36.8**	**45.8**
Japan	62 814	85 944	5.7	4.5	96 037	117 950	9.4	7.0
China	73 782	250 413	6.7	13.2	69 244	302 832	6.8	18.0
Israel	5 158	6 222	0.5	0.3	5 633	3 085	0.6	0.2
India	5 129	22 056	0.5	1.2	2 356	6 002	0.2	0.4
Commonwealth of Independent States in Asia	1 137	4 274	0.1	0.2	183	1 538	0.0	0.1
Newly Industrialised Economies in Asia	201 505	358 245	18.2	18.9	186 439	305 095	18.2	18.1
Arab States in Asia	5 886	25 441	0.5	1.3	140	335	0.0	0.0
Other in Asia (excl. Japan, China, India, Israel)	20 868	39 919	1.9	2.1	16 346	33 591	1.6	2.0
Oceania	**15 315**	**23 820**	**1.4**	**1.3**	**3 400**	**3 979**	**0.3**	**0.2**
Other groupings								
Arab States all	10 543	36 114	1.0	1.9	943	1 780	0.1	0.1
Commonwealth of Independent States all	7 834	30 919	0.7	1.6	6 037	7 402	0.6	0.4
OECD	777 776	1 131 807	70.3	59.6	770 362	1 098 817	75.3	65.3
European Free Trade Association	20 871	31 776	1.9	1.7	22 790	40 359	2.2	2.4
Sub–Saharan Africa (incl. South Africa)	7 693	16 333	0.7	0.9	943	2 843	0.1	0.2
Other in Asia (incl. Japan, China, India, Israel)	167 752	404 554	15.2	21.3	189 616	463 461	18.5	27.5
Selected countries								
Argentina	1 112	6 040	0.1	0.3	607	1 156	0.1	0.1
Brazil	7 940	14 106	0.7	0.7	5 429	9 276	0.5	0.6
Canada	22 919	27 111	2.2	1.6	30 748	40 825	2.8	2.1
Cuba	325	451	0.0	0.0	66	248	0.0	0.0
Egypt	798	1 436	0.1	0.1	13	6	0.0	0.0
France	45 108	65 841	4.1	3.5	53 529	79 263	5.2	4.7
Germany	85 367	130 723	7.7	6.9	93 803	153 876	9.2	9.1
Iran (Islamic Republic of)	2 487	955	0.2	0.1	65	403	0.0	0.0
Mexico	29 489	42 921	2.7	2.3	28 955	33 500	2.8	2.0
Republic of Korea	34 626	59 967	3.1	3.2	46 992	101 199	4.6	6.0
Russian Federation	5 082	21 293	0.5	1.1	5 042	4 151	0.5	0.2
Turkey	4 909	13 559	0.4	0.7	585	1 778	0.1	0.1
United Kingdom	57 792	71 077	5.2	3.7	69 974	61 294	6.8	3.6
United States of America	212 598	273 682	19.2	14.4	164 771	222 212	16.1	13.2

Note: Methodology based on Standard International Trade Classification, as proposed in OCDE/GD(97)216; all Import figures are minus re-imports; all export figures are minus re-exports.

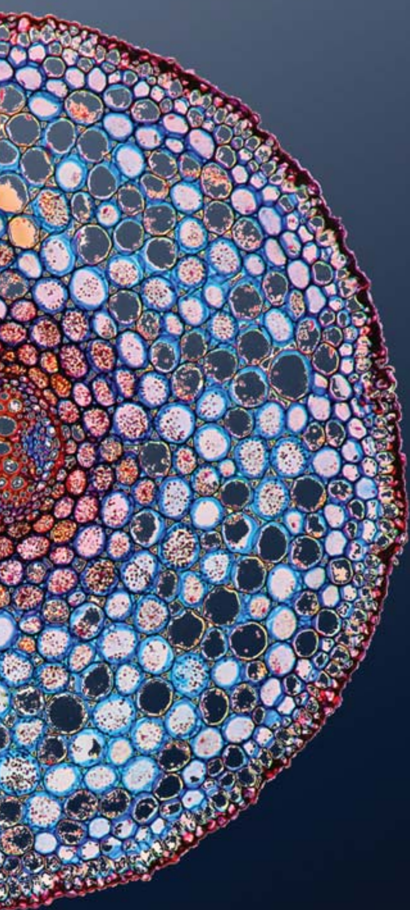
Source: COMTRADE Database of the United Nations Statistical Division, as of May 2010, and UNESCO Institute for Statistics estimations



Increasingly, international diplomacy will take the form of science diplomacy in the years to come.
Irina Bokova
Director-General
of UNESCO

In the decade to 2007, the world experienced an unprecedented period of economic growth. The cycle was brought to a halt when the fall-out from the 'sub-prime' mortgage crisis in the USA in 2008 triggered a global economic recession. Two years on, what impact has the global recession had on knowledge creation around the world?

Written by a team of independent experts who are each covering the country or region from which they hail, the *UNESCO Science Report 2010* analyses the trends and developments that have shaped scientific research, innovation and higher education over the past five years. The report depicts an increasingly competitive environment, one in which the flow of information, knowledge, personnel and investment has become a two-way traffic. Both China and India, for instance, are using their newfound economic might to invest in high-tech companies in Europe and elsewhere to acquire technological expertise overnight. Other large emerging economies are also spending more on research and development than before, among them Brazil, Mexico, South Africa and Turkey.



If more countries are participating in science, we are also seeing a shift in global influence. China is a hair's breadth away from counting more researchers than either the USA or the European Union, for instance, and now publishes more scientific articles than Japan.

Even countries with a lesser scientific capacity are finding that they can acquire, adopt and sometimes even transform existing technology and thereby 'leapfrog' over certain costly investments, such as in infrastructure like land lines for telephones. Technological progress is allowing these countries to produce more knowledge and participate more actively than before in international networks and research partnerships with countries in both North and South. This trend is fostering a democratization of science worldwide. In turn, science diplomacy is becoming a key instrument of peace-building and sustainable development in international relations.

Taking up from where its predecessor left off in 2005, the *UNESCO Science Report 2010* proposes a world tour of the status of science today that should enable 'science watchers' everywhere to decipher the trends that are shaping our rapidly changing world.

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