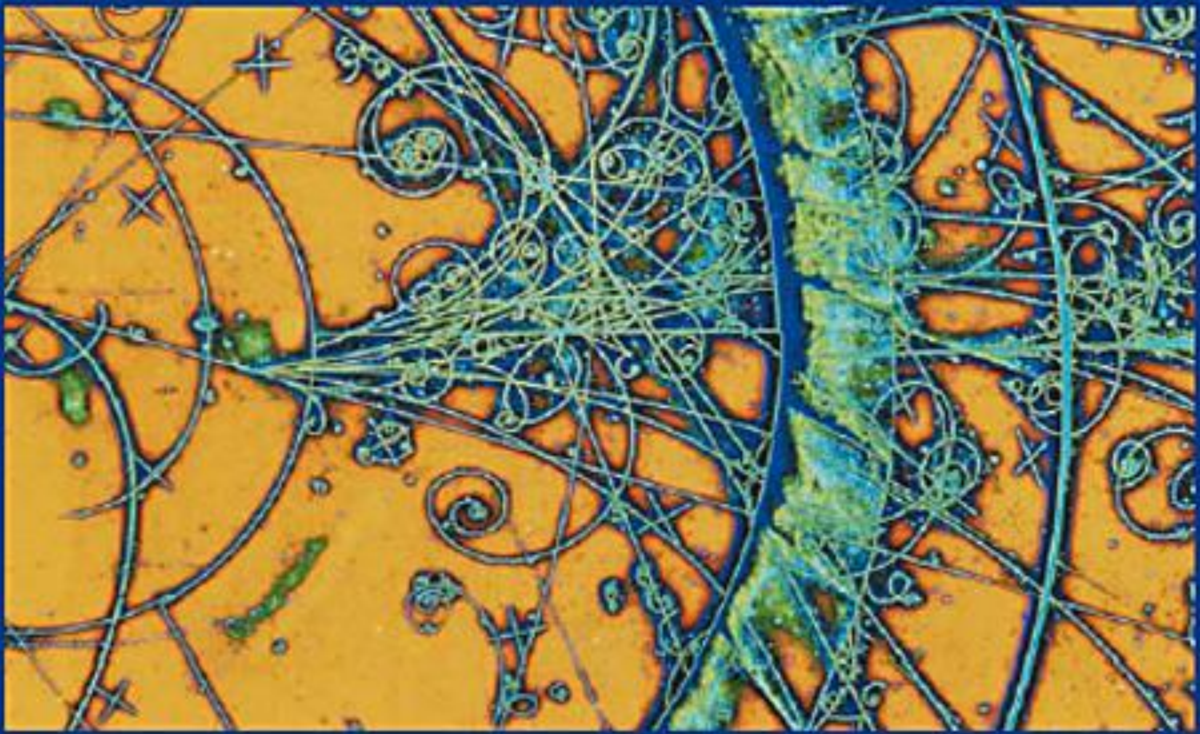
UNESCO SCIENCE REPORT 2005



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UNESCO SCIENCE REPORT 2005

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Foreword

The *UNESCO Science Report 2005* takes us on a world tour. Through the eyes of an international team of experts, it analyses the current state of science around the globe. What new trends have emerged since the previous report was published in 1998? What events have helped to reshape the scientific enterprise? For example, what has been the impact on science of the Stability Pact for South-East Europe adopted in 1999, the New Partnership for Africa's Development (NEPAD) launched by the African Union in 2001, and the enlargement of the European Union from 15 to 25 Member States in 2004? What distinguishes the scientific profiles of different countries and regions? In what ways are relations between governments, the private sector and 'knowledge institutions' (universities and research bodies) changing, and with what implications for scientific development?

The World Conference on Science has come and gone but its legacy remains. Organized in 1999 by UNESCO and the International Council for Science (ICSU), the World Conference on Science made numerous recommendations. How have these translated into national science policies? For instance, are governments' policy decisions acknowledging that the returns and applications derived from basic research irrigate the entire research system and that basic research therefore requires sustained public support?

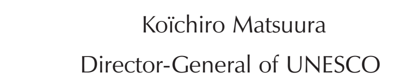
In his introduction, Peter Tindemans summarizes the key themes explored throughout the report. The desire to build knowledge societies has become an overriding goal of governments the world over, he notes. Human resources are naturally a key component of this effort. At the same time, governments, industry and other actors in the scientific enterprise are coming to realize 'that building up human resources can be accompanied by large-scale problems', not least of which is the phenomenon of brain drain, be it internal or external. One of the most effective bulwarks against brain drain is a strong university system, but which countries can boast of a strong university system today?

If the 'knowledge society' is one key concept in the present report, a second is 'innovation'. We shall see that private industry has come to dominate the funding of research and development (R&D) in many countries but that still more is expected of it. However, Tindemans warns that it will not be companies that fund the greatest proportion of basic research in academic institutions in the years to come, despite the fact that universities play an increasingly important role in the innovation system. We find out why in the present report.

We shall also see that Asia's role on the international scene is growing rapidly, driven largely by China's dynamism. This trend is challenging the dominance of the triad comprising Japan, the USA and the European Union. Asia has now overtaken Europe in terms of world share of expenditure on R&D, for instance. However, with hundreds of millions of Asian children still living in poverty, the benefits of R&D are still not reaching large segments of the population who are deprived of such ' basics' as good nutrition, access to safe water, sanitation and shelter. Let us not forget that one of the key recommendations of the World Conference on Science was for R&D to target social needs and development-related problem-solving .

Elsewhere, countries less well-known for their scientific endeavour, such as Turkey, are emerging on the international scene. Science may not yet be a global enterprise but the circle of players is definitely widening. International cooperation is not only helping countries to 'catch up' but is also becoming indispensable to the very exercise of science. We live in exciting times.

I trust that the information, data and informed analysis contained in these pages will prove to be invaluable reference material for public and private sector decision-makers, scientists, students, journalists and all those interested in the unfolding story of science. If these pages provoke reflection and policy debate, the *UNESCO Science Report* will have served its purpose.



Koïchiro Matsuura
Director-General of UNESCO

Introduction

Producing knowledge and benefiting from it: the new rules of the game

PETER TINDEMANS

SETTING THE SCENE

There is little doubt that the metaphor most widely used in the present *UNESCO Science Report* is that of a knowledge economy or, as we should say, *knowledge society*. But is it more than a metaphor? Yes, indeed. This introductory chapter will be highlighting some important elements of this new mindset about science and technology (S&T).

Most of the chapters in the present report go beyond updating information on the recent efforts of regions to develop research and development (R&D). The chapters also provide an overview of S&T policies covering a longer period, against the backdrop of what is now perceived as being foremost on the minds of governments, enterprises, research bodies and universities: how to develop a knowledge society.

If we take it for granted that there is real substance to the concept of knowledge societies, there is all the more reason for governments, industry and other actors to take their role in this global movement very seriously. Is this conclusion borne out by the regional reports that follow the present chapter? The answer is that many of these actors are trying, a few are enjoying the first signs of success and all are coming to realize that building up human resources can be accompanied by large-scale problems. This trend will also be addressed in the following pages.

There is another catchword that has gained currency, to the point of even replacing S&T at times, and that is the word 'innovation'. Employed by economists since Schumpeter,[1] it has become the staple food of politicians, industrialists and university managers over the past decade. Many policies on S&T are being restyled into innovation policies. Moreover, the predominance of the private sector in countries that have succeeded in developing and applying S&T suggests that there is a need to rethink the roles of governments, universities and research institutes. We shall thus reflect in this introductory chapter on the role of the private sector and on various corollaries, such as the need for a strong interaction with knowledge institutions and public authorities (the Triple Helix) but also a rethinking of the rules of the game such as in the area of patents. Classical sector-based industrial policies will most likely be more difficult to implement. The scientific profiles of the USA, Europe and Japan can be read as both an indication of the past and a look into the future.

The various chapters in the *UNESCO Science Report* demonstrate that the institutional framework for S&T is going through a period of important adaptation, a fourth theme for this introduction, which will focus on the academic sector. Venerable as they are, universities in most places are nevertheless going to need to reposition themselves to meet the expectations of society, industry and their own students. Autonomy and accountability will be the guiding concepts for rethinking their role. This represents a key task for governments, not least because a strong university system nestled in the midst of a society – one which is equipped to embrace entrepreneurship, open interaction and communication – is vital to countering one of the most serious of problems in a globalizing world: brain drain.

Of course, many more themes emerge from the various chapters that follow. Space constraints preclude covering such issues as the life sciences revolution or sustainability, or what is perhaps the greatest challenge of all, namely whether societies and individuals will be able to find fitting responses to the many deep ethical issues raised by S&T, in a world that is shrinking through globalization – a phenomenon that, by the same token, is laying bare widely differing traditions, points of view and priorities.

HOW DIFFERENT IS A KNOWLEDGE SOCIETY FROM PREVIOUS SOCIETIES?

It is now customary to affirm that knowledge, education, science, technology and innovation have become the

1. Austrian economist who lived from 1883 to 1950.

prime drivers of progress that is itself targeting that most cherished of goals, the knowledge society. Although a much-abused incantation, the concept of the knowledge society carries a very real and practical meaning. It is thus worthwhile to clarify its meaning.

Borrowing economists' parlance, we might say that societies produce goods, services and quality of life – the latter being actually a special category of services. These services result in such highly valued benefits as a sustainable environment, good healthcare and different forms of cultural expression. Government policy underlies the services produced by government. Producing these goods and services requires land, capital goods, human capital, information and knowledge capital, and institutions. These are all termed 'production factors'.

If we now compare traditional societies with modern societies, it becomes evident that both the production factors mentioned above and the products and services that result are heavily transfused with knowledge: not just knowledge in the form of accumulated experience, but science-based knowledge. Take any product or service and the way it is produced, and the differences will stand out. A modern pharmaceutical drug incorporates a lot of advanced pharmaceutical – and often biotechnological and genetic – knowledge and is produced with advanced process machinery. Compare that with medicinal plants, the use of which used to require experiential knowledge only. To feed one person in 1900 required half a hectare of land and more than one year of labour; that same half-hectare now feeds 10 persons on the basis of just one and a half days of labour. The difference lies in the scientific knowledge that went into developing better fertilizers, machinery, seed and crop varieties (the many new Bangladesh rice varieties mentioned in the South Asia chapter of the present report being a nice example), crop rotation schemes and so on. The resulting food often has a high nutritional value coupled with health-improving features.

The cars we drive cannot be produced at a reasonable price without advanced machinery; they themselves embody an accumulation of scientific and engineering knowledge. Nowadays, cars also include information capital, in the form of navigation systems based on the Global Positioning System. 'Producing' a sustainable environment is impossible without advanced ecological simulation models. One could equally take as an example modern communication, transportation or energy infrastructure. Inventing, designing, producing – and often also using – these goods and services requires highly educated, skilled individuals.

Most of the institutions within a society are evidently being transformed as well. Corporations have taken on a new face; financial institutions have evolved to cope with technology-based global instantaneous capital flows. Institutions dispensing education are having to adapt to lifelong learning.

In point of fact, there is an even deeper dimension to knowledge societies. The communal aspect of society living, the mutual understanding of different ethnic, religious or other groups, the public discourse, the dialogue between governments, non-governmental organizations (NGOs), industry and the population at large: all these interactions are increasingly based on complementing, and often replacing, traditional beliefs and inherited views or misconceptions by a more rational, knowledge-based discourse.

It is of course impossible to define the threshold above which a society can be qualified as a knowledge society. It could be said that A.N. Whitehead first sowed the seeds of the concept in *Science and the Modern World*, when he stated that the greatest invention of the nineteenth century was that of the method of invention. This said, the pervasive impact of science is now often quantifiable. And gradual as the process may be, it is now so far advanced in many parts of the world that being part of the globalized world and nourishing corresponding ambitions leaves us no choice but to develop and use production factors 'transfused with knowledge'. Education (and more general learning by individuals and organizations), research and innovation are the key words for this process of 'transfusion'.

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ONLY A FEW NEWCOMERS ARE PRODUCING SCIENCE AND BENEFITING FROM IT

Input into R&D production

The world devoted 1.7% of gross domestic product (GDP) to R&D in 2002. In monetary terms, this translates into US$ 830 billion,[2] according to estimates by the UNESCO Institute for Statistics (December 2004). These global figures conceal huge discrepancies, of course. They reflect the enormous divide in terms of development, prosperity, health and participation in the world economy but also in world affairs in general. These discrepancies are therefore cause for great concern.

The question is, are current trends indicative of a more balanced situation emerging, or do the USA, Europe and Japan continue to dominate knowledge production and remain the ones profiting overwhelmingly from knowledge-turned products and services – in other words, wealth?

It will take a handful of indicators to answer that question. While it is possible to argue at length about the merits of each and every individual indicator, there is no doubt that, where there are wide margins between the scores of regions or countries, these margins do reflect an underlying reality.

Table 1 presents the key indicators for world GDP, population, gross expenditure on R&D (GERD) and personnel in 2002. The shares of North America and Europe[3] in world GERD are on a gently downward sloping path. North America was responsible for 38.2% of world GERD in 1997 but 37.0% in 2002. For Europe, the corresponding figures are 28.8% in 1997 and 27.3% in 2002.

The most remarkable trend is to be found in Asia, where GERD has grown from a world share of 27.9% in 1997 to 31.5% in 2002. As for the remaining regions, Latin America and the Caribbean, Oceania and Africa, these each account for just a fraction of the total, at respectively 2.6% (down from 3.1% in 1997), 1.1% (stable) and 0.6% (stable).

Oceania need not be worried by its small world share, of course. With a population of just 30 million (compared with 766 million for Africa and 505 million for Latin America), Oceania can boast of a GERD per capita and as a percentage of GDP that falls comfortably within the range of the countries of the Organisation for Economic Cooperation and Development (OECD).

However, to unearth where the interesting dynamics are taking place and where there is a genuine cause for concern, we need to look at smaller parts of each of these continents.

In North America, there are some discrepancies and these are naturally of some concern to local and state governments. These governments all vie for public or private investment in R&D but, as this occurs in a completely integrated economy with a highly mobile labour force and a great variety of natural endowments spawning more specialized sub-economies, the standard of living of citizens in the different states is far less varied than regional GERD. R&D is concentrated in just a small number of states: in the USA, for example, 60% of all R&D is carried out in just six states, with California alone accounting for 20%. (See the chapter on the USA.)

With 25 Members since the accession of ten new countries from Central, Eastern and Southern Europe in May 2004, the European Union (EU) now accounts for 90% of European GERD. A further two countries, Bulgaria and Romania, are due to join in 2007. With integration proceeding, the EU ought to conjure up similar, if less pronounced, images of an integrated economy with strongly varying regional concentrations of production factors, including knowledge production factors. That the ten new Member countries no doubt will 'catch up', by attracting greater investment in R&D and generating higher levels of income, is a natural process and does not imply a trend simply towards deconcentration. More worrying from an economic perspective is that one of the underlying issues in the current debate about the future direction of the EU concerns its capacity to accept regional differences, which may be wise economically, but which are politically difficult to swallow. The fact that the R&D budget of the EU represents just 5% of public

2. All US$s in this chapter are PPP $s.
3. Europe here includes notably Russia, Ukraine and Belarus.

Table 1
KEY INDICATORS ON WORLD GDP, POPULATION AND GERD, 2002

	GDP (in billions)	% world GDP	Population (in millions)	% world population	GERD (in billions)	% world GERD	% GERD /GDP	GERD per inhabitant
World	**47 599.4**	**100.0**	**6 176.2**	**100.0**	**829.9**	**100.0**	**1.7**	**134.4**
Developed countries	28 256.5	59.4	1 195.1	19.3	645.8	77.8	2.3	540.4
Developing countries	18 606.5	39.1	4 294.2	69.5	183.6	22.1	1.0	42.8
Less-developed countries	736.4	1.5	686.9	11.1	0.5	0.1	0.1	0.7
Americas	**14 949.2**	**31.4**	**849.7**	**13.8**	**328.8**	**39.6**	**2.2**	**387.0**
North America	11 321.6	23.8	319.8	5.2	307.2	37.0	2.7	960.5
Latin America and the Caribbean	3 627.5	7.6	530.0	8.6	21.7	2.6	0.6	40.9
Europe	**13 285.8**	**27.9**	**795.0**	**12.9**	**226.2**	**27.3**	**1.7**	**284.6**
European Union	10 706.4	22.5	453.7	7.3	195.9	23.6	1.8	431.8
Comm. of Ind. States in Europe	1 460.0	3.1	207.0	3.4	17.9	2.2	1.2	86.6
Central, Eastern and Other Europe	1 119.4	2.4	134.4	2.2	12.4	1.5	1.1	92.6
Africa	**1 760.0**	**3.7**	**832.2**	**13.4**	**4.6**	**0.6**	**0.3**	**5.6**
Sub-Saharan countries	1 096.9	2.3	644.0	10.4	3.5	0.4	0.3	5.5
Arab States Africa	663.1	1.4	188.2	3.0	1.2	0.1	0.2	6.5
Asia	**16 964.9**	**35.6**	**3 667.5**	**59.4**	**261.5**	**31.5**	**1.5**	**71.3**
Comm. of Ind. States in Asia	207.9	0.4	72.6	1.2	0.7	0.1	0.4	10.3
Newly Indust. Asia	2 305.5	4.8	374.6	6.1	53.5	6.4	2.3	142.8
Arab States Asia	556.0	1.2	103.9	1.7	0.6	0.1	0.1	6.2
Other Asia	1 720.0	3.6	653.7	10.6	1.4	0.2	0.1	2.1
Oceania	**639.5**	**1.3**	**31.8**	**0.5**	**8.7**	**1.1**	**1.4**	**274.2**
Other groupings								
Arab States All	1 219.1	2.6	292.0	4.7	1.9	0.2	0.2	6.4
Comm. of Ind. States All	1 667.9	3.5	279.6	4.5	18.7	2.2	1.1	66.8
OECD	28 540.0	60.0	1 144.1	18.5	655.1	78.9	2.3	572.6
Selected countries								
Argentina	386.6	0.8	36.5	0.6	1.6	0.2	0.4	44.0
Brazil*	1 300.3	2.7	174.5	2.8	13.1	1.6	1.0	75.0
China	5 791.7	12.2	1 280.4	20.7	72.0	8.7	1.2	56.2
Egypt*	252.9	0.5	66.4	1.1	0.4	0.1	0.2	6.6
France	1 608.8	3.4	59.5	1.0	35.2	4.2	2.2	591.5
Germany	2 226.1	4.7	82.5	1.3	56.0	6.7	2.5	678.3
India*	2 777.8	5.8	1 048.6	17.0	20.8	2.5	0.7	19.8
Israel	124.8	0.3	6.6	0.1	6.1	0.7	4.9	922.4
Japan	3 481.3	7.3	127.2	2.1	106.4	12.8	3.1	836.6
Mexico	887.1	1.9	100.8	1.6	3.5	0.4	0.4	34.7
Russian Federation	1 164.7	2.4	144.1	2.3	14.7	1.8	1.3	102.3
South Africa	444.8	0.9	45.3	0.7	3.1	0.4	0.7	68.7
United Kingdom	1 574.5	3.3	59.2	1.0	29.0	3.5	1.8	490.4
United States of America	10 414.3	21.9	288.4	4.7	290.1	35.0	2.8	1005.9

* GERD figures for Brazil, India and Egypt are all for 2000.
Note: For Asia, the sub-regional totals do not include China, India or Japan in any of the tables in the present chapter.

Source: UNESCO Institute for Statistics estimations, December 2004.

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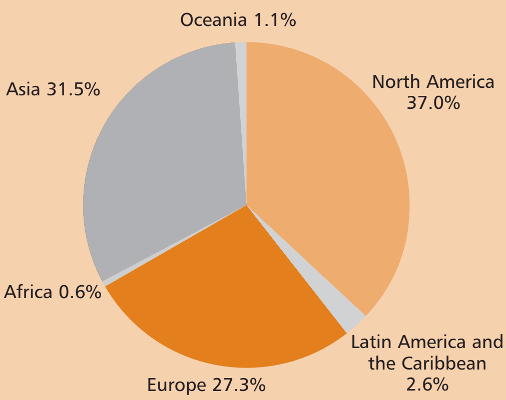
Figure 1
WORLD SHARES OF GERD, 2002
By region



Source: see Table 1.

expenditure on R&D by Member States also demonstrates that there is no such thing yet as a truly European R&D market.

As far as Asia is concerned, it is now very clear that the so-called Newly Industrialized Asian economies, together with China and, to a lesser extent, India have become serious contributors to world GERD and to the stock of knowledge. In 2002, China contributed 8.7% of world GERD, up from 3.9% in 1997. This compared with 6.4% for the Newly Industrialized Asian economies, up from 3.9% in 1997, even if the percentage remained stable between 1997 and 2000. India contributed 2.5% to world GERD in 2000, up from 2.0% in 1997. The complicated political scene and slowly broadening technological base – now firmly rooted in information and communications technology (ICT), space, pharmaceuticals and biotechnology – are taking India along a gently upward-sloping path: the advantage is perhaps that it is easier to maintain a steady pace on a gentle slope than on a steeper climb.

The trend in the number of researchers tends to paint a similar picture to that of financial investment in R&D. Not surprisingly, but still indicative of the new era we live in, there were more researchers in China in 2002 than in Japan and more in the Newly Industrialized Asian economies as a whole than in Germany.

The leading Asian economies share a strong commitment to S&T: the Republic of Korea, Singapore and Taiwan of China devote more than 2% of GDP to R&D. As for China, it is well on the way to realizing its goal of a 1.5% GERD/GDP ratio by 2005. Meanwhile, India has set its own sights on crossing the 2% threshold in the coming years. The world will no doubt witness more sweeping changes in the S&T landscape in the coming decade.

Taking a bird's eye view of the dynamics of S&T production obliges us to deal separately with the Community of Independent States (CIS), made up of the countries of the former Union of Soviet Socialist Republics (USSR) in Europe and Asia. Under Soviet rule, most of these now independent states had built up strong R&D systems, albeit unbalanced ones from an economic perspective.

Since the disintegration of the USSR more than a decade ago, the R&D systems of all these states have become a shadow of their former selves, yet their size still stands out. The proportion of GDP spent on R&D by the Russian Federation, for example, still stands at 1.3%. Moreover, the number of researchers in Russia, 3 400 per million inhabitants, is the third-highest in the world, after Japan (5 100) and the USA (4 400). The downside is that expenditure per researcher amounts to a pittance in the Russian Federation, translating into low salaries and negligible expenditure on equipment, housing and consumables. Added to the still inconclusive restructuring of the Russian R&D system, explained vividly in the chapter on the Russian Federation, this implies poor working conditions. Although the situation definitely seems to be stabilizing and even improving with a slight

Table 2
WORLD RESEARCHERS, 2002

	Researchers (thousands)	% world researchers	Researchers per million inhabitants	GERD per researcher (US$ thousands)
World	**5 521.4**	**100.0**	**894.0**	**150.3**
Developed countries	3 911.1	70.8	3 272.7	165.1
Developing countries	1 607.2	29.1	374.3	114.3
Less-developed countries	3.1	0.1	4.5	153.7
Americas	**1 506.9**	**27.3**	**1 773.4**	**218.2**
North America	1 368.5	24.8	4 279.5	224.5
Latin America and the Caribbean	138.4	2.5	261.2	156.5
Europe	**1 843.4**	**33.4**	**2 318.8**	**122.7**
European Union	1 106.5	20.0	2 438.9	177.0
Comm. of Ind. States in Europe	616.6	11.2	2 979.1	29.1
Central, Eastern and Other Europe	120.4	2.2	895.9	103.4
Africa	**60.9**	**1.1**	**73.2**	**76.2**
Sub-Saharan Countries	30.9	0.6	48.0	113.9
Arab States Africa	30.0	0.5	159.4	40.9
Asia	**2 034.0**	**36.8**	**554.6**	**128.5**
Comm. of Ind. States in Asia	83.9	1.5	1 155.0	8.9
Newly Indust. Asia	291.1	5.3	777.2	183.7
Arab States Asia	9.7	0.2	93.5	66.6
Other Asia	65.5	1.2	100.2	20.9
Oceania	**76.2**	**1.4**	**2 396.5**	**114.4**
Other groupings				
Arab States All	39.7	0.7	136.0	47.2
Comm. of Ind. States All	700.5	12.7	2 505.3	26.7
OECD	3 414.3	61.8	2 984.4	191.9
Selected countries				
Argentina	26.1	0.5	715.0	61.5
Brazil*	54.9	1.0	314.9	238.0
China	810.5	14.7	633.0	88.8
France	177.4	3.2	2 981.8	198.4
Germany	264.7	4.8	3 208.5	211.4
India*	117.5	2.1	112.1	176.8
Israel*	9.2	0.2	1 395.2	661.1
Japan	646.5	11.7	5 084.9	164.5
Mexico*	21.9	0.4	217.0	159.7
Russian Federation	491.9	8.9	3 414.6	30.0
South Africa	8.7	0.2	192.0	357.6
United Kingdom*	157.7	2.9	2 661.9	184.2
United States of America*	1 261.2	22.8	4 373.7	230.0

* India 1998, Israel 1997, United States 1999, United Kingdom 1998, Brazil 2000, Mexico 1999.

Source: UNESCO Institute for Statistics estimations, December 2004.

rise in the budget for R&D, it is too soon to say that R&D is taking off in the Russian Federation.

The situation is much bleaker in the CIS states of Asia. Nowhere in the world is GERD per researcher as low as here, at just US$ 8 900, compared with US$ 200 000 in many developed states and US$ 30 000 in the Russian Federation. Nor are there any signs that the situation is improving in these states.

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Many of the countries from South-East Europe are also still struggling to make a comeback after a turbulent decade. Having built up the same command-economy type of institutions as in the USSR, they suffered economic upheavals similar to those of the CIS states in the 1990s, with hardship compounded by civil war in the case of the former Yugoslav republics.

Unlike in Asia, there is no discernible steady upturn in R&D in Latin America and the Caribbean. On the contrary, there actually seems to be a downturn. The region's share in world GERD has fallen back from 3.1% in 1997 to 2.6% in 2002. Moreover, three countries – Brazil, Mexico and Argentina – account for 85% of the region's GERD, leaving the remainder with average expenditure of no more than 0.1% of GDP – with the small but notable exception of Cuba, at 0.6%.

The situation in Africa is even bleaker. The GERD/GDP ratio is already low, for both the sub-Saharan countries and the Arab states of Africa, at 0.3% and 0.2% respectively, but even that paints a picture that is rosier than reality: South Africa is responsible for 90% of GERD in sub-Saharan Africa and, as we shall see in the chapter on Africa, Egypt and to a lesser extent Tunisia, Morocco and Algeria carry out practically all R&D in the Arab states of Africa. Certainly, there are encouraging signs in a number of countries but, after a prolonged period of disruption, many countries are struggling simply to get back to where they were in the 1970s and early 1980s. On the whole, the situation is still deeply distressing and the distance to travel so far.

What is true for the Arab states of Africa also holds for the Arab states of Asia, albeit to a somewhat lesser degree. A handful of countries account for most of the sub-region's GERD, among them Jordan, Kuwait and Saudi Arabia. Some might argue that the reason for the dismal performance from even the fossil fuel-rich countries lies in their relatively high income per capita. One could counter this argument by saying that the fossil fuel-rich countries could afford to spend much more on R&D but are apparently not sufficiently convinced of the need to invest in a knowledge economy. Yet, no country will be able to achieve and durably maintain prosperity and a high quality of life without using the results of research and ensuring a well-educated population. As the last sentence of the chapter on the Arab region cogently puts it, if the Arab states are to fully develop their potential in S&T, they will need to implement reforms to build societies which promote tolerance, allow freedom of expression, encourage free thinking and respect human rights.

Output

Turning to output of R&D production, the global situation here barely differs from that of input to R&D. It is true that the USA has now been overtaken by the European Union in terms of the number of scientific articles, as we shall see in the chapter on the European Union, but if one limits this survey to publications and citations in the highest impact journals, the USA remains very much in the lead.

That the number of publications funded by the public purse is substantially higher in Europe than in the USA may suggest much greater productivity per researcher but there is actually a simple explanation for this: military R&D comprises more than 50% of public R&D expenditure in the USA but much less in Europe.

It will come as no surprise that the triad formed by the USA, Europe and Japan dominates scientific articles in the world. The share of other regions is usually (much) lower than their GERD shares. Yet, one should also look behind the veil of regional coverage to see how individual countries are faring. Turkey, for example, is making rapid progress (see the chapter on South-East Europe) and will no doubt begin making its presence felt on the world scene a few years from now.

Patent statistics present a stark picture of disparities in the world. Whereas the developing nations account for 22% of world GERD (Table 1 and Figure 1), they represent just over 7% of all patents granted by the United States Patent and Trademark Office (USPTO) (Table 3) and as little as 3% of patent applications to the European Patent Office (EPO) (Table 4). This is to be expected of course, as patents are indicative of a strong, mature business environment where there are marked incentives to innovate. This type of

Table 3
PATENTS GRANTED AT USPTO,1991 AND 2001

	Total 1991	Total 2001	% world 1991	% world 2001
World	**96 268**	**166 012**	**100.0**	**100.0**
Developed countries	94 285	154 999	97.9	93.4
Developing countries	2 215	12 128	2.3	7.3
Less-developed countries	–	8	–	0.0
Americas	**53 848**	**93 321**	**55.9**	**56.2**
North America	53 679	92 988	55.8	56.0
Latin America and Caribbean	194	449	0.2	0.3
Europe	**19 955**	**31 128**	**20.7**	**18.8**
European Union	18 504	29 124	19.2	17.5
Comm. of Ind. States in Europe	–	350	–	0.2
Central, Eastern & Other Europe	1 670	2 193	2	1.3
Africa	**128**	**160**	**0.1**	**0.1**
Sub-Saharan countries	121	146	0.1	0.1
Arab States Africa	7	14	0.0	0.0
Asia	**23 028**	**45 163**	**23.9**	**27.2**
Comm. of Ind. States in Asia	–	9	–	0.0
Newly Indust. in Asia	1 436	9 811	1.5	5.9
Arab States in Asia	10	37	0.0	0.0
Other in Asia	17	58	0.0	0.0
Oceania	**527**	**1 127**	**0.5**	**0.7**
Other groupings				
Arab States All	17	51	0.0	0.0
Comm. of Ind. States All	–	359	–	0.2
OECD	94 667	158 317	98.3	95.4
Selected countries				
Argentina	19	53	0.0	0.0
Brazil	66	149	0.1	0.1
China	63	298	0.1	0.2
Egypt	4	11	0.0	0.0
France	3 154	4 516	3.3	2.7
Germany	7 914	12 122	8.2	7.3
India	31	231	0.0	0.1
Israel	336	1 098	0.3	0.7
Japan	21 144	33 721	22.0	20.3
Mexico	36	120	0.0	0.1
Russian Federation	–	338	–	0.2
South Africa	115	132	0.1	0.1
United Kingdom	2 969	4 622	3.1	2.8
United States of America	51 703	89 565	53.7	54.0

* USSR in 1991 = 179 patents

Source: USPTO data compiled by Canadian Science and Innovation Indicators Consortium (CSIIC).

Table 4
REGIONAL ORIGINS OF PATENTS AT THE EPO, USPTO AND JPO, 2000

	Total 1991	Total 2000	% world 1991	% world 2000
World	**29 901**	**43 625**	**100.0**	**100.0**
Developed countries	27 788	40 210	92.9	92.2
Developing countries	2 113	3 415	7.1	7.8
Less-developed countries	0	0	0.0	0.0
Americas	**12 301**	**17 696**	**41.1**	**40.6**
North America	10 492	15 504	35.1	35.5
Latin America and Caribbean	1 809	2 192	6.0	5.0
Europe	**8 228**	**12 599**	**27.5**	**28.9**
European Union	7 382	11 642	24.7	26.7
Comm. of Ind. States in Europe	43	78	0.1	0.2
Central, Eastern & Other Europe	803	879	2.7	2.0
Africa	**18**	**28**	**0.1**	**0.1**
Sub-Saharan countries	17	28	0.1	0.1
Arab States Africa	1	0	0.0	0.0
Asia	**9 179**	**12 945**	**30.7**	**29.7**
Comm. of Ind. States in Asia	0	0	0.0	0.0
Newly Indust. in Asia	150	698	0.5	1.6
Arab States in Asia	1	3	0.0	0.0
Other in Asia	8	6	0.0	0.0
Oceania	**175**	**357**	**0.6**	**0.8**
Other groupings				
Arab States All	2	3	0.0	0.0
Comm. of Ind. States All	43	78	0.1	0.2
OECD	27 822	40 610	93.0	93.1
Selected countries				
Argentina	5	11	0.0	0.0
Brazil	6	34	0.0	0.1
China	12	93	0.0	0.2
Egypt	1	0	0.0	0.0
France	161	489	0.5	1.1
Germany	3 676	5 777	12.3	13.2
India	9	46	0.0	0.1
Israel	104	342	0.3	0.8
Japan	8 895	11 757	29.7	27.0
Mexico	6	15	0.0	0.0
Russian Federation	37	76	0.1	0.2
South Africa	17	28	0.1	0.1
United Kingdom	1 250	1 794	4.2	4.1
United States of America	10 217	14 985	34.2	34.3

Notes: UNESCO Institute for Statistics estimations of patents applied for at the EPO, USPTO and JPO.

Source: OECD, Patent Database, September/October 2004.

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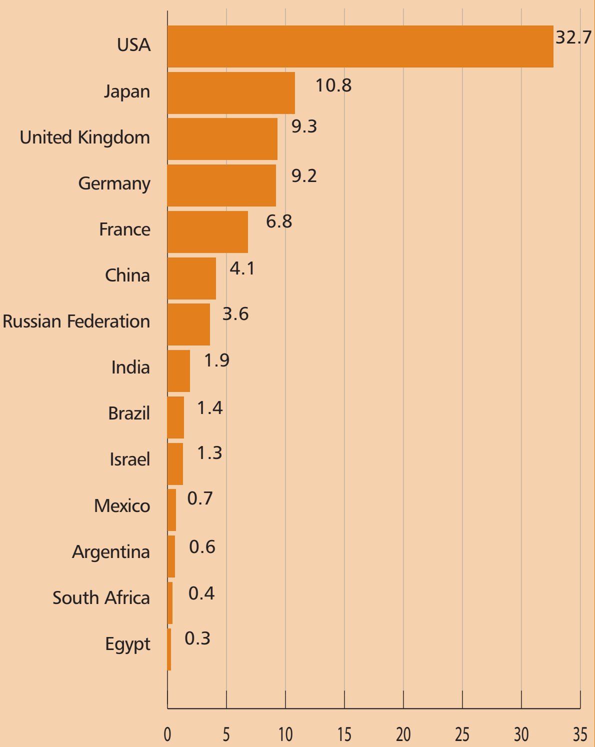
business environment is still in its infancy or having a hard time surviving in many developing countries. It takes more than time to create an environment conducive to patents, but time is an important factor. It is for this reason that we cannot yet see China's prowess in GERD reflected in a visible share of the USPTO and EPO patent data: it accounted for 0.2% of USPTO patents granted in 2001, and 0.3% of patent applications to the EPO in 2000. The same goes for Turkey, which has seen a sharp increase in publications but the rise is still to come in patents. The Newly Industrialized Asian economies, with their longer tradition, are now clearly visible, with 5.9% of patents granted by the USPTO and 1.5% of patent applications to

Figure 2
WORLD SHARES OF SCIENTIFIC PUBLICATIONS, 2001
Selected countries (%)



Source: see Table 5.

Table 5
WORLD SHARES OF SCIENTIFIC PUBLICATIONS, 1991 AND 2001

	Total		% world	
	1991	2001	1991	2001
World	**455 315**	**598 447**	**100.0**	**100.0**
Developed countries	420 089	524 306	92.3	87.6
Developing countries	46 694	103 757	10.3	17.3
Less developed countries	979	1 526	0.2	0.3
Americas	**206 772**	**232 856**	**45.4**	**38.9**
North America	199 943	216 652	43.9	36.2
Latin America and Caribbean	8 227	19 960	1.8	3.3
Europe	**187 683**	**276 152**	**41.2**	**46.1**
European Union	164 470	241 071	36.1	40.3
Comm. of Ind. States in Europe	12 026	25 018	2.6	4.2
Central, Eastern & Other Europe	15 224	25 184	3.3	4.2
Africa	**7 058**	**8 608**	**1.6**	**1.4**
Sub-Saharan countries	4 636	5 105	1.0	0.9
Arab States Africa	2 431	3 536	0.5	0.6
Asia	**73 542**	**134 870**	**16.2**	**22.5**
Comm. of Ind. States in Asia	813	1 047	0.2	0.2
Newly Indust. in Asia	6 521	24 253	1.4	4.1
Arab States in Asia	1 470	2 012	0.3	0.3
Other in Asia	1 331	3 315	0.3	0.6
Oceania	**13 126**	**19 655**	**2.9**	**3.3**
Other groupings				
Arab States All	3 838	5 416	0.8	0.9
Comm. of Ind. States all	12 706	25 902	2.8	4.3
OECD	408 354	519 951	89.7	86.9
Selected countries				
Argentina	1 719	3 756	0.4	0.6
Brazil	3 105	8 564	0.7	1.4
China	6 340	24 367	1.4	4.1
Egypt	1 651	1 830	0.4	0.3
France	27 335	40 485	6.0	6.8
Germany	37 112	55 212	8.2	9.2
India	9 848	11 620	2.2	1.9
Israel	5 409	7 744	1.2	1.3
Japan	42 653	64 655	9.4	10.8
Mexico	1 307	4 049	0.3	0.7
Russian Federation	9 718	21 315	2.1	3.6
South Africa	2 618	2 657	0.6	0.4
United Kingdom	40 789	55 363	9.0	9.3
United States of America	179 615	195 660	39.4	32.7

Note: The sum of the numbers, and percentages, for the various regions exceeds the total number, or 100%, because papers with multiple authors from different regions contribute fully to each of these regions.

Source: ISI, data compiled by Canadian Science and Innovation Indicators Consortium (CSIIC).

Table 6
WORLD SHARES OF SCIENTIFIC PUBLICATIONS, 1991 AND 2001
By field

	Biology		Biomedical research		Chemistry		Clinical medicine		Earth and space	
	1991	2001	1991	2001	1991	2001	1991	2001	1991	2001
World	**37 755**	**45 482**	**76 337**	**93 557**	**58 580**	**77 351**	**150 788**	**190 400**	**22 536**	**33 376**
Developed countries	34 202	40 103	72 545	85 646	51 723	62 894	142 361	173 692	20 860	30 415
Developing countries	4 953	8 537	5 343	11 596	8 231	18 177	10 784	22 129	2 661	5 478
Less-developed countries	216	350	109	213	57	59	488	694	43	91
Americas	**18 844**	**18 857**	**38 432**	**44 568**	**18 404**	**20 456**	**71 801**	**81 593**	**12 287**	**16 074**
North America	17 951	16 751	37 303	42 262	17 602	18 247	69 972	77 710	11 822	15 064
Latin America and Caribbean	1 155	2 747	1 339	2 865	877	2 504	2 207	4 742	626	1 460
Europe	**12 135**	**19 101**	**31 222**	**40 958**	**27 917**	**37 855**	**62 126**	**85 483**	**9 103**	**16 493**
European Union	11 109	17 007	27 485	37 020	22 649	30 574	57 326	78 919	7 937	14 368
Comm. of Ind. States in Europe	341	1 101	1 820	2 339	3 535	5 693	1 043	925	645	1 726
Central, Eastern & Other Europe	859	1 669	2 569	3 440	2 240	3 401	4 829	8 259	779	1 615
Africa	**1 257**	**1 445**	**788**	**973**	**1 278**	**1 290**	**2 227**	**2 456**	**453**	**597**
Sub-Saharan countries	1 008	1 153	644	774	416	341	1 793	1 858	325	411
Arab States Africa	249	284	146	198	862	974	441	592	128	184
Asia	**5 464**	**8 012**	**9 943**	**16 773**	**13 134**	**23 190**	**18 309**	**32 799**	**2 491**	**5 073**
Comm. of Ind. States in Asia	24	33	130	46	241	293	71	48	36	68
Newly Indust. in Asia	539	1 372	617	2 558	1 211	3 808	1 460	4 915	192	865
Arab States in Asia	136	174	104	168	211	232	543	712	108	114
Other in Asia	249	454	134	310	188	626	402	942	60	164
Oceania	**2 590**	**3 309**	**2 063**	**2 919**	**1 093**	**1 537**	**4 428**	**6 616**	**1 095**	**1 914**
Other groupings										
Arab States All	379	447	248	358	1 059	1 151	971	1 285	229	295
Comm. of Ind. States All	360	1 128	1 919	2 379	3 738	5 958	1 099	970	672	1 774
OECD	33 989	40 037	70 539	85 392	48 067	59 929	141 579	176 816	20 308	29 890
Selected countries										
Argentina	221	569	257	572	253	475	430	932	96	246
Brazil	304	954	585	1 255	263	1 123	806	1 985	204	474
China	294	982	307	1 984	1 169	5 915	789	2 897	329	1 190
Egypt	165	164	98	88	657	573	251	349	92	70
France	1 520	2 341	4 845	6 515	4 241	5 145	7 861	10 751	1 523	2 968
Germany	2 300	3 032	5 957	8 342	5 855	7 388	10 642	16 520	1 725	3 299
India	925	841	1 110	1 522	2 587	2 788	1 380	1 789	607	613
Israel	561	593	902	1 163	386	617	1 870	2 527	223	368
Japan	2 866	3 929	6 756	9 353	7 249	9 686	11 959	19 244	994	1 968
Mexico	209	639	198	471	122	392	287	821	130	416
Russian Federation	300	1 000	1 520	2 195	2 848	4 903	891	800	579	1 602
South Africa	505	490	402	442	290	241	859	742	220	285
United Kingdom	3 041	4 113	7 276	9 399	4 263	5 366	16 142	19 994	2 226	4 131
United States of America	14 880	14 045	34 018	38 955	15 702	16 233	63 794	70 796	10 278	13 332

Note: The sum of the numbers, and percentages, for the various regions exceeds the total number, or 100%, because papers with multiple authors from different regions contribute fully to each of these regions

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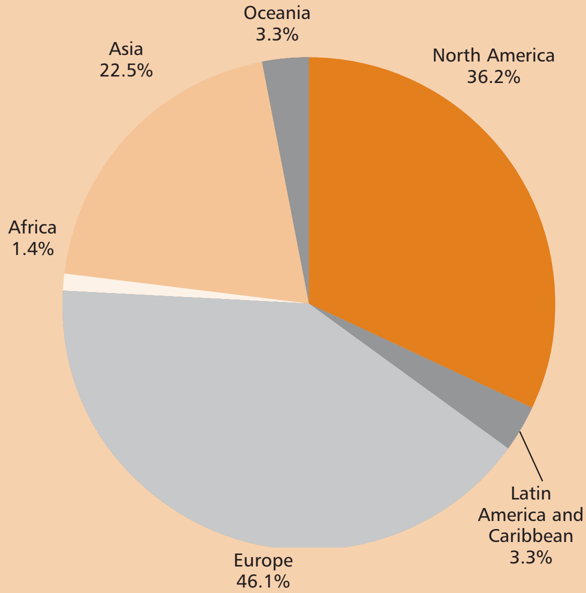
Engineering and technology 1991	Engineering and technology 2001	Mathematics 1991	Mathematics 2001	Physics 1991	Physics 2001	Unknown 1991	Unknown 2001
35 340	**55 858**	**8 162**	**14 278**	**65 507**	**88 004**	**310**	**142**
31 436	44 723	7 507	12 445	59 148	74 253	307	135
5 044	14 639	1 047	3 029	8 627	20 161	4	12
33	55	3	4	30	61	–	0
16 360	**18 832**	**4 369**	**5 727**	**26 155**	**26 689**	**120**	**60**
16 050	17 635	4 223	5 304	24 901	23 620	119	59
378	1 379	188	508	1 456	3 754	1	1
11 913	**22 611**	**3 384**	**7 466**	**29 696**	**46 108**	**187**	**77**
10 347	19 267	3 032	6 633	24 520	37 217	65	68
768	2 435	178	706	3 696	10 078	–	16
967	2 092	220	533	2 628	4 172	133	3
437	**693**	**58**	**197**	**560**	**951**	**–**	**4**
180	217	30	83	240	265	–	2
257	485	28	116	320	703	–	2
8 406	**18 852**	**1 209**	**2 999**	**14 578**	**27 156**	**8**	**17**
44	53	27	38	240	466	–	0
1 344	5 207	122	588	1 036	4 935	–	4
220	372	25	51	123	188	–	1
90	338	31	84	176	398	1	0
643	**1 357**	**220**	**448**	**992**	**1 554**	**2**	**0**
466	847	53	164	433	865	–	2
802	2 481	203	743	3 913	10 453	–	16
30 822	45 053	7 312	12 160	55 546	70 543	192	130
89	204	26	81	347	677	–	0
155	737	80	240	707	1 795	1	1
936	4 300	272	1 016	2 244	6 083	–	0
196	268	11	21	181	295	–	2
1 512	3 212	503	1 695	5 325	7 841	5	16
2 852	4 303	677	1 391	7 092	10 926	12	11
1 165	1 503	127	198	1 947	2 365	–	1
390	675	193	382	882	1 418	2	1
4 312	7 122	426	785	8 086	12 558	5	9
62	274	39	81	260	956	–	0
580	1 816	143	591	2 857	8 393	–	15
121	185	25	65	196	207	–	0
2 673	4 479	678	1 093	4 457	6 779	33	9
14 151	15 622	3 830	4 819	22 853	21 806	109	52

Source: ISI data compiled by Canadian Science and Innovation Indicators Consortium (CSIIC).

Figure 3
WORLD SHARES OF SCIENTIFIC PUBLICATIONS, 2001
By continent



Note: The sum of the percentages, for the various regions exceeds 100%, because papers with multiple authors from different regions contribute fully to each of these regions.

Source: see Table 5.

the EPO. With the notable exception of North America, Europe, Japan and Israel, the rest of the world is virtually absent, illustrating the stark odds to be overcome. The Russian case deserves special mention. The Russian Federation has an extremely small number of international patents to its credit, an image only partly nuanced by the large number of domestic patents granted; this is more a reflection of the once (and enduring?) dominant role of state industry than of a globally competing industry (see the chapter on the Russian Federation).

Much more difficult to interpret are indicators of international trade in high-tech products (Table 7). One reason is that usually broad sectors as a whole are redefined as high-, low- or medium-tech sectors, even though there are often large differences among sub-sectors. Another reason is the dissection of the manufacturing or production process. Drawings,

Table 7
INTERNATIONAL TRADE IN HIGH-TECH PRODUCTS, 2002
In US$ million

	Aerospace products				Armaments				Chemistry (less pharmaceuticals)			
	Import	% World	Export*	% World	Import	% World	Export*	% World	Import	% World	Export*	% World
World	**99 112**	**100.0**	**112 228**	**100.0**	**5 199**	**100.0**	**5 887**	**100.0**	**25 400**	**100.0**	**22 941**	**100.0**
Developed countries	83 032	83.8	98 713	88.0	3 766	72.4	5 071	86.1	19 424	76.5	16 619	72.4
Developing countries	16 038	16.2	5 212	4.6	1 411	27.1	433	7.3	5 858	23.1	5 273	23.0
Less-developed countries	42	0.0	8 304	7.4	23	0.4	384	6.5	118	0.5	1 049	4.6
Americas	**29 116**	**29.4**	**43 300**	**38.6**	**1 836**	**35.3**	**2 922**	**49.6**	**6 768**	**26.6**	**5 005**	**21.8**
North America	26 872	27.1	39 622	35.3	1 678	32.3	2 690	45.7	4 616	18.2	3 899	17.0
Latin America and the Caribbean	2 244	2.3	3 678	3.3	157	3.0	232	3.9	2 152	8.5	1 107	4.8
Europe	**48 500**	**48.9**	**57 674**	**51.4**	**2 065**	**39.7**	**2 247**	**38.2**	**12 340**	**48.6**	**11 871**	**51.7**
European Union	46 162	46.6	54 402	48.5	1 555	29.9	1 791	30.4	10 682	42.1	10 841	47.3
Comm. of Ind. States in Europe	345	0.3	1 076	1.0	5	0.1	52	0.9	876	3.4	270	1.2
Central, Eastern & Other Europe	1 965	2.0	2 156	1.9	497	9.6	393	6.7	497	2.0	737	3.2
Africa	**1 607**	**1.6**	**8 415**	**7.5**	**63**	**1.2**	**401**	**6.8**	**612**	**2.4**	**1 332**	**5.8**
Sub-Saharan countries	1 095	1.1	8 400	7.5	49	0.9	401	6.8	410	1.6	1 327	5.8
Arab States Africa	511	0.5	14	0.0	14	0.3	0	0.0	202	0.8	4	0.0
Asia	**16 951**	**17.1**	**2 112**	**1.9**	**1 006**	**19.4**	**288**	**4.9**	**5 297**	**20.9**	**4 527**	**19.7**
Comm. of Ind. States in Asia	7	0.0	3	0.0	0	0.0	0	0.0	10	0.0	1	0.0
Newly Indust. in Asia	5 844	5.9	1 190	1.1	290	5.6	87	1.5	1 330	5.2	2 680	11.7
Arab States in Asia	77	0.1	1	0.0	301	5.8	0	0.0	184	0.7	29	0.1
Other in Asia	1 065	1.1	23	0.0	191	3.7	41	0.7	746	2.9	524	2.3
Oceania	2 938	3.0	728	0.6	229	4.4	30	0.5	383	1.5	207	0.9
Other groupings												
Arab States All	588	0.6	16	0.0	315	6.1	1	0.0	386	1.5	34	0.1
Comm. of Ind. States All	352	0.4	1 079	1.0	5	0.1	52	0.9	885	3.5	271	1.2
OECD	83 349	84.1	98 854	88.1	4 187	80.5	5 130	87.1	19 297	76.0	16 950	73.9
Selected countries												
Argentina	189	0.2	83	0.1	2	0.0	7	0.1	169	0.7	207	0.9
Brazil	703	0.7	2 767	2.5	13	0.2	205	3.5	532	2.1	409	1.8
China	3 472	3.5	6	0.0	4	0.1	2	0.0	560	2.2	35	0.2
Egypt	0	0.0	0	0.0	1	0.0	0	0.0	41	0.2	1	0.0
France	7 007	7.1	18 235	16.2	87	1.7	252	4.3	2 421	9.5	2 887	12.6
Germany	11 208	11.3	16 837	15.0	101	1.9	216	3.7	1 573	6.2	2 551	11.1
India	648	0.7	3	0.0	3	0.1	2	0.0	108	0.4	345	1.5
Israel	555	0.6	14	0.0	0	0.0	0	0.0	92	0.4	217	0.9
Japan	5 284	5.3	872	0.8	217	4.2	155	2.6	2 267	8.9	695	3.0
Mexico	350	0.4	783	0.7	37	0.7	18	0.3	436	1.7	191	0.8
Russian Federation	311	0.3	888	0.8	5	0.1	52	0.9	650	2.6	220	1.0
South Africa	812	0.8	67	0.1	0	0.0	7	0.1	139	0.5	219	1.0
United Kingdom	15 013	15.1	11 112	9.9	577	11.1	601	10.2	1 267	5.0	1 967	8.6
United States of America	22 099	22.3	39 615	35.3	1 250	24.0	2 689	45.7	3 681	14.5	3 899	17.0

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Computers and office machines				Electrical machinery				Electronics-telecommunications			
Import	% World	Export*	% World	Import	% World	Export*	% World	Import	% World	Export*	% World
304 189	**100.0**	**269 052**	**100.0**	**33 161**	**100.0**	**29 372**	**100.0**	**472 106**	**100.0**	**421 235**	**100.0**
219 007	72.0	134 611	50.0	19 008	57.3	19 361	65.9	244 424	51.8	234 283	55.6
85 002	27.9	132 064	49.1	14 143	42.7	9 447	32.2	227 339	48.2	180 187	42.8
181	0.1	2 377	0.9	10	0.0	564	1.9	343	0.1	6 765	1.6
89 989	**29.6**	**35 688**	**13.3**	**7 147**	**21.6**	**5 411**	**18.4**	**110 750**	**23.5**	**65 248**	**15.5**
78 620	25.8	24 560	9.1	5 331	16.1	3 677	12.5	87 751	18.6	51 504	12.2
11 369	3.7	11 127	4.1	1 817	5.5	1 734	5.9	22 999	4.9	13 744	3.3
117 910	**38.8**	**86 323**	**32.1**	**11 380**	**34.3**	**10 085**	**34.3**	**131 204**	**27.8**	**134 657**	**32.0**
110 738	36.4	85 511	31.8	10 660	32.1	9 391	32.0	121 071	25.6	131 286	31.2
789	0.3	51	0.0	102	0.3	256	0.9	2 191	0.5	477	0.1
5 467	1.8	712	0.3	449	1.4	358	1.2	6 161	1.3	2 396	0.6
1 815	**0.6**	**3 379**	**1.3**	**218**	**0.7**	**718**	**2.4**	**3 789**	**0.8**	**7 779**	**1.8**
1 180	0.4	3 370	1.3	96	0.3	689	2.3	2 365	0.5	7 123	1.7
635	0.2	9	0.0	122	0.4	28	0.1	1 424	0.3	656	0.2
90 130	**29.6**	**142 928**	**53.1**	**14 084**	**42.5**	**13 010**	**44.3**	**222 018**	**47.0**	**212 808**	**50.5**
33	0.0	0	0.0	4	0.0	0	0.0	81	0.0	5	0.0
44 095	14.5	97 549	36.3	5 753	17.3	4 299	14.6	124 731	26.4	134 404	31.9
723	0.2	12	0.0	61	0.2	2	0.0	1 346	0.3	27	0.0
8 395	2.8	21 948	8.2	1 791	5.4	2 751	9.4	24 948	5.3	26 796	6.4
4 346	1.4	735	0.3	332	1.0	149	0.5	4 345	0.9	742	0.2
1 358	0.4	21	0.0	184	0.6	30	0.1	2 770	0.6	683	0.2
822	0.3	52	0.0	106	0.3	256	0.9	2 272	0.5	482	0.1
230 291	75.7	161 407	60.0	21 829	65.8	21 277	72.4	276 644	58.6	271 992	64.6
155	0.1	33	0.0	24	0.1	7	0.0	143	0.0	51	0.0
1 139	0.4	154	0.1	213	0.6	51	0.2	2 710	0.6	1 479	0.4
15 642	5.1	14	0.0	3 290	9.9	2	0.0	43 772	9.3	31	0.0
165	0.1	1	0.0	29	0.1	0	0.0	254	0.1	1	0.0
11 398	3.7	6 005	2.2	1 002	3.0	648	2.2	12 971	2.7	14 162	3.4
24 072	7.9	14 053	5.2	3 118	9.4	2 795	9.5	25 872	5.5	29 312	7.0
1 294	0.4	142	0.1	150	0.5	11	0.0	2 587	0.5	431	0.1
872	0.3	237	0.1	920	2.8	485	1.7	1 806	0.4	3 592	0.9
19 076	6.3	23 026	8.6	2 115	6.4	5 460	18.6	22 745	4.8	47 522	11.3
7 880	2.6	10 915	4.1	1 420	4.3	1 670	5.7	15 604	3.3	12 135	2.9
636	0.2	35	0.0	71	0.2	217	0.7	1 723	0.4	325	0.1
853	0.3	79	0.0	70	0.2	29	0.1	1 741	0.4	244	0.1
19 073	6.3	14 634	5.4	1 705	5.1	2 238	7.6	19 953	4.2	28 459	6.8
70 500	23.2	24 560	9.1	4 827	14.6	3 677	12.5	77 386	16.4	51 504	12.2

Table 7 (continued)

	Non-electrical machinery				Pharmaceuticals				Scientific instruments			
	Import	% World	Export*	% World	Import	% World	Export*	% World	Import	% World	Export*	% World
World	**23 241**	**100.0**	**25 256**	**100.0**	**51 756**	**100.0**	**50 102**	**100.0**	**102 976**	**100.0**	**97 804**	**100.0**
Developed countries	15 954	68.6	22 970	90.9	43 247	83.6	46 145	92.1	69 837	67.8	80 276	82.1
Developing countries	7 278	31.3	1 297	5.1	8 297	16.0	3 592	7.2	33 049	32.1	15 636	16.0
Less-developed countries	9	0.0	989	3.9	212	0.4	365	0.7	90	0.1	1 892	1.9
Americas	**6 189**	**26.6**	**6 544**	**25.9**	**11 476**	**22.2**	**7 888**	**15.7**	**28 805**	**28.0**	**25 813**	**26.4**
North America	4 606	19.8	6 157	24.4	8 654	16.7	7 173	14.3	23 858	23.2	23 018	23.5
Latin America and the Caribbean	1 583	6.8	387	1.5	2 822	5.5	716	1.4	4 947	4.8	2 795	2.9
Europe	**10 452**	**45.0**	**14 192**	**56.2**	**32 249**	**62.3**	**37 826**	**75.5**	**38 172**	**37.1**	**44 140**	**45.1**
European Union	8 860	38.1	11 699	46.3	25 722	49.7	29 866	59.6	34 113	33.1	39 081	40.0
Comm. of Ind. States in Europe	511	2.2	717	2.8	652	1.3	92	0.2	1 040	1.0	693	0.7
Central, Eastern & Other Europe	953	4.1	1 741	6.9	5 465	10.6	7 673	15.3	2 498	2.4	4 270	4.4
Africa	**280**	**1.2**	**997**	**3.9**	**1 012**	**2.0**	**422**	**0.8**	**1 032**	**1.0**	**2 061**	**2.1**
Sub-Saharan countries	91	0.4	996	3.9	451	0.9	405	0.8	589	0.6	1 985	2.0
Arab States Africa	189	0.8	1	0.0	561	1.1	17	0.0	443	0.4	75	0.1
Asia	**6 071**	**26.1**	**3 470**	**13.7**	**6 345**	**12.3**	**3 759**	**7.5**	**33 442**	**32.5**	**25 286**	**25.9**
Comm. of Ind. States in Asia	47	0.2	1	0.0	30	0.1	0	0.0	30	0.0	9	0.0
Newly Indust. in Asia	1 700	7.3	381	1.5	1 240	2.4	1 977	3.9	10 253	10.0	8 351	8.5
Arab States in Asia	489	2.1	1	0.0	779	1.5	37	0.1	694	0.7	17	0.0
Other in Asia	1 461	6.3	337	1.3	664	1.3	44	0.1	4 407	4.3	3 281	3.4
Oceania	**249**	**1.1**	**52**	**0.2**	**674**	**1.3**	**208**	**0.4**	**1 526**	**1.5**	**503**	**0.5**
Other groupings												
Arab States All	678	2.9	2	0.0	1 340	2.6	54	0.1	1 136	1.1	92	0.1
Comm. of Ind. States All	557	2.4	718	2.8	681	1.3	93	0.2	1 070	1.0	702	0.7
OECD	17 143	73.8	22686	89.8	44 002	85.0	46 249	92.3	74 922	72.8	82 755	84.6
Selected countries												
Argentina	71	0.3	13	0.1	193	0.4	138	0.3	109	0.1	43	0.0
Brazil	364	1.6	9	0.0	966	1.9	97	0.2	1 180	1.1	165	0.2
China	1 195	5.1	5	0.0	682	1.3	12	0.0	9 688	9.4	4	0.0
Egypt	2	0.0	0	0.0	194	0.4	9	0.0	83	0.1	0	0.0
France	1 226	5.3	1 624	6.4	4 024	7.8	4 115	8.2	4 781	4.6	4 635	4.7
Germany	2 100	9.0	3 158	12.5	4 896	9.5	4 048	8.1	7 431	7.2	13 952	14.3
India	119	0.5	20	0.1	405	0.8	658	1.3	812	0.8	266	0.3
Israel	75	0.3	129	0.5	104	0.2	38	0.1	676	0.7	701	0.7
Japan	986	4.2	2 597	10.3	2 442	4.7	991	2.0	6 882	6.7	12 657	12.9
Mexico	873	3.8	345	1.4	790	1.5	338	0.7	2 756	2.7	2 543	2.6
Russian Federation	254	1.1	605	2.4	479	0.9	74	0.1	830	0.8	478	0.5
South Africa	76	0.3	6	0.0	171	0.3	21	0.0	433	0.4	67	0.1
United Kingdom	2 108	9.1	2 228	8.8	2 959	5.7	3 893	7.8	5 793	5.6	6 300	6.4
United States of America	3 596	15.5	6 157	24.4	7 522	14.5	7 172	14.3	19 573	19.0	23 018	23.5

Notes:
* All export figures are minus re-exports. Armenia: Re-exports not subtracted.

component parts and subsystems come from all over the world and make several voyages across the globe before reaching their final resting place where all will be assembled. Even then, this may differ from the site for packaging and distribution.

Moreover, volumes of trade depend very much on the size of the countries concerned. Even if we define country conglomerates in order to arrive at more equal sizes, we should then ideally subtract all 'inter-conglomerate' trade. In pharmaceuticals for example, the world's total

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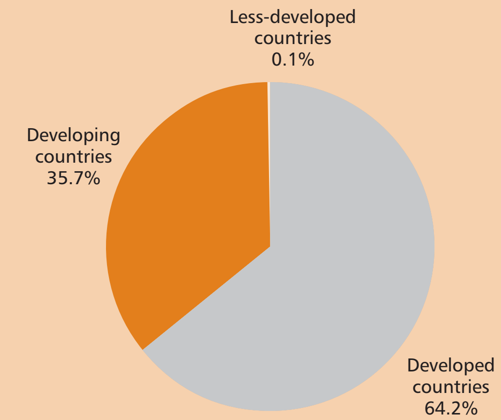
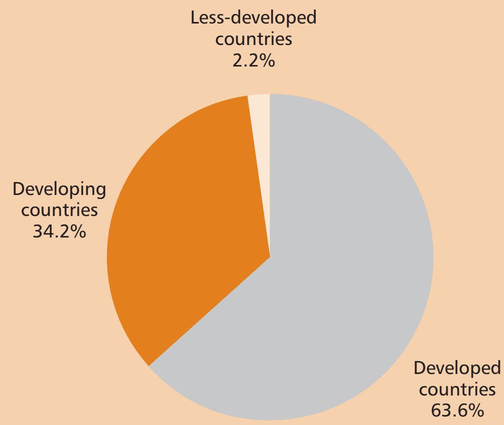
Import	% World	Total Export*	% World
1 117 139	**100.0**	**1 033 878**	**100.0**
717 698	64.2	658 048	63.6
398 414	35.7	353 141	34.2
1 027	0.1	22 689	2.2
292 076	**26.1**	**197 819**	**19.1**
241 986	21.7	162 299	15.7
50 090	4.5	35 520	3.4
404 270	**36.2**	**399 016**	**38.6**
369 563	33.1	373 868	36.2
6 510	0.6	3 685	0.4
23 953	2.1	20 437	2.0
10 428	**0.9**	**25 503**	**2.5**
6 327	0.6	24 696	2.4
4 101	0.4	806	0.1
395 345	**35.4**	**408 187**	**39.5**
242	0.0	19	0.0
195 235	17.5	250 919	24.3
4 653	0.4	126	0.0
43 669	3.9	55 743	5.4
15 021	**1.3**	**3 352**	**0.3**
8 754	0.8	933	0.1
6 752	0.6	3 704	0.4
771 663	69.1	727 300	70.3
1 055	0.1	583	0.1
7 821	0.7	5 334	0.5
78 304	7.0	111	0.0
768	0.1	13	0.0
44 918	4.0	52 563	5.1
80 370	7.2	86 922	8.4
6 126	0.5	1 879	0.2
5 101	0.5	5 414	0.5
62 016	5.6	93 976	9.1
30 146	2.7	28 937	2.8
4 960	0.4	2 894	0.3
4 296	0.4	740	0.1
68 448	6.1	71 432	6.9
210 433	18.8	162 291	15.7

Source: COMTRADE (2002). Methodology based on SICT Rev. 3, as proposed in OCDE/GD(97)216.

Percentage of world high-tech imports

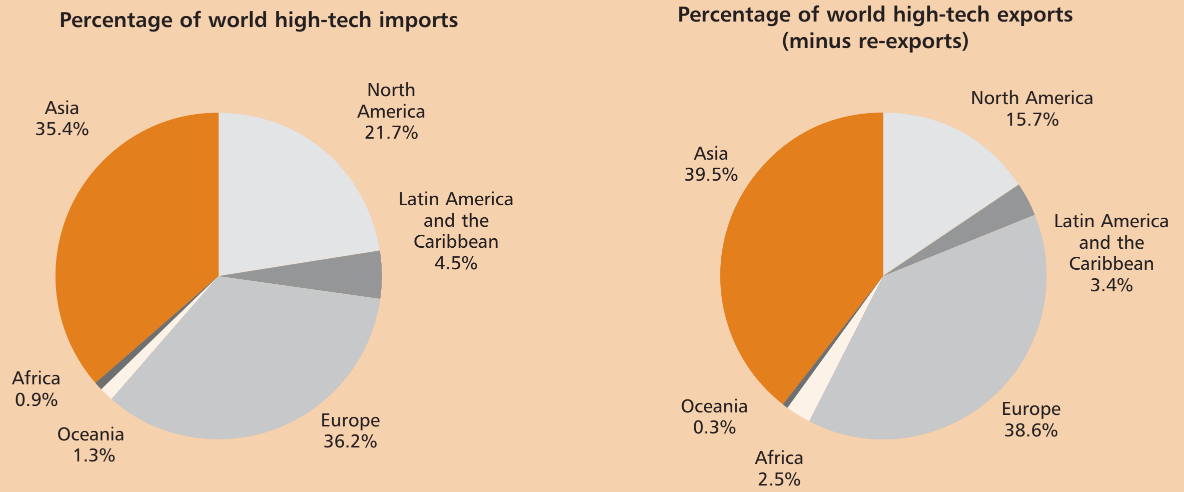


Percentage of world high-tech exports (minus re-exports)



imports in 2002 amounted to almost US$ 52 billion, a considerable share of which were intra-European imports. However, total pharmaceuticals sales that same year amounted to US$ 400 billion. As a consequence, import and export statistics tell many stories which have to be disentangled to uncover the reality by breaking down figures for sectors and countries. High shares of high-tech exports do not therefore always correlate very well with technological capabilities. Using cheap labour in foreign-dominated factories with little technology transfer

Figure 4
WORLD HIGH-TECH IMPORTS AND EXPORTS, 2002
By continent



Source: see Table 7.

may help with the statistics but less with development.

Considering data for the USA and the EU reveals that US exports are sometimes deceptively low but that is to be expected for most sectors in a large economy. By contrast, the EU data are deceptively high because of the large amount of intra-EU trade.

Carefully read, however, high-tech import and export statistics do show some interesting features. The prominent position of the Newly Industrialized Asian economies stands out, especially in computers and office machines, in electronics and telecommunications and to a lesser extent in electrical machinery, for example.

The observation that the emergence of China is not yet reflected in patent statistics is confirmed by its weak position so far in high-tech exports. At the same time, the dynamics are clearly visible: China now imports more scientific instruments, electronics and telecommunications products and electrical machinery than Japan.

A strong position in aerospace and military technology can be read into the large export shares for the USA. Similarly, the large export shares for scientific instruments and electrical machinery seem to be an indication of Japan's continuing strong position in high-quality manufacturing, the volume of which is even growing, according to recent statistics, in a trend that is swimming against the outsourcing tide.

INNOVATION: THE TRIPLE HELIX AS A NECESSARY CONDITION

Since gaining acceptance in policy circles in the mid-1970s, the word 'innovation' has gained ever-more prominence. Indeed, the proverbial alien visitor to our planet could easily come to the conclusion that life on Earth is all about innovation. It is the talk of the town all over the world. National or regional systems of innovation have become the standard term for describing the many activities, parties and arrangements which interact to underpin successful innovative economies and societies.

This dynamic is known as the 'Triple Helix', the way in which cooperation between companies, knowledge institutions and government bodies pushes the economy continually upwards, like Ralph Vaughan Williams's 'Lark ascending'.

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Or, in the mesmerizing words of the children's choir of a Kampala primary school gracing with its presence the National Meeting on Science, Technology and Innovation in Uganda in March 2005, 'Innovation is an invitation to elevation'.

Simultaneously, the so-called linear model of innovation – basic research providing the input to applied research, which in turn underpins technologies resulting in innovation – has been relegated to the rubbish heap of history.

It is indeed of great importance to develop systematically the interaction between universities, research institutes, enterprises, local and regional governments, chambers of commerce, schools, banks, venture capital funds or private investors. This will result in networks or systems of innovation and clusters of economic activity, the very fabric out of which innovative economies and societies are woven; for even in a globalizing world where ICT is driving global technology flows, local, regional and national knowledge networks play a crucial role in shaping innovative success and social progress.

Yet, we must not confuse the roles played by the various parties, nor overlook the different natures of science, technology and innovation. The underlying processes have been described conveniently as three interlinked cycles. The first describes the development of science; the second, the development of technologies and problem-solving, and the third, the development of innovations. Here, an innovation in its most rudimentary form is simply a new idea that has proven successful as a product on the market, as a therapy applied in hospitals, as a new policy arrangement adopted by governments worldwide and so on.

The three cycles overlap and there are multiple interactions at various times between the persons and organizations involved in any one of these cycles. This said, the persons and organizations involved usually differ from cycle to cycle. This has to do with different personal capabilities, mentalities and aspirations, different reward systems or varying institutional missions.

The private sector plays a crucial role in both the innovation cycle and the technology cycle, but much less so in the science cycle. That is one reason for the private sector to strengthen links with universities. Universities and institutes for basic science dominate the science cycle, but for them too, closer links with industry or public sector stakeholders have become essential.

The new relations among the components of the Triple Helix are certainly still taking shape but clear patterns are emerging. Let us first concentrate on the dominance of private sector funding of GERD, followed by the new mechanisms for interaction. We shall then look at the new equilibrium on key issues like intellectual property before studying the implications for government's role.

Industry increasingly dominates R&D funding

The importance of the private sector's role is reflected in the fact that it finances the lion's share of national R&D in the developed nations. For every country or region aspiring to play a role in today's emerging knowledge societies, this is now an ineluctable challenge that goes beyond simply making funds available for R&D from the public purse. The private sector must play a leading role and this role can no longer be stimulated artificially by massive government subsidies. The various chapters that follow in the present *UNESCO Science Report* provide ample, remarkable evidence of this.

In the USA, industry has come to dominate the performance of R&D. A ten-fold increase in real terms between 1953 and 2000 has brought the amount of R&D performed by industry from US$ 3.6 billion in 1953 (or US$ 18.9 billion in 1996 prices) to US$ 199.6 billion in 2000 (equivalent to US$ 186.7 billion in 1996 prices).

Moreover, whereas government subsidies accounted for 40% of industrial R&D in the USA in 1953, these had dropped back to just 10% by 2000 (Table 2 in the chapter on the USA). Industry funded 66% and performed 72% of R&D in the USA in 2000.

The same goes for other large OECD countries. In Japan, the UK, Germany and France, for example, industry performed over 63% of all R&D and funded between 54% (France) and 69% (Japan) of it. The UK seems to be the odd one out, with industry funding just 46% of all R&D. The explanation for this anomaly is to be found in the 18% financed from abroad, to a large extent by foreign companies.

It is true however that the average for the 15-Member EU (56% in 2001) is much lower than the figures for either the USA or Japan. This is now the cause of greatest concern in the EU and is widely interpreted as a sign of a lack of vitality and of perceived opportunities. In 2002, the EU vowed to devote 3% of GDP to R&D by 2010, two-thirds of which is to come from private industry. This is logical, since nowhere in the world does R&D funded by the public purse account for more than 1% of GDP. However, in the EU, industry contributes just 1% to the average expenditure for Member countries of 1.81% of GDP. This places the onus on industry to increase its share of spending on R&D. This is the model expounded by countries that already more than meet the EU target, such as Sweden or Finland or, if we look beyond the EU, Switzerland.

In this respect, it is interesting to note that, in each of Turkey, Bulgaria and Romania, industry contributes more than 50% of GERD.

Apart from Japan, just three countries or territories in Asia devote more than 2% of GDP to R&D: Singapore, the Republic of Korea and Taiwan of China. Industry contributes 50% in Singapore, 63% in Taiwan of China and 74% in Korea (OECD data for 2003 or last available year). In China, state-owned and private industry together perform 61% of R&D.

Industry performs just 23% of R&D in India. Whether or not industry manages to develop this role in the coming years will be decisive for India's chances of raising GERD from just over 1% to the declared goal of 2% of GDP.

The private sector's performance of R&D in India can be compared with that for Latin American giants Brazil (33%) and Mexico (30%); the estimates for other Latin American countries are however much lower.

At the other end of the spectrum, we have Africa, where industry plays only a very minor role in all but South Africa. The same is true for the Arab states in Asia.

So far, we have covered industry's share of national GERD. What about industry's role in taking over partial funding of university research to compensate, as some would have it, for its reduced emphasis on carrying out basic research itself? There is no room for optimism here. It will not be companies that fund the lion's share of academic research. The remarkable fact is that 60% of all university research in the USA is funded by the federal government, largely through five major agencies (see the chapter on the USA). A further 6–7% takes the form of industrial contracts, an equal amount is made up of state contributions and the remainder is funded from the universities' own income (which may of course include donations from companies, or more generally from the business community). This is remarkable because it runs counter to the cherished beliefs and hopes of many cash-strapped governments or eager university managers.

From isolation to interaction

Across the world, companies have gradually but markedly reduced their investments in the development of science. Their own laboratories are rarely the scientific strongholds they once were, as for example in the heyday of Bell Labs in the USA. Bell Labs invented the first transistors (between 1947 and 1952) and can count 11 Nobel laureates among past employees. Today, more than 90% of the scientists and engineers at Bell Labs focus on the needs of service providers, with the company maintaining only a small long-term research programme exploring wireless and optical networking, the Internet, multimedia communications, physics and mathematics.

This illustrates a second aspect: company labs are less and less closed shops. They must concentrate on core competences but at the same time keep track of an ever-wider spectrum of potentially relevant fields. A field such as bionanoelectronics exemplifies the interwovenness of scientific developments, and hence the need to cast one's net widely. Moreover, companies are looking for ways of being involved in generating value from knowledge they have developed outside their core business, without taking the lead themselves.

In finding solutions, companies have come to accept that, even in a globalizing world, proximity effects – being able to interact with companies, universities and institutes nearby – have lost nothing of their importance, as economists have

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established beyond a doubt. Companies are therefore engaging in an ever-larger number of alliances with competitors and suppliers in pre-competitive research or with companies from different market niches to open up new market segments at the interface of their own specialization.

Companies are also engaging in a wide range of relations with academia, for the private sector's smaller role in the development of science does not mean it no longer values science or links with universities. Quite the opposite is true. Companies consider science to be relevant, hold universities in high esteem for what they do best – education and frontier research – and want to build an intensive relationship with them.

Some companies are creating 'open campuses', an open space around their research laboratories to which they invite not only other R&D companies but also public research institutes and teams with whom interaction is expected to lead to further innovation. One example is the High Tech Campus Eindhoven in the Netherlands with the Philips Research Laboratory as a core.

Regional clusters are emerging within countries. The forerunner of these is Route 128 in the Boston area of the USA. More familiar may now be Silicon Valley, the established example from the same country. Later manifestations of these regional clusters are the city of Grenoble in southern France and the Bay Area around San Francisco in the USA.

In the present report, we can read about the ambitious decision by the Japanese to reform policies in order to accommodate these new conditions: the creation of Technopolises and regional clusters, of Technology Licensing Offices at universities and the ambition to establish 1 100 start-up companies within three years. India's three biotechnology clusters (Hyderabad, Bangalore and Delhi) are another example.

All these developments demonstrate the on-going validity of the arguments published in what remains, six years on, the most authoritative survey of the importance of basic academic research in the science cycle, *The Economic Benefits of Publicly Funded Basic Research: A Critical Review* by Salter and Martin (1999). Basic academic research is a source of technological opportunity; a source of new interactions, networks, technological options and hence of broadening technological diversity; and a source of skills to translate knowledge into practice, enhance the ability to solve complex technical problems and an entry ticket to the world's stock of knowledge.

Issues of principle in university–industry cooperation

The stronger links between companies, universities and research institutes have brought centre-stage a number of crucial issues touching upon the very essence of public sector responsibilities. These issues have arisen in part because of a new mutual positioning of firms and universities. Whereas the famous industrial research laboratories of the past were in a sense part of academia, the question now is whether academia has perhaps become too much a department of industry. The quest for patentable research results or for income from clinical trials, for example, has led many an individual faculty member – and entire university departments on campuses across the world – into a grey area where values such as independence, integrity, collaboration, openness and the public availability of results acquired by public money are put at risk.

One should probably argue that the debates emerging around these issues demonstrate that academia, industry and public authorities are trying to establish a new equilibrium where, on the one hand, those values proper to academic activities are safeguarded and, on the other hand, the value of the results of research (which is no longer solely an intellectual or cultural value but also an economic or a societal value) is recognized more explicitly.

There are many strands to these attempts to establish a new equilibrium. One relates to the role of universities. Whereas, in building up S&T capacities in a country, it is difficult to avoid shorter-term application-driven research, there is little doubt that, in mature systems, this should be left to specialized institutes or industry. Another strand deals with code-of-conduct issues surrounding, for example, the faculty member doubling as an entrepreneur.

Much wider issues relate to the global patent system. Ever more parties recognize that the current patent system and the arrangements related to the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) cannot adequately and fairly cope with issues such as the patentability of genes and natural resources. India's struggle to change the rules of the patent regulations (see the chapter on South Asia) illustrates the case for this.

However, we are also witnessing a much richer range of approaches to making available affordable solutions for infectious diseases that plague the developing world. HIV/AIDS strategies are one example but so are new public–private arrangements such as the one between the University of California at Berkeley (USA), OneWorld Health and the Melissa and Bill Gates Foundation. This trio is cooperating to produce a genetically engineered version of one of the most effective anti-malaria drugs, as reported by Bennett Davies in *The Scientist* in 2005. Here, royalty-free licences from a university, a non-profit drug development company and a charity are the ingredients of a new combination.

On a similar note, we all recall the controversy surrounding the human genome project a few years ago, when there was talk of commercializing the project to sequence the human genome. At the crucial juncture, the Wellcome Trust, a UK charity, teamed up with the US government. The Wellcome Trust increased massively its own investment in the project so that its own Sanger Institute could decode one-third of the 3 billion letters that make up 'the code of life'. Today, the completed sequences are freely available to the world's scientific community. While recognizing the important contribution made by the private consortium involved in sequencing the human genome, almost everyone heaved a sigh of relief when all the information on the human genome gained through the project was made available to the public. This near-miss sends a clear signal that the world needs to set limits to what can be done by private companies without guarantees that the results will be made freely available and usable.

Changing roles for government

The dominant role of private industry's contribution to GERD in all major knowledge economies makes it essential for governments to establish an environment for private industry that is conducive to investment in technology and development. That is why it is so important for governments to enhance the transparency of markets, establish solid intellectual property protection regimes and create stability and financial markets in which trust and openness, rather than corruption and clientelism, are the rule. Of course governments should continue to invest in basic science, infrastructure for research and high-quality education, however the latter may be financed. That is not for this introduction to expand upon.

Where such strong emphasis is placed on encouraging private companies to lead a country's R&D effort, it does however raise an interesting question: where does that leave the government's industrial policies? The answers are complex. In the future, countries will still go through a natural succession of industrial stages, driven by a combination of natural endowments and more general comparative advantages. However, the ubiquitous nature of ICT provides opportunities nowadays which cut across this natural sequence by enabling countries to 'leapfrog'. Globalization and the increasing openness of the world's trade regime, coupled with the consequent need for governments to provide flexible economic conditions, will make it much more difficult in the future to maintain such industrial policies, except in small countries like Singapore that happen to be at the crossroads of global trade or financial flows, or large countries like the USA which wish to maintain their ascendancy over the world when it comes to the space and defence industries.

Figure 7 in the chapter on Japan showing the scientific profiles of Japan, the USA and the EU ('the triad') is most enlightening in this regard. It reveals Japan's focus on physics and materials science, and the American leaning towards the earth and space sciences. The most interesting aspect of these scientific profiles is however the strong emphasis in the USA on medical and life sciences, as opposed to almost a disregard for the physical and material sciences and chemistry. This illustrates the importance of creating flexible conditions and strong incentive systems to develop emerging fields, in this case the medical and life sciences.

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Equally illustrative of the ubiquitous nature and potential of ICT is an observation that emanates from the chapter on the USA. There, it is mentioned that the R&D intensity of service industries in the USA is probably higher than in manufacturing, though it is much more difficult to pinpoint the sources of innovation for service industries. It does, however, underscore, the need for closely knit networked societies because interactions are crucial. The Triple Helix has become an essential condition.

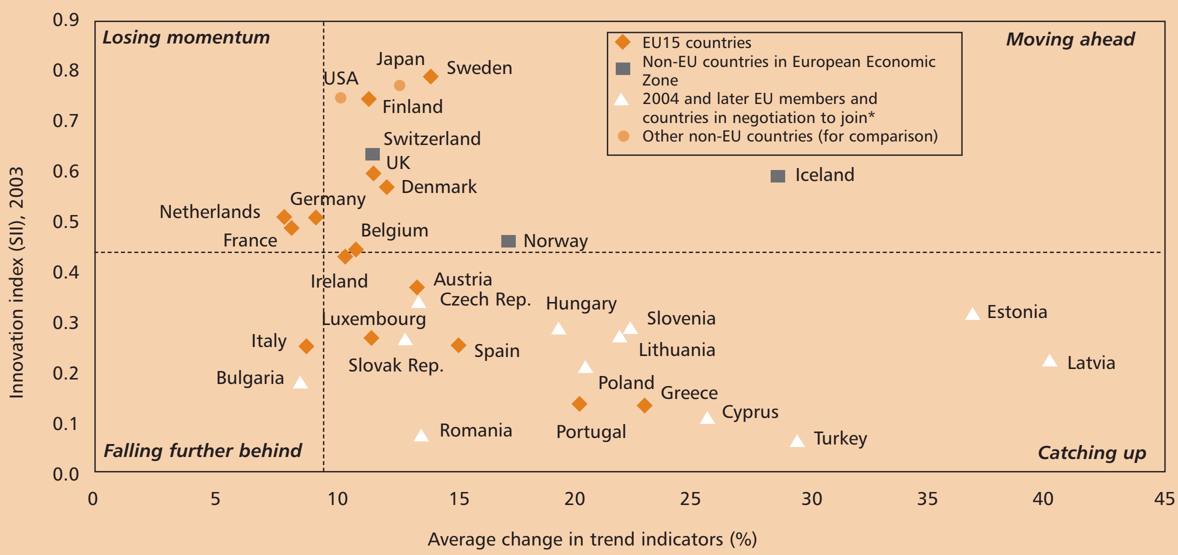
Measuring innovation

As innovation is at the heart of the Triple Helix, we are increasingly seeing attempts to capture not just input to S&T and the output of research but innovation itself, as the mechanism through which S&T 'delivers'. This desire to measure innovation can be seen, for example, in the EU, which nowadays uses an innovation index (SII). This index is composed of various indicators for measuring human resources (ranging from science and engineering graduates and investment in lifelong learning to employment in high-tech sectors); knowledge creation (such as R&D expenditure and patents); transmission and application of knowledge (such as the number of innovating small and medium-sized enterprises); and innovation finances, output and markets (such as venture capital availability and the share of high-tech in manufacturing industry).

A dynamic picture of where countries stand in terms of innovation emerges if we add the average annual change in each of these indicators over the past three years. This gives us the trend. Figure 5 illustrates the position of the 25 Members of the EU and of some other countries, among them the USA and Japan.

While it is clear that it does not yet make much sense to rank most countries from other parts of the world along these lines, they too should keep in mind that, in the longer run, closing on more developed knowledge-based societies requires that they pick up on development paths expressed in this type of graph.

Figure 5
TREND IN INNOVATION IN THE EUROPEAN UNION (25), 2000–03
Non-EU members are given for comparison



* Excludes Malta for which data are not available.

Source: http://trendchart.cordis.lu/scoreboard2003/index.html

Institutional issues with a focus on universities

A knowledge society requires a different institutional set-up from traditional societies and the industrial societies of the past 50 years in that the private sector will play an important role in the former. That does not mean however that the role of education and research institutions, be they public or private, is diminishing. Nor does it imply a dwindling role for governments.

The importance of a national vision

In developed countries and developing countries alike, governments need to have a clear, longer-term vision of the role of the various components – private companies, universities, government institutes, but also supportive mechanisms for technology transfer, or quality and safety control – of a science, technology and innovation system. Governments also need to have a clear idea of what needs to be done to stimulate the growth and interaction of these stakeholders.

Let us take one lesser-known example, that of Romania. Strongly motivated by its imminent membership of the EU in 2007, Romania has formulated six clear strategic goals, ranging from increasing GERD and stimulating enterprise R&D to institutional reforms (see the chapter on South-East Europe). In developing countries, there are three dangers that are hard to avoid without clear strategic goals. In the description of 'Median Africa', the chapter on Africa depicts the dangers of a market-oriented system. This is not a market formed by innovative national companies but rather one where international donors, aid programmes or multinational companies create powerful incentives for researchers which cannot be matched by a national S&T system unable to provide careers, modern equipment, professional standards and a vision which places the country in control of its own development.

In many Arab countries, we are seeing another danger, as depicted in the chapter on the Arab region, namely a situation where the main input to technology comes through turnkey investments by large foreign companies and international engineering consultancies. There is no anchoring of the technology on which the productive sector rests in the S&T system of the country itself.

Even when a much more developed S&T system exists, as in Latin American countries, caution should be exercised before engaging in international collaboration. This should bring not merely technology transfer but also capacity-building. The government must have a vision of what institutional building is needed and mould any policies accordingly, including those governing international collaboration and international donor involvement.

Tensions in the university system

Many of the tensions surrounding the evolution of a strong S&T system in developing countries surface in the university system. Examples abound in the various chapters of this *UNESCO Science Report*.

In many developing countries, a combination of factors is at work. An explosion in the higher educational system is on-going or imminent almost everywhere. With output exceeding local needs, a pool of unemployed or underemployed qualified graduates is being created. Moreover, most graduates are in the fields of management or business training, the arts and humanities, or sometimes in theoretical sciences, with little emphasis on applied sciences. This overproduction results in a mass exodus of graduate students, leading to a significant 'brain drain'. A multitude of new, often private universities have sprung up, usually focusing on 'fashionable fields'.

Russia's 3 400 new private universities offer a cautionary tale of what can happen in non-developing countries also when a lack of policies and regulations prevails. With the exception of a few, often smaller private universities, quality standards are lacking and there are no career policies based on performance. Few incentives for collaboration, sharing of equipment and concentration exist. Unfortunately, even the best-qualified researchers will soon lose their edge if they work in isolation because they will fail to keep up with the advances of modern science. Clear government policies are essential to reverse

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a situation which is now only too commonplace. In the absence of any policy identifying how public and private universities could cooperate to form a thriving higher education sector, there is one oversized national public university and a great many sub-standard private ones.

Universities in a globalizing world

It is not only in developing countries that universities are coming under great pressure to adapt to a new environment. Globalization is making its presence felt, as are the new demands on teaching and research, such as the need to address interdisciplinarity.

Here, we shall focus on globalization. The attention being given in 2004 to the ranking of the world's universities by Shanghai's Jiao Tong University is probably the best illustration of globalization. This is both because the ranking does not come from a traditional western university or magazine and because it brings into the picture universities across Asia and Oceania. High-quality tertiary institutions underscore the prominent position that China, India and the Newly Industrialized Countries in Asia are gradually claiming in the production of S&T. No doubt, these institutions have also been instrumental in bringing these countries to prominence. The Indian Institutes of Technology (see the chapter on South Asia) are an interesting example, their students being among the most sought-after by top American universities. The mobility of students and staff will raise the stakes for universities all over the world. Unavoidably, universities which are still often tightly bound up with national regulations and funding schemes will have to become much more autonomous. This goes hand in hand with much more transparent accountability regimes towards funding sources and with accreditation schemes.

There is another inevitable task which universities often choose to ignore and that is the task of defining realistically what they want to be. They do not need to emulate the American system to be struck by reasons for its strength. One of these strengths is the differentiation in mission and quality. The countries of the EU – and non-Member European countries – are now all in the process of moving towards a homogeneous Bachelor–Master–PhD system. However, it is difficult to see how the European university system can be sustainable if the tradition is maintained of every university performing significant amounts of research, or even extending this activity to institutes for higher professional education. In the USA, out of 3 400 degree-granting tertiary institutions, only 127 are research universities granting doctorates. Germany alone counts about 120 universities all claiming their share of the research pie. Moreover, this is not counting the professional universities of the *Fachhochschule* and the universities devoted to the arts, the *Kunst- und Musikhochschulen*.

In the United Kingdom, the government favours concentrating research but the House of Commons has come up with a plan for regionalizing research. Germany and, more recently, France have come to realize that large organizations for basic research outside the university system may do wonderful work but that, for the country's vitality, much closer links need to be established with universities. The German government's recent attempt to create 'elite universities' has been largely thwarted and turned into a funding mechanism for excellence programmes. Similarly, it remains to be seen whether the Japanese Centre of Excellence Programme (see the chapter on Japan) will result in further differentiation and concentration.

However, differentiation is not the only aspect of higher education that distinguishes the US system from the European one. Until now in Europe, with the exception of the UK, social expectations tended to mean that a two- or three-year degree comparable to a Bachelor's was not perceived as being a genuine university degree. Interestingly, this was also the case among employers. That attitude is both unsustainable and unnecessary for the labour market and for the integration of citizens into a knowledge society. The jury is out on whether the EU's formal introduction of Bachelor's and Master's degrees in all countries of Europe in an attempt to create a homogeneous pan-European Higher Education Area by 2010 is capable of forcing the system into a new equilibrium.

An important contribution to a thriving university system, and one that helps to enhance quality, differentiation and concentration, comes from having one or more professional research councils providing grants on a meritorious basis. The various chapters show that this lesson is beginning to be assimilated. China, the Russian Federation, Japan, Mexico and South Africa have all created bodies allocating grants on the basis of merit. In many other countries where such schemes exist but have fallen victim to political interference and nepotism, there is a growing acceptance of the need for reform. Even in Europe, there seems to be agreement on the need for a European Research Council to strengthen Europe's science base. This Council would create a 'uniform attractive force' for the best scientists which would not be handicapped by the limitations inevitably existing in national systems, or in the target-oriented environment of the EU's Framework Programmes for R&D.

CONCLUSION

To sum up, we have discussed a number of important cross-cutting issues in this overview of the state of science in the world. We have seen how players are repositioning their science, technology and innovation systems to cope with new realities.

However, if we single out one particular issue, perhaps the gravest concern for policy makers in large parts of the world is the almost intractable problem of brain drain. If there is one incentive for governments to strengthen universities, shape an environment conducive to private enterprise, remove stifling rules and build an open society, it is brain drain. By creating attractive conditions for highly trained personnel, countries can incite their 'human capital' to stay home, or return, to contribute to the development of their country or region.

Science is becoming increasingly dependent on international collaboration. Nowadays, scientists can participate in virtual research with collaborators who may be in the next room or on the next continent. Even if researchers have come to appreciate the advantages of globalization – or precisely for that reason – governments can give them reasons to want to work from home.

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He was Rapporteur-General of the World Conference on Science (1999) co-organized by UNESCO and the International Council for Science and of a government conference on genetically modified food (2000) co-organized by the OECD and the United Kingdom. He has also been Coordinator (with Pierre Papon) of the Europolis project on S&T policies for Europe.

Within the Netherlands administration, he was responsible for research and science policy until 1999, his first major achievement being the coordination of a first major framework for the country's innovation policy in 1979.

Peter Tindemans chaired the OECD Megascience Forum (1992–99) and COSINE Policy Group (1987–91) for a pan-European computer networking infrastructure. As a member of the Eureka High-level Group until 1991, he was involved in the preparation of European Union Framework Programmes. A former member of the Governing Board of Euroscience, an NGO promoting science in Europe, he sits on the Steering Group of the Initiative for Science in Europe (ISE).

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United States of America

J. THOMAS RATCHFORD and WILLIAM A. BLANPIED

Science and technology (S&T) in the USA prospered greatly in the 1990s. Gross domestic expenditure on research and development (GERD) approached US$ 265 billion in 2000, an increase of 74% (41% in constant, or inflation-adjusted, dollars) in a decade.

Since 2000, increases have been harder to come by, as the sections that follow will demonstrate. In 2002, GERD came to approximately US$ 292 billion, with industry contributing two-thirds and the Federal Government slightly over one-quarter. Since 1980, the year industry pushed ahead of the Federal Government as a source of research and development (R&D) funding, industry has become the dominant source of R&D support. The federal role in providing a nurturing policy environment for all S&T, however, remains essential. The government is also the sole supporter of defence technology and the principal supporter of basic research in US colleges and universities.

Increases in industry spending on R&D appear to have stalled since 2000, resulting in probable small decreases (in constant dollars). Tight budgets have accompanied growing emphasis on R&D management and assessment, including technology roadmapping, 'collaboratories' and Web-enabled innovation tools. In parallel, the Internet has boosted efficiency in data exchange and scientist-to-scientist communications and stimulated the development of an almost instantaneous 'grey' literature in various specialties. The Federal Government has joined the current trend towards assessment by applying tools mandated by the Government Performance and Results Act (GPRA) to research programmes.

Since 1980, average government expenditure for all areas of R&D has risen by 3.5% per year, a trifle compared with the leaps and bounds in industry spending. Despite these increases, support (in constant dollars) for most science and engineering disciplines has remained essentially flat for the past decade, with one notable exception: the biosciences. Generous support for the biosciences has brought constant advances in basic research, new products and processes in industry, and greater efficiency in the service sector. Frontier discoveries have replenished the store of basic knowledge and paved the way for new commercial developments.

The US public has a more supportive attitude towards science than do populations in other countries (see pages 40–41). It remains favourably inclined towards the scientific enterprise, while questioning some applications of specific technologies, such as genetic engineering. The US scientific community's leadership enjoys more public confidence than any other institution save medicine. Notwithstanding this, the public portrayal of scientists in entertainment and the media is often far from flattering.

Nor is public concern and nervousness about employment and the outsourcing of jobs, which has been made possible by widely applied new technologies, totally unfounded. Rather, it is a sign that greater attention needs to be paid to skills training in science and engineering to ensure that professional profiles move with the times.

R&D EXPENDITURE AND TRENDS

Figure 1 shows the trends in terms of total GERD and GERD by source of funds between 1953 and 2000, expressed in both current and constant dollars. Figure 2 presents a breakdown of GERD in 2002 by source of funds.

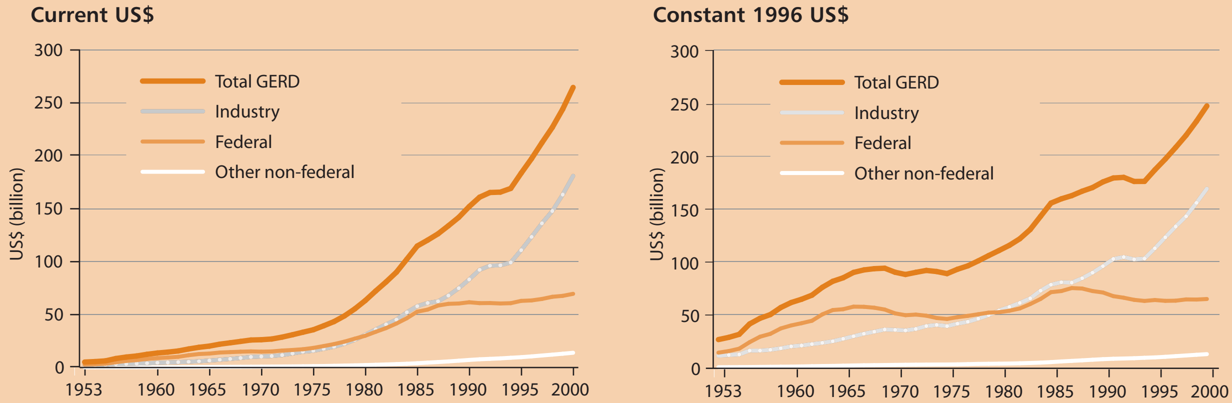
The USA accounts for approximately 44% of the R&D expenditure of all the countries of the Organisation for Economic Co-operation and Development (OECD) combined. In 2000, the USA's GERD amounted to 150% more than that of Japan (the second-largest contributor) in terms of purchasing power parity (PPP). The GERD/GDP ratio for the same year was 2.63% for the USA and 3.01% for Japan.

FRONTIER DISCOVERIES

Scientists (many of them foreign born) working at US institutions continued to obtain important results across a broad spectrum of scientific fields in 2003. These included both results with potential for commercial application and those that serve primarily to deepen human understanding of the physical universe.

In its 19 December 2003 edition, *Science*, the respected journal of the American Association for the Advancement of Science, published its annual 'Breakthrough of the Year' report. By consensus, the journal's editorial staff attributed

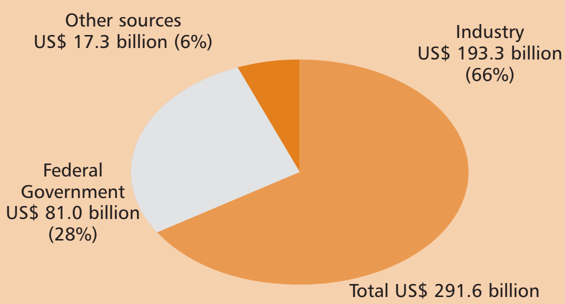
Figure 1
GERD IN THE USA BY SOURCE OF FUNDS, 1953–2000



Source: MEXT (2002a) *Science and Engineering Indicators – 2002.*

the most significant scientific accomplishment of the year to the confirmation, by means of independent observations by three US research teams, that 73% of the mass energy of the universe consists of so-called dark energy. (Only 4% of the mass energy of the universe exists in the form of ordinary matter, a further 23% being accounted for by dark matter.) The three sets of measurements that led to this conclusion were: determination of the anisotropy of the microwave background pervading the universe, which enabled the re-creation of an image of the cosmos when it was only 400 000 years old; observations of distant super novas, and observations of galactic clusters. The latter two sets of observations also indicated that the universe was 13.7 billion years old, give or take a few hundred million years.

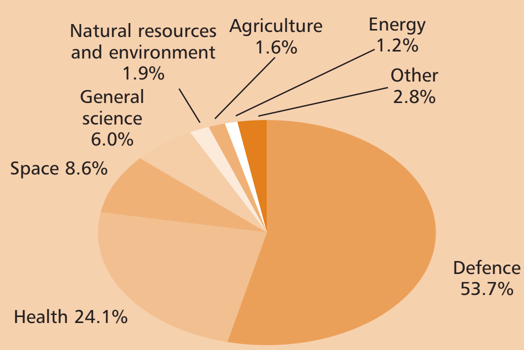
Figure 2
GERD IN THE USA BY SOURCE OF FUNDS, 2002



Note: Other sources include universities and colleges, state and local governments, and non-profit organizations.

Source: MEXT (2002b) *National Patterns of R&D Resources.*

Figure 3
FEDERAL R&D BUDGET IN THE USA BY FUNCTION, 2003



Source: American Association for the Advancement of Science R&D Budget Program.

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The character of dark energy, the existence of which was first suspected about a decade ago, is not well understood. What is certain, however, is that it counteracts the gravitational attraction among the galaxies that comprise ordinary matter, causing the universe to expand at an accelerating rate rather than a decelerating rate, as had once been suggested. The dominance of dark matter could ultimately lead to the literal explosion of galaxies, stars, planets and even atoms themselves.

In the runner-up category for 2003, *Science* cited research by US investigators demonstrating that genes known to cause depression are activated only when combined with stress. Another runner-up was acknowledged for advances in understanding the genetic basis of schizophrenia and bipolar disorder. Falling into the same runner-up category were numerous studies that, taken together, provide specifics about the effects of global warming. These include research on melting ice, drought, decreased plant productivity and altered plant and animal behaviour.

R&D AND THE FEDERAL GOVERNMENT

Federal funding

In the ten years leading up to 1995, federal R&D expenditure declined slightly (in constant dollars) and has never recovered since (Figure 1).

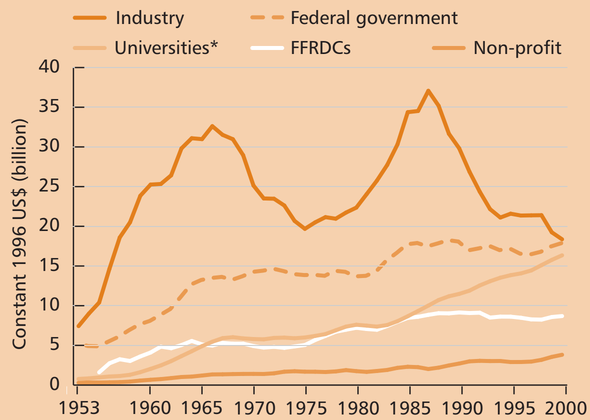
Figure 3 shows the breakdown in federal expenditure on R&D in 2003 by function. Of the total, approximately half was devoted to national defence and a quarter to health. The USA is unique among OECD countries in its heavy emphasis on these two functions.

Figure 4 illustrates the breakdown of federal R&D funds for 1953–2000 by performing sector. Specific to the USA, Federally Funded Research and Development Centers (FFRDCs) are managed by a non-governmental organization on behalf of the Federal Government.

Principal supporting agencies

Although approximately 25 of the agencies within the Federal Government invest a portion of their annual budgets in R&D, a mere six of these account for well over 90% of fiscal year 2003 federal R&D expenditure. The appropriations of these six cabinet departments and independent agencies are given in Table 1.

Figure 4
FEDERAL SUPPORT FOR R&D IN THE USA BY PERFORMING SECTOR, 1953–2000



* Including colleges.
FFRDCs = Federally Funded Research and Development Centers.

Source: MEXT (2002a) *Science and Engineering Indicators – 2002.*

The R&D appropriations of US$ 562 million for the 2003 fiscal year did not qualify the Department of Homeland Security (DHS) – created on 5 November 2002 in response to the terrorist attacks of 11 September 2001 – for a place of honour among the top departments and agencies. The R&D budget of the DHS, which supports programmes and facilities previously under the jurisdiction of a number of other agencies, was already approximately 25% that of the Department of Agriculture in 2003. This suggests that the new department might come to play a significant role in federal R&D performance and support within the next few years. For example, the requested budget for the DHS in the 2004 fiscal year was US$ 835 million, an increase of almost 50% over its budget for the previous year.

Support and performance by mission agencies

With a single exception, all of the Federal Government's cabinet departments and independent agencies that perform

Table 1
THE SIX LEADING FEDERAL GOVERNMENT AGENCIES IN THE USA, 2003

Total R&D funding	US$ billion
Department of Defense (DoD)	58.6
Department of Health and Human Services (HHS)	27.6
National Aeronautics and Space Administration (NASA)	11.0
Department of Energy (DoE)	8.2
National Science Foundation (NSF)	3.9
Department of Agriculture (USDA)	2.2

Basic research funding	US$ billion
Department of Health and Human Services	14.1
National Science Foundation	3.4
Department of Energy	2.6
NASA	2.4
Department of Defense	1.4
Department of Agriculture	0.9

and/or support R&D do so in pursuit of their congressionally mandated missions. By contrast, the National Science Foundation (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.

Of the Federal Government's US$ 81.0 billion in R&D expenditure in 2002, US$ 21.6 billion was devoted to laboratories and other facilities managed directly by a federal department or agency. An additional US$ 10.5 billion was allocated to 36 FFRDCs (often called national laboratories), which are managed by universities, private companies and non-profit institutions on behalf of, and with full support from, the Federal Government. Of these 36 centres, 16 are university-managed, 4 are industry-managed and 16 are managed by non-profit organizations.

DoE-supported national laboratories

The majority of FFRDCs (16) are funded by, and managed on behalf of, the Department of Energy (DoE), which in 2002 provided 61% of the total funding for all FFRDCs. Approximately 60% of the 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. Although the first two have been managed from the outset by the University of California, the DoE announced in 2003 its intention to open up the management to bids from other potential contractors. In 2001, expenditure on Sandia – which is managed by a subsidiary of Lockheed Martin Corp. – amounted to approximately US$ 1.6 billion, the largest of any national laboratory. Next in order of expenditure was the Jet Propulsion Laboratory (US$ 1.36 billion), funded by the National Aeronautics and Space Administration (NASA) and managed by the California Institute of Technology, followed by Los Alamos (US$ 1.33 billion).

DoE-supported national laboratories include several whose purpose is to house and maintain large-scale research facilities on behalf of university user groups. These facilities include 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 the Associated Universities, Inc.

Other supporters of national laboratories

In addition to those supported by the DoE, nine FFRDCs are supported by the Department of Defense (DoD), a further five by the NSF and one each by NASA, the National Institutes of Health, the Department of Transportation, the Nuclear Regulatory Agency, the National Security Agency and the Internal Revenue Service.

INDUSTRIAL R&D

The beginning of the twenty-first century has been harsh to industrial R&D in the USA, as recession has taken its toll. In real terms – that is, after inflation is taken into account – US industrial spending on R&D hit a peak in 2000 and has declined ever since.

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The second half of the twentieth century: a prosperous era

The second half of the twentieth century was a prosperous era for industrial R&D in the USA. Beginning in 1953, when the NSF launched its annual survey of industrial R&D, company-funded R&D increased relentlessly every year to 2000. In 1953, for example, about US$ 3.6 billion of R&D was performed by industry. Of this total, US$ 1.4 billion was funded by the Federal Government. By 2000, the total R&D performed by industry had grown to US$ 200 billion, all but US$ 19 billion being funded by industry itself. This trend over the past half-century is shown in Table 2.

The American R&D scene clearly has changed since the Second World War from one dominated by Federal Government spending to one overwhelmingly influenced by industry financing. This has resulted in a fundamental repositioning of the roles of government and industry. Although the Federal Government is still the predominant sponsor of basic research, especially in the universities, industry funding overwhelms government support of development activities. This has contributed to a remarkable increase in technological intensity in the global market place. This growing technological intensity will be further scrutinized later in this section. Industry dominance in R&D resources in the USA is illustrated in Figure 5, which shows the industry share of US R&D expenditure since 1953.

The USA is not alone in experiencing a relative decrease in government funding of R&D. Government support for R&D relative to that of the private sector is down for all industrialized countries, although large differences still remain among nations. For example, the US Government-financed portion of R&D (excluding defence-related R&D expenditure) fell from 33% in 1980 to 15% in 2002; over the same period, government funding in Germany fell from 40% to 30%.

Table 2
TRENDS IN TOTAL FUNDS FOR INDUSTRIAL R&D IN THE USA, 1953–2001
By source of funds, in current and constant dollars (million)

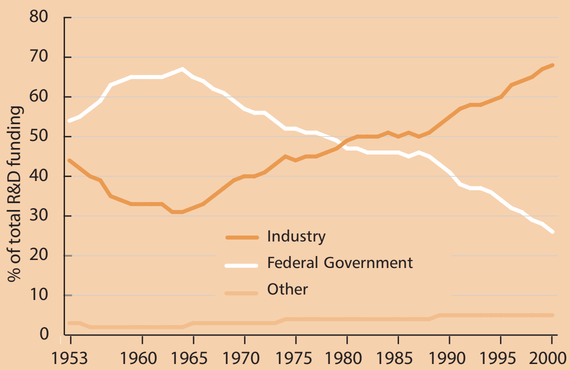
	Total R&D[1]		Federal[1]		Company[2]	
	Current dollars	Constant 1996 dollars	Current dollars	Constant 1996 dollars	Current dollars	Constant 1996 dollars
1953	3 630	18 857	1 430	7 429	2 200	11 429
1958	8 389	38 766	4 759	21 992	3 630	16 774
1963	12 630	54 913	7 270	31 609	5 360	23 304
1968	17 429	66 270	8 560	32 548	8 869	33 722
1973	21 249	63 241	8 145	24 241	13 104	39 000
1978	33 304	69 052	11 189	23 199	22 115	45 853
1983	65 268	94 756	20 680	30 023	44 588	64 733
1988[3]	97 015	120 951	30 343	37 829	66 672	83 122
1993[3]	117 400	124 827	22 809	24 252	94 591	100 575
1998[3]	169 180	163 934	24 164	23 415	145 016	140 519
1999[3]	182 711	174 592	22 535	21 534	160 176	153 059
2000[3]	199 539	186 677	19 118	17 886	180 421	168 791
2001[3]	198 505	181 416	16 899	15 444	181 606	165 971

1 Beginning with 2001, statistics for total and federally funded industrial R&D exclude data for Federally Funded Research and Development Centers (FFRDCs).
2 The company-funded R&D in this table is the industrial R&D performed within company facilities funded from all sources except the Federal Government.
3 Statistics for 1988 onwards have been revised since originally published. For more information, see the technical notes in *Survey of Industrial Research and Development Methodology*: 2001 at http://www.nsf.gov/sbe/srs/sird/start.htm.

Note: Gross domestic product (GDP) implicit price deflators were used to convert current dollars to constant (1996) dollars.

Source: National Science Foundation (2001). *Survey of Industrial Research and Development: 2001.*

Figure 5
SHARES OF NATIONAL US EXPENDITURES ON R&D, BY SOURCE OF FUNDS, 1953–2000



Source: MEXT (2002a) *Science and Engineering Indicators – 2002.*

This dramatic repositioning of industry as the predominant funder of research does not mean that the almost hundred-fold increase in R&D funding by industry over the past 50 years was completely without pause. From the late 1960s until 1975, there was a noticeable slackening in industry's infatuation with technology development. Constant-dollar growth declined in 1970, 1971 and 1975. From then until 2000, strong growth resumed with only minor hiccups in 1987 and 1993. The effects of this extended run-up on the federal–industry R&D balance are shown in Figure 1, with the pauses apparent in the constant-dollar representation.

Slow start for industrial R&D in the 21st century

With the end of the 1990s' stock market 'bubble' and a new economic recession, the fortunes of industrial R&D have suddenly turned bleak. The year 2000 saw a robust – though not record-setting – 7% increase in R&D performed by industry (in constant dollars). Although only estimates have been available since then, it appears that support for R&D performed by industry declined by 3% in 2001, by 4% in 2002 and by another 1% in 2003. It should be noted that percentages for these years also reflect R&D funding in constant dollars. Table 2 shows NSF data to 2001; estimates for 2002 and 2003 come from the NSF and the Industrial Research Institute (IRI).

The forecast for 2004 is not encouraging. The annual R&D trends forecast released by IRI in December 2003 (see, for example, *Chemical and Engineering News*, 22 December 2003, p.13) indicates that more companies plan to reduce R&D expenditure than plan to increase it. More encouraging is the news that, among the survey participants, the number of companies expecting to increase R&D spending by more than 5% rose in comparison to the previous year. Also expected to increase are contact with federal laboratories, participation in joint ventures, and alliances for R&D and involvement in research consortia with university and industry partners.

Technological intensity of industrial competition

Companies everywhere are running harder to succeed against global competitors in technology. This effort to keep up and get ahead is often referred to as the 'technological intensity of the industrial enterprise'. Usually measured in terms of the ratio of R&D expenditure to net sales (although a more sophisticated measure is 'value added', or sales minus cost of materials), this ratio has increased substantially over time. It varies greatly between industry groups. For example, in the USA, the ratio for food, primary metals and broadcasting and television is less than 0.5%, whereas communications equipment, software and scientific R&D services are well into double digits. Table 3 shows technological intensity for US industries in 2000 to 2001.

The data in Table 3 should be interpreted with care. First, the table includes only those companies that perform R&D; many companies, especially small businesses, do not. Also, a company is classified as entirely 'manufacturing' or 'service-oriented'. If sales evolve from majority manufacturing to majority service, the company's classification changes as well. This can be an important distinction for some large companies.

R&D in the service sector

One of the more interesting questions is whether the service industries will maintain the traditional emphasis on R&D and

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technology development found in the manufacturing sector. This appears to be the case. Note that, for 2001, the ratio of R&D to sales for the non-manufacturing (more or less what we deem 'service') industries in the USA was actually greater than for manufacturing. Bearing in mind that manufacturing represents only about 20% of the economy in the USA, and given the trend towards an increasingly service-oriented economy, this increasing dependence on R&D is encouraging.

Table 3
FUNDS FOR INDUSTRIAL R&D PERFORMANCE IN THE USA, BY INDUSTRY, 2000 AND 2001
As a percentage of net sales of companies that performed industrial R&D in the USA

Industry	2000	2001*
Distribution by industry:		
All industries	3.8	4.1
Manufacturing	3.6	4.0
Food	(D)	0.5
Beverage and tobacco products	0.7	0.4
Textiles, apparel and leather	(D)	(D)
Wood products	0.8	1.1
Paper, printing and support activities	(D)	(D)
Petroleum and coal products	(D)	(D)
Chemicals	5.9	4.9
Basic chemicals	2.4	2.2
Resin, synthetic rubber, fibres and filament	5.6	(D)
Pharmaceuticals and medicines	(D)	7.8
Other chemicals	(D)	(D)
Plastics and rubber products	(D)	(D)
Non-metallic mineral products	1.8	2.4
Primary metals	0.5	0.7
Fabricated metal products	1.4	1.7
Machinery	3.9	4.3
Computer and electronic products	9.0	12.4
Computers and peripheral equipment	6.5	(D)
Communications equipment	9.9	17.0
Semiconductor/other electronic components	7.5	10.6
Navigational, measuring, electromedical and control instruments	12.0	12.6
Other computer and electronic products	4.3	(D)
Electrical equipment, appliances and components	(D)	3.1 (S)
Transportation equipment	4.0	4.2
Motor vehicles, trailers and parts	(D)	(D)
Aerospace products and parts	7.3	5.7
Other transportation equipment	(D)	(D)
Furniture and related products	0.8	0.9
Miscellaneous manufacturing	8.7	6.6
Medical equipment and supplies	(D)	(D)
Other miscellaneous manufacturing	(D)	(D)
Other manufacturing	–	–

Industry	2000	2001*
Distribution by industry:		
All industries	3.8	4.1
Non-manufacturing	4.1	4.3
Mining, extraction and support activities	1.0	(D)
Utilities	(D)	0.0
Construction	(D)	1.4
Trade	5.3	6.2
Transportation and warehousing	(D)	2.5
Information	4.1	(D)
Publishing	16.3	15.1
Newspaper, periodical, book, database	2.0	2.7
Software	20.5	19.4
Broadcasting, telecommunications	0.5 (S)	(D)
Radio/television broadcasting	(D)	1.1
Telecommunications	(D)	(D)
Other broadcasting, telecommunication	(D)	(D)
Other information	5.1	(D)
Finance, insurance and real estate	1.2	(D)
Professional, scientific and technical services	18.7	16.8
Architectural, engineering and related services	10.8	7.5
Computer systems design and related services	12.3	17.4
Scientific R&D services	42.9	47.7
Other professional, scientific and technical services	6.6	2.4
Management of companies and enterprises	4.4	7.8
Health care services	3.2	4.2
Other non-manufacturing	1.0	1.5

* Beginning with 2001, statistics for total and federally funded industrial R&D exclude data for Federally Funded Research and Development Centers (FFRDCs).

(D) = Data have been withheld to avoid disclosing operations of individual companies.
(S) = Imputation of more than 50%.
(–) = Indicates data not collected.

Source: National Science Foundation (2001). *Survey of Industrial Research and Development: 2001.*

International comparisons are difficult in almost all areas of S&T but especially so for industrial R&D. It appears, however, that service industries in most, if not all, industrialized countries have greatly increased R&D expenditure since the mid-1980s. This trend is particularly pronounced in the USA, where the share of US service industry R&D expenditure is larger than that of service industries in other major industrialized nations.

OTHER FUNDERS AND PERFORMERS

Approximately 6.0% of total US national R&D expenditure not generated in 2002 by industry or the Federal Government was accounted for by universities, state governments and non-profit organizations.

State governments

State governments were estimated to have provided approximately US$ 2.4 billion in directly targeted support for R&D in 2002, virtually all of it performed in universities and colleges within state borders. Additionally, an appreciable fraction of the US$ 7.5 billion spent on R&D by universities themselves came from general purpose funds provided by state governments. The share of institutional support at state universities in 1999 represented 24%, as opposed to 9% in private universities.

States differed considerably in the amounts of R&D performed by their universities, industries and Federal Government facilities. Virtually all of these activities were funded by industry or by the Federal Government. In 2000, the six states of California, Michigan, New York, New Jersey, Massachusetts and Illinois accounted for approximately 50% of the total national R&D effort, with California alone accounting for approximately 20%. California also led all other states in the level of R&D performed by universities and industry (including industry- and university-managed FFRDCs). Maryland ranked first in terms of the dollar level of performance by federal government facilities.

Funding by non-profit organizations

During the period from 1994 to 2000, annual growth in real terms in the R&D performed by non-profit organizations increased by an average of 5.3% per year, 8.0% of which was accounted for by funds provided by the organizations themselves. During this same period, industry performance in real terms increased by 7.0% and university performance by 3.1%. In 2002, US non-profit organizations expended US$ 7.3 billion in support of R&D. This breaks down to US$ 2.7 billion for R&D conducted in universities and US$ 4.6 billion for R&D in facilities that non-profit organizations other than universities own and manage. R&D performed by FFRDCs managed by non-profit organizations and funded by the Federal Government accounted for an additional US$ 4.6 billion.

The example of the Carnegie Institution

Prior to the Second World War, several facilities managed by non-profit organizations other than universities were prominent contributors to the US research effort. For example, the Carnegie Institution of Washington was the sole supporter of the 60-inch (1.5-metre) and later the 100-inch (2.5-metre) telescopes at the observatory conceived in 1904 by George Ellery Hale and constructed on Mt Wilson in southern California. In 1928, the Carnegie began construction of the 200-inch (5-metre) telescope at Mt Palomar, with substantial support from the Rockefeller Foundation. Today, the Carnegie Institution is one of a handful of non-governmental organizations (NGOs) that continue to conduct quality scientific research with their own funds supplemented by government grants, often in cooperation with university scientists. The institution supports and manages a Southern Hemisphere Observatory in Las Campanas, Chile. Additionally, active research continues in its Departments of Terrestrial Magnetism, Embryology, Global Ecology and Plant Biology and in its Geophysical Laboratory.

UNIVERSITIES

During the past 50 years, US universities have moved from the periphery of the national research system, which they occupied prior to the Second World War, to a position at its vital centre. Although they perform only 11% or so of

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national R&D in dollar terms, universities perform approximately 50% of basic research. This function has become increasingly important as industry has largely abandoned long-term basic research in favour of more focused, short-term applied research. Since the mid-1990s, the number of patents granted to universities has increased substantially, as has the royalty income derived from licensing those patents. Between 1991 and 1999, gross royalties obtained by US universities from their patenting activity increased from US$ 130.0 million to US$ 675.5 million. Even though these amounts are trivial compared with the total US$ 30 billion worth of R&D performed by universities in 2000, these data indicate that an increasing fraction of university research is potentially available for exploitation by industry. While universities are equally, if not more, 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 their research function, particularly in disciplines that have a reasonable potential for commercial development.

Research universities

The bulk of academic research and advanced teaching functions is carried out by a relatively small number of US universities. According to the Carnegie Foundation for the Advancement of Teaching, there are currently almost 3 400 degree-granting institutions in the USA serving approximately 14.5 million students. Among these, the foundation classifies 127 as research universities, defined as institutions that offer a full range of baccalaureate and graduate programmes, and obtain more than US$ 15.5 billion 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%.

Research support

Of the US$ 30 billion in R&D performed by US universities in 2000, 69% was expended for basic research, 24% for applied research and 7% for development. The Federal Government accounted for 58% of the total and universities themselves for a further 20%. The remainder was made up by industry (7%), by state and local governments (7%) and by non-profit organizations and individual philanthropy.

Quality of research universities

By several yardsticks, US research universities, taken collectively, qualify as the world's best in science and engineering. For example, in 1999, more than 30% of the approximately 530 000 S&T articles published in journals around the world and listed by the Philadelphia-based Science Citation Index (SCI) involved at least one US author. Of these authors, 74% were from academia. US research universities remain the destination of choice for many foreign graduate students. In an intriguing report published in 2003, the Shanghai Jiao Tong University's Institute of Higher Education rated and ranked the world's top 500 universities in terms of teaching quality and research performance. Of the top 50 institutions, 35 were in the USA; of the top 10, eight were in the USA, with Cambridge and Oxford Universities in the UK being the remaining two. Interestingly, the highest-ranking university in the non-English speaking world was Tokyo University, which ranked 19th.

International competition

Despite their high quality, US research universities face increasing international competition. In 1986, the USA produced almost 40% of the world's S&T articles – their authorship being dominated by academics – compared with 31% for Western Europe. In 1999, Western Europe accounted for approximately 36%, the US share having receded to around 30%. Asia has also demonstrated an impressive increase in publications, accounting for 16% of the world total in 1999, compared with 10% in 1986.

Although foreign enrolment in US graduate schools is still rising, the number of Asian students seeking doctorates at home now exceeds the number who study in the USA. 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 (see also *The visa issue*, page 36).

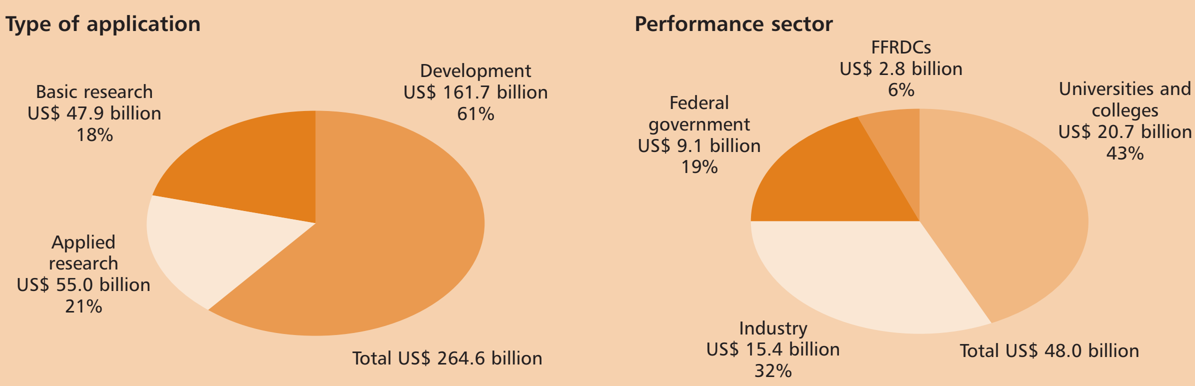
That a Chinese organization should decide to carry out an exhaustive survey to rank the world's leading universities may itself suggest that Chinese universities intend to become internationally competitive. One possible indicator is that 50% of all graduate courses offered by Tsinghua University in Beijing will be taught in English by 2008. Not only will this require proficiency in English on the part of the university's Chinese students; the move is also intended to attract larger numbers of foreign students, including Americans.

BASIC RESEARCH

Support for basic research has been a cornerstone of US science policy ever since the immediate post-Second World War years, when Vannevar Bush presented his influential 1945 report, *Science – the Endless Frontier*, to President Harry Truman. In his report, Bush argued that the Federal Government had not only 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 Republican and Democratic presidential administrations for decades. Both political parties in the US Congress have upheld this position, the only major issues in dispute being the level of support and its distribution among agencies, programmes and disciplines. Some disagreements among the parties have also arisen over federal support of some pre-competitive R&D in industry. See Figure 6 for basic research funding and performance in 2000.

Prior to the Second World War, the Federal Government provided no support for basic research in universities and performed little or no basic research in its own laboratories. That situation began to change after the war in keeping with Bush's recommendation. By 1953, the first year consistent R&D expenditure data were collected, the Federal Government had become the primary supporter of basic research. It has retained that status ever since. However, its share has decreased from 70.5% in 1980 to 48.7% (US$ 23.3 billion) in 2000. This drop reflects an increase in non-federal funding for basic research rather than a decrease in federal funding. Between 1980 and 2000, federal support rose by an average of 3.5% per year, compared with an average rise of 10.0% per year for industry over the same period.

Figure 6
BASIC RESEARCH FUNDING IN THE USA, 2000
By type of application and performance sector



Source: MEXT (2002a) *Science and Engineering Indicators – 2002.* Ministry of Education, Culture, Sports, Science and Technology, Tokyo.

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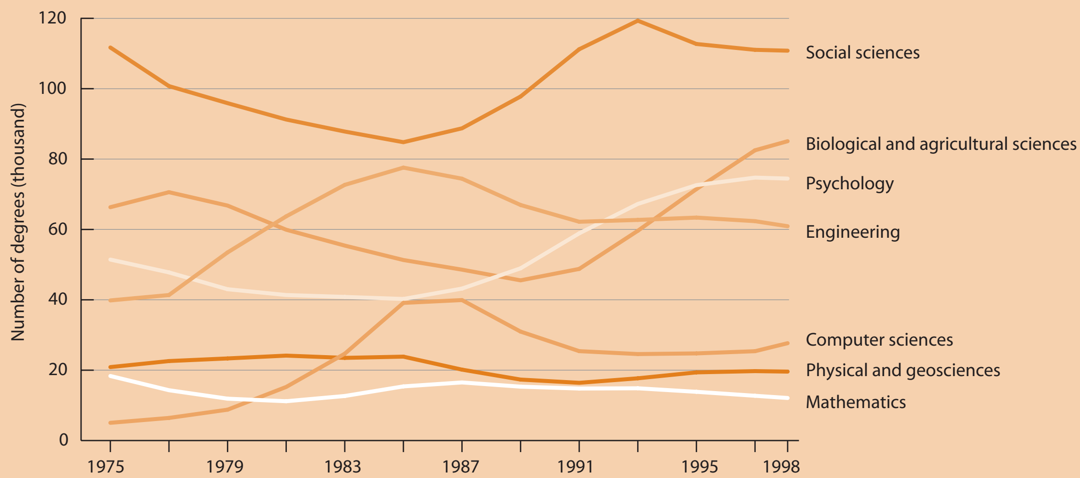
Figure 7
BACHELOR'S DEGREES EARNED IN SELECTED SCIENCE AND ENGINEERING FIELDS IN THE USA, 1975–98



Note: Geosciences include earth, atmospheric and ocean sciences.

Source: MEXT (2002a) *Science and Engineering Indicators – 2002.*

The same six government cabinet departments and independent agencies that accounted for the bulk of total federal R&D funding in 2003 accounted for virtually all federal basic research funding, but in a different order (Table 1, page 28).

HUMAN RESOURCES

The US science and engineering workforce

According to US census results, there were 10.5 million individuals in the US workforce in 2000 who held at least one college degree in a science or engineering field. Of this total, 3.3 million, or approximately 31%, were directly employed in science and engineering occupations. Approximately 74% of those with Bachelor's degrees and 62% with Master's degrees were employed by the private for-profit sector, whereas 48% of those with doctorates were working in the academic sector. Significantly, approximately 67% of the total 10.5 million – more than twice the percentage of those directly engaged in science or engineering pursuits – reported that their responsibilities were closely related to their science or engineering degrees. Fields of employment for degree holders who were not directly engaged in science and engineering typically included administration, management, marketing, sales and pre-college education.

Higher education in science and engineering

Figure 7 illustrates the trends in Bachelor's degrees awarded by US colleges and universities in selected science and engineering fields over a 23-year period.

Although concerns have been voiced for well over a decade now that too few US undergraduate students are choosing to specialize in science or engineering fields, a major crisis in the supply of human resources in these fields has yet to materialize. One possible legitimate ground for these concerns used to be that the college-age cohort in the US population was steadily declining. However, that trend is now expected to reverse, with the number of individuals in the college-age cohort projected to rise from 17.5 million in 1997 to 21.2 million by 2010, resulting in a probable expansion in higher education. The dual challenge is to ensure that the percentage of students who elect to specialize in science and engineering fields remains at least constant and that the education they receive fulfils the employment requirements for at least the first half of the twenty-first century.

In 1998, US students earned 2.2 million degrees at all levels, of which approximately 540 000 were in science or engineering fields. Of the latter, approximately 391 000 were Bachelor's degrees, 94 000 were Master's degrees, and 27 000 were PhDs. Associate degrees from two-year colleges accounted for the remaining 28 000. From 1975 to 1998, the ratio of science and engineering Bachelor's degrees to total Bachelor's degrees held steady at approximately 33%. Degrees in engineering, which were 4.5% of total Bachelor's degrees in 1975, rose to 7.8% of the total in 1985 before declining steadily to 5.1% in 1998. In most tertiary fields of study, the number of degrees fell or remained constant during the 1990s, reflecting a drop across the board in college and university enrolments throughout the decade. The sole exception was the number of Bachelor's degrees in biological and agricultural sciences, which rose steadily during the 1990s (Figure 7).

Foreign students

Students born outside the USA continue to account for a substantial portion of US science and engineering degrees, particularly at the graduate level. Among those in graduate programmes in 1999, Chinese- and Indian-born students accounted for the vast majority, numbering about 33 000 and 23 000 respectively (or about 35% and 25% of the total). In that same year, foreign students earned almost 50% of all PhDs in engineering, mathematics and computer sciences, and approximately 35% of PhDs in the natural sciences.

Although foreign-student enrolment in US universities is still rising, the number of PhDs in natural sciences and engineering awarded by Asian institutions has been growing more rapidly. Asian institutions awarded almost 20 000 PhDs in 1998, on a par with the USA. Moreover, the number has since declined slightly in the USA. In many instances, the quantitative increase in the number of PhDs awarded by Asian institutions has been matched by a concurrent increase in the quality of graduate education in leading Asian universities. As a result, since 1995, a growing number of Chinese, Korean and Taiwanese students have been obtaining their doctoral degrees at universities in their home countries rather than in the USA or other favoured foreign destinations, such as France and the UK.

The visa issue

An additional, disturbing factor that could result in a decline in the number of foreign graduate students in US universities is a direct consequence of the more stringent and protracted procedures required of foreign scholars and students seeking to obtain US entry visas instigated since the terrorist attacks of 11 September 2001. These visa requirements could have a considerable impact on students from countries such as China and India, from which US institutions draw by far their largest foreign contingents. According to the US Department of State, the number of applications for student (F) visas, which peaked at 320 000 in 2001, declined to 257 000 in 2002 and to 236 000 in 2003 (*Science*, 5 March 2004, p. 1 453).

CHANGING TOOLS OF R&D MANAGEMENT

Industrial R&D management and assessment

Although industry in the USA has greatly increased investment in research in recent years, the pressure to utilize these resources to maximum efficiency is immense. Matching research resources to the wide array of opportunities is an ever-present challenge for companies and their R&D management teams. As a result of these pressures, financial constraints and opportunities for technological development, a number of research management and assessment tools have been developed that are widely used today.

There are several types of industrial research, and none of their descriptions inspire unanimity. Perhaps the most straightforward classifications (sometimes referred to as tiers) are basic research; programmes to create core technological competence for the corporation; projects to develop

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products with, or for, corporate business units; and manufacturing process R&D.

A variety of metrics has been developed to measure the performance of a company's process for developing technology. These metrics will be addressed shortly, but let us first look at some of the research management tools.

Technology roadmapping

This is a methodology used for producing a document that identifies alternative technological paths for reaching a specific performance objective for a product or process. The roadmap contains information to permit 'correct' decisions for investing in technologies and to leverage those investments so that system requirements and performance targets can be satisfied within certain time periods. It describes the technologies that need to be developed and provides information required to make trade-offs between alternative technological paths.

There are different types of technology roadmaps. Typically, they address a product or process need. Larger corporations sometimes use an emerging-technology roadmap, which is broader in scope and addresses the company's role in the development of the emerging technology in the context of the company's projected competitive advantage.

Web-enabled innovation

Not surprisingly, the Internet has invaded R&D management and produced tools that have made a substantial contribution to the innovation process. Sometimes referred to as Web-enabled innovation, these tools go beyond merely using the Web to speed up communications and share information more broadly. They also build bridges between scientists and engineers by moving ideas from research to development.

It appears that companies in different industries use Web-based R&D tools differently. The more research-oriented companies, such as those found in the biotechnology and pharmaceutical industries, use Web tools to accelerate research. Their aim is to use common, Web-enabled tools to increase the rate of discovery by sharing knowledge and research tools and resources more effectively. Other companies, such as those involved in high-tech hardware development, use Web tools to drive the development of new products: Web tools assist managers in putting management discipline into the development process, and in developing and implementing technology roadmaps.

Recent trends in assessing industrial R&D

Just doing research is not enough. It must lead to economically profitable results, such as successful new products, or the parent company will be in trouble. For this reason, the industrial R&D community has expended great efforts to develop metrics that are appropriate for assessing various types of R&D. Although the application of these metrics can be proprietary, general methodology is openly discussed within industry technical groups like the Industrial Research Institute.

R&D assessment metrics are both qualitative and quantitative. For example, R&D strategic goals may be judged against how well they match a company's overall strategic objectives and the scope of the technology addressed. On the other hand, the R&D process may be qualitatively described in terms of productivity and timeliness. Quantitative metrics are becoming more widespread. In this case, R&D strategic goals may be measured by counts of innovations, patents and refereed papers. The R&D processes might be measured by counting deliverables, attainment of technical specifications, meeting assigned completion times, time to market, and so on. The point is that reasonable measurables are specified ahead of time for the R&D effort to be judged quantitatively. These measurements in turn lead to the ability to develop useful indices, such as the R&D Effectiveness Index, R&D Innovation Index and R&D Quality Index. The R&D Innovation Index, for example, could be defined as the ratio of revenue generated from products introduced in the past four years divided by total corporate revenues in the same period.

Rethinking R&D management approaches

New R&D management approaches do not always work out as expected, even when initial results seem promising. In the early to mid-1990s, pharmaceutical companies became enamoured of 'combinatorial chemistry' as a more effective way of finding new drugs. This approach used machines to create huge numbers of chemical combinations that were then tested by robots to see which ones reacted promisingly with biological specimens. Drug companies and prestigious editors spoke of a revolution in medicinal chemistry. The CEO of one multinational pharmaceutical company stated that empirical research approaches were out of date. The company then spent US$ 500 million buying a combinatorial chemistry company.

All did not turn out well. Some researchers described the approach as 'garbage in, garbage out'. Others claimed it eliminated chances for serendipity. The *Wall Street Journal*, in its 24 February 2004 front-page story on the topic, quoted Nobel laureate Arvid Carlsson, 'It replaces intellectual creativity with a robot – a highly sophisticated robot, admittedly – but a robot can never have intuition.' The *Journal* cited a study by David Newman of the National Cancer Institute that concluded that combinatorial chemistry through the end of 2002 had failed to create a single drug approved by the Food and Drug Administration (FDA). Of 350 cancer drugs in human trials, only one originated from combinatorial chemistry. There have been changes in methodology that may yet turn this record around, perhaps in combination with old-fashioned laboratory research methods. This is a question for the decade ahead.

R&D assessment and management in government

It is not only industry that wants assurance that its funds for R&D are being wisely spent. Government also wants better management and credible assessment of its R&D investments. This concern by government for R&D assessment is part of a wider interest in government efficiency and effectiveness mandated by the GPRA. It has taken a long time to figure out how government agencies can best measure research results, especially those of basic research.

The NSF has won kudos for its efforts to evaluate its programmes of support for basic research. The NSF has done this by integrating strategic planning, budgeting and performance measurement. The direct products of NSF support of basic research are encapsulated in its strategic goals: people, ideas, tools and organizational excellence. The longer-term results from NSF investments are captured in the foundation's mission statement: 'To promote the progress of science; to advance the national health, prosperity and welfare; to secure the national defence; and for other purposes'.

NSF has prepared annual performance plans and reports in the context of an 'investment model'. Figure 8, taken from the NSF Strategic Plan for 2003–08, portrays this model.

Key to the success of this approach to evaluating basic research is the use of an external expert review panel. The panel members assess programme results and achievement against research goals on a qualitative basis, in principle not unlike 'visiting committees' at industrial, government and academic laboratories. The fact that this type of committee predated GPRA and was deemed useful in earlier NSF programme evaluations has built confidence in the process.

With over 22 000 active awards in the NSF portfolio, the logistical challenge involved in evaluating such a large body of research is formidable. Practical tools were enlisted, such as sampling and the preparation of hundreds of notable research results relevant to the GPRA goal performance indicators. Together with the material developed by the visiting committees for many of the individual programmes, these data provided the external expert review panel with the information it needed to make hard value judgments. A verification and validation contractor provided the external expert review panel with assistance in assuring the integrity of the overall process of producing and sampling data and information.

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Universities and technology development

Passage of the Bayh–Dole Act in 1980 created a uniform patent policy among federal agencies funding research. It also enabled small businesses, non-profit organizations and universities to retain title of intellectual property developed with federal funds. This change in policy resulted in a sea change in university patenting. Patents issued to universities increased from fewer than 250 per year in 1980 to over 2 400 by 1997. There are now more than 200 universities engaged in this kind of technology transfer.

Although credible indicators of success have yet to be unambiguously established, many in the university community perceive university–industry partnerships encouraged by Bayh–Dole to be accelerating the process of knowledge-based innovation. Metrics supporting this view include numbers of patents and licences, licensing revenue and resulting commercial products.

A contrary view is that Bayh–Dole has, perhaps inadvertently, removed some academic research advances from academic laboratories and stalled scientific progress (see, for example, Rai and Eisenberg, *American Scientist*, January–February 2003). This is probably of most concern in the biomedical community, where research tools have been restricted by intellectual-property controls. One commonly cited example is the restrictions on the research uses of the 'OncoMouse' technology (transgenic mice) licensed by Harvard University.

There being strong protagonists on both sides of the issue, it will be interesting to see how this experiment involving intellectual property and academic research plays out in the years ahead.

With growth in academic intellectual property has come the university technology licensing office (TLO). If the university laboratories are the technology developers, the TLOs are the sales staff. One can go to a university TLO website and find a list of available technologies, photographs of eager licensing managers, diagrams of the technology commercialization process and answers to frequently asked questions.

Another policy tool designed to accelerate the flow of government-funded R&D results into the market place is aimed at government laboratories. The Cooperative Research and Development Agreement (CRADA) allows

Figure 8
NATIONAL SCIENCE FOUNDATION INVESTMENT MODEL, USA

What NSF invests	What NSF invests in	What NSF investments produce	What NSF investments lead to
■ Time ■ Money ■ Knowledge and skills ■ Partners' resources	Research, education, equipment and facilities ■ Individuals ■ Institutions ■ Collaborations ■ Fundamental science and engineering ■ Centres ■ Capability enhancement ■ Large facilities ■ Infrastructure and instrumentation ■ FFRDCs ■ Polar tools and logistics	■ People (competitive science and engineering workforce) ■ Ideas (discoveries and new knowledge) ■ Tools (state-of-the-art science and engineering infrastructure) ■ Organizational excellence (capable, responsive NSF)	■ Prosperity ■ Security ■ Health and welfare ■ Environmental quality ■ International leadership ■ Human understanding

Source: National Science Foundation Strategic Plan FY 2003–2008.

federal laboratories to work with industry, universities and other organizations on cooperative R&D projects. One incentive for the non-federal partners is the possibility of using expensive and sometimes unique research facilities.

INTERNATIONAL COOPERATION AND COMPETITION IN R&D

On a global scale, one sees increases in both cooperation and competition in R&D. This holds true for industry as well as for academia and government research installations.

Research alliances

Hundreds of new alliances in technology or research are formed each year by companies in areas such as information technology, biotechnology, automotive technology and advanced materials. Not surprisingly, the majority of such alliances involve companies headquartered in the USA, Western Europe and Japan. It is not uncommon for companies to cooperate closely in technology development in one line of business or in one geographical market, while competing fiercely in another. The common goal is to develop technology-intensive products at minimum cost while preserving market advantage wherever possible.

Cooperation in small science

Just as the rise of the Internet has enabled Web-based R&D in industry, it has also enabled more effective and efficient cooperation in cross-border academic research, especially between individual investigators. The past decade has seen an atrophy of formal, government-to-government research cooperation protocols and an increase in projects between individuals. This increased collaboration is reflected in the scientific literature. One in five scientific papers co-authored by US scientists had at least one non-US author in 1999, compared with one article in ten in 1988.

Cooperation in megascience

Although most research collaboration needs no government involvement, there are exceptions. Megascience projects (predominantly basic scientific research projects involving very expensive central facilities or large, distributed-research programmes spread over many geographic locations) are often too costly for any one country to fund and execute. They need greater involvement by governments and the institutions of organized science (e.g. academies, associations and professional societies). The USA took the lead in establishing the OECD Megascience Forum in 1992 (changed to Global Science Forum in 1999). It has also supported the European-led Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN), where, beginning in 2007, collisions between protons and ions at higher energies than ever before achieved will permit the re-creation of conditions prevailing in the early universe.

Trade in technology

Comparing almost anything of significance between countries is difficult. This is doubly so when it comes to technology and the economic consequences of its applications in the global market place. A great deal of effort has gone into comparing output of high-tech companies in different countries with special attention paid to high-tech exports. Counting of patents has been invoked as an indicator of innovation. Data on the consumption of high-tech products has also been cited as an indicator of the technological intensity of a national economy.

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 payments of royalties and licensing fees. Figure 9 shows the balance of technology trade from 1987 to 1999 for the USA. Although not all of this is 'technology' as usually understood by scientists and engineers, and the majority of the trade takes place between affiliated companies, trade in technology is still a useful concept and figure of merit.

SCIENCE, TECHNOLOGY AND THE US PUBLIC

Attitudes towards science and technology

Periodic surveys commissioned by the NSF for over 20 years indicate strong and consistent public support for scientific research. For example, 81% of the approximately 2 000 respondents to a 2001 survey agreed with the statement

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'Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the Federal Government'; 72% agreed that 'With the application of S&T, work will become more interesting'; and 85% believed that 'Because of S&T, there will be more opportunities for the next generation'. According to data in the 2000 *Science and Engineering Indicators*, the US public's support of science and technology is greater than public support in Europe, Canada and Japan.

Attentiveness

Although the US public is generally supportive of scientific research, only 15% of those who responded to the 2001 survey felt they were well informed about S&T issues, compared with approximately 35% who regarded themselves as poorly informed. Despite these data, the survey indicated that a large fraction of respondents do pay attention to, and form definitive attitudes towards, specific science-related issues. Nearly 80% of those who responded to the 2001 survey believed in the existence of global warming and 53% regarded it as a serious problem. While there is strong positive support for research in general, attitudes towards some specific applications are more problematic. For example, support for genetic engineering appears to be eroding. From 1985 to 1999, most of the respondents whom the NSF survey defined as 'attentive to S&T' agreed that the benefits of genetic engineering outweighed the harmful results. However, the percentage of those who held this opinion dropped from 64% in 1999 to 49% in 2001.

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 remains second only to its confidence in medicine, and is considerably greater than its confidence in other institutions such as education, the press and television, according to the 2001 survey. This has been the case since 1973, when public attitudes were first surveyed. In fact, public confidence in science has risen steadily since 1973, and by 2001 it was trailing only slightly behind public confidence in medicine, which had levelled off during the same period. The only institution that has come close to medicine and science in inspiring public confidence is the US Supreme Court, which has enjoyed a sharp rise in confidence since 1996.

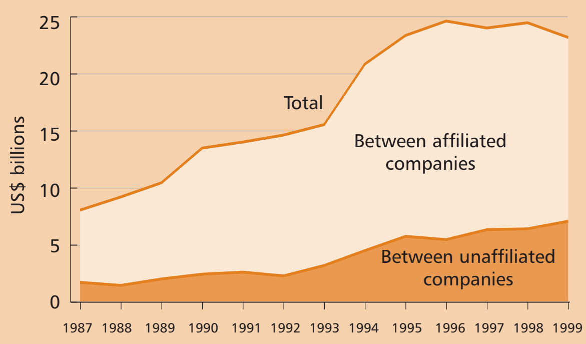
THE FUTURE

If we have learned anything, it is that the future will be different from the past. Concerns about misuse of technology, outsourcing of jobs and the future of the domestic economy are rife among the US public. Confidence in the ability of science to assure economic growth has eroded coincident with the recent economic recession and stock market retreat.

What happened to the tech bubble?

The stock market 'bubble' of the late 1990s in the USA and some other countries is widely believed to have been fuelled by high-flying technology stocks, if not in fact caused by an irrational attraction to those stocks by investors. By late 2003, many of the Silicon Valley entrepreneurial companies were

Figure 9
US TRADE BALANCE OF ROYALTIES AND FEES, 1987–99



Source: MEXT (2002a) *Science and Engineering Indicators – 2002.*

UNITED STATES OF AMERICA

'rebooting', while others were long past any hope of revival. What was the difference between those that made a comeback and those that did not? Many of the Internet and other technology companies that survived and prospered have done so with professional management teams who replaced the 'geeks' (i.e. the technical entrepreneurs) who developed the unique technology on which the companies were founded.

But what about the myriad tech start-ups that were launched by professional managers (or at least financial professionals), despite the fact that the start-up had no technological comparative advantage? Although their business plans may have utilized the Internet or prominently displayed other fashionable technological apparatus, fundamental new technology was missing in very many cases. How many business plans were based on pseudotechnology? Was 'tulip mania' – a reference to the seventeenth-century Dutch speculation in modish tulip bulbs that pushed prices to absurd heights, resulting in a crash in 1637 that wiped out many fortunes – more prevalent among the financial types than among the geeks? The answer may be found in an article published by the *New York Times* on 26 October 2003, which notes that 'most of the young companies that survived the crash – and the start-ups that have arisen since – are based on innovation and are run by people with deep technical skills'.

Technology and jobs

Free trade and globalization have long been viewed as threats to jobs, especially by those individuals employed in manufacturing, whose jobs require limited skills. A new concern that has entered the political arena in the USA is 'offshoring' service jobs to low-cost labour sites outside the USA. Companies that outsource services – including high-skill engineering or scientific tasks – overseas refer to the process as 'harnessing service price deflation'. A mid-2003 research report by Gartner Inc. predicted that at least one out of ten technology jobs in the USA would move overseas by the end of 2004. Offshoring and outsourcing have become election issues in some parts of the country.

Next steps

S&T in the USA continue to underlie the nation's economy, by some measures the most innovative in the world. The best US universities and research institutions remain world leaders. The national policy environment for invention and innovation in the USA is supportive and appears to be effective. The USA has at least its share of the world's best companies.

But times are changing. Just as the twentieth century saw a rise in competition between companies on a global scale, the twenty-first century will evidently see the rise of competition between individuals. This is because, for the first time in history, technology has enabled well-educated professionals in other countries to compete for jobs in the USA without leaving home. This, more than anything else, serves as a wake-up call for improving education in the USA, especially in science and engineering. Since human resources are the most important of all national resources, their enhancement must be a top priority in the years ahead. If this does not happen, the USA will no longer be able to maintain its position of leadership in science, engineering and economic prosperity.

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Industrial Research Institute publications, for example, *Research-Technology Management*, flagship journal of the IRI, offer a wealth of excellent articles on industrial R&D management and assessment, as well as other best practices of industrial R&D.

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Latin America and the Spanish-speaking Caribbean

ANA MARÍA CETTO and HEBE VESSURI

As a consequence of the general trend towards globalization, international scientific activity is currently experiencing unprecedented dynamism and interactivity. Scientific cooperation has expanded and diversified in recent decades, thanks to increasing mobility and the use of new communications channels, the creation of specific mechanisms and instruments, the participation of new actors and a new interest in and concern for problems transcending geopolitical frontiers or requiring expensive facilities. Cooperation has been extended to practically all areas of knowledge and, in one way or another, all countries share in it. The impact of these evolving forms of cooperation on science and scientific affairs can clearly be seen in the way science is organized, its work and its results. To reflect this new dimension, the present chapter focuses specifically on international scientific cooperation in Latin America and the Caribbean.

Latin America has by no means remained a stranger to this process. How is cooperation organized in this region, what are its motivations, how does it operate, what obstacles and challenges does it face? Does it take full advantage of the opportunities, and does it make the most of them for Latin American science? Has this cooperation supported Latin America in its process of integration at the international level? Are all countries of the region involved in this process?

We felt it opportune to table questions like these and to contribute to finding answers to them. To do this, it was necessary to undertake a prior exercise of collecting and systematizing a body of information which, today, is widely dispersed and indeed sometimes not even available. As we know only too well, there is a great wealth of material on scientific collaboration which is never recorded in reports. Similarly, it would be absurd to claim that the present chapter gives a full and faithful account of all that occurs in terms of scientific cooperation in the region. Rather, it is offered as the partial result of a serious, although necessarily limited, attempt which we hope may assist and guide all our readers with a specific interest in the subject. We shall point out from the outset the low level of activity of the Latin American region and the existence of a greater potential for participation, and will indicate those areas which appear to us to represent the principal advantages as well as threats.

As is customary, the term Latin America (or LAC) will be used in this chapter to cover all countries of the subcontinent, including those of the Caribbean; we shall nevertheless try to avoid an overlap with the chapter dealing with the non-Spanish-speaking countries which forms part of the present report.

COOPERATION FOR DEVELOPMENT

It is no coincidence that the subject of international cooperation assumed special importance at the World Conference on Science (Budapest, 1999) organized by UNESCO and the International Council for Science (ICSU), where scientists and society renewed their pledge to confront together the challenges of sustainable development. Today considerable moves are afoot in the area of cooperation for development, which involve defining new strategies with sounder criteria for the selection of programmes and investments in scientific and technical cooperation. Renewing the institutional agreements for these strategies invariably poses the three classic questions: (i) Why? Is it solidly motivated?; (ii) What? Do the programmes make sense? and (iii) How? Is implementation effective?

The answers to these questions put a new complexion on the situation, largely reflecting the growing role of science and technology (S&T) as factors for development in the industrialized and newly industrializing countries, and the perception of this role in those countries, still within the context of the national interest. Nowadays, developing countries – and all countries of Latin America fall into this category in one way or another – are all more or less aware of the need to strengthen their still weak S&T capabilities, and to that end to make use of cooperation as one of the drivers by which to expand further their horizons beyond their national borders. With time, the quest for mere unilateral technical assistance is giving way to a both more complete and more equitable concept of cooperation between parties who, albeit unequal, are entitled to participate fully in defining its modes and parameters. This necessarily implies the development of a national capacity on the part of governments to determine and harmonize action, and the will to work with a wide spectrum of countries and institutions with very different agendas and interests.

Scientific cooperation in Latin America cannot be conceived of as being marginal to, or independent of, the challenges and limitations of development. On the contrary, its vocation is to overcome those challenges and limitations. It is compelled to take account of the need for an effective balance between growth and equity, management and participation, small- and large-scale efforts, immediate concerns and long-term solutions, global programmes and attention to local needs; and to be governed by common sense – by an awareness of what can work, and why and how. When resources are so limited, and when needs are ever increasing, these criteria are particularly important.

For the countries of the North, scientific cooperation with Latin America has in general terms been pursued institutionally within the framework of 'development aid'. Correspondingly, agencies of scientific and technical cooperation and other specific instruments have been set up in most countries since the 1960s. The cumulative experience of these 40 years, the way in which the very concept of development has evolved, the gradual abandonment of the legacies of colonialism and the growing distance between the constituent parts of the so-called Third World compel developed countries to question the relevance of the 'aid' they provide and to revise their cooperation policies, with the aim of increasing their efficiency in terms of the three classic issues mentioned earlier. However, one must not lose sight of the fact that industrialized countries have first and foremost an interest in cooperating with their counterparts. When countries see in S&T a way of positioning themselves in the international marketplace, the traditional spirit of cooperation of the scientist is easily surpassed by the national imperative to compete.

When we speak of international competition, there is an issue of balance of power, both at the level of institutions and of the people involved. Hence, the importance of developing a capacity for cooperative partnership. In any form of collaboration there is an asymmetry which should be recognized; its result is mutually beneficial precisely in those cases where there are shared objectives and both parties give the best they can and receive the best they can, without that necessarily implying equality in the size or nature of their contributions. Clearly, in practice these principles work better in some fields than in others, and in specific instances and circumstances.

In the following pages the concrete experience of Latin America is presented by means of a necessarily brief and schematic summary of the programmes and cooperative actions among countries of the region and with the rest of the world. For reasons of space, this will be based on a selection, arbitrary as all selections are, of examples that may serve to illustrate experiences of cooperation in various fields. Before that, however, we shall provide a number of basic indicators which give a quantitative idea of the overall context in which science and cooperation are progressing in Latin America.

BASIC INDICATORS

Table 1 provides contextual indicators, whereas Table 2 contains figures relating to science, technology and higher education. Most of these data are themselves the product of regional and international cooperation: they were prepared by the Ibero-American Network of Science and Technology Indicators (*Red Iberoamericana de Indicatores de Ciencia y Tecnologìa*, RICYT) based on information supplied by its member countries, in accordance with the regulations of the Organisation for Economic Co-operation and Development (OECD) *Frascati Manual*, adjusted to reflect the characteristics of the Latin American countries.

For comparison purposes, we present the most recent figures generally available. It can thus be seen that considerable differences exist between countries in terms not only of size and population, but also of funding for S&T and the human resources devoted to activities in this area. It should be made clear that in most cases the percentage of investment in

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Table 1
CONTEXTUAL INDICATORS FOR LATIN AMERICA AND THE CARIBBEAN, 2000

	Population	GDP Total	GDP Per capita	
	millions	million US$	US$	HDI[1]
Argentina	35.85	284 204	7 900	0.844
Barbados	0.27	2 155	8 000	0.871
Bolivia	8.20	8 729	1 100	0.653
Brazil	166.11	594 247	3 600	0.757
Chile	14.69	70 019	4 800	0.831
Colombia	42.32	85 243	2 000	0.772
Costa Rica	3.81	11 301[2]	3 000	0.820
Cuba	11.22	27 635	2 500	0.795
Dominican Rep.	8.55	19 723	2 300	0.727
Ecuador	12.64	13 649	1 100	0.732
El Salvador	6.26	13 217	2 100	0.706
Guatemala	11.39	19 332	1 700	0.631
Guyana	0.77[3]	601[3]	800	0.708
Haiti	8.09[2]	4 234[2]	500	0.471
Honduras	6.60	5 831	900	0.638
Jamaica	2.56[2]	7 083[2]	2 800	0.742
Mexico	97.36	574 512	5 900	0.796
Nicaragua	5.07	2 423	500	0.635
Panama	3.00	11 196	3 700	0.787
Paraguay	5.78	7 727	1 300	0.740
Peru	25.94	53 512	2 100	0.747
Trinidad and Tobago	1.29	8 107	6 300	0.805
Uruguay	3.32	20 053	6 000	0.831
Venezuela	24.17	121 263	5 000	0.770
Latin America	**483.06**	**1 944 918**	**3 900**	–
LAC[4]	**505.26**	**1 965 996**	**3 900**	**0.767**
Ibero-America	**542.97**	**2 920 328**	**5 400**	–
Subtotal	**868.08**	**13 689 205**	**15 800**	
Canada	30.77	874 398	28 400	
Portugal	9.99[2]	175 074	17 500	0.880
Spain	39.93	800 837	20 100	0.913
USA	282.13	9 872 900	35 000	0.939
WORLD	**6 054.10**	**31 499 000**	**5 200**	**0.722**

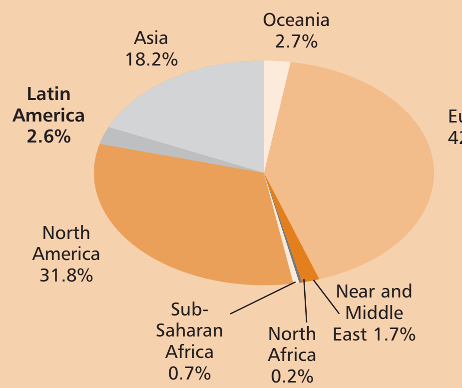
1 Human Development Index.
2 1999.
3 1998.
4 Including non-Latin Caribbean countries.

Source: For population and GDP: RICYT (2002) *El Estado de la Ciencia. Principales Indicadores de Ciencia y Tecnologia Iberoamericanos/ Interamericanos 2002*, Ibero-American Network of Science and Technology Indicators, Buenos Aires; for HDI: UNDP (2004) *Human Development Report 2003*, United Nations Development Programme; for world total: World Bank (2003) *World Development Indicators*.

S&T still fluctuates considerably from year to year, depending on both economic and political circumstances, which naturally affects the stability and development potential of national S&T systems. Overall, however, these indicators highlight the general problem of the serious shortage of resources, both human and financial, going to S&T activities in the region.

Some additional figures may help to situate LAC in the world context (Table 3). Whereas the region represents 8.3% of the world's population and 8.9% of total GDP, it contributes just 3.2% of world expenditure on research and development (R&D); whilst industrialized Asia, with six times the population, contributes 35.0% (OST, 2004). The richest nations each devote between 2% and 3% of their GDP to R&D, whereas the LAC countries typically devote between 0.1% and 1.0% to R&D, averaging 0.6%. Only the non-industrialized nations of Asia (excluding India) and those of sub-Saharan Africa devote a lower percentage to R&D, with the exception of South Africa (0.8%). When the figures for these countries are viewed as a whole, one observes a relatively marked correlation between this percentage and per-capita GDP. The distance between LAC and the group of most developed countries is so great that

Figure 1
LATIN AMERICA'S WORLD SHARE OF SCIENTIFIC PUBLICATIONS, 2001



Source: OST (2004) *Science and Technology Indicators*. Observatoire des sciences et des techniques, Paris.

Table 2
S&T INDICATORS FOR LATIN AMERICA AND THE CARIBBEAN, 2000

	S&T expenditure as % of GDP, 2000		S&T personnel[1] 1999/2000		University	Doctorates,[2] 2000	
	S&T[3]	R&D	Total	Researchers	graduates[2], 2000	Total	Per million population
Argentina	0.50	0.44	52 836	35 015	23 162[4]	–	–
Bolivia	0.54	0.28	1 310	1 050	3 575	8[5]	1.0
Brazil	–	1.05	163 945	77 822	95 455[4]	3 687	22.2
Chile	–	0.56	13 300	6 105	16 012	75	5.1
Colombia	0.36	0.18	9 653	4 987	33 184[4]	–	–
Costa Rica	1.58[4]	0.35[4]	–	–	–	–	–
Cuba	1.05	0.53	64 074	5 378	8 130	175	15.6
Ecuador	0.19	–	–	–	–	–	–
El Salvador	0.84[7]	0.08[7]	–	1 172	4 240	–	–
Guatemala	–	–	–	–	2 344[4]	–	–
Honduras	0.06	0.05	2 167	479	2 349	–	–
Mexico	–	0.40	–	–	86 527	667	6.9
Panama	0.91	0.40	1 676	446	3 456	–	–
Paraguay	1.00[5]	0.08[5]	2 322[5]	543[5]	706	8[5]	1.4
Peru	1.29	0.11	–	–	16 012	1[7]	–
Trinidad and Tobago	–	–	1 732	547	495	9	7.0
Uruguay	–	0.24	3 874	2 513	1 683	19	5.7
Venezuela	–	–	–	4 688	11 367[7]	–	–
LAC	**0.79**	**0.58**	–	**235 495**	**319 435**	**5 017**	**10.2**
Ibero-America	–	**0.69**	–	**385 378**	**372 927**	**10 772**	**21.3**
Canada	–	1.81	140 440[6,4]	90 810[4,6]	35 193[7]	2 320[7]	75.4
Portugal	–	0.77[4]	36 872[4]	28 375[4]	–	534	–
Spain	–	0.94	178 188[4]	116 595[4]	40 342	3 920	98.2
USA	–	2.68	–	1 943 000[4]	317 553	20 005	70.9
Total	–	**2.21**	–	**2 413 544**	**729 604**	**33 488**	**61.7**

1 Individuals (head count).
2 Natural and exact sciences, engineering and technology, medical and agricultural sciences.
3 Including R&D.
4 1999.
5 2001.
6 Full-time equivalent.
7 1998.

Source: RICYT (2002) *El Estado de la Ciencia. Principales Indicadores de Ciencia y Tecnològia Iberoamericanos/ Interamericanos 2002,* Ibero-American Network of Science and Technology Indicators, Buenos Aires.

it reaffirms of itself the need for the region's S&T development, both to build on original, innovative ideas, regardless of formulae generated in and for other contexts, and to take maximum advantage of regional cooperation efforts.

One commonly employed indicator of comparative scientific output is the volume of contributions to specialist publications and periodicals, although it is well known that this is a partial and imperfect indicator because it leaves out other products of scientific activity such as textbooks, monographs, popular introductions, the setting up of laboratories, the registration of patents, etc. In international statistics for 2001, LAC scores a contribution of just 2.6% (Figure 1) of the world total of publications on the basis of articles in mainstream periodicals, i.e. those listed by the Institute for Scientific Information (ISI) (in SCI and COMPUMATH). Although this figure has increased in recent years (it was only 1.4% in 1990 and 1.8% in 1997), it is much lower than that for Asia (18.2%) and almost insignificant compared with those for North America (31.8%) and Europe (42.1%) (OST, 2004).

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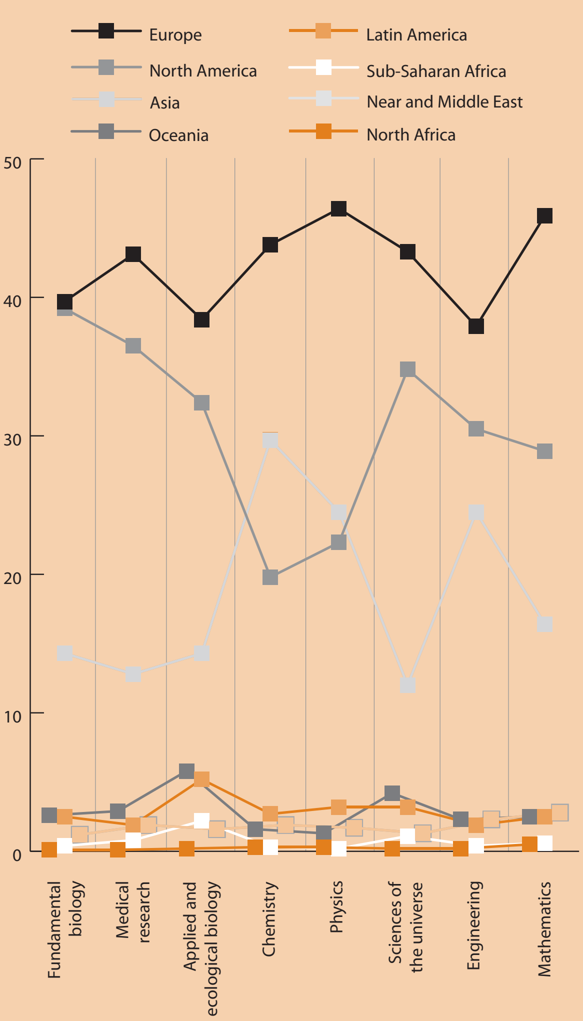
Table 3
LATIN AMERICA'S SHARE OF WORLD GERD, GDP AND POPULATION, 2001
By region

	Population (millions)	World population (%)	World GDP (%)	World GERD (%)
Europe[1]	881	14.5	26.6	27.6
Near/Middle East	225	3.7	2.9	1.1
North Africa	122	2.0	0.9	ns[2]
Sub-Saharan Africa	644	10.6	2.9	0.6
North America	317	5.2	21.2	35.9
Latin America	**505**	**8.3**	**8.9**	**3.2**
Asia	3 386	55.0	35.0	30.1
Oceania	30	0.5	1.5	1.3

1 Includes Russia and Turkey.
2 Not significant.

Sources: OECD, UNESCO, Eurostat and Atlaseco data published in OST (2004) *Science and Technology Indicators*. Observatoire des sciences et des techniques, Paris.

Figure 2
REGIONAL DISTRIBUTION OF PUBLICATIONS BY DISCIPLINE, 2001
As a percentage of world total



Source: Data from Institute for Scientific Information (ISI), Thomson Scientific, Philadelphia, USA; OST (2004) *Science and Technology Indicators*. Observatoire des sciences et des techniques, Paris.

When one analyses the distribution of these publications by scientific discipline, one finds considerable variations, as can be seen in Figure 2. This shows a relative strength of the biological sciences, especially in the applied and ecological fields, and a weakness of engineering and medical research, as measured by their presence in ISI listed journals. When different databases are used, whether multidisciplinary or by subject, the percentages for the contribution of LAC vary, as can be seen in Table 4 and Figure 3, the highest figure being that for agricultural research (6.4% according to the Commonwealth Agricultural Bureau).

The relative contributions from the different countries of the region to these publications are very unequal. Brazil contributes invariably more than 40%, Argentina and Mexico a further 20% each, Chile, Venezuela, Cuba and Colombia less than 8% each, and the remaining countries together an equivalent proportion.

CHARACTERISTICS OF SCIENTIFIC COOPERATION

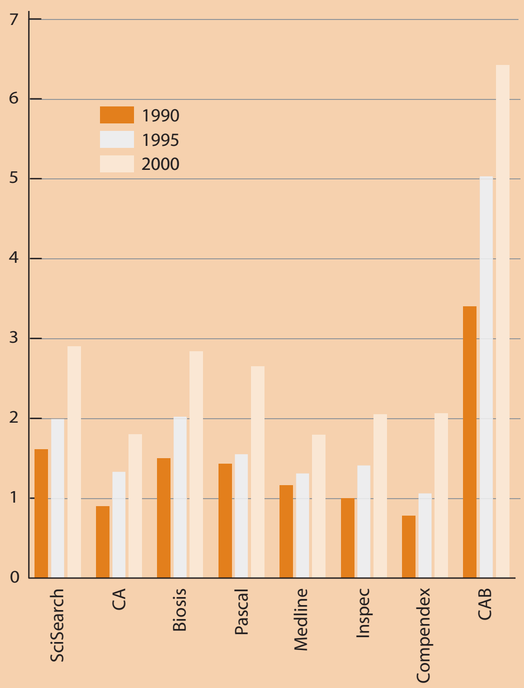
Scientific collaboration is an old phenomenon; an article by more than one author is known to have been published as early as 1678. Collaboration of this kind can take various forms at different levels, from simply giving advice, passing on a piece of information or exchanging ideas, to carrying out a research project. Although collaboration commonly obeys the need for specialized contributions in order to achieve research objectives, there are many other reasons why

Table 4
PUBLICATIONS IN DATABASES, LATIN AMERICA AND THE CARIBBEAN, 2000

	LAC	Ibero-America	World total
SciSearch	28 657	55 661	988 156
CA	13 651	28 277	757 444
Biosis	16 246	30 037	572 218
Pascal	13 555	29 173	511 617
Medline	8 584	19 429	479 731
Inspec	6 882	13 890	335 089
Compendex	4 692	9 810	228 235
CAB	10 431	14 499	162 507

Source: RICYT (2002) *El Estado de la Ciencia. Principales Indicadores de Ciencia y Tecnologia Iberoamericanos/ Interamericanos 2002*, Ibero-American Network of Science and Technology Indicators, Buenos Aires.

Figure 3
LATIN AMERICA'S WORLD SHARE OF SCIENTIFIC PUBLICATIONS, 2001
As a percentage of world total



Source: OST (2004) *Science and Technology Indicators*. Observatoire des sciences et des techniques, Paris.

scientists work with others, whether to acquire new skills or knowledge, to enrich their ideas mutually, to optimize resources, to access expensive laboratories or local data or specimens, to extend the impact or range of influence of their work, or simply to work in a different atmosphere or with colleagues from other parts of the world.

People working together continue to form the basis of scientific cooperation, even when it is organized between institutions or internationally. In the case of LAC, a significant part of this interpersonal collaboration originates in periods spent abroad by scientists for their training, chiefly in institutions in developed countries, and sometimes continues for many years on the same basis. The influence of this phenomenon on the type of science pursued in the countries of the region, the subjects selected, the means of publication, etc., is clear, especially in the most basic areas of physics, mathematics, chemistry and biology.

However, many other initiatives exist which give rise to cooperation. Sometimes these come from scientists in countries of the North who need access to some particular field or resource found in Latin America; in such cases, collaboration often – but not always – ensues with local scientists, typically in disciplines such as geophysics, botany, ecology and geology. In other, perhaps fewer instances it concerns research representing a priority for the countries of the region, generally in agronomy, public health, the environment, water and biodiversity.

There has been an increase of late in the influence of organizations specially created for cooperation, or that have cooperation as part of their brief. Sometimes this influence has resulted in support for or a strengthening of pre-existing forms of collaboration, or has meant a change of direction or even the creation of new areas and patterns of collaboration. Certainly, the earmarking of funds proves to be an important and sometimes determining factor in deciding on cooperation projects.

For the above reasons, information on international cooperation is hard to obtain and often partial, jumbled and patchy, which complicates analysis. The principal materials containing relevant information on cooperation

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in and with LAC, which have also been used in preparing this chapter, are:

- official reports, documents and web pages (of cooperation institutions, organizations and agencies);
- databases on scientific output (in particular, on co-authorship of publications);
- studies and analyses by experts in the subject (normally undertaken with a specific purpose, based on prior information and specially conducted interviews).

Given the multiplicity of levels and actors involved in cooperation, any way of classifying the information is bound in some respect to be arbitrary. Being aware of the problems this can present, we have arranged this exposition under two major headings: cooperation among groups or institutions, and cooperation on an international scale (bilateral and multilateral; international funding agencies).

COOPERATION AMONG GROUPS OR INSTITUTIONS

Laboratories and researchers

The level in question here is that at which research is actually conducted and knowledge produced. In practice, instances of this kind of cooperation take the form of periods spent by researchers, doctoral or post-doctoral students in foreign laboratories, the sending of preliminary results or samples, seminars, symposia and the like, and are carried out in two different ways:

- they are based on treaties or agreements, and are the material outcome of these; sometimes through participation in international institutions or organizations – such as the international agronomy centres of CGIAR or the International Centre for Theoretical Physics in Trieste – or through national or regional initiatives, such as bilateral agreements between national S&T organizations of Ibero-America, or SHIP (the Southern Hemisphere system for postgraduate exchange), or international institutions such as the INCOS and ALFA (Latin America Academic Training) programmes of the European Union (EU), PICS (Scientific International Cooperation Programme), ECOS (Evaluation-Orientation of Scientific Cooperation) in France, CYTED (Ibero-American Programme on Sciences and Technology for Development) in Spain, etc.;
- or they are carried out directly on the initiative of the parties concerned, without reference to wider agreements, although they often give rise to such agreements.

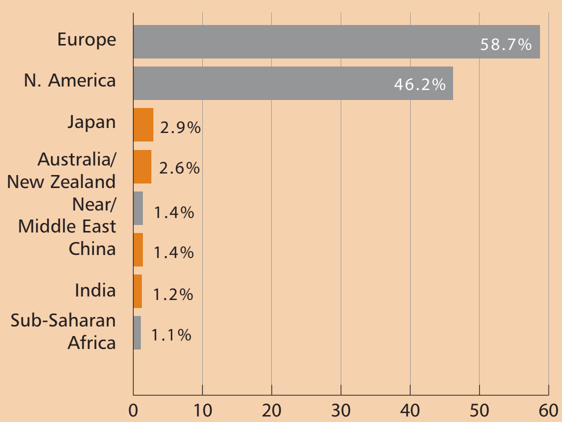
It is generally the case that no systematic record is kept of scientific cooperation and its results, which makes analysis difficult. Some outputs are of a tangible nature and can give an albeit partial idea, while others are intangible and in many cases of great interest and impact beyond the purely scientific. Collaboration is always expected to produce something which could not be achieved by the same parties working individually; however, this value added is often not accounted for, and does not even form part of expressly stated objectives. This is particularly the case with so-called 'spontaneous collaboration', which arises from initiatives taken by co-workers or research groups.

One of the principal tools in use at present as a partial indicator of international cooperation among scientists is bibliometric analysis of co-publications. Although we are aware that the use of international databases has serious limitations, especially where countries of intermediate development are concerned, no alternative data sources yet exist to provide a more representative picture. The databases most commonly used for these studies are, once again, those of ISI, which maintains a complete record of the names and addresses of authors. Consequently, the data recorded refer once again to 'mainstream science', and it should be borne in mind that this does not fully cover all cooperation, especially among Latin American colleagues. It is important to remember that Latin American scientists publish their work to a great extent – hard to gauge but perhaps of the order of 50% – in periodicals not surveyed by ISI, especially in the most applied areas or those more particularly of local interest.

International studies indicate a noteworthy overall increase in collaboration in the recent past: the average number of authors per document increased from 1.83 in 1955 to 3.89 in 1998, as the percentage of documents signed by a single author fell. An analysis of international co-authorship reveals the predominance of the USA, with a recent increase in interaction between two or more continents, outside traditional areas of big science such as space studies and studies of experimental high energy physics. Among European countries, Spain maintains strong relationships with Latin America (except Brazil), its strongest collaborative efforts being with Cuba. A statistical analysis of the figures seems to show that international co-authorship increases the productivity of the countries and authors involved, as well as the visibility and impact of their work (measured by peer review and frequency of citation).

As far as the LAC countries are concerned, the overall figures (excluding the non-Latin countries of the Caribbean) show a relatively low percentage of collaboration: LAC contributes around 6% of collaboration with Europe and North America (in fact this is the region which collaborates the least with scientifically more advanced countries), and only around 1% of collaboration with other countries or regions.

Figure 4
INTERNATIONAL CO-PUBLICATIONS INVOLVING LATIN AMERICAN AUTHORS, 2001
By country and region



Note: These figures take account of the presence of co-authors and do not sum to 100%.

Source: OST (2004) *Science and Technology Indicators*. Observatoire des sciences et des techniques, Paris.

Figure 4 shows marked preferences in the percentage distribution of regions or countries with which Latin American scientists collaborate. Traditionally there has been a clear predominance of Europe and the USA. Interestingly, however, co-authorship with Asian scientists has increased substantially, from ca. 6% reported in 1997 to over 18% in 2001. When data covering co-publication with Europe are broken down by country, the clear predominance of France emerges, followed by the UK, Germany and Spain (Fernández, 2004).

Table 5 shows the number of co-publications undertaken within Latin America, with Europe and with the USA between 1999 and 2002. There is a marked contrast between countries that tend to cooperate more with Europe (Bolivia, Cuba and, to a lesser extent, Argentina, Brazil and Chile) and others preferring to work with the USA (the Central American countries, the Dominican Republic, the non-Latin Caribbean and, to a lesser extent, Peru and Mexico). Only a few countries of the region exhibit a tendency to cooperate among themselves: Uruguay, Cuba and, to a lesser extent, Paraguay.

The distribution of co-publications by subject area reported in the recent past showed a preponderance of physics (due mainly to Chile, Brazil, Argentina and Mexico) and biomedicine (a subject area favoured by Uruguay and Paraguay). On the other hand, only half the countries record any co-publication at all in mathematics. It should be added that most of these co-publications are the work of two authors only, although in physics there are also multi-authored publications, especially in nuclear and particle physics, due mainly to the Brazilian participation in the European network of the European Organization for Nuclear Research (CERN) for more than ten years (Fernández, 2004).

In contrast, an analysis of communications presented at regional meetings (not normally registered in ISI journals) in the field of optics, of which 20% are internationally co-authored, has shown a marked increase in the collaboration among Ibero-American colleagues and a

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Table 5
INTERNATIONAL COLLABORATION WITHIN AND BEYOND LAC, 1999–2002

	International collaboration	Within LAC	With EU	With USA
Argentina	5 391	1 566	3 296	2 304
Barbados	83	14	28	57
Belize	14	2	4	14
Bolivia	245	94	164	99
Brazil	13 110	2 058	6 761	5 813
Chile	3 484	837	2 081	1 625
Colombia	1 337	529	740	679
Costa Rica	500	144	236	289
Cuba	718	558	624	102
Dominican Rep	87	34	27	70
Ecuador	276	121	182	164
El Salvador	29	17	13	19
Guatemala	202	74	66	152
Haiti	44	7	8	39
Honduras	76	38	39	51
Jamaica	236	31	93	135
Mexico	7 392	1 357	3 392	3 632
Nicaragua	82	36	52	46
Panama	321	61	106	220
Paraguay	71	34	44	35
Peru	595	209	254	378
Trinidad & Tobago	189	19	77	70
Uruguay	552	325	343	242
Venezuela	1 461	415	780	655

Source: ISI data, provided by Fernández (2004).

simultaneous decline in collaborations with the rest of the world (Gaggioli, 2001).

Mention should be made of an analysis of the MERCOSUR countries, based on ISI data and the regional database PERIODICA. It can be observed that Paraguayan scientists tend to publish in international co-authorship, but not with their neighbours, while there is a high percentage of co-authorship between Argentina and Brazil that has risen since 1986, when two major collaboration programmes were set up between them, the school of informatics (Escuela de Informática) and CABBIO (see page 59). On the other hand, however, the establishment of the MERCOSUR alliance in 1991 did not appear to have any notable effect on co-publications between the four countries (Narváez *et al.*, 1999).

Cooperation between scientific institutions

The most common mechanisms for cooperation between research bodies, universities or academies of science are of two kinds:

- bilateral cooperation agreements between two research institutions specifying the aims, methods, means and duration of the planned cooperation activities;
- membership of such institutions in permanent coordinating and programming structures such as ICSU, UNESCO, etc., which are examined separately.

Universities

In general, Latin American universities that conduct research and teaching in the sciences have been traditionally linked to the international world. Their scientific capacity can be said to have largely developed with inputs from cooperation, chiefly with countries of the North. In recent decades, universities have in almost all countries organized their cooperation by means of special units, usually coming under the rector's office, which are responsible for preparing and carrying out cooperation policies, for which purpose they link up increasingly with regional and international bodies. The very creation of these offices reflects the growing importance and complexity of international cooperation for universities. Generally the offices have made an effort to forge the necessary links with the foreign ministries and national S&T bodies of their countries so as to coordinate their activities more effectively.

In some cases universities have offices abroad in order to back up their internationalization, one example being the creation of International University Exchange Inc. by the University of Chile.

Elsewhere national bodies have appeared such as the International Colombian Cooperation Agency and the Colombian Cooperation Network, set up to meet the challenge of the internationalization of higher education. Similarly, in Mexico the National Association of Universities and Higher Education Institutions (ANUIES) has taken on responsibility for implementing broad-based international agreements on S&T cooperation.

The growing importance of regulatory responsibility, especially in relation to quality assurance, funding, accreditation, relevance to national goals, equity and access, appears to be a national and regional response to a trend towards more commercially oriented institutional mobility across borders. In the past decade, a new kind of academic mobility has been added to the traditional movement of students and teachers. This new kind of international mobility is being promoted by institutions and other providers, but also by programmes and curricula, in a limited set of countries.

The General Agreements on Trades in Services (GATS) of the World Trade Organization, adopted in 1995, extends international trade into the services area. This largely untested agreement leaves a number of issues outstanding, especially those concerning public services. There are fears, for example, that GATS could unravel government regulations and eliminate public sector jobs in a broad range of service areas, including energy, water distribution, postal delivery and education. This is because GATS entitles foreign companies to compete for service contracts in its member countries. In one notable case, an international consortium was allocated the water distribution sector in Cochabamba, Bolivia, only for riots to break out when many of the poor subsequently discovered that their water bills had skyrocketed.

In education, a general shift from development aid to trade in cross-border higher education could further disadvantage the development of higher education institutions and research activities in developing countries. Currently there is a movement for Latin American universities to support the UNESCO/OECD Guidelines which provide an educational international framework for cross-border education (Knight, 2004; Hugonnier, 2005).

Scientific academies and societies

Recently, national academies of science and their equivalents have stepped up their exchange programmes for researchers and corresponding members, and joint projects with sister institutions in other countries – in particular with the US National Academy of Sciences, the UK Royal Society and other European institutions. Some academies have also done much to promote horizontal cooperation through the establishment of regional or subregional federations, such as the recently formed Caribbean Scientific Union (Comunidad Científica del Caribe).

The Latin American Academy of Sciences (ACAL) was founded in 1982, with support from the Pontifical Academy of Sciences and established in Caracas. To foster the development and integration of LAC, it promotes cooperation between scientific institutions, exchanges of researchers, regional scientific activities, the conduct of science policy studies and the spreading of interest in science and science education for all. It now has 205 members in Argentina, Brazil, Colombia, Costa Rica, Chile, Cuba, Ecuador, Guatemala, Honduras, Mexico, Panama, Peru, Uruguay and Venezuela, in addition to Germany, France and the USA. However, its presence is little felt in the region. Its academicians are recognized researchers, proposed and elected by themselves. ACAL has from the outset been sponsored by the Simón Bolívar Foundation, UNESCO, ICSU and the Third World Academy of Sciences (TWAS, recently renamed the Academy of Sciences of the Developing World).

National scientific societies also conduct a variety of exchanges, traditionally with their counterparts in the countries of the North, though recently much of their effort has gone into regional cooperation through the creation of *ad hoc* networks or their incorporation in existing networks (see below).

In addition, since 2000, the National Academies of Argentina, Bolivia, Brazil, Chile, Colombia, Cuba, Dominican Republic, Guatemala, Mexico, Peru and Venezuela have enjoyed active membership of the Inter-Academy Panel, with a view to strengthening their capacity for participation in science policy issues at national and international levels.

Various networks

The most successful instruments in facilitating multilateral cooperation include networks. Internationally, these have in fact become a mechanism for cooperation backed by

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scientists and their organizations and also by their supporting institutions, thanks to the great benefits to cooperation in return for low initial investment – even if the need for stable permanent financing to ensure the continuity of activities is often overlooked. LAC has seen the emergence of many networks, for example:

- between university institutions such as the Montevideo Group, the Caribbean University Level Programme (CULP), the Union of Latin American Universities (UDUAL: see page 61), the Mexico Central America University Network (ANUIES – National Association of Universities and Higher Education Institutions, Mexico/CSUCA – Confederation of Central American Universities), university networks with European countries, etc., or covering a variety of activities in science;
- special-purpose networks in scientific cooperation: linking scientific societies, mixed networks of societies and governments, and those of researchers, laboratories or research centres, etc.

Among university networks, the following are remarkable for their scientific activities:

The Association of the Montevideo Group of Universities (AUGM), founded in 1991 with the aim, among others, of helping to build up a critical mass of high-level human resources and develop S&T research, including innovation processes and technological adaptation and transfer, in strategic areas. AUGM brings together 12 state and autonomous universities: five in Argentina, five in Brazil, one each in Paraguay and Uruguay, all relatively close to each other, which facilitates exchanges and joint initiatives. Its Escala programme operates through single disciplinary groups in areas of strategic importance for the region, such as materials science and engineering, natural bioactive products and their applications, applied mathematics, molecular virology, fine chemistry, mechanical engineering and production. Recent activities include the first meeting of the Regional Centre for Studies of the Genome, the outcome of an agreement between AUGM and the Max Planck Institute, with headquarters in the National University of La Plata (UNLP). AUGM is in fact a virtual university, with a supportive distribution of resources and highly qualified university staff. Its rapid growth has shown the conditions to be right for regional integration; it has even defined itself as being inherently a process of integration, regardless of what may be achieved in other current processes pursuing the same end.

The Inter-University Centre for Development (CINDA) is an institution comprising major universities in Latin America and Europe, whose basic aim is to link them all together to study the main problems of development. The members of the network are chosen for their high quality and as representing a variety of institutional practices. At present it has 31 member universities in Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Italy, Mexico, Panama, Peru, Spain and Venezuela. Its University Science and Technology programme seeks to help develop the S&T capacity of Latin American universities and its use by government and by institutions of the productive sector, through study, training and advisory projects in such areas as: the S&T development system, the administration of S&T activities, outreach university work, technology management, and higher education and international cooperation.

The Ibero-American University Association for Postgraduate Studies (AUIP) is a non-governmental body concerned with furthering postgraduate and doctoral studies in Ibero-America and financed by its member institutions. It now comprises more than 120 prestigious institutions of higher education in Portugal, Spain and LAC and dispenses in common several thousand postgraduate programmes in almost all fields of knowledge. It provides information and communication services on available postgraduate opportunities, cooperates in internal and external assessment processes and the recognition and harmonization of the curricula offered; it facilitates mobility and exchanges of teachers and students, encourages academic and research work by means of networks of centres of excellence in various fields of knowledge, sponsors academic and scientific events clearly related to the courses provided; and organizes international roving courses on subjects of

The University of São Paulo, Brazil

One example of a university which is outstandingly dynamic in its international cooperation activities is the University of São Paulo (USP), which in addition to its traditional responsibilities plans to take a proactive role in order to increase its visibility on the international scene. For this, it relies on the International Cooperation Commission (CCI), a unit in the rector's office which maintains close contact with the Ministry for Foreign Affairs, embassies of foreign countries, international bodies, etc.

The university's activities reflect the high levels of cooperation fostered with other universities of the region. It participates in the following university networks: CINDA (Inter-University Centre for Development), ALFA (Latin America Academic Training), RECLA (University Network for Continuing Education in Latin America and the Caribbean), FAUBAI (Advisory Faculty of the Brazilian Universities for International Affairs), IAU (International Association of Universities), OUI (Inter-American University Organization), UDUAL (Union of Latin American Universities), AULP (Association of Portuguese-Language Universities), Santos Dumont (Brazilian and French Universities Network at jointly supervised doctoral thesis level), PETE (Partnership for Environmental Technology Education), and ISTEC (Ibero-American Science and Technology Education Consortium).

USP has 20 centres which conduct regional or international programmes in various fields, through agreements between universities or programmes assisted by the National Council for Scientific and Technological Development (CNPq), the São Paulo State Foundation for the Support of Research (FAPESP) or other external sources. It is estimated that some 50% of cooperation is on lines initiated by its teaching staff, not channelled through CCI. Almost all agreements are with universities in the most industrialized countries, reflecting the university's extensive role as a recipient of knowledge (sandwich Doctorates, post-Doctorates abroad, foreign visiting professors, etc.), although USP has more recently emerged as a partner in international research of definite substance. Furthermore, under its Student Programme Agreement it receives a large number of students from abroad, both undergraduate and postgraduate, mainly from LAC and Africa. Countries with which it has the most agreements are Japan (19), followed by France (18), the USA (17) and Italy (15). Given the existence of MERCOSUR, it is worth noting that there are only eight agreements with Argentina, and one each with Uruguay, Paraguay and Chile. In addition to respecting and furthering cooperation initiatives by teachers, CCI coordinates activities in three priority thematic areas: the environment and sustainable development, MERCOSUR and Latin America in general, and countries with Portuguese as their official language.

As the largest Brazilian university, USP recognizes that it has not done all it might have to spread knowledge of its experience, in particular to neighbouring countries. It therefore aims at acting as a university hub between the best world research centres and the least developed regions (even within Brazil), taking advantage of the fact that many of its teachers are familiar with both. It also seeks to increase its participation in government policies with an international component, creating closer links with organizations in the United Nations system, ICSU and other non-governmental organizations (NGOs). In this way it hopes to give Brazil a place in international issues which call for academic study, while steering clear of more pressing interests.

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interest to teachers and directors of postgraduate and doctoral studies.

One recent university initiative has been the creation in 2002 of the Network of Public Macro-universities of Latin America and the Caribbean at the initiative of the National Autonomous University of Mexico (UNAM), the Central University of Venezuela (UCV) and UNESCO's Latin American Institute of Higher Education (IESALC), representing more than 2 million students, 80% of graduate programmes and between 40% and 50% of scientific research in the region. This network aims to promote, fund, develop and assess quality certification criteria, as well as to foster research within the network, as a contribution to the creation of a common research space. It has defined some priority areas, among which are governance, new citizenry and civil society, neuroscience, genomic science, nanotechnology, earth sciences, sustainable development, economic integration and social inequality. Presently the network hub is located at UNAM in Mexico.

The last few decades have seen the emergence of regional or subregional scientific networks of a single disciplinary or multidisciplinary nature designed basically to promote the development of research and postgraduate studies, such as the Latin American Biotechnology and Bioengineering Association (ALABYB), the Latin American Association of Space Geophysics (ALAGE) and many others. For reasons of space, we merely give a brief selection:

The Latin American Network of Biological Sciences (RELAB), formed in 1985, started out in 1975 as a UNDP-financed project. In 1981 it served as a model for the creation by ICSU and UNESCO of international biology networks (IBNs). It now has 15 national, seven regional and two associate members. The national members are countries whose governments appoint a National Committee; regional members are societies bringing together biologists from the main biological science fields; and associate members are the Latin American Centre for Biological Sciences (CLAB) and the Association of Deans and Directors of Biology Schools and Faculties in Ibero-America. From 1975 to 1985 the network financed postgraduate scholarships, training courses, bi- and tri-national projects and numerous activities of National Committees. In its second stage (1985–94) most activities focused on intensive courses, workshops and symposia. In 1991 the RELAB Corporation was further set up to support scientific activities in member countries. Funding is now provided mainly by the countries and the Pan-American Health Organization (PAHO), supplemented by contributions from international organizations such as UNESCO and ICSU. In 2001, in view of the magnitude and variety of tasks, RELAB decided to set up coordinated facilities for the following additional themes: the perception of biology by society; the media and education; scholarships; internships; meetings and courses; relations with PAHO; bio-informatics; genomics and proteomics; and biodiversity and biotechnology.

The ICSU decision in 1993 to merge its two bodies IBN and COSTED (Committee for Science and Technology in Developing Countries) gave rise to the creation of regional networks in other basic science disciplines, along the lines of RELAB; and ICSU and UNESCO gave assistance for the creation of the Coordinating Committee of Latin American Science Networks (CCRCLA), which also served as the COSTED Regional Secretariat. These networks, whose activities chiefly concern the training of high-level scientists and the consolidation of research, with special attention to relatively less developed countries, have been recognized as an effective model of regional cooperation and as sources of advice for international organizations. However, as with other similar initiatives, they are constantly faced with the challenges of maintaining active contact with their associates and securing steady funding for their activities. In addition to RELAB, this set of networks includes the:

- Latin American Physics Network (RELAFI), set up in 1996 as part of the joint action taken by the Latin American Physics Centre (CLAF: see below) and the Latin American Federation of Physics Societies (FELASOFI). The latter comprises 18 societies with 8 000 members, and forms part of the Ibero-American

Union, of which the Spanish Royal Physics Society and the Portuguese Physics Society are also members;

- Mathematical Union of Latin America and the Caribbean (UMALCA), comprising the nine mathematical societies of Argentina, Brazil, Chile, Colombia, Cuba, Mexico, Peru, Uruguay and Venezuela, and representatives of Bolivia, Ecuador and Costa Rica;
- Latin American Chemical Science Network (RELACQ), with members from 12 countries: Argentina, Bolivia, Brazil, Chile, Colombia, Cuba, Mexico, Panama, Paraguay, Peru, Uruguay and Venezuela, through the intermediary of National Chemical Societies, with the exception of Paraguay and Uruguay, represented by the chemical science unit in the sole university institution in each country;
- Latin America Network of Astronomy (RELAA), covering the countries of the region in which astronomy exists as a professional activity. It has approximately 550 members, distributed by country as follows: Argentina (150), Brazil (200), Chile (25), Mexico (150), Uruguay (10) and Venezuela (15).

In 2002, ICSU decided to dissolve COSTED/IBN and replace it with regional ICSU offices in each of Africa, Asia, the Arab states, and Latin America and the Caribbean. ICSU reasoned that regional offices would allow it to interact more closely with the scientific community in these countries than previously. It is planned to locate the new ICSU Office for Latin America in Mexico.

Through its Regional Office in Montevideo, UNESCO has also recently assisted in the creation of several regional or subregional networks of educational institutions and research centres, mainly to coordinate and strengthen postgraduate programmes in various scientific disciplines, for example: RED-CienciA (R&D and Postgraduate Programmes Network in Central America, 1998), CARISCIENCE (R&D and Postgraduate Programmes Network in the Caribbean, 1999) and GEOLAC (Latin America and the Caribbean Network of Faculties/ Departments of Geosciences, 2001). These innovations are intended to strengthen and make better use of each institution's scientific and educational resources with a view to furthering the sustainable and equitable development of the region's smallest countries.

Noteworthy in another connection is the Interciencia Association (AI), a federation of organizations for the advancement of science, founded in 1974 on the initiative of the American Association for the Advancement of Science (AAAS) to promote scientific cooperation and public awareness of the value of science in the American hemisphere. AI now has member associations in Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Ecuador, Jamaica, Mexico, Panama, Peru, Puerto Rico, Trinidad and Tobago, Uruguay, USA and Venezuela. It has its executive secretariat in Panama City, and publishes in Caracas the prestigious journal *Interciencia,* devoted to scientific topics linked to development. In order to avoid overlapping, AI frequently collaborates with other bodies in promoting S&T, in particular with the Organization of American States (OAS) offices, the US National Science Foundation, the Inter-American Development Bank (IADB) and CYTED.

There are also networks directly linked with research groups to conduct joint activities in the form of projects in which groups complement their capacities and share the tasks. Particularly in Europe and the USA, such networks help to transform ways of producing knowledge by encouraging the acquisition of new methods, access to more sophisticated instruments, inter- and transdisciplinarity and the tackling of more wide-ranging objectives. One example in Latin America seen as a success story is CABBIO (see box).

A more recent example, in a different context, is the FLACAM Network (Latin American Forum of Environmental Sciences), founded in 1988 to develop scientific and training links between non-governmental organizations (NGOs) of the Southern Cone. FLACAM members now include a number of universities, research centres and foundations. Its headquarters are in La Plata, Argentina, and it has members in Argentina, Bolivia, Brazil, Chile,

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CABBIO

CABBIO, the Argentine-Brazilian Biotechnological Centre, which dates from 1985, is a coordinating body combining official and private working groups in Argentina and Brazil involved in special production-related projects, financed equally by both governments. It is a subregional integration programme in biotechnology that has helped to consolidate national activities in support of both long-standing and recent groups.

One of its most important tasks concerns banks of microbial families and micro-organisms, which collect and preserve the existing biodiversity of the region. Despite its importance, CABBIO has suffered a period of relative stagnation, due at least in part to resistance from the markets to genetically modified products, which many of its projects seek to develop.

Fifty doctoral theses and 150 technology training exchanges were part of the outcome of projects up to 1999. In the same period CABBIO's teaching activities consisted of 133 further training courses attended by 1 850 graduates. Since 1993, graduates from Uruguay and Paraguay have also been attending and graduates from the Latin American Biotechnology Network (RELABIO-UNDP) have been able to enrol. CABBIO courses are recognized for doctoral programmes in most of the region's universities.

CABBIO participates in the specialized meetings of RELAB-UNDP (Latin American Network of Biological Sciences), RELABIO-UNDP, ICGEB (International Centre for Genetic Engineering and Biotechnology), WIPO (World Intellectual Property Organization), the Cooperative Programme for Technological, Agro-alimentarial and Agroindustrial Development of South America (PROCISUR), MERCOSUR and BIOLATINA.

Colombia, Cuba, Italy, Mexico, Paraguay, Peru, Spain, Uruguay and Venezuela. FLACAM's objectives are:

- training researchers for activities in specific projects on the ground;
- carrying out applied research projects for sustainable development;
- promoting the creation of a critical mass of human resources for environmental training and management in Latin America.

Since 1990 it has been running a Master's degree course in sustainable development, open to students from the region, and in 1994 the UNESCO Chair in Sustainable Development was set up in association with this network.

Information networks

The importance of telecommunications and information infrastructures was recognized at the 1994 Summit of the Americas held in Miami, when governments urged the main institutions to acquire access to networks of this kind. In 1992, OAS had approved the creation of the Inter-University Hemispheric Scientific and Technological Information Network (RedHUCyT), and provided it with funding as seed capital. The main aim of RedHUCyT is to link up Member States' institutions to the Internet for S&T information exchange. OAS also supports, among others, the following regional S&T information systems:

- LAC-INFOCyT Scientific and Technological Information System;
- Ibero-American Network of Science and Technology Indicators (RICYT);
- Ibero-American Information System for Periodical Publications (LATINDEX);
- Latin American Chemical Science Network (RELAQ);
- Multinational Specialized Information System in

Biotechnology and Food Technology for Latin America and the Caribbean (SIMBIOSIS);
- Regional Network for Information on Agricultural Research in the Southern Cone;
- Inter-American Metrology System (SIM);
- Pan-American Standards Commission (COPANT).

In particular, RICYT was set up by CYTED (see below) in late 1994. From its inception, RICYT has conducted its activities in coordination with OAS. This cooperation strategy was strengthened when the Network became responsible for carrying out the Regional Science and Technology Indicators project financed by the Inter-American Council for Integral Development (CIDI). RICYT's general objective is to promote the development of instruments for the measurement and analysis of S&T in Ibero-America with the aim of gaining in-depth knowledge of science and its uses as a policy instrument in decision-making, taking into account:

- the incorporation of the region in international systems of science, technology and innovation indicators;
- analysis of the specific problems of the region, in areas such as bibliography, bibliometry, the institutional organization of S&T statistics and the training of specialists in indicators and other subjects; and
- the creation of a Latin American norm for specific aspects of S&T activities in the region.

In its activities for the training of human resources, RICYT works with the UNESCO Chair on Science and Technology Indicators.

Also outstanding among the regional activities in the information field is LATINDEX, an automated scientific periodical information system for LAC, Portugal and Spain. The system was set up in 1995 to disseminate, provide access to and raise the quality of the journals produced in the region, and it is the outcome of cooperation with a network of regional clearing houses which operate in a coordinated manner with shared resources, seeking to:

- pool efforts in the various participating regions and countries regarding the production, dissemination, systematization and use of scientific information;
- reinforce and upgrade science publishing in the LAC region;
- increase the international visibility and coverage of such publications;
- use the information processed as a basis for by-products; and
- influence national and international circles in regard to scientific information, documentation and publication.

The first of its products, the online Latindex Directory, contains basic information on more than 13 000 scientific or academic journals. Present members of the system are institutions in Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, Mexico, Nicaragua, Peru, Portugal, Puerto Rico, Spain, Uruguay and Venezuela.

In a more recent initiative, Brazil's successful Scientific Electronic Library Online, SciELO, has been extended to Chile, Cuba and Spain; it has also given rise to SciELO Public Health, which stocks scientific articles from a growing number of Ibero-American countries. Another online library has been developed under the name of Red AlyC to cover articles from journals in all disciplines of the social sciences. Combined, these efforts are contributing to a greater international presence and utilization of the scientific literature produced in the region.

Emigrant networks

Emigrant networks have been set up to do something about the brain drain of qualified scientists, seen as a loss to countries and the region as a whole. Given the importance of this issue, it has to be recalled at some length, although unfortunately there is no precise information indicating the extent of the phenomenon and how best to tackle it.

As already noted, many young students (and also technicians and professionals) of Latin American origin enrol in universities abroad to round off their scientific education. Many are sent on scholarships from their own countries or institutions, others hold scholarships from foreign institutions, and still others take employment in the host country which enables them to complete their training. For many of the developed countries, attracting

Qualified migrants: a present and future challenge

At its meeting in Antigua, Guatemala, in October 2001, the Latin American Union of Universities (UDUAL) discussed at length the problem of brain drain and produced a declaration on the following lines:

In developed countries the demand for specialized professionals has led to the adoption of policies and programmes designed to attract highly qualified migrants. The present global context confronts Latin American societies with profound challenges and dilemmas, since their economic development will depend to a great extent on their own scientific and technological progress. The intensification of academic and professional links in an international context of inequality is partly responsible for the fact that the accumulation of knowledge and the creation of a 'critical mass' in science does not produce the benefits originally hoped for by the Latin American countries.

The available statistics show that qualified migrants tend to remain in the countries in which they specialize. Influential factors are not only the differences in working conditions and levels of entry of qualified professionals but also the political instability and economic crisis in most countries of Latin America. The economic losses represented by the non-return of highly qualified professionals are borne by the countries of origin. Thus the price paid by Latin America for 'exporting' talent is usually underestimated, which makes it urgent to devise and apply alternative policies. UDUAL therefore proposes steps to:

- Establish government policies designed to recover highly qualified professionals by means of programmes promoting either their return or renewed links with them, which programmes should receive technical and financial support from international organizations.
- Improve the quality of employment in Latin America with respect to both salaries and working conditions, thereby encouraging the retention and/or recovery of highly qualified professionals.
- Promote cooperation agreements between Latin American countries and countries receiving qualified migrants, in order to make the latter active agents of scientific, technological and human development in their countries of origin.
- Intensify links between Latin American universities for the purpose of joining forces to create wider and more diversified critical masses of qualified professionals who will stimulate scientific and technological development in their countries in parallel with the development of knowledge in the social sciences, humanities and arts.
- Create and consolidate postgraduate programmes of excellence to be jointly conducted by Latin American universities so as to enable their students and teachers to complete their training in their own academic setting.

UDUAL likewise resolved to set up a committee to collect and analyse information for the sake of determining the best possible policies to counter the phenomenon.

qualified personnel has become a central policy objective, which includes the active recruitment and retention of foreign students. The USA, in particular, officially hails as a success the fact that almost 50% of foreign students who graduated in science and engineering in 1990/91 were still living in the USA five years later. Statistics provided by the National Science Foundation itself show, for example, that 13% of the foreigners working in R&D in the USA in 1999 came from Latin America (37 400 of whom were Mexicans, 25 700 Cubans, 16 600 Jamaicans, 15 800 Colombians and 12 500 Argentines (NSF, 2001). Graduates remaining in the USA after completing their studies thus contribute their talents to its workforce. More generally, over one-third of the scientists and engineers in Silicon Valley are of foreign origin, and a high proportion of the scientists working in the USA who are awarded Nobel Prizes were born elsewhere. For some LAC countries, this migration means that a greater percentage of their economically active population of professionals contribute to the workforce in the USA than back home (during the 1990s this was the case for Bolivia, Chile, Guyana, Jamaica, Panama, Paraguay, Trinidad and Tobago and Venezuela; see Pellegrino (2001)).

Several national S&T bodies in the region have introduced specific measures to address the problem of the emigration of scientists. The greatest difficulty seems to be to prevent emigration itself, since this would require a substantial improvement in working conditions for scientists in their own countries to lessen the lure of the countries of the North. Since trying to recover emigrant scientists is expensive and not that effective, some bodies have preferred to re-establish and maintain contact with them from a distance. This is intended to assist a brain gain policy, where the aim is to draw on the intellectual capacity of expatriate researchers without hoping to bring them home. Recently, the development of communications and transport has produced a great variety of migration patterns also being utilized in the LAC countries for temporary exchanges of specialists and a means of partially offsetting the losses due to emigration. Since, however, qualified workers are beginning to be seen as a rare commodity worldwide, it is to be expected that the developed world will come up with even greater incentives for scientists from elsewhere. This makes it all the more urgent to create better conditions so as to retain scientists in the LAC countries.

Out of 41 knowledge exchange networks comprising expatriates from 30 countries, according to 1999 data, seven are Latin American and based in Argentina, Colombia, El Salvador, Peru, Uruguay and Venezuela (Pellegrino, 2001). The Caldas Network was officially set up in November 1991 by Colciencias as one of the first initiatives for drawing together the LAC 'scientific diaspora'. Within this network a start was made on establishing a new status for emigrant Colombian scientists as focal points in creating and strengthening international links for the benefit of science in Colombia. Its activities include a start on forming denser networks to take in research projects between groups of researchers in Colombia and Colombian researchers abroad (e.g. the BIO-2000 project and the Automation Project), who have provided each project with access to the network built up by them in their countries of residence. However, once projects reach an initial stage of consolidation, in a typical network dynamic, they go underground and out of sight for the initial network; and this may have happened also with the Caldas Network. Relations continue solely between the individuals and institutions involved. In other words, at a given time each project creates its own independent network of relations, making it difficult to gauge and examine its coverage.

COOPERATION AT THE COUNTRY LEVEL

Bilateral and multilateral intergovernmental agreements

Bilateral agreements in LAC are usually expressed through cooperation agreements between national S&T bodies. The basic duties of these bodies are to organize international mobility programmes, either through grants or the transfer of researchers. They also draw up bilateral agreements with countries in other regions, multilateral agreements as in the case of bodies set up at a regional level such as the EU, MERCOSUR, NAFTA (North American Free Trade Agreement), OAS, CAN (Andean Community of Nations) and the Andrés Bello Convention, and agreements within the framework of international institutions such as UNESCO, ICSU and TWAS. Over the last few years, the international cooperating offices of the national S&T bodies have significantly extended their activities and regularly manage a portfolio of several

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hundreds or even thousands of cooperation conventions or agreements with foreign or international organizations and institutions. Noteworthy efforts have recently been made to draw up cooperation agreements geared towards technological modernization, involving both research and development teams and businesses in industrialized countries.

Postgraduate education and research training remain an important element of North–South cooperation. In several LAC countries, this modality is favoured by the institutions themselves, which require young researchers to gain experience in a prestigious foreign institution (of 'excellence') before taking them on. Over the last decades, the presence of Latin American students has substantially increased (including from those countries offering postgraduate training of international repute) in Northern universities, particularly in the USA, as mentioned previously. In 1995, 91 358 Latin American students enrolled abroad, a substantially lower figure than that for Asian students (IIE, 1996), but nonetheless significant as compared to the total number of graduate students enrolled in the region itself.

Cooperation with the USA

US international scientific cooperation is an activity that involves various agencies in response to the variety of opportunities arising throughout the world in science and engineering. The National Science Foundation (NSF) is notable for the international component of its research, postgraduate education, postdoctoral positions, and to a lesser extent, pre-university and university education programmes. Most of its international activities revolve around 'field' sciences, both bilateral and multilateral. With regard to LAC, such activities include for instance astronomical observatories, such as the Inter-American Observatory of Cerro Tololo in Chile or the Ushuaia site in Argentina; the Inter-American Institute for Global Change Research (IAI) and the Organization for Tropical Studies (OTS) in Costa Rica; the global network of seismographs, which includes Mexico; and the Brazilian and Colombian sites of the Long-Term Ecological Research (LTER) group. Furthermore, all the US centres that are supported by NSF are open to scientists and students from other countries. In the area of high-energy physics, in particular, there has been a long-standing collaboration of research groups in Latin America with Fermilab in Chicago, promoted by its Director Emeritus, the Nobel Laureate Leon Lederman.

Since 1973 the AAAS has conducted a programme promoting cooperation with LAC, structured around three priority areas: bringing new actors into the LAC scientific world, promoting cooperation and scientific ability in LAC, and introducing interdisciplinary solutions to development problems in the region. In recent years, the programme has organized scientific conferences and symposia, as well as interdisciplinary sessions during its annual meeting focusing on topics such as ethnobotany and bioprospecting during the new millennium, and international scientific funding and cooperation in LAC. The AAAS has also been cooperating with the Interciencia Association since its foundation.

Philanthropic foundations have historically been part and parcel of the means by which the foreign policy interests of the USA were advanced. The Ford Foundation, Rockefeller, Kellogg and Carnegie Corporation programmes have been linked to the development of distinct areas of S&T knowledge in Latin America. Similarly, agencies such as the National Institutes of Health (NIH) and National Aeronautics and Space Administration (NASA) maintain cooperation programmes with various LAC countries and have Latin American employees.

Cooperation with Canada

Notable in its efforts to foster cooperation with Latin America is the Canadian International Development Research Center (IDRC) which, since its creation in 1970, has fostered and supported research on problems facing developing countries through the funding of university researchers, governments, commercial firms and non-profit organizations. Recently, its support for national policy research has increased both at its headquarters and its regional centre in Montevideo. In the fields of environment and natural resource management, it has programmes for the sustainable use of biodiversity and natural resource management in LAC (MINGA); the other major fields are information and communication technologies and social and economic equity. Over the last three years, more than 25 research projects and activities have received support from the Pan-Global Networking Programme introduced by IDRC.

Cooperation with Spain and other European countries

By any reckoning, Spain is the European country that has been most involved in cooperation with Latin America in recent years, with the support of various programmes, through the Spanish Agency for International Cooperation (AECI). The AECI yearly offers grants for Latin American graduates to undertake PhD courses and research in Spain, various Latin American countries and Portugal, through the Becas Mutis Programme. For example, between 1991 and 1997, over 9 000 grants were awarded, the main recipients of which were Mexico, Argentina and Cuba. The MEC-MAE (Ministry of Education-Ministry of Foreign Affairs) Programme for Scientific Cooperation with Latin America aims to promote joint activities in the framework of scientific research projects by Spanish and Latin American technicians and scientists, as well as knowledge transfer through postgraduate course provision.

The abovementioned Ibero-American Programme on Sciences and Technologies for Development (CYTED), set up in 1984 through a framework agreement concluded by 19 countries, stands out for its scale and importance. Since 1995, CYTED has been officially included in the Latin American Summit Cooperation Programmes as an invaluable tool for integration. By 2001 it had generated 76 thematic networks, 95 research projects and 166 innovation projects involving over 10 000 Latin American scientists and technologists; moreover, it participates in other initiatives to offset resource expenditure. The thematic areas currently encompassing the 19 subprogrammes are: Support for Science and Technology Policies, Environment, Energy Resources, Information and Communication Technologies, Health and Food Technology and Materials Technology.

The other European industrialized countries each have permanent cooperation programmes for development, usually conducted by offices dependent on the ministry of foreign affairs. A significant part of such cooperation – which for instance exceeds 30% in the case of Sweden – is channelled through international or multilateral organizations such as the United Nations agencies, the World Bank Group and regional development banks; moreover, in several European countries, development cooperation is focused primarily on Africa and South Asia, then on LAC. In contrast, purely scientific cooperation with developing countries is generally subject to bilateral agreements concluded with national S&T bodies to facilitate academic exchange, further closer links among research groups and support the training of leading scientists. As regards scientific cooperation with LAC, areas of major interest for European countries are natural resources, tropical agriculture, health, and to a lesser extent mathematical, physical and engineering sciences; priority areas are clearly reflected in the portfolio of LAC countries appearing as partners in these cooperation agreements.

Although the traditional donor–recipient pattern still prevails in the field of development cooperation, in the specific field of bilateral academic cooperation between Europe and LAC this pattern has been largely replaced by the concept of horizontal cooperation among peers or colleagues who jointly define their objectives and share their knowledge, for their mutual benefit. Those directly involved in this kind of cooperation have, to some extent, managed to transmit this new vision to official development cooperation circles.

Cooperation with the EU

EU cooperation policy with LAC endeavours to reconcile Europe's contribution to socio-economic development in the region with European scientific and economic interests. The pursuit of this policy has helped European scientists to gain access to sites with environmental, agricultural, ecological and other characteristics of particular relevance to research. Areas of cooperation have been chosen

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following extensive dialogue with LAC scientific authorities; thus, agriculture and agro-industry, health, the environment, and information technologies were defined as priority areas. Nevertheless, in order to make the most of the available human potential, research has also been supported in other fields such as materials and earth sciences and certain engineering sciences.

During the 1990–94 period, two complementary schemes operated: Sciences and Technologies for Development (STDIII) and International Scientific Cooperation (ISC), the latter geared towards building lasting relationships between EU and LAC scientists. A scheme combining these ideas was introduced in 1994–98, the INCO–DEV Programme for Scientific and Technological Cooperation with Developing Countries, focusing mainly on three sectors: sustainable management of renewable natural resources, sustainable improvement of agricultural and agro-industrial production, and health. By 1998, 900 activities involving 2 780 institutional partners had received support, with a European contribution of approximately € 200 million. (By the same date, 17 000 multinational projects, most of them intra-European, had been financed, including approximately 85 000 partnerships among groups or laboratories). This Programme has fostered the development of Euro-Latin American research networks involving at least one LAC and two European countries; over 200 Latin American organizations have participated in these networks although 95% are coordinated by European researchers. Cooperation was most intensive with Brazil, followed by Argentina and Mexico and, to a lesser extent, Colombia and Chile; the European countries involved were predominantly the UK, France, Spain and Germany. Since 1999, for a four-year period, the INCO-DEV component of the fifth EU Framework Programme has been supporting problem-oriented research, while maintaining the regional and thematic approach of the previous programme, combined with a section on research into sustainable development policies.

Furthermore, the ALFA Programme for cooperation between the EU and LAC in the area of higher education offers the opportunity for multilateral academic interaction between the two regions. One of its basic dimensions is academic mobility, the aim being to promote the highest possible level of knowledge, discourage the brain drain, generate a critical mass, stimulate bilateral research interests – regional or bi-regional – help to focus scarce resources, and develop infrastructure. Another of ALFA's fundamental objectives is to form networks, based on the requirement for at least three Latin American and three European institutions to team up. This objective is linked to the purpose of promoting the international dimension and improving the quality of education. A third component of the programme is continuing education, aimed at maintaining the highest possible levels of abilities in the workforce. During the second phase of the ALFA+ Programme, between 2000 and 2005, the EU made a contribution of € 42 million. A new component of postdoctoral and higher education grants, ALFA+ involves an increase in programme funding.

Agreements among the countries of the region

After the 'lost decade' of the 1980s, there was a reactivation of integration processes. As a result of this new impetus, the current integration map of LAC is quite different from that of a few years ago. In 2000 there were four common markets, ten free trade treaties, with others under negotiation, and many additional agreements (including 65 partial agreements). This change has led some to call the 1990s the 'decade of Latin American and Caribbean integration'. The pragmatic and realistic way in which the integration process has evolved has led to the creation of subregional and bilateral, rather than multilateral, agreements, for the sake of more flexible and functional mechanisms. But attempts at intra-regional integration have in practice come up against persistent weaknesses and obstacles connected with development problems and political and financial instability, so the prevalent trend is still that countries join the dominant economic and financial system separately. The world is globalizing and Latin America is not even getting itself together.

Despite their few integrative outcomes, the holding of the Ibero-American Summits, annually since 1991, must be regarded as an improvement. Although the recent summits have revolved around free trade, sustainable development and democracy, S&T has not been entirely excluded from the agenda. Noteworthy here is the first regional meeting of ministers responsible for S&T, held in Cartagena, Colombia, in 1996 and attended by 30 countries of the hemisphere (including the USA), with the cooperation of the IADB and OAS. The Cartagena Declaration is regarded as a milestone in the history of the region, as strategic guidance and as a common framework for lines of action. The resultant Plan of Action outlines three basic strategies: strengthening of existing cooperation activities and creation of new joint programmes, establishment of new funding mechanisms, and introduction of a coordination and monitoring mechanism. Governmental action in the field of cooperation is now guided largely by the Cartagena documents.

Various cooperation programmes in the region have contributed to the development of its S&T infrastructure; in addition to those already mentioned, they include the programmes conducted by IADB, OAS, the United Nations Industrial Development Organization (UNIDO), the Latin American Commission for Science and Technology (COLCYT), the Caribbean Council for Science and Technology (CCST), the international agricultural research and development system (which is coordinated by CGIAR), regional and sub-regional systems like IICA (Inter-American Institute for Cooperation on Agriculture) and the agricultural research cooperation programmes (PROCIs). New programmes have been launched more recently, including the Common Market of Scientific and Technical Knowledge (MERCOCYT), the above-mentioned Inter-American Institute for Global Change Research, the International Research Institute for Climate Prediction (IRI), the GLOBE Programme and others in the field of sustainable development.

In this context, one should also mention the Commission for the Scientific and Technological Development of Central America and Panama (CTCAP), an intergovernmental organization with headquarters in Tegucigalpa created to coordinate the subregion's S&T policy in harmony with each member country's socio-economic policies and programmes. Since its inception in 1976, it has played a decisive part in strengthening the S&T infrastructure in the countries of the region, which has resulted in a series of legal documents, programmes and projects that contribute to its development.

At present, the strategic areas and policy lines of the OAS Inter-American Science and Technology Programme (PRICYT) are logically based on the Cartagena Declaration and the Plan of Action adopted in March 1996. They take into account the Strategic Plan for Partnership for Development 1997–2001 of the Inter-American Council for Integral Development (CIDI) and mandates given by the OAS General Assembly and Summits of the Americas, together with experience gained in the region in formulating and implementing S&T policies and the contribution of the MERCOCYT Programme. The three major thematic areas regarded as crucial to the region's development under PRICYT are science, technology and innovation to promote social development, strengthen the entrepreneurial sector and promote sustainable development and the preservation of a healthy environment.

Member States' voluntary contributions to the projects are used to fund activities; in particular, the consequence of this is access to funds insofar as they are associated with multinational projects. The Inter-American Commission on Science and Technology (COMCYT) is in charge of carrying out programme actions and of evaluating their results.

The Organization of Ibero-American States for Education, Science and Culture (OEI), previously the Ibero-American Bureau of Education, was set up as an intergovernmental organization to promote cooperation among Ibero-American countries in the fields of education, science, technology and culture in the context of all-round development. Its headquarters are in Madrid and it has regional offices in Argentina, Colombia, El Salvador, Mexico and Peru and a technical office in Chile. The OEI's funding comes from Member States' assessments and voluntary contributions and from any contributions by institutions, foundations and other bodies to

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The Latin American Centre for Physics

The Latin American Centre for Physics (CLAF) was founded in 1962 further to a UNESCO resolution; the constituent assembly of CLAF was held in Buenos Aires in 1966. Its headquarters are at the Brazilian Center for Research in Physics (CBPF) in Rio de Janeiro and a subsidiary office has been operating in Mexico City for the Mexico, Central America and Caribbean region since 1993.

CLAF is funded by member states, of which there are now 13. The largest cash contribution comes from Brazil, which also contributes with headquarters maintenance, the payment of staff salaries and 25 PhD and post-PhD fellowships. Argentina grants two fellowships and Mexico contributes the same amount to the subsidiary office as to CLAF.

CLAF maintains substantial relations with international organizations. UNESCO has cooperated in the holding of meetings in Havana of potential users of the Microtron accelerator located there. ICTP cooperation has encouraged physics research in the relatively less developed countries, and a cooperative PhD programme has been in place with the universities of the region since 1999. In 1998, an agreement was signed with the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, and two Latin American students went to do their PhD studies there. At the beginning of 2001, an agreement was also signed with CERN in Geneva to hold a joint school of high-energy physics in Latin America every two years. An agreement was signed recently with the Academy of Sciences of Bolivia and the University of La Paz to confer international status on the Chacaltaya Observatory, with the provision of international funds.

CLAF systematically supports schools and conferences on the most varied topics, totalling 40 in 2000: 13 in Brazil, 8 in Argentina, 4 in Mexico, 4 in Chile, 3 in Colombia, 2 in Bolivia, 2 in Costa Rica and 1 each in Cuba, Peru, Uruguay and Venezuela. CLAF's limited resources have meant that meetings were largely dependent on other sources. The human resources training programme has become the most substantial one conducted by CLAF. As a whole, the percentages for the various research areas are as follows: 22% particles, fields and cosmology; 19% materials science; 16% optics; 14% condensed matter; 16% statistical physics; 6% nuclear physics; 6% astrophysics; and 3% atomic physics.

specific projects. Its Science, Technology, Society and Innovation Programme (CTS+I) involves two complementary approaches, one emphasizing S&T linkages with society, and the other giving special attention to the educational aspects of S&T. OEI's most recent initiatives include the encouragement of CTS+I chairs and the creation in 2001 of an electronic journal also called CTS+I.

Cooperation with and among international organizations

International organizations involved in science differ significantly in terms of their objectives and nature; some are United Nations agencies, others are based on intergovernmental agreements, and others still are NGOs. Such bodies do not generally conduct research themselves but, in their field of competence, promote or support international research projects, or recommend priorities to governments or to other international organizations. Most of the United Nations agencies (e.g. the World Health Organization (WHO), the Food and Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA)) have specific mandates – such as raising levels of nutrition and living standards, increasing agricultural productivity, or promoting the peaceful application of nuclear technology – and carry out a range of technical cooperation activities aimed at fulfilling those mandates. The paragraphs that follow refer briefly only to agencies most directly involved in scientific cooperation activities, and more specifically those of relevance to LAC.

The United Nations University (UNU) has been functioning since 1975 as an autonomous body under the auspices of the United Nations and UNESCO, with 13 research and training centres and programmes, the thematic foci of which are peace, governance, development science, technology and society, and environment and sustainable development. One of its specialized programmes, the Programme for Biotechnology in Latin America and the Caribbean (BIOLAC), founded with the backing of the Venezuelan government in 1988 and based in Caracas, is being reoriented in the present biennium to focus on three strategic areas through specific projects: Biosafety working guidelines for LAC, Bioethics studies in the LAC context, and the Bioinformatics network for LAC. With regard to human resources training, BIOLAC offers fellowships for research and training periods abroad in bioethics and biosafety.

Although there has usually been some Latin American participation in the various UNU programmes, mostly through training courses, it is considered that adding a few strategic partners in the region would considerably reinforce cooperation ties and give the University's activities a more integrated focus. In this respect, UNU is paying attention to new project initiatives that may originate in countries of the region.

UNESCO undertakes a great many activities in LAC, mostly in the important fields of environment and sustainable development, and basic sciences and engineering. These activities often form part of major international programmes in which UNESCO works with other organizations (see below), seeking to coordinate efforts and create synergies to make better use of resources. This strategy has practically become a necessity given the financial limitations facing the Organization. UNESCO implements other, more *ad hoc* activities in the fields of science policy; women in S&T (a regional Chair has recently been established in this subject, based in the Latin American Faculty of Social Sciences (FLACSO) in Argentina); and transdisciplinary themes (such as the project Educating for a Sustainable Future).

UNESCO's presence in the region is increased through the activities of its Regional Office for Science and Technology for Latin America and the Caribbean (ROSTLAC), based in Montevideo. In the basic sciences, support has been given to undergraduate and postgraduate university programmes and to the establishment of scientific networks such as those mentioned above. In the earth sciences, the Organization has supported human resources training, research projects under the International Geological Correlation Programme (IGCP), and training and assistance in emergency situations caused by natural disasters. In the ecological sciences, UNESCO has strengthened the programme on Man and the Biosphere (MAB) through the Latin American Network of Biosphere Reserves (IberoMAB), the establishment of MAB Committees and support for their activities. It also encourages the conservation of biodiversity and sustainable development through the participation of local communities, academic institutions and governments, and supports human resources training in the ecological sciences. In the water sciences (International Hydrological Programme), it has contributed recently to the Latin America and Caribbean Hydrological Cycle and Water Resources Activities Observation and Information System (LACHYSIS), the Water Centre for the Humid Tropics of Latin America and the Caribbean (CATHALAC) in Panama, and the hydrological data electronic network for LAC. In the marine sciences, it took part in the Major UNESCO Inter-regional Project on Research and Training Leading to the Integrated Management of Coastal Systems (COMAR project); it coordinates the BioPlata project, intended to establish an information and consultation system on biodiversity in the Río de la Plata, the coast and coastal lagoons, and also supports the ECOPLATA Project – Integrated Management and Sustainable Development of the Uruguayan Coast of the Río de la Plata. Through an agreement with the University of Puerto Rico and the Caribbean

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Pierre Auger Observatory Project

The Pierre Auger Observatory Project is an international effort to study the high-energy cosmic rays that collide with the Earth's atmosphere. There is as yet no satisfactory explanation for the origin of these rays, and the world scientific community hopes that the project will contribute to solving this mystery, thus providing a better understanding of the universe and perhaps of its beginning.

Two giant detector arrays, each covering 3 000 square kilometres, one in the southern hemisphere (Pampa Amarilla, Mendoza Province, Argentina) and the other in the northern hemisphere (Millard County, Utah, USA) will measure the arrival direction, energy, and composition of the air showers produced by high-energy cosmic rays (above 10^{19} eV) on colliding with the atmosphere; this will be made possible by the 1 600 particle detectors and three atmospheric fluorescence detectors in each of the Observatories.

The Auger Project was designed in a series of workshops in Paris (1992), Adelaide (1993), Tokyo (1993) and, lastly, Fermilab (1995). It includes more than 200 scientists from over 55 institutions in 19 countries: Argentina, Armenia, Australia, Bolivia, Brazil, China, Czech Republic, France, Germany, Greece, Italy, Japan, Mexico, Poland, Russian Federation, Slovenia, the UK, the USA and Viet Nam. With the backing of the respective governments, construction work has begun on the site in Argentina, and at a later stage work will begin on the US site. Although construction of the first observatory, budgeted at around US$ 50 million, will be completed in 2005, some preliminary observations of cosmic showers have already been recorded. The groups in Latin America taking part in the Project belong to the following institutions:

- Argentina: TANDAR Department of Physics, National University of La Plata, National University of Cuyo, National Technological University, University of Buenos Aires, Bariloche Atomic Centre, National Space Activities Commission, Institute of Astronomy and Space Physics (IAFE), Argentine Institute of Radioastronomy, Regional Centre for Scientific and Technological Research;
- Bolivia: University of San Andrés (Universidad Mayor de San Andrés);
- Brazil: State University of Campinas, Federal University of Rio de Janeiro, Cosmology and High-Energy Experimental Physics Laboratory-CBPF, University of São Paulo;
- Mexico: IPN Research and Advanced Studies Centre (CINVESTAV), National Autonomous University of Mexico (UNAM), Autonomous University of Puebla and University of San Nicolás de Hidalgo in Michoacán.

At present, the above institutions are taking part in the construction of the Observatory, mainly through:

(1) the design, optimization and installation of the particle detectors;

(2) the design of some components of the fluorescence detectors' optical system;

(3) the design of data-handling software. There are also various theoretical groups whose participation will be evident once data are recorded by the Observatory.

Development Bank, it supports the Coast and Beach Stability in the Eastern Caribbean (COSALC) project, which involves 11 countries and territories whose economies are largely dependent on their coasts: Anguilla, Antigua and Barbuda, Dominica, Grenada, the British Virgin Islands, the US Virgin Islands, Montserrat, St Lucia, St Kitts and Nevis, St Vincent and the Grenadines, and Trinidad and Tobago. It also supports activities in the region organized by the Intergovernmental Oceanographic Commission (IOC).

The multilateral organizations that are not part of the United Nations system also have highly varied objectives. Some are research centres proper, purpose-built for high-cost programmes that are beyond the capacities of any one country. Here, more than in any other aspect, is perhaps where differences can be seen in the region's participation as compared with other regions of the world. It is difficult for countries in the region to gain access to megascience, that is, projects requiring hugely expensive facilities concentrated in one place, such as high-energy laboratories, large telescopes and radio telescopes, observation satellites, and so on, except where geography dictates the location of equipment in one of them, as in the case of the astronomical observatories (see *World Science Report* 1998). In this context, the Geneva-based European Organization for Nuclear Research European Laboratory for Particle Physics (CERN), a major centre for particle physics research, warrants special mention. Founded in 1954, it currently has 20 member states, all of them European; however, some 6 500 scientists from 500 universities and of more than 80 nationalities go to CERN's laboratories to conduct research, and they include a good share of the particle physicists working in LAC. Since 1990 CERN has signed cooperation agreements with Brazil, Chile, Argentina, Peru, Colombia, Mexico and Ecuador.

When research takes place in a more 'deconcentrated' way, in laboratories scattered across different contexts, opportunities open up for high-quality research groups in the region that can thus gain access to better equipment, literature and (at least in theory) manage to take part eventually in exploiting solutions to cutting-edge problems that may also prove to be highly relevant. An example of this kind was the Brazilian experience in the Organization of Nucleotide Sequencing and Analysis (ONSA), a virtual network on genomics with more than 50 Brazilian laboratories, through a project whose main goal was to create a network of laboratories in the State of São Paulo to sequence the complete genome of the bacteria *Xylella fastidiosa*, the pathogen causing a disease damaging 34% of Brazil's orange crop (São Paulo State is one of the largest orange-producing regions in the world, with almost 30% of the world production of orange juice). Foreign scientific cooperation was sought for defining crucial issues such as, for example, the choice of the organism to be mapped, and for discussing eventual promising directions to be followed in research, but the programme, the network and the cooperation mechanisms (as well as the funding) were basically defined by the country itself. The sequencing of the bacteria was finalized in January 2000, almost four months ahead of schedule. This was the first time scientists had ever mapped the structure of the genome of a plant pathogen. The key to its success, it has been argued, would be in the way the complex actors' integration was managed.

Other large-scale international programmes are also 'deconcentrated', such as those dealing with the study of climate change, oceanography, meteorology and so on. These programmes are often coordinated by a national committee, which is in turn in contact with a general secretariat; intergovernmental programmes such as the above-mentioned IOC and IGCP operate in this way.

Prominent in the non-governmental sphere are the programmes under the auspices of the International Council for Science (ICSU), founded in 1931 to promote international scientific activity. With a membership of 98 national scientific members (academies and S&T national organizations), 26 international scientific union members and 28 scientific associates, ICSU can draw on a wide spectrum of scientific expertise to address major international, interdisciplinary issues. Furthermore, it acts as a focus for the exchange of ideas and information and the development of standards in science, organizes and participates in major international conferences and fosters the creation of networks with similar objectives. From time to time, and in conjunction with other organizations, it promotes the creation of major international programmes, such as the World Climate Research

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Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), the International Programme of Biodiversity Science DIVERSITAS, and the Global Terrestrial, Ocean and Climate Observing Systems.

LAC takes part in ICSU through national members in 11 countries – Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Jamaica, Mexico, Uruguay and Venezuela – and through the voluntary participation of scientists from the region in various international bodies and programmes. Nevertheless, the limited active participation of LAC scientists and, in general, those of developing countries in these forums means that the issues surrounding science in these countries are not sufficiently understood and heeded. This has prompted ICSU's decision to set up regional offices, as mentioned above, one of which will operate in Latin America. Some international unions also have regional committees, such as the International Brain Research Organization (IBRO), or committees for developing countries, such as the International Union of Geodesy and Geophysics (IUGG) and the International Union of Pure and Applied Physics (IUPAP). In other cases, there are national associations (as in the case of physiological sciences, and the history of science) or regional networks and federations (such as the Federation of Latin American Immunological Societies) associated with international unions. Most of the unions provide small subsidies to help organize scientific meetings in LAC and pay for visits by young researchers, and travel costs for researchers from leading laboratories. Other unions or programmes carry out specific projects on local themes (in meteorology, geography, geology, etc.), usually with the participation of local scientists.

With regard to international scientific programmes, it must be noted that a Latin American presence in them is often impeded not only by a lack of support for individual participation by scientists, for whom such responsibilities come on top of their already heavy workload, but also by the lack of local material and organizational infrastructure required for such programmes. To take just one example, there are no data centres in the region linked to the World Data Centres System.

The International Centre for Theoretical Physics (ICTP), based in Trieste, Italy, has been a key institution for scientific cooperation with developing countries. It was founded in 1964 by Abdus Salam, a Nobel Prize-winning theoretical physicist of Pakistani origin, and functions under the auspices of UNESCO and the International Atomic Energy Agency (IAEA), with the Italian government as its main source of funding. It supports developing countries through four programmes: affiliated centres, networks, visiting researchers and scientific meetings. The programmes and networks supported by ICTP in LAC are considered particularly successful, thanks to the long-standing collaboration between educational institutions in the region. In the past fifteen years, ICTP has given partial financial support to more than 400 meetings organized in LAC. Furthermore, ICTP has programmes for donating books and laboratory equipment which it has extended since 1986 to the fields of biology and chemistry with backing from TWAS. Other centres in Trieste that provide support for science in developing countries in various fields are the International Centre for Genetic Engineering and Biotechnology (ICGEB) and the International Centre for Science and High Technology (ICS).

TWAS is an autonomous organization founded in 1983 in Trieste, also under the leadership of Abdus Salam. Its objectives include recognizing and supporting excellence in science being carried out in developing countries, and facilitating contacts among scientists in those countries, and between them and the rest of the world. Of its 661 members elected up to 2003, 23% are from LAC, distributed as follows: Argentina (20), Bolivia (1), Brazil (58), Chile (17), Colombia (5), Costa Rica (1), Cuba (6), Ecuador (1), Guatemala (2), Jamaica (2), Mexico (23), Peru (4), Trinidad and Tobago (2), Uruguay (1) and Venezuela (9).

The Academy carries out various programmes to support developing countries, and has also played a key role in creating the Third World Network of Scientific

Organizations (TWNSO) and the Third World Organization for Women in Science (TWOWS), both of which have an important level of Latin American participation. Thanks to an agreement between TWAS and the Brazilian Academy of Sciences, a TWAS regional office for Latin America and the Caribbean has recently been established.

The International Foundation for Science (IFS), based in Sweden, was set up in 1972 to support developing countries in their capacity to carry out research in the fields of use, management and conservation of natural resources. The organization has become important in the region through its financial backing, together with a scrupulous selection and follow-up of grantees after the grant has finished. Timely support for young researchers at the start of their scientific careers in their own countries is a factor that tends to curb the loss of this scientific talent. IFS policy has favoured Latin America through the award of a high proportion of grants to young researchers in the region (30% of the total of over 3 000), including its most advanced countries, such as Argentina and Mexico. National organizations from the following countries are members of IFS: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guyana, Haiti, Jamaica, Mexico, Panama, Peru, Uruguay and Venezuela, in addition to the Caribbean Academy of Sciences, the Caribbean Agricultural Research and Development Institute, and the Tropical Agronomic Research and Training Centre. A good many Latin American scientists work with IFS as consultants, members of its committees and members of its Board of Trustees. The most common area of study in LAC is that of animal husbandry (animal disease and nutrition).

The Interacademy Panel (IAP) is a global network of the world's science academies, launched in 1993. Its primary goal is to help member academies work together to advise citizens and public officials on the scientific aspects of critical global issues. IAP is particularly interested in assisting young and small academies to achieve these goals. IAP has a membership of 92 scientific academies from around the world, including 11 from LAC.

International financial institutions

By virtue of its scope, the World Bank has considerable influence on the main thrust of higher education, S&T and changes in infrastructure. In the past decade, the World Bank's efforts to promote S&T have been stepped up; however, they have been geared more towards supporting specific programmes in certain sectors, such as agriculture and health, and have been defined more from a global perspective than in terms of the interests of the countries themselves. The World Bank is currently looking into the possibility of supporting new areas of S&T in developing countries and of offering new forms of support for regional S&T programmes. Over and above the specific characteristics of each country, the common trend is to encourage private sector funding and implementation of R&D, which entails reducing the role of state institutions, the declared intention being to raise quality and equity in higher education, increase and strengthen S&T human resources and create the necessary support services to enhance the effectiveness of public and private investments in S&T.

Similarly, the IADB has had a significant influence on the way people in Latin American countries think about S&T funding. Since 1968, it has been operating with an explicit S&T policy that was geared initially to S&T capacity-building in public universities and research centres, through investment in fellowships and infrastructure. Around 1980, the IADB moved towards promoting private sector demand and linkages between knowledge producers and users and technologies. It was during this second stage that the peer review system was introduced as effective practice for the establishment of the distinctive quality standards of the world of science. During the past decade, the IADB has shifted towards funds for technological development, tenders for the non-reimbursable funding of research projects and services in S&T, human resources training, the strengthening of infrastructure, the diffusion of technology, information and dissemination activities and the study and coordination of policies for national innovation systems. These elements are a clear indication of the way in which agreements between the

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IADB and the national S&T bodies have been adjusting over the years to changing demands. Table 6 gives an idea of the size of the effort in recent years, implying an important proportion of funding disbursed for S&T activities.

SOME FINAL REMARKS

One of the constraints that cooperation systematically faces is finance, particularly with regard to the possibility of making independent decisions on programme definition. A great deal of cooperation funding seems to come from loans, such as those provided by the World Bank, the IADB and other bodies which, while allowing some room for manoeuvre for establishing contacts and linkages in disciplinary or thematic networks with other national, regional or international groups, impose on the other hand the conditions under which such activities can be undertaken and lead to debt being incurred, with a cumulative effect known to all. Unfortunately, no reliable data and figures are available on the subject. Several questions therefore remain open, for consideration in other studies. For example, how much is being earmarked for S&T cooperation in the Latin American region? How (un)stable are budgets allocated for such cooperation? To what extent does external funding provide benefits or entail inconvenient restrictions? Do agreements and statements of intent remain a dead letter for lack of financial resources, or for lack of political interest? It would seem that some of these questions are relevant since the amounts committed from states' contributions to regional activities have not kept pace with inflation during the last few decades. Generally speaking, even the contributions made by the most developed countries of the region to this type of supranational activity are not higher than the amounts granted within those same countries as subsidies to individual research groups. In LAC, international cooperation generally still does not systematically form part of national S&T programmes.

Attempts have recently been made to set up a regional fund to finance S&T cooperation, in particular the initiative concerning the Ibero-American Fund for Scientific and Technological Integration (FIICYT), which the Ibero-American Summit, at the request of Chile, submitted to the IADB for funding in 1998. A new initiative in the region, PROSUL, came into being at the end of 2001 as a result of a proposal submitted by Brazil in August 2000 at the meeting of the Presidents of South America in the context

Table 6
IDB FUNDING OF S&T IN LATIN AMERICA
Selected countries

	Project description	Year	Amount million US$	% of disbursement for S&T
Argentina	Technological modernization, 2nd S&T programme	1999	140.00	14.60
Brazil	FINEP II	1995	160.00	97.60
Chile	Technological innovation	2000	100.00	16.20
Colombia	3rd S&T programme	1995	100.00	89.10
Ecuador	S&T programme	1995	24.00	99.70
Guatemala	Technological development programme	1999	10.70	0.00
Mexico	S&T programme	1993	116.18	86.20
Nicaragua	Technological innovation support	2001	6.79	0.00
Panama	Support to competitive production sectors	1998	14.20	55.40
Panama	Implementation support for S&T and innovation	2000	3.30	19.00
Uruguay	Technological development	2000	30.00	2.50
Venezuela	2nd stage S&T programme	1999	100.00	15.10

Source: IADB, *Annual Reports*. Inter-American Development Bank, Washington, DC.

of the establishment of an integrated South American body for science, technology and innovation, outlined in the Budget Law under the title Development of Joint Science and Technology Projects between Brazil and the Countries of South America. The programme seeks to step up cooperative efforts in S&T, to organize links between multilateral organizations and the cooperation projects supported and to provide the South American S&T system with an instrument for the formulation of a specific regional strategy in this field.

The international scientific scene currently offers a highly complex picture and the situation of the Latin American region still appears to be both economically and politically unstable, which weakens its bargaining power. In a hardening climate between North and South owing to the emergence of too many causes of friction, the difficult negotiations over the growing debt, the painful economic adjustments demanded by the International Monetary Fund (IMF), pressure in relation to licences and intellectual property rights problems in general, the application of free trade agreements, protection from foreign investments, efforts to control drug trafficking, the proliferation of weapons, including nuclear arms, and terrorism all play a part in encouraging the developed countries to redefine the significance and scope of their cooperation, if not to adopt an attitude of withdrawal and reluctance towards cooperation with developing countries, including those of Latin America.

Under the new conditions, traditional scientific communities are being sidelined both by commercially oriented multilateral organizations, which prefer to avoid scientists and seek profitable partners and business relations with local businesses, and by international organizations seeking involvement in causes such as poverty alleviation, the defence of the rights of minorities and social empowerment. It has become clear that the United Nations system is not prepared to lead in the mobilization of S&T for sustainable development; not the World Bank, nor the regional development banks, nor the bilateral agencies, nor private foundations will take up this role in the near future. In its own interests, LAC must tackle this void by taking the political decision to mobilize S&T for its development.

New forms of international cooperation in Latin America will probably emerge in areas and sectors where there is real interdependence, as well as institutions, programmes and activities that could provide solutions and interest all the parties involved. To organize cooperation on real foundations, an adequate, stable and reliable mechanism must be set up. The task for Latin American countries that wish to take part in this new type of cooperation is to establish and guarantee the quality and competence of the various institutions and groups that are to become the local base for international exchanges. In view of the gaps between the developed and the Latin American countries, in terms of both wealth and skills, these links will take a very long time to become truly symmetrical as regards resources and the transfer of knowledge, but they must at least be as symmetrical as possible in terms of the effort invested by each party in identifying the other's needs, situation and prospects. This problem is especially acute for the smallest or the least advanced countries in the field of S&T. The strengthening of ties among the countries of the region so that they can reinforce each other and progress in an integrated manner is indispensable if LAC wishes to begin to compete as a force to be reckoned with on the international scene.

As was noted *inter alia* at the Meeting of Ministers Responsible for Science and Technology in Havana in 1999, there is untapped potential in LAC for the horizontal transfer of knowledge and technologies under mutually advantageous conditions, and for the creation of alliances between the productive sector and research groups in various countries to develop endogenous technologies for production under socially and environmentally sustainable conditions. It is also important to make an effort to regionalize and internationalize the universities and coordinate them so that their curricula can be strengthened and made to respond to the region's real needs, and facilitate the exchange of scientists and mobility of graduate students for a better use of the region's resources. It is also necessary

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to exchange criteria and points of view on national legislation on science, technology and innovation and to strengthen consultation and coordination in order to work out joint positions for Latin American countries in international forums and meetings to enable them to defend common points of view and prevent decisions from being taken which would widen even further the S&T gap between them and the more developed countries. The solidarity component of integration processes must be strengthened to take advantage of the opportunities afforded by globalization, which should be regarded not as a kind of uniformity or subordination but from the perspective of sharing benefits without eliminating differences, of preserving endogenous features while enriching the universal dimension.

This chapter was prepared in 2001 and has been partially updated.

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The CARICOM countries

ISHENKUMBA A. KAHWA and HAROLD RAMKISSOON

The Caribbean region is an archipelago of small and relatively young island nations in the Caribbean Sea combined with a few neighbouring countries on the contiguous coast of Latin America. The island nations range from a size of 103 square kilometres (Montserrat) to 10 000 square kilometres (Jamaica).

The countries of the Caribbean are largely English speaking, with the exception of Dutch-speaking Suriname, French-speaking Haiti and Spanish-speaking Cuba and the Dominican Republic (see chapter on Latin America for coverage of the two latter countries). This chapter deals only with the members of the Caribbean Common Market (CARICOM) (see box on page 79 and Table 1).

The English-speaking island nations have developed strong cultural, economic and educational links through institutionalized mechanisms. For example, the University of the West Indies (UWI), founded in 1948, is pivotal to tertiary education for many of these island nations, whereas CARICOM – not to mention the game of cricket – provides the 'glue' that binds the Caribbean people together.

Caribbean nations do however have diverse natural resources, economic policies and political strategies which have produced a considerable variety of economic, educational, industrial and cultural achievements.

NEW TRENDS IN HIGHER EDUCATION

Besides the UWI, which has three main campuses (one each in Barbados, Jamaica and Trinidad), there are the University of Guyana with two campuses, the University of Technology (Jamaica) and the University of Suriname, which are publicly funded. The Northern Caribbean University (Jamaica) is private (Table 2). There are other major publicly funded tertiary institutions important to science and technology (S&T), such as the Sir Arthur Lewis Community College (St Lucia), College of the Bahamas, Barbados Community College, College of Science, Technology and Applied Arts (Trinidad and Tobago), College of Agriculture, Science and Education (Jamaica), Belize College of Agriculture, and Central American Health Science University (Belize Medical College). These institutions allow S&T students to complete the junior portions of first degree programmes in their own countries at a relatively low cost and in familiar cultural surroundings before heading to major campuses in Barbados, Jamaica and Trinidad to complete their degrees.

A recent addition is the University of Trinidad and Tobago, which came on stream in July 2004. Initially, this university is offering programmes only in the sciences and engineering, at both the undergraduate and postgraduate levels.

The UWI has established postgraduate programmes leading to MSc, MPhil and PhD degrees. Enrolment in higher-degree programmes in 2002/03 amounted to 4 638, of which 1 726 (37%) were in S&T disciplines. The University of Technology, University of Guyana and University of Suriname are also expanding and consolidating their postgraduate programmes.

In the mid-1990s, the UWI was the recipient of an Inter-American Development Bank loan of US$ 56 million guaranteed by governments to consolidate, strengthen and expand S&T infrastructure (equipment and laboratories) and human resource capabilities (laboratory technicians and academic staff). The UWI's S&T teaching and research are improving as a result of this investment. Figure 1 shows research output over three decades. Steps will need to be taken to improve scholarly output from the agricultural and engineering sciences; however, the engineering faculty is credited with playing a vital role in building the vibrant manufacturing and petrochemical industries in Trinidad.

One of the very noticeable trends within the region's tertiary education is the under-representation of males. Since 1982, the number of female students registered at the UWI has not only caught up with that of males but even exceeded it. In 1999/2000, male students constituted only 33.7% of total enrolment and 31.3% of the graduating class.

The trend in S&T disciplines is similar, but the ratios still favour males. Some 3 491 males, or 51.2% of the total, enrolled in programmes in the agricultural, engineering, medical and natural sciences in 1999. The overall figure is largely influenced by the domination of male students in engineering sciences (79.3%).

Table 1
KEY INDICATORS FOR THE CARICOM COUNTRIES, 2001–03

	Population (thousands) 2001	HDI ranking[1] 2002	GDP growth (annual %) 2001	GDP per capita, PPP (current inter-national $) 2001	Public expenditure on education as % of GDP 2001	Public expenditure on tertiary education as % of total expenditure on education 1999–2001	GERD as % of GDP 2002	Internet penetration 2003 (% total pop-ulation)[2]
Antigua and Barbuda	72	55	2.3	10 620	3.5	15.1	–	12.82
Bahamas	307	51	4.5[3]	16 690[3]	4.0[1]	–	–	26.49
Barbados	268	29	-2.1	15 410	6.7	29.9	–	37.08
Belize	245	99	5.1	5 920	6.8	16.2	–	10.89
Dominica	78	95	-3.9	5 580	5.6	–	–	16.03
Dominican Republic	8 485	98	2.9	6 380	2.5	10.9		–
Grenada	81	93	-4.7	7 040	4.5	–	–	16.90
Guyana	762	104	3.4	4 320	4.5	–	–	14.22
Haïti	8 111	153	-1.1	1 640	1.1	–	–	1.80
Jamaica	2 603	79	1.5	3 850	6.8	19.2	0.08	22.84
Montserrat	3	–	–	–	–	–	–	–
St Kitts and Nevis	42	39	3.3	12 030	8.5	21.2	–	21.28
St Lucia	147	71	-6.3	5 290	7.7	12.8[4]	–	8.24
St Vincent and Grenadines	118	87	0.9	5 410	10.0	5.2	0.15	5.98
Suriname	429	67	4.5	–	10.2[2]	8.8[4]	–	4.37
Trinidad and Tobago	1 294	54	3.3	9 180	4.3	3.7	0.10[4]	10.60

1. Human Development Index as defined by UNDP (1–55 corresponds to high human development).
2. Data for Antigua and Barbuda, Belize, Dominica and Guyana are for 2002.
3. 2000.
4. 2001.

Source: for population and education data (except tertiary): UNESCO (2005) *Education for All: the Quality Imperative*. *EFA Global Monitoring Report*. UNESCO Publishing, Paris; for tertiary education and HDI data: UNDP (2004) *Human Development Report.* Oxford University Press, New York and Oxford, UK; for GDP figures: WDI CD ROM 2004; for GERD: UNESCO Institute for Statistics S&T database (2005); Internet penetration: UN Millennium Development Indicators: http//unstats.un.org

The situation is believed to reflect an increasingly underperforming male population, a new phenomenon in gender imbalance and its implications, which is under study. The proportion of women in academic positions at the UWI is increasing. They represented 33.2% of academic staff in 1998 and 36.8% the following year, including professorial appointments.

STRUCTURE AND ORGANIZATION OF RESEARCH

All Caribbean nations, individually and through CARICOM, recognize that they will have to make major progress in absorbing and applying S&T to achieve better living conditions for their people. Little attention has been paid to how this might be done or to the roles of various levels of scientific research activity (curiosity-driven versus application-targeted basic research and applied research directed towards problem solving).

There seems to be no mechanism for setting research goals and priorities, judging whether any research goals have been met, or evaluating research results from within and outside the Caribbean for their potential beneficial impact on the lives and economies of the region. This is a very serious policy and management deficiency that must be corrected quickly if S&T innovation is to be entrenched in the Caribbean culture and the productivity of its science enterprise is to grow to optimal levels.

The lack of a conceptual framework for understanding and evaluating innovation in the region has meant that

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many research programmes have been established and maintained without any performance evaluation or the requisite infrastructure, financial and human resources to achieve their mission. For these reasons, alumina, bananas, sugar, tropical rainforests and other resources of vital economic interest to the region have remained poorly understood, and their diverse potential is largely unexplored.

What is most distressing is that there are significant earnings from economic activity in these areas, but there is no endogenous research and development (R&D) capacity to sustain them. There are of course bright spots of excellent achievement in research in the region, but this is largely a result of determined individual effort and initiative rather than a planned and sustained cultural movement towards regional or national scientific excellence in the economically vital fields.

Research is conducted in universities, national and regional publicly funded special research institutions and, to a limited extent, in the private sector. Examples of national research institutes are the Scientific Research Council in Jamaica, the National Agriculture Research Institute in Guyana and the Institute of Marine Affairs in Trinidad and Tobago. The Caribbean Agriculture Research and Development Institute and the Caribbean Environmental and Health Institute are two of the better-known regional institutes.

Guyana boasts a unique centre for research into international forest conservation, *Iwokrama*[1], which encompasses 3 600 square kilometres of lush pristine tropical rainforest in central Guyana. The centre receives research grants from a number of countries as well as from international donor agencies, but it has no core funding.

R&D OUTPUT

The scholarly publication rates of research institutions outside the academic sector are insignificant. Of the research papers published by academic institutions between August 1999 and July 2000, approximately 92% originated from the regional research facility, the UWI, which has recorded significant growth in publication rates as shown in Figure 1.

1. Amerindian word meaning 'place of refuge'.

CARICOM

The Caribbean Community and Common Market (CARICOM) succeeded the Caribbean Free Trade Association (CARIFTA). CARICOM was established by the Treaty of Chaguaramas – signed initially by Barbados, Jamaica, Guyana and Trinidad and Tobago – which came into effect on 1 August 1973.

Today, CARICOM is composed of 15 members, the most recent admissions being Suriname (1995) and Haiti (1997). The CARICOM members are Antigua and Barbuda, Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

The Treaty of Chaguaramas creating a single market and economy has been ratified and is due to come into effect in July 2005. In addition to trade, it contains provisions for the setting up of a Caribbean Court of Justice.

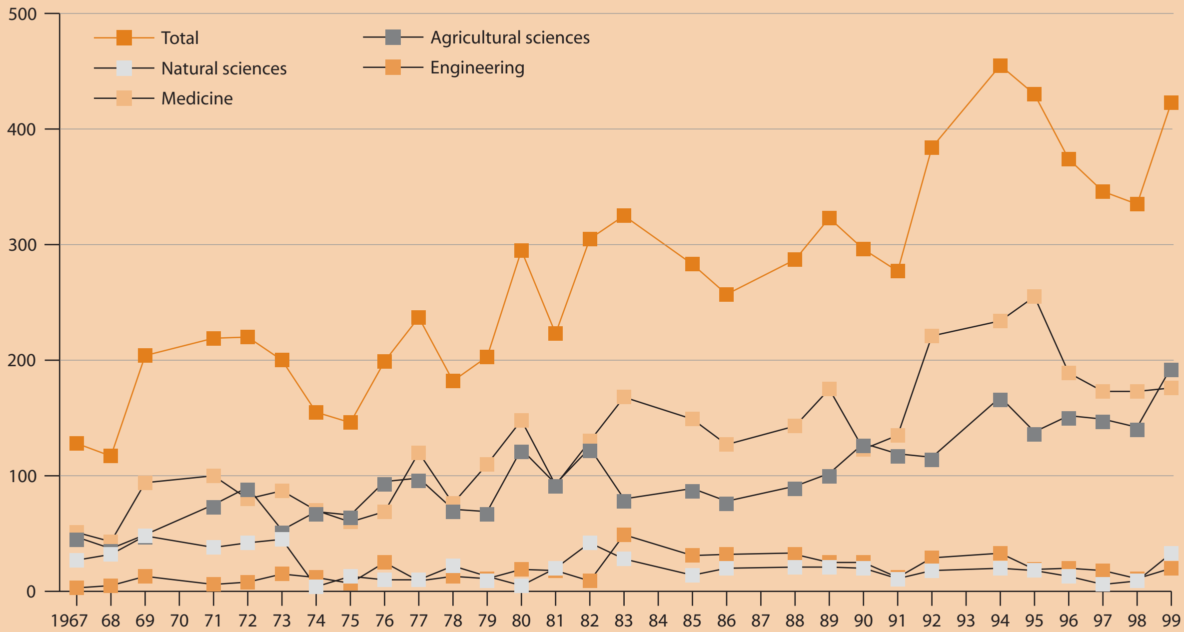
Source: CARICOM website: http://www.caricom.org

Table 2
UNIVERSITY ENROLMENT IN THE CARIBBEAN, 2000

University	S&T fields	Total
University of the West Indies	6 822	23 369
University of Technology	2 823	6 636
University of Guyana	1 207	4 962
University of Suriname	178	509
Northern Caribbean University	320	3 000

Source: UWI (2000) *Official Statistics for 1999/2000*; compiled from responses to authors' survey. University of the West Indies.

Figure 1
TRENDS IN S&T PUBLICATIONS OF THE UNIVERSITY OF THE WEST INDIES, 1967–99



Source: Departmental reports.

Publications from other tertiary institutions over the same period amount to 31. Overall, the region's 6.4 million inhabitants published 460 papers in refereed journals: at 71 papers per million inhabitants, the figure is encouraging. It compares favourably with figures for Latin America identified in UNESCO's *World Science Report 1996* (Figure 5, p. 59), which showed fewer than 50 research papers per million inhabitants for all but Argentina and Chile in 1993. Only the latter country, with a figure of 90, boasted a better publication rate than the Caribbean. Cuba in 1990 had a rate of 14 per million. This said, the figures for Singapore and Taiwan of China for the same year were 375 and 200, respectively, which means the Caribbean has a long way to go.

Among the peer-review journals in which the region's papers appeared are periodicals from the region. These are concentrated mainly in five science journals, three of which are based at the UWI. *Tropical Agriculture*, which was first published in 1924, is the region's longest-surviving journal. The *West India Medical Journal* is the region's premier scientific journal, which today reaches over 75 countries with about 700 individual subscribers and a circulation of over 2 000. Like *Tropical Agriculture*, it is published quarterly. Published biannually by the Faculty of Engineering at the Trinidad Campus, the *West Indian Journal of Engineering*, which first appeared in 1967, has a very impressive list of international advisers/reviewers. Its contents, though, are to a large extent local. The *Jamaican Journal of Science and Technology*, containing peer-reviewed papers in many fields, is published twice a year by the Scientific Research Council. The Bahamas *Journal of Science* is published twice a year by Media Enterprises Limited.

R&D EXPENDITURE

Gross expenditure on R&D (GERD) is modest. For example, even in the biggest island nations, it amounts to only

0.08% (Jamaica, 2002) and 0.10% (Trinidad and Tobago, 2001). The amount of funds actually available to R&D is proportionate to the tiny size of the Caribbean economies (Table 1).

In Jamaica, the Environmental Foundation of Jamaica, with normal funding of up to US$ 100 000 per project selected from peer-reviewed applications, is the most significant single source of substantial research funding. The Foundation supports environmental conservation, sustainable development and closely related research projects and promotions, for which it has approved over US$ 8 million in support of 421 projects since 1994 (disbursements for 1999/2000 amounting to some US$ 1.8 million for 52 projects). The Commonwealth Caribbean Medical Research Council also provides small grants.

Success in competitive funding awards from external sources is modest. Commercialization of research results is a potential source of revenue, and the region is active in intellectual-property developments. The sale of licences in educational software by the UWI to an international company, new food products turned out by the Scientific Research Council, and the Small Business Incubators at the University of Technology in Jamaica are some encouraging examples. The Centre for Resource Management and Environmental Studies in Barbados has been responsible for developing sources of renewable energy, which today meet 15% of the island's needs. The Centre expects to double this proportion to 30% by 2012.

Recently, the region's academic institutions have attracted international companies to operate resident R&D activities. Funds earned from such arrangements are ploughed back into research infrastructure (e.g. as a significant contribution to a new 500 MHz NMR at the UWI in Jamaica). There is a similar arrangement at the UWI's Cave Hill campus in Barbados with the company BioChem Pharma.

POLICIES FOR S&T

Some countries do have S&T and industrial policies that are strategically linked. Others are in the process of formulating such policies. These call for the establishment of national coordinating and management agencies for S&T, and this has been achieved with some measure of success. In Jamaica, the National Commission on Science and Technology succeeded in establishing a technology fund of US$ 2 million, of which about US$ 820 000 was disbursed in 2000. This fund serves as catalytic venture capital for technology innovators and investors. Generally, though, policies have become outdated, and their implementation has been slow owing to lack of personnel and funding.

ETHICAL DIMENSIONS OF R&D

Ethical pressures are being brought to bear in field trials of genetically modified plants and animals, human consumption of genetically modified foods and the complex web of environmental health, occupational safety and economic development. Generally, issues of preservation of the environment and promotion of human health are now better understood because of educational activities undertaken by researchers, environmental-protection advocates and tourism interests, the last being a major source of the region's income. However, more needs to be done in understanding and assessment of risk to public health.

TRENDS IN INDUSTRIAL R&D

Industrial activity is very low, with the exception of Trinidad and Tobago, which has oil, gas, a thriving petrochemical industry and other industries that are taking advantage of relatively low energy costs, and Jamaica, Guyana and Suriname where bauxite mining and alumina production are well established. These industries tend to rely heavily on parent companies overseas for R&D, which stifles endogenous S&T and frustrates bright young people seeking challenging and fulfilling research careers at home.

We note, however, that major alumina, oil, gas and petrochemical, and sugar (and related products) establishments have modestly supported research activities at universities in the region, including through endowments and graduate-student scholarships in selected research areas. But these are usually sporadic rather than consistent or long term, and graduates of such programmes have frequently not found employment in the sectors that supported their research, undermining the evolution of an endogenous R&D base in the region.

The vibrant tourism industry does not usually employ highly trained scientists but could do better by supporting research in information technology, environmental management and marine science, which are important to the tourism business.

REGIONAL AND INTERNATIONAL COOPERATION

Given the geography, small population and limited human and financial resources of the Caribbean region, it is critical to focus first and foremost on regional cooperation in order to build a science enterprise with the requisite critical mass. There are three regional scientific organizations in existence: the Caribbean Council of Science and Technology (CCST), the Caribbean Academy of Sciences (CAS) and CARISCIENCE.

Caribbean Council of Science and Technology

CCST was adopted by governments and established in 1981 with limited members drawn from policy makers and scientists. One of its first activities was to prepare an S&T policy document for the Caribbean; unfortunately, not very much seems to have been done in the way of subsequent implementation.

Caribbean Academy of Sciences

A non-governmental organization (NGO), CAS was launched amidst much fanfare in 1988, with promises of support from some regional governments. This support did not materialize. Nonetheless, the academy, whose members are leading scientists in the region, has been able to mount some programmes and an Annual Scientific Meeting, which is the only forum in the Caribbean at which scientists from all disciplines may present their research work. CAS has a very successful Distinguished Lecture Series programme, which to date has attracted three Nobel Prize winners. Internationally, it plays an active role on the InterAcademy Panel, a global network of the world's national and regional science academies that was launched in 1993, and whose main focus is on the scientific aspects of critical global issues.

As part of its tenth anniversary celebrations, CAS hosted a major Conference on Furthering Cooperation in Science and Technology for Caribbean Development in 1998.

CARISCIENCE

CARISCIENCE is of more recent vintage, having been launched in Jamaica in 1998. It is a UNESCO network of R&D and postgraduate programmes in the basic sciences in five Caribbean countries. An organization administered by active researchers for researchers, its main objective is to promote academic excellence and to improve the quality of scientific research in the region. Its record in its short period of existence is impressive. With limited funding, it has been able to assist a number of scientists, particularly young and female researchers, and encourage cooperation and exchange within the region. It has also introduced a relinking of expatriate Caribbean scientists and presents annual CARISCIENCE–UNESCO–Academy of Sciences for the Developing World (TWAS) Awards to outstanding postgraduate students.

Boosting regional cooperation

There is a need for CCST and CAS – which both seem to be experiencing funding problems – to start dialoguing and developing a framework for mutual cooperation and strengthening cooperative scientific activities, especially among universities. Centres of excellence, particularly in areas of science that impact on development, can enhance regional development, minimize duplication and optimize use of human resources.

The International Centre for Environmental and Nuclear Sciences, which is focusing on the linkages between geochemistry, food, health and the economy, is one such example. A Centre for Renewable Energy, to be located in Barbados, is expected to come on-stream in 2002. Chances are that regional governments and other institutions will take the Caribbean science enterprise seriously if scientists and their organizations arrange themselves into a more productive critical mass that speaks with a single voice.

There are also a few well-established, active scientific associations, such as the Caribbean Solar Energy Society, the

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Caribbean Chemical Engineering and Chemistry Association and the Caribbean Congress of Fluid Mechanics, whose regular scientific meetings attract international gatherings.

The development of S&T in the Caribbean can be boosted by greater cooperation with international bodies and on an individual level with scientists from the developed countries. The latter would enable our scientists to keep abreast of their field and increase their chances of accessing funding.

With respect to international bodies, UNESCO has demonstrated in a tangible manner its commitment to the region. It has played a major role in bringing CARISCIENCE into existence and has also supported a number of conferences, including the historic 1998 conference in Trinidad.

Other organizations from which the region has benefited are TWAS, the Organization of American States, the International Council for Science (ICSU) and the International Foundation for Science.

SPECIAL DIFFICULTIES

The most serious difficulties are lack of funding, inability to attract and keep quality staff, poor working conditions (including salaries), maintenance of equipment and staff development opportunities.

In Guyana and Suriname, these problems are acute, owing mainly to the very weak economies of these countries. In the United Nations Development Programme's *Human Development Report 2004*, Guyana, for example, ranked 104th out of 177 countries under the Human Development Index (HDI). Very limited funds are available for research and the purchase and maintenance of equipment; weak infrastructure – including an unreliable supply of electricity – tests the patience of researchers; and only a few scientific journals are available. In addition, scientists at the universities in these two countries carry very heavy teaching loads, leaving them little time for research.

To compound the problem, staff income is anything but attractive; this is reflected in the countries' inability to attract highly qualified scientists and the scholastically unproductive phenomenon of moonlighting. In the Faculty of Natural Sciences at the University of Guyana, out of 33 full-time staff, only six have PhDs and some have only a first degree. A paltry five international papers were recorded at this university last year. The situation in these two countries calls for intervention by the international scientific community.

The hub of scientific activities in Barbados, Jamaica, and Trinidad and Tobago is centred around the campuses of the UWI. Scientists here are much more fortunate than their counterparts in Guyana, Suriname and most countries in the Caribbean and Latin America. They enjoy better salaries and working conditions, as well as such fringe benefits as travel grants and access to limited internal research grants. The major need encountered here is mainly that of adequate research funding and better management of the science enterprise to match the productive potential of the academic staff and the science infrastructure. The creation of a Regional Research Council to fund research of interest to and focused on regional problems has been proposed to the Heads of Caribbean governments. At their annual meeting in 1999, these governments endorsed a proposal by the UWI to establish a Caribbean Regional Research Agency.

The challenge of migration affects the Caribbean greatly. For example, in the years 1991-2000, Jamaica saw some 20 000–25 000 (close to 1% of the population) emigrate each year (Planning Institute of Jamaica, 2000). Over 11%–15% of those migrating have skills or professions that might include S&T fields. Emigration rates of professionals and skilled Caribbean people can be expected to increase, owing to aggressive recruitment campaigns by foreign employers. For example, over 800 Caribbean teachers were sought for the New York state education system in May 2001.

The region's leadership finds the contribution made by the diaspora to the balance of payments, in particular, significant enough to warrant its attention. However, research institutions have not developed creative mechanisms for expatriate scientists to participate in the regional science enterprise. This needs to be done. Moreover, working conditions and the state and productivity of the science enterprise itself will need improving in order to minimize the effects of brain drain.

There are also minor problems, such as poor staff retention, lack of a systematic approach to staff development, lack of short-term research attachments, recruitment difficulties in competitive areas like information technology and a seeming lack of motivation among some researchers that has gone unchecked for too long. Substantive evaluation of research programmes and researchers themselves is lacking, as is action from management to combat mediocrity, or a collective will to award differential benefits for highly productive researchers. This has stalled the development of an endogenous research culture.

POPULARIZATION AND PUBLIC SUPPORT

Science popularization and raising public understanding of science to stimulate support have been taken seriously in the region. Activities have taken diverse forms, such as science lectures of public interest or that expose the region to high-quality science elsewhere, as well as public forums bringing together researchers, government policy makers, the media, private sector and NGOs to discuss challenges, opportunities and strategies for S&T development.

Various science interest groups in the region have organized science fairs, workshops, annual conferences, open days for schoolchildren, science days on university campuses, prime-time discussions with popular radio talk-show hosts and participation in national and international mathematics and informatics Olympiads. Trinidad and Tobago's popular Yapollo, an interactive science exhibition for schoolchildren, has toured other Caribbean countries.

It is encouraging to note that the government of Trinidad and Tobago is about to construct a science centre. Jamaica also operates a small but symbolic science centre. Funds for these programmes have come from direct government and institutional budgets, the national science coordinating bodies, local industries, CARISCIENCE and international science organizations such as the Royal Society of Chemistry.

FUTURE TRENDS

In spite of the obstacles faced by the scientific community in the Caribbean, it has managed to contribute to the development of science as well as to national and regional development. Approximately 46% of the Caribbean population lives below the poverty line. As governments and other interest groups become more aware of the potential of S&T in fighting poverty and as an engine of economic growth, we expect a need for greater focus on the following areas:

- human resources development;
- exploration of alternative forms of energy (solar, wind, geothermal and biomass);
- use of biotechnology in agriculture to boost food production and exports and reduce the high food-import bill;
- development of strategic alliances rather than 'paper' agreements among research institutes and strengthening of regional cooperation in science;
- materials development, especially those utilizing regional resources (alumina, limestone, petroleum and related products or high value-added products);
- health challenges and diseases affecting the region;
- exploitation of natural products;
- entrenchment in regional culture of standards guaranteeing quality products, to protect consumers and enhance global competitiveness of Caribbean products.

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Harold Ramkissoon is Professor of Mathematics at the University of the West Indies campus in Trinidad. He received his training in mathematics in Jamaica and Canada. He has been the recipient of an Alexander von Humboldt Fellowship (Germany), a Fulbright Fellowship (USA) and a Third World Academy of Sciences Fellowship (China). In the course of his academic career, he has published over 75 research papers.

Professor Ramkissoon is a founding member and President of both the Caribbean Academy of Sciences and the Caribbean Congress of Fluid Mechanics. Recently, he was elected Vice-President of the Caribbean Scientific Union, which is based in Bogotá, Colombia. He serves on the Executive of the Inter-Academy Panel headquartered in Trieste, Italy, and is the Executive Secretary of CARISCIENCE.

In recognition of his contribution to science and the development of science in the Caribbean, he has been the recipient of a National Award (the Chaconia Gold Medal), the Key to the City of Havana and the Simon Bolivar Gold Medal from the University of Simon Bolivar, Venezuela.

The European Union

LAURENCE ESTERLE

INTRODUCTION

The year 2004 saw the European Union (EU) swell from 15 to 25 Member States with the entry of ten countries from Eastern and Southern Europe (Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia). Accession on such a large scale was a first in Europe and cannot be compared with the successive waves of accession to the European Community, such as that of Greece in 1981, Portugal and Spain in 1986, or Austria, Finland and Sweden in 1995. Nearly 75 million people joined the EU in 2004, swelling its population by 20% (Table 1). The 115,000 additional researchers will need to integrate the European Research Area; this area remains a shared goal of all Member States, even if it is not yet a reality.

In 2000, the meeting of the European Council in Lisbon undertook to create a European Research Area by creating a joint dynamic for research and development (R&D) and increasing expenditure to make the EU 'the most competitive and dynamic knowledge-based economy in the world'. In Barcelona in 2002, the European Council reasserted this objective and proposed that the level of expenditure on research and development (GERD) be raised to 3% of GDP by 2010. To date, we are still far from this target: the GERD/GDP ratio was only 1.9% on average for the EU in 2001 and the entry of the new Member States lowers this proportion to 1.8% (Table 1). Only two countries of the 15-member European Union (EU15) have exceeded the 3% target and most of the others do not even come close; not a single new member measures up to the European average (Table 2).

Under the circumstances, what objectives can the 25-member EU realistically set itself? Should it raise the performance of the most advanced countries to a level comparable to that of the USA and Japan or concentrate efforts on boosting those countries far below the European average? In this chapter devoted to the EU, science and

Table 2
GERD/GDP RATIO IN THE EU, 2001, AND CHANGE, 1996–2001

Country/zone	GERD/GDP 2001 (%)	Change 2001/1996 (%)
Germany	2.51	+11
France	2.23	-3
United Kingdom	1.89	+1
Italy	1.07	+6
Spain	0.96	+16
Netherlands	1.89	-6
Greece	0.64	+31
Belgium	2.17	+21
Portugal	0.84	+47
Sweden	4.27	+23
Austria	1.92	+20
Denmark	2.39	+29
Finland	3.42	+35
Ireland	1.17	-11
Luxembourg[1]	1.71	–
EU15	1.91	+7
Poland	0.67	-6
Czech Republic	1.30	+25
Hungary	0.95	+46
Slovakia	0.65	-31
Lithuania	0.68	+31
Latvia	0.44	-4
Slovenia	1.57	+9
Estonia	0.66	+1
EU25[2]	1.81	+7

Notes
1 Data from 2000.
2 Excludes Cyprus and Malta.

Sources: OECD (*Main S&T Indicators*) and EUROSTAT data, OST estimations and computing.

Table 1
POPULATION, GERD AND GDP in the EU, 2001
USA and Japan are given for comparative purposes

Country/zone	Population (millions)	GDP (G$)	GERD (G$)	GERD/GDP (%)
EU15	381	9 680	185	1.91
EU25	455	10 383	189	1.82
USA	286	10 020	275	2.74
Japan	127	3 390	104	3.06

Sources: OECD (*Main S&T Indicators*) and EUROSTAT data, OST estimations and computing.

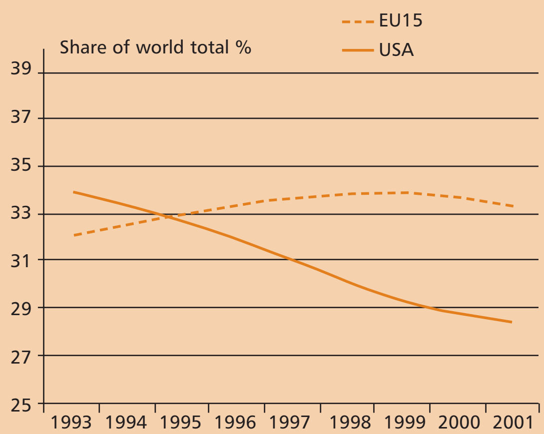
technology (S&T) indicators will show the strengths and weaknesses of a widespread region that occupies a prominent place on the international R&D scene. The assets and shortcomings of the now enlarged EU will also be set out.

A GREAT SCIENTIFIC POWER

In 1993, the scientific production of the 15-member EU, calculated in terms of share of the world's scientific publications recorded in the SCI database, was lower than that of the USA (Figure 1). In 1995, the EU overtook the USA and in 2001 its production was five points higher than that of the USA. In other words, the EU15 – which now accounts for one-third of the world's scientific production – asserted itself in the last decade of the twentieth century as the world's leading scientific power. Enlargement to 25 increased the share of scientific publications, which accounted for nearly 36% of the world total in 2001 (Figure 2).

This performance is the result of two trends: a decline in the USA's share of world scientific production in the 1990s coupled with an increase in the EU's share, particularly in the early 1990s. If we compare scientific production and GERD, the European performance is remarkable. The USA's domestic expenditure on R&D is very much greater than that in the EU. The same holds for public expenditure (by universities, research bodies, etc.) which is the main producer of fundamental knowledge (Table 3). It can therefore be said that academic research is thriving in the EU, even if, in fact, it varies greatly from one country to another, as we shall see.

Figure 1
SCIENTIFIC PUBLICATIONS IN THE EU AND USA, 1993–2001
As percentage of world total



Sources: ISI data, OST treatments.

The EU's scientific production as a share of the world total exceeds that of the USA in all disciplines. For instance, the share of the EU15 is close to 38% in world medical research, where it may be regarded as highly specialized (Table 7). On the other hand, it is less specialized in the engineering sciences (less than 30% of world production) but nonetheless ahead of the USA. The entry of ten new Member States significantly increases the EU's scientific production in physics, mathematics and chemistry, prominent disciplines in the Eastern European countries.

This rather rosy picture should be qualified, however. Although the EU has indeed gained in terms of scientific production, that is in the number and share of scientific publications, it has progressed a great deal less in terms of visibility, as measured by the number of citations. In 2001, the publications of the EU15 received one-third of citations worldwide (Figure 2), a much lower figure than that of the USA, which accounted for 42% of the total. Even though the USA's share has been decreasing since 1993 while that of the EU has remained stable, the fact that the gap between the EU and the USA persists reflects differences in the impact of science in the two great world powers.

This gap is also due to differences between the two regions in terms of the branches of science concerned. The EU's impact index, as measured by the ratio of the number of citations to that of publications, is higher than the world average value of 1 in all but two disciplines: medical research and basic biology. These are the very disciplines with a high impact index in the USA. Is this a reflection of the difference in investment in the life sciences and medical research between Europe and the USA? Europe

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will have to make sure it remains very competitive in these fields, both considered essential for innovation.

EUROPE LOSING GROUND IN TECHNOLOGY

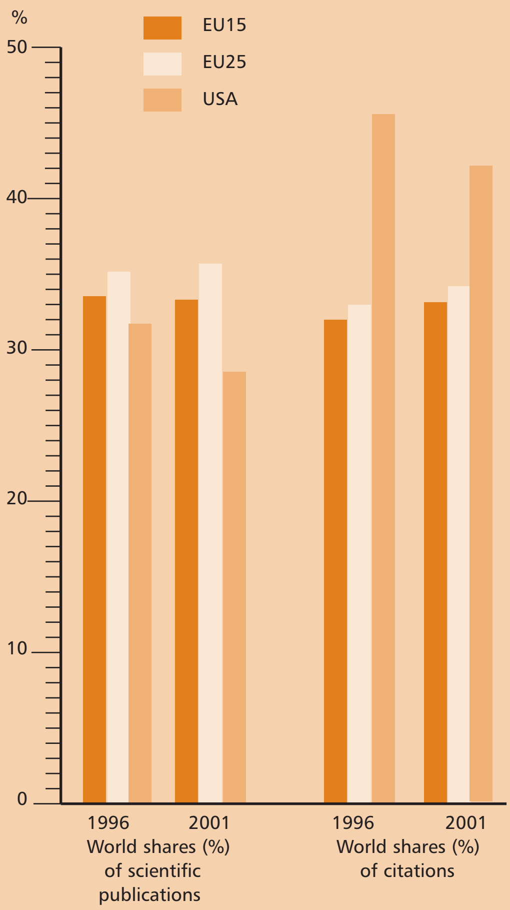
Although European scientific research can compete with that of the USA, the situation is quite different when it comes to technological research. Two indicators show the relative weaknesses of the EU: the volume of R&D expenditure by businesses (BERD) and the share of patent applications filed.

BERD in the USA is 70% higher than corporate expenditure in the EU15. The difference amounted to $PPP80 billion[1] in 2001 when the EU was still restricted to 15 members. BERD represented 2% of GDP in the USA as against 1.24% of GDP in the EU. By looking at the source of funding for R&D in businesses (Table 4), we see two reasons for this disparity. First is the level of public aid provided directly to businesses. In 2001, public contracts for businesses represented approximately US$20 billion in the USA, double that in the EU15. Second, there is a substantial difference in firms' own investment in R&D between the USA and Europe: US$70 billion in 2001 and growing because BERD is progressing rapidly in the USA but only very slowly in the EU.

Such wide disparities are not found in all industrial sectors. Expenditure on R&D by European (EU15) businesses is comparable to that of their American counterparts in some sectors. These include transportation, which amounted to approximately $PPP19 in 2000, and pharmaceuticals, which represented $PPP13 (Table 5). By contrast, the electronic sector, which ranks top in the EU with 20% of R&D expenditure by the private sector (i.e. $PPP21), accounts for one-third of R&D expenditure by businesses in the USA (i.e. $PPP55). In the buoyant sector of engineering and computing services, the USA spends 80% more than the EU.

These differences in terms of investment are reflected in the respective abilities of the EU and the USA to innovate, as measured by filed patent applications. In 2001, the EU15 filed 42% of European patent applications (Figure 3), compared with nearly 50% in 1986. European production fell sharply in the late 1980s and early 1990s (Figure 4). It seems to have evened out since 1998. Meanwhile, there was a significant rise in the USA: whereas the share of European patent applications filed by the USA amounted to 28% in 1986, this had climbed to 33% only ten years

Figure 2
SCIENTIFIC PUBLICATIONS AND CITATIONS IN THE EU AND USA, 1996 AND 2001*
As percentage of world total



* Calculated on the basis of the fractional principle as a percentage of the scientific publications or citations recorded in the Science Citation Index (SCI), an 'expanded' database produced by the Institute for Scientific Information (ISI, Thomson Scientific, Philadelphia, USA). Indicators are based on three years' averaging.

Source: see Figure 1.

1. The unit of account is per billion dollars by converting national currency to US$ using 'purchasing power parities' (PPPs).

Table 3
GERD IN THE EU AND THE USA, 1996 AND 2001*
By sector

Country/zone	GERD (G$) 1996	GERD (G$) 2001	GERD performed by the public sector ($PPP) 1996	GERD performed by the public sector ($PPP) 2001	GERD performed by the private sector ($PPP) 1996	GERD performed by the private sector ($PPP) 2001
EU15	134	185	50	65	84	120
EU25	136	189	–	–	–	–
USA	198	275	53	74	145	201

* The government, higher education and non-profit institutions sectors recorded separately under the OECD classification have been grouped here in the public sector category.

Sources: OECD (Main S&T Indicators) and EUROSTAT data, OST estimations and computing.

later. This rise also reflects the mounting interest of American businesses in the European market. Conversely, the share of US patents granted to European inventors declined from 24% in 1986 to 17.5% in 1998 and seems to have levelled off since then.

Here again, this global assessment fails to account for sectoral disparities. In the European patent system, the EU leads in the machine transport sector (57% of the world total in 2001) and in the sectors of household consumption, construction building and public works (55% of the total). The EU has a different profile in the US patent system with regard to specialization, reflecting the interest of a number of industrial sectors in the US market. Europe specializes in chemistry and materials, industrial processes, machine transport, pharmaceuticals and biotechnologies.

Table 4
BERD IN THE EU AND USA, 2001*
By volume and source of funds

Country/zone	BERD (G$) Funding by industry	BERD (G$) National public contracts	BERD (G$) Total execution
EU15	110.6	9.8	120.3
USA	181.3	19.2	200.5

* The data here incorporate both foreign and business funding.

Sources: OECD (Main S&T Indicators) data, OST estimations and computing.

In 2001, in each of these four technological branches, it filed more than 20% of the patents granted by the US Patent and Trademarks Office (USPTO).

It can be concluded from this analysis of R&D expenditure and S&T production that the EU is holding its own in terms of scientific performance but lagging behind when it comes to technology, in a context of inadequate expenditure on research, especially by the business sector. This assessment led the Barcelona European Council to emphasize the need to increase industrial investment in R&D.

DISPARITIES WITHIN THE EU REINFORCED BY ENLARGEMENT

Although the EU can be considered a single region comparable to the USA, there are significant differences within Europe as regards R&D. These differences will only be accentuated by the addition of ten new Member States. The disparities first appear in terms of the GERD/GDP ratio, which can vary as much as threefold from one country to another. Even when the EU counted only 15 members, expenditure on R&D ranged from a high of more than 4% in Sweden to less than 0.7% in Greece. In other words, depending on the country, the percentage of GDP can be more than double the European average (1.91% for the EU15 in 2001) or less than half of it. Both Slovenia and the Czech Republic, the new Member States with the greatest R&D intensity, fall below the European average. The largest of the new Member States, Poland, spends less than 0.7% of

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GDP on R&D. Even the GERD of Poland, the Czech Republic and Hungary combined was only equivalent to GERD by Belgium in 2001.

If we classify EU countries by their position with regard to the GERD/GDP ratio and the way in which that ratio evolved between 1996 and 2001, we can distinguish five groups of countries (apart from Cyprus, Luxembourg and Malta) (Table 2 and Figure 3).

The first group is represented by only two countries, Finland and Sweden. The ratio of GERD to GDP is higher than in the USA or Japan and growing. These countries maintain a high level of R&D.

The second group is made up of seven of the EU15 countries. GERD as a percentage of GDP is higher than the European average but lower than the ratio in the USA. Two sub-groups can be identified in terms of the way in which this ratio has changed:

- countries in which R&D expenditure has increased, namely Austria, Belgium, Denmark and to a lesser degree Germany;
- countries where there was no increase between 1996 and 2001, namely France, the Netherlands and the UK.

The third group is made up of seven countries which fall below the European average but where the percentage is higher than 0.9%. Three new Member States figure among these countries. Here again, two sub-groups can be distinguished:

- four countries in which GERD has increased in relation to GDP: the Czech Republic, Hungary, Portugal and to a lesser degree Spain;
- three in which it is stable or declining: Slovenia, which has the highest proportion of GERD in relation to GDP among the new Member States, Ireland and Italy.

The last group comprises six countries, including only one from the EU15, Greece. In two of these countries – Greece and Lithuania – GERD as a percentage of GDP is rising sharply. In the others, Latvia, Poland and especially Slovakia, it is declining.

The situation is clearly complex. Attention will certainly have to focus both on countries in the last group, which are a very long way from the target of 3% of GDP, and on those countries below the threshold of 1.9% which are showing signs of limiting investment in R&D. In sum, seven of the 23 Member States (excluding Malta and Cyprus where GERD/GDP ratio is negligible) will need to make a big effort to catch up; of these, six are new Member States.

The situation of the new Member States is often compared to that of the countries that joined the EU during the earlier waves of enlargement. The situation of the latter countries varies considerably, however. The GERD/GDP ratio for Ireland, which joined in 1973, has overtaken that of Italy, whereas the ratios for Spain and Portugal have increased and are still progressing. On the other hand, the ratio for Greece, which has been in the EU for 20 years, remains low despite steep growth.

The disparities observed in terms of financial resources are again visible when it comes to scientific production as

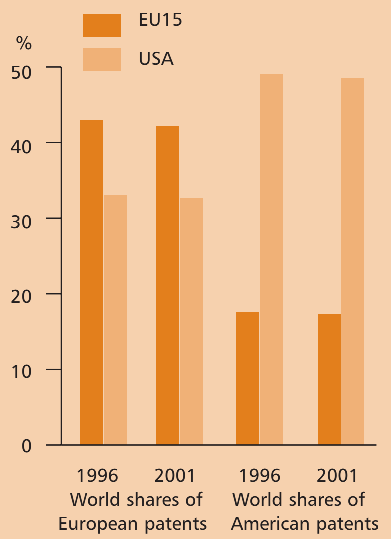
Table 5
BERD IN THE EU AND USA, 2001
By economic sector

	BERD ($PPP)	
Economic sector	**EU15**	**USA**
Total manufacturing	89.6	129.6
Aeronautics	7.6	10.3
Electronics	21.3	55.3
Pharmaceuticals	13.0	12.9
Machinery and equipment	11.2	10.6
Transports	18.5	19.9
Chemicals	10.9	11.2
Natural resource-intensive industry	4.5	6.4
Labour-intensive industry	2.6	3.0
Total services	14.3	17.6
Electricity, gas and water supply	1.0	0.2
Construction	0.6	0.2
Transport/telecommunication services	3.0	2.4
Engineering/computing services	9.7	14.8
Grand total	103.8	147.2

The differences observed between this and the previous tables are due to the use of two different OECD databases (ANBERD and PIST), which are not updated at the same time. Data are not available for Austria, Greece, Luxembourg or Portugal and are therefore not counted in the figures for the EU.

Sources: OECD (ANBERD) data, OST estimations and computing.

Figure 3
PATENT APPLICATIONS FILED BY EU AND USA IN EU[1] AND USA, 1996 AND 2001[2]
As percentage of total



1 European patents include applications submitted to the European Patent Office and those submitted through the TCP channel which designate the European countries.
2 Indicators are calculated on the basis of the fractional principle and are based on three years averaging.

Sources: INPI, EPO and USPTO data, OST and CHI-Research computing.

measured by the world share of scientific publications. Three EU countries – France, Germany and the UK – accounted for more than a 5% share each of the world's scientific publications in 2001 (Table 6). These three countries account for 55% of the publications of the EU25; add Italy, the Netherlands and Spain, and the figure exceeds 75%. In other words, the remaining 19 countries share between them one-quarter of European scientific production.

In terms of trends, mention must be made of the increase in scientific production by the countries that joined the EU in 1986. For example, Portugal's world share, albeit small at 0.3% in 2001, nevertheless increased by nearly 70% between 1996 and 2001. As for Spain, its share rose from 2.1% in 1996 to 2.5% in 2001, widening the gap with the Netherlands which ranks next. Scientific production by the three heavyweights of European research – France, Germany, the UK – on the other hand, has remained stable, or even slipped slightly.

Still looking at scientific production, the ten new Member States carry little weight in this domain. Together, they contribute less than 3% of the world total, with Poland, the Czech Republic and Hungary being the main contributors. However, the trends between 1996 and 2001 were generally positive, especially for the three countries just mentioned, whose world share rose by between 4% (Czech Republic) and close to 20% (Poland). Mention should also be made of the upswing in Slovenia, which has boosted scientific production by 60% in five years.

An analysis of scientific production by discipline shows marked differences between countries in terms of positioning and specialization (Table 7). Overall, it shows a dearth of scientific production by the new Member States in medical research and basic biology, with a more marked contribution to world science in terms of chemistry, physics and mathematics.

In terms of technological production, Germany is far ahead of the other European countries, with an 18% share of European patents in 2001 (Table 8). Only two other countries, France and the UK, can boast a share of more than 5%. Taken together, France, Germany and the UK file more than 70% of the patent applications from the entire EU and thus technological production is to a large extent concentrated in these three countries. Next in line is Italy, with a share of over 3%.

Among the EU15 Member States, six stand out for having achieved remarkable growth in technological production: Finland, Greece, the Netherlands, Portugal, Spain and especially Ireland. The share of the latter more than doubled between 1996 and 2001. What about the then-candidate states? While their share of European patents remained extremely low in 2001, there were signs of growth in some of them, particularly the Czech Republic and Poland. Although the functioning of the intellectual property systems of the Eastern European countries has already been aligned on the system of the European

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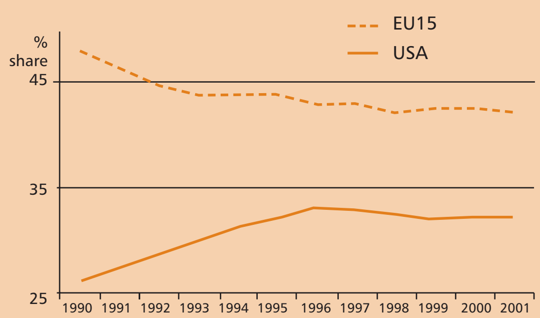
Figure 4
SHARE OF EUROPEAN PATENTS, EU15 AND USA, 1990–2001



Sources: INPI and OEB data, OST treatments.

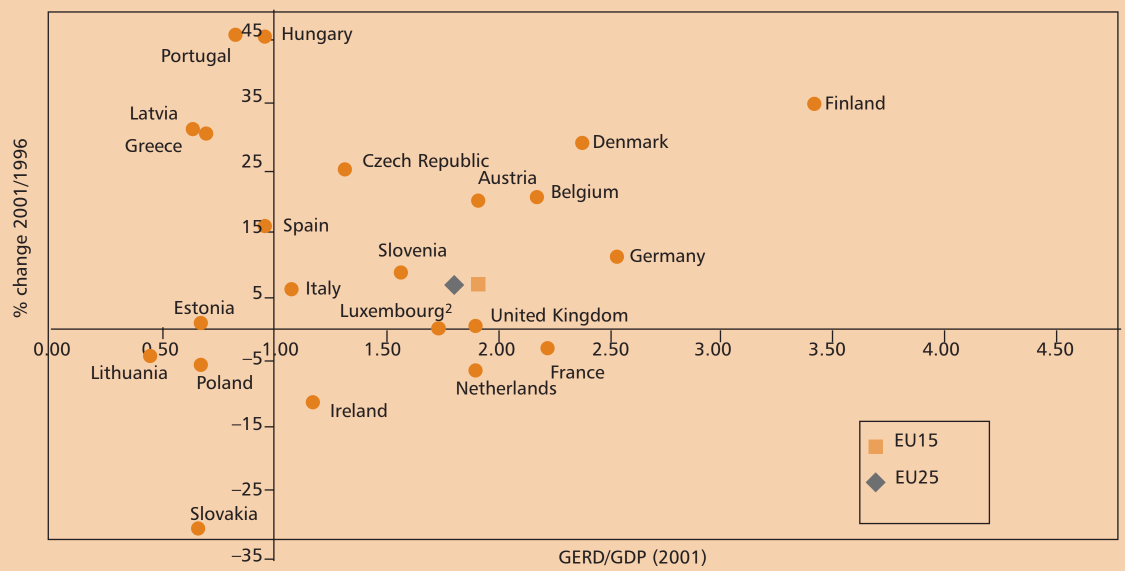
Patent Office to a large extent, there is still a long way to go to make local actors aware of the strategic dimensions of industrial property. It will be interesting to monitor patent trends in the new Member States to ascertain how the countries are developing and establishing their own technologies in the European area.

CONSIDERABLE HUMAN POTENTIAL

The European Research Area boasted nearly 15 million students enrolled in higher education at the Master's and Doctoral levels in 2001 (Table 9). Close to 3 million of these students were being educated in the new Member States. Between 1998 and 2001, the total number of students in Master's and Doctoral programmes increased by 4% in the 15-member EU but by as much as 10% in the 25-member EU – evidence of substantial growth in the new Member States. Whereas student numbers remain stable in France and Germany, they have grown by between 30% and 50% in the new Member States.

The 25-member EU produced more than 80 000 PhDs in 2001, nearly 6 000 of which were awarded in the new Member States. There was an overall increase of 20% for the entire EU25 between 1998 and 2001. In the EU15 countries, close to 40% of PhD holders are

Figure 5
GERD/GDP RATIO IN EU25,[1] 2001, AND CHANGE, 1996–2001



Notes: 1 Excludes Cyprus and Malta. 2 Data from 2000.

Sources: OECD (*Main S&T Indicators*) and EUROSTAT data, OST treatments.

Table 6
SHARE OF EU25 COUNTRIES IN WORLD SCIENTIFIC PUBLICATIONS, 1996 AND 2001*

Country/zone	World shares (%) of scientific publications 1996	2001	Change 2001/1996 (%)
Germany	6.8	7.0	+4
France	5.4	5.1	-5
United Kingdom	8.2	7.5	-8
Italy	3.3	3.5	+5
Spain	2.1	2.5	+19
Netherlands	2.0	1.9	-8
Greece	0.4	0.5	+28
Belgium	1.0	0.9	-1
Portugal	0.2	0.3	+68
Sweden	1.5	1.5	-2
Austria	0.6	0.7	+13
Denmark	0.7	0.7	0
Finland	0.7	0.7	+5
Ireland	0.2	0.3	+12
EU15	**33.3**	**33.4**	**0**
Poland	0.9	1.0	+19
Czech Republic	0.4	0.4	+4
Hungary	0.3	0.4	+11
Slovakia	0.2	0.2	-20
Slovenia	0.1	0.2	+60
EU25	**35.3**	**35.7**	**+1**
World total	**100.0**	**100.0**	**0**

* Calculated on the basis of the fractional principle as the percentage of the scientific publications or citations recorded in the SCI 'expanded' database produced by ISI (Institute for Scientific Information - Thomson Scientific, Philadelphia, USA). Indicators are based on three years' averaging. Countries that published fewer than 400 publications in 2001 are not included.

Sources: ISI data, OST computing.

women but this percentage varies from country to country: for example, the figure is as high as 51% in Italy but only 31% in the Netherlands. Overall, the new Member States tend to have a higher proportion of women among PhD holders.

In the EU25, there were nearly 2 million full-time-equivalent (FTE) workers in the R&D sector in 2001. This number increased by 15% between 1996 and 2000. One million were working as researchers in 2001, a 20% increase over 1996 (Table 9). These increases were concentrated chiefly in the 15 Member States of the time, especially Spain and the UK, and in the private sector. Growth was smaller in the new Member States, where the ratio of research staff to the working population was lower than the European average (5.2 per 1,000). There is therefore considerable scope for expansion in the new Member States.

In a nutshell, the population of future young researchers and of researchers is growing in the EU. Nevertheless, there are two disturbing factors: the disaffection with science among young people and the threat the brain drain poses to the new Member States, including at the intra-regional level. Countries will have to build up their national resources. Since women represent just one-third of European researchers in the public sector and one-sixth in the private sector, their access to scientific careers will also be a major challenge in the coming years.

Strengthening R&D potential will call for political responses at both the national and EU levels. The European Research Area must offer an environment that can hold its own against international competition.

A STRONGER CAPACITY FOR INTRA-EUROPEAN COOPERATION

The heterogeneity of the European Research Area makes it essential to have powerful tools which contribute to its cohesion. Such tools have existed for a long time. They were developed within the framework of the EU or that of intra-European cooperation between states: Framework Programmes for R&D, the Eureka initiative, the European Space Agency (ESA), major European initiatives such as the European Organization for Nuclear Research (CERN) and so on. All levels of action are concerned: training, researcher mobility, the implementation of S&T projects, access to major facilities, and cooperation between industrialists. For the most part, these tools have proved effective.

In the field of training, for instance, more than 110 000 European students were given the opportunity to pursue their tertiary studies abroad within Europe in 2000 under the European Union's Erasmus programme. The number of Erasmus fellowships increased by 70%

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between 1995 and 2000. Obviously, student flows are not evenly distributed between countries. The UK remains the leading host country, with 20% of student intake in 2000. However, Spain is now proving a serious challenger to France and Germany. The new Member States send more students abroad than they host. Student mobility, however, may be compounding brain drain from the new Member States, which are already suffering from a serious shortage of scientific personnel. Retaining young researchers, or ensuring they return to their countries of origin, is a major challenge for these countries but one that will only be met if working conditions at home are excellent and competitive.

As young scientists embark on scientific careers, the fellowship scheme of the Framework Programme, which goes by the name of Marie Curie fellowships, is intended to facilitate student mobility within the EU. The numbers involved are however still small: there were fewer than 3 000 beneficiaries under the fifth Framework Programme (from 1998 to 2002), with wide disparities between countries. These efforts are clearly insufficient and, although precise data are lacking, there are signs

Table 7
SHARE OF EU25 COUNTRIES IN WORLD SCIENTIFIC PUBLICATIONS, 2001*
By discipline

	World shares (%) of scientific publications per discipline								
Country/zone	**Basic biology**	**Medical research**	**Applied biology-ecology**	**Chemistry**	**Physics**	**Astro and geo-sciences**	**Engineering**	**Mathematics**	**Total**
Germany	6.8	7.4	5.4	7.6	8.4	6.2	5.9	7.1	7.0
France	5.3	5.1	4.4	5.2	5.7	5.5	4.2	7.8	5.1
United Kingdom	7.8	9.7	6.8	5.4	5.1	8.2	7.2	5.1	7.5
Italy	3.5	4.0	2.3	2.9	4.0	3.8	3.2	4.1	3.5
Spain	2.5	2.4	3.3	3.1	2.1	2.5	1.9	3.6	2.5
Netherlands	2.0	2.4	1.8	1.3	1.3	2.0	1.6	1.3	1.9
Greece	0.3	0.6	0.5	0.5	0.5	0.7	0.8	0.7	0.5
Belgium	1.0	1.1	1.0	0.8	0.9	0.8	0.8	1.0	0.9
Portugal	0.3	0.2	0.4	0.5	0.4	0.4	0.5	0.5	0.3
Sweden	1.7	1.9	1.6	1.1	1.2	1.4	1.2	0.9	1.5
Austria	0.7	1.0	0.6	0.6	0.6	0.6	0.5	0.7	0.7
Denmark	0.9	0.9	1.1	0.4	0.6	1.0	0.5	0.5	0.7
Finland	0.8	1.0	1.0	0.5	0.5	0.8	0.6	0.5	0.7
Ireland	0.3	0.3	0.4	0.2	0.2	0.2	0.2	0.3	0.3
EU15	**33.7**	**37.9**	**30.5**	**30.0**	**31.4**	**34.0**	**29.2**	**33.9**	**33.4**
Poland	0.7	0.5	1.1	1.9	1.7	0.8	1.1	1.5	1.0
Czech Republic	0.4	0.2	0.9	0.7	0.5	0.4	0.3	0.7	0.4
Hungary	0.4	0.3	0.5	0.6	0.4	0.2	0.3	0.9	0.4
Slovakia	0.2	0.1	0.4	0.3	0.2	0.1	0.1	0.3	0.2
Slovenia	0.1	0.1	0.1	0.2	0.2	0.1	0.3	0.3	0.2
New Member States	1.9	1.2	3.1	4.0	3.2	1.8	2.2	3.9	2.3
EU25	**35.6**	**39.1**	**33.6**	**34.0**	**34.5**	**35.8**	**31.4**	**37.9**	**35.7**
World total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

* Calculated on the basis of the fractional principle as the proportion of the publications or citations recorded in the SCI 'expanded' database produced by ISI (Institute for Scientific Information – Thomson Scientific, Philadelphia, USA). Indicators are based on three years averaging.
The countries which published fewer than 400 publications in 2001 are not included.

Sources: ISI data. OST treatments.

Table 8
SHARE OF SELECTED EU25 COUNTRIES IN EUROPEAN PATENTS, 1996 AND 2001*

Country/zone	World shares (%) of European patents 1996	2001	Change 2001/1996 (%)
Germany	17.7	17.9	+1
France	7.1	6.1	-14
United Kingdom	5.8	5.3	-8
Italy	3.3	3.1	-4
Spain	0.6	0.7	+16
Netherlands	2.2	2.5	+11
Greece	0.0	0.1	+17
Belgium	1.1	1.1	-3
Portugal	0.0	0.0	+25
Sweden	2.1	2.2	+5
Austria	1.0	0.9	-6
Denmark	0.8	0.8	-1
Finland	1.1	1.2	+11
Ireland	0.1	0.2	+137
EU15	**43.0**	**42.2**	**-2**
Poland	0.0	0.1	+54
Czech Republic/Slovakia	0.1	0.1	0
Hungary	0.1	0.1	+57
EU25	**43.3**	**42.5**	**-2**
World total	**100.0**	**100.0**	**0**

* Indicators are calculated on the basis of the fractional principle and are based on three years averaging. The countries that registered fewer than 50 European patents in 2001 are not shown in the table. Given the difficulty in differentiating with certainty the findings for the Czech Republic and Slovakia, the two countries have been assessed and are presented together in this table.

Sources: NPI and EPO data, OST computing.

that young researchers often prefer North America to Europe for their postgraduate studies. Lastly, the question of a common status for European researchers is on the political agenda as a means of fostering intra-European mobility. It remains to be seen whether Member States are sincerely in favour of it or whether they prefer to play their individual cards in these times of intense international competition.

The Framework Programme remains the major instrument for cooperation among European laboratories. Between 1998 and 2002, the fifth of these programmes – which associated the then-candidate countries – generated over 11 000 projects involving participation by more than 70 000 teams from various public and private laboratories. Six teams participated in a project on average. This sort of tool certainly facilitates European cooperation, yet the overall picture must be qualified by two comments. First, industrialists tend to disengage from these projects, considered too burdensome in terms of return on investment and as not always tying in with industrialists' own international strategies. Second, the financing of research by these projects constitutes only a small part of laboratories' expenditure. Overall, the funding of the Framework Programme represents only 3.5% of European public finance, although the proportion is as high as 26% for Greece and 11% for Ireland. In the latter countries, the Framework Programme is an essential source of funding for R&D, which is also a weak point.

Here again, concentration is a major feature. Some 40% of participation in the Framework Programme involves British, French and German teams, thereby reinforcing collaboration between the laboratories of the larger countries. There was little cooperation with the then-candidate countries under the fifth Framework Programme, the ten new Member States representing only 5% of participation. Yet cooperation with the new Member States began as early as 1992 under the third Framework Programme through a specific programme. The fourth Framework Programme also enabled some 30 'centres of excellence' to be funded in a number of accession countries. The Framework Programme is just one among many research-financing windows in Europe, of which there are more in some countries than in others. It is an open question whether the Framework Programme can remain the only means of funding research at the European level. Major projects like the proposed European Research Council are in any case currently under discussion.

But will the Framework Programme, as it is presently structured, or any other mechanism, succeed in strengthening research in those countries where it is undeveloped? Competition is intense for a limited number of funded

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projects, a situation that could well lead to proposals from these countries' teams being rejected for the simple reason that they are too numerous to be taken on board.

In addition to the Framework Programme, there are other major non-Community European bodies, such as CERN and ESA mentioned earlier, and the European Synchrotron Radiation Facility (ESRF), which are the mainstays of major infrastructure for research in Europe. With a combined annual budget of approximately € 3.5 billion, these bodies are also exposed to broad international cooperation and help to structure R&D in Europe.

Through these mechanisms, scientific cooperation has certainly been strengthened within the EU. This can be measured by the share of scientific publications co-signed by teams from various countries of Europe. In 2001, the contribution of individual countries to international co-publications with another member of the EU ranged from 45% for Germany to nearly 75% for Portugal. European co-publications have been rising significantly, especially for the countries where scientific production is growing, as in the case of Portugal. For the EU15 countries, the proportion of co-publications produced with US laboratories is now considerably lower than that of European co-publications.

There were still few co-publications by the EU15 countries with the new Member States in 2001. Relations with neighbouring states are a major factor here: 10% and 12% of the co-publications involving Austria and Finland respectively were being produced with one of the future Member States. By contrast, in Spain and the UK, co-publications with the new Member States represented less than 5% of the total. Evolving trends in co-publication between the 'old' and 'new' Member States will be a good indicator of whether the European Research Area is truly expanding.

Table 9
STUDENTS AND RESEARCHERS IN EU25 COUNTRIES, 2001

Country/zone	Enrolled students in Master's and PhD courses (thousands)	Number of graduated PhDs	Number of FTE researchers (thousands)
Germany	2 084	24 796	264
France	2 032	10 404	177
United Kingdom	2 067	14 147	158
Italy	1 812	4 044	66
Spain	1 834	6 453	80
Luxembourg[1]	–	–	2
Netherlands	504	2 533	45
Greece	–	–	15
Belgium	359	1 317	32
Portugal	388	2 791	18
Sweden	358	3 388	46
Austria	290	1 871	–
Denmark	191	795	19
Finland	280	1 797	37
Ireland	167	572	8
EU15[2]	**12 075**	**74 908**	**987**
Poland	1775	4 400	57
Czech Republic	260	1 066	15
Hungary	331	793	15
Slovakia	144	532	10
Lithuania	103	37	8
Latvia	136	261	3
Slovenia	91	298	4
Estonia	58	149	3
EU25[2]	**14 992**	**81 657**	**1 102**

Notes
1 Data from 2000.
2 The totals exclude EU countries for which data are unavailable or insignificant.

Sources: OECD (*Main S&T Indicators*), OECD *Education at a Glance* and EUROSTAT data, OST estimations and computing.

(R)EVOLUTION IN RESEARCH SYSTEMS IN THE NEW MEMBER STATES

The reasons for the gap between the old and new EU Member States are largely systemic. Since the collapse of the Soviet bloc in 1989, institutional reform has been initiated widely in most of the new Member States. National systems have been either entirely rebuilt or remodelled and all have been greatly transformed over the past 15 years, even if this restructuring is still work in progress. The role and place of science academies, which used to bear sole responsibility for basic research in the Soviet era, has changed. Conversely, the role of universities has generally been strengthened and

R&D in Central and Eastern Europe: change is the only option

In the 1990s, Central and Eastern European countries had to contend with major budgetary difficulties when it came to financing R&D. A restructuring of the systems inherited from the Soviet era went hand in hand with a reduction in funding of R&D as a percentage of GDP, at least during the first half of the decade. Although the decline seems now to have been halted, the GERD/GDP ratio remains weak in most of these countries, ranging between 0.4% and 0.8% of GDP, and is much lower than the average of the 15-member EU (1.9% in 2001), itself considered insufficient. The private sector's share in funding R&D remains negligible.

The Central and Eastern European countries originally had monolithic and hierarchical national R&D structures, the central feature of which was an academy of sciences. The research system was consistent with the Soviet model: on the one hand, a technological development sector in the state industrial institutes and, on the other, an academy of sciences responsible both for fundamental research and for the implementation of national science policy. Those structures were changed during the transition period, rather abruptly in some countries, and aligned more on the Anglo-Saxon model for the organization of research, a move fairly consistent with the recommendations of the EU and the OECD. Research was then gradually transferred to the universities and funded by various agencies, some of which had specific objectives. Governments took over control of the system from the academies and framed national science policies, which were more effectively brought into line with the international context as the prospect of joining the EU became more compelling.

The R&D personnel factor remains crucial for the future of national research and innovation systems. Overall, in the countries of Central and Eastern Europe, the number of researchers per 1 000 in the labour force is well below the EU average of 5.2 per 1 000. It is a major asset for the countries, however, that researchers are usually highly qualified. This has enabled them to maintain excellence. Unfortunately, because of the economic difficulties encountered during the transition to a market economy, infrastructure is obsolete and salaries pitiful. This not only undermines the attractiveness of local public research but is also nourishing both internal brain drain (to other branches) and external brain drain (abroad).

Even more disastrous for the younger generations is the demotivating effect of a combination of inadequate pay, outdated laboratory equipment and isolation brought about by the break-up of research teams. Increasingly, young students are rejecting activities that do not guarantee them the quality of life to which they legitimately aspire. An adverse consequence of this has been the ageing of the research population, markedly so in some countries. A number of countries are conscious of the problem (particularly the Baltic countries) and are beginning to introduce strategies to lure researchers back from overseas, such as by offering them a level of responsibility which would probably elude them abroad.

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As might be expected from the trends in GERD and the number of researchers, scientific production in Central and Eastern European countries is small, having declined gradually during the early years of transition and even throughout the decade in the case of Bulgaria. The drop has now levelled off, with some countries even recording a rise, in particular Slovenia.

The growth in scientific co-publications shows the speed with which the research teams in these countries have opened up to international cooperation. This has certainly been greatly facilitated by the forced march towards membership of the EU, as can be seen from the prominent place of the large European countries among initial partners, with Germany topping the list. The anticipated rise of the new Member States to prominent positions in the Framework Programmes for community research should help enhance this European partnership.

Chemistry, physics and mathematics are the fields in which researchers from the Central and Eastern European countries publish most; they are also the most visible fields. By contrast, all the life science disciplines are still poorly developed in the new EU Member States. Belonging to the European Research Area, whether or not it is effective or still in the planning in 2007, will probably prompt national research to focus on certain pre-eminent disciplines and the structuring of a network of laboratories around a few selected centres with a high international profile that are likely to attract private investment and foreign scientific partnership.

In the sphere of technology, Central and Eastern European countries are conspicuous by their absence when it comes to the filing of patent applications. Structures for the protection of intellectual property did not exist 15 years ago; entry into the EU has obliged these countries to adopt reforms bringing them into conformity, eventually, with international regulations. Furthermore, rather than giving rise to the creation of new technologies, economic specialization in these countries in terms of R&D tends to favour importation of new technologies, followed by implementation of these in the traditional sectors of the national production system.

Whereas the national research and innovation systems of the countries in the region are at a serious historical disadvantage in the face of international competition, there is every reason to hope for improvement. There is first of all their remarkable, demonstrated ability to adapt national structures within the space of a few years to the widely globalized environment of S&T. Moreover, the relocation of industrial production has released an increasing flow of foreign direct investment, a trend that is no doubt going to amplify in the coming years and which may offer a real opportunity to attract R&D. Last but not least, effective integration into the EU should enable these countries to gain access to structural funds and ease the financial burden of the structural reforms undertaken since the transition got under way. If these funds are used appropriately, they will serve primarily to improve essential infrastructure, make sound investment for the future and overcome the most serious handicaps.

It is clear that those countries with a political leadership that succeeds in defining and implementing S&T priorities – and keeping to them – will be best placed to attract foreign investment and partnerships.

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Is the European Union's objective over-ambitious?

At the Lisbon European Council 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'. In 2002, at the Barcelona European Council, they agreed that spending on R&D in the EU should be increased and approach 3% of GDP by 2010, against the 2002 figure of 1.9%. Not all the present Member States, including the new ones, are expected to be able to achieve this objective individually by 2010, but all must contribute to it. Growth must be achieved by increasing R&D funding by businesses, in order to bring it up to two-thirds of total R&D investment, a proportion which has already been reached in some European countries.

Given the 25-member EU's average of 1.8%, is this 3% target still realistic for all European countries?

Only in two European countries in 2001 did R&D expenditure exceed the 3% target: in Sweden (4.27% of GDP) and Finland (3.42%). Both these countries have an exceptionally high share of corporate funding (more than 70% of R&D expenditure); corporate funding represents 3% of GDP in Sweden and 2.4% in Finland. Public sector funding also represents a higher share of GDP than that of the EU countries as a whole but somewhat closer to other countries such as France.

Are Sweden and Finland a model for the other European countries? Taking the example of Finland, the steep growth in GERD in the 1990s was mainly accounted for by the electronics industries. Today, these industries represent more than 50% of business expenditure. While Finland succeeded in specializing in a niche sector on an international scale, its exceptional position is based on a very small number of industries and was secured in a context that was highly profitable at the time for that sector. Even if this model might conceivably be applied to other similar-sized countries, such as some of the new EU Member States, it cannot be applied across the board in Europe, where research is much more diversified.

Apart from Sweden and Finland, only four countries in the EU spend more than 2% of GDP on R&D: Germany, Denmark, France and Belgium, in decreasing order. The GERD of all these countries represents more than 60% of the total for the 15-member EU. The 3% target is therefore ambitious, even over-ambitious, for the entire 25-member EU, since it requires many countries to make up a gigantic shortfall immediately.

Lastly, the decline in the EU's attractiveness for investment in R&D by the private sector is becoming a major concern. In recent years, the research laboratories of multinational firms have tended to locate in the USA. Asian countries such as China, India, and the Republic of Korea have also begun to compete internationally. To remain competitive in the technological sphere, European countries must therefore develop basic research. The question of their scientific expertise, greatly dependent on the quality of education and on human resources in the public sector, will be crucial.

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universities have been provided with greater resources. However, long stifled by the science academies under the Soviet system, universities now have to catch up and building scientific excellence takes time. Moreover, the massive spread of higher education has led to a great demand for teaching; this is the main obstacle to the development of university research.

Although it may be an asset for the new Member States to be focusing on basic research in universities once more, the benefits will only emerge in the long term. In the meantime, public authorities will need to bolster the university sector over a prolonged period.

As for industrial research, the transformation of heavy industries from the Soviet era into modern industries has been sluggish. Once centralized, the demand for industrial development has now given way to the harsh reality of competition on the world market. Using the example of Hungary, businesses financed less than 40% of GERD in Hungary in 2001, as against 56% on average for the EU15; and whereas BERD represents 1.26% of GDP in the EU15, it accounts for less than 0.30% in Hungary. In several countries, the growth in corporate funding for research is trailing behind growth in public funding, a trend that is cause for concern, particularly in relation to the target of devoting 3% of GDP to R&D set by the European Council.

Some hope may come from the direct foreign investment flowing into the new Member States but this cannot offset the low level of industrial funding for research. The interest shown by European and US firms seems primarily driven by the desire to establish themselves in a low-cost area for production and to position themselves in expanding markets. These ventures are rarely intended to make use of local S&T expertise. However, foreign investment has provided the momentum for the development of a number of technological niches (such as pharmaceuticals and motor vehicles in Slovenia, information and communication technology in Estonia and lighting in Hungary).

In summary, whereas the new Member States are trailing in industrial research, they have a strong tradition in academic research to fall back on, even though this sector lacks resources.

THE FUTURE: AN OPEN BOOK

The state of R&D in the EU is a mixed bag: the heavyweights, such as France, Germany and the UK, are experiencing stagnation, whereas the new Member States are continuing to trail behind. Should we be pessimistic about the chances of achieving a European Research Area?

The main issue is whether countries can overcome economic hurdles and find the political capacity to defend research in an often difficult context. Efforts by the new – but also the older – Member States will be hindered by financial restrictions resulting from the need to control budget deficits in countries wishing to join – or remain in – the euro zone. The over-ambitious target of 3% of GDP will not be achieved by 2010 in the 25-member EU and will have only a slight chance of being achieved in the 15-member EU. The entry of ten new Member States should prompt a fresh look at Europe's objectives and needs. Where should efforts be focused and where do priorities lie? Should disparities be allowed to grow? Should centres of excellence be promoted? Should countries be provided with back-up whenever integration is not possible? Clearly, there is broad scope for reflection. The first move of this new EU should be to devise a major common project for R&D.

The task may be made easier by the fact that eight out of ten citizens in the new Member States see science as an asset. We must not disappoint these new citizens of the EU; rather, we should see to it that R&D contributes to their economic development and social well-being.

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In 1999, Laurence Esterle was appointed Deputy Director of the Observatoire des sciences et des techniques (OST), a French public institute responsible for producing S&T indicators and analysing R&D systems. She went on to become Director of OST two years later, a post she occupied until the end of her mandate in May 2005.

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South-East Europe

GEORGI ANGELOV, KOSTADINKA SIMEONOVA and IVO SLAUS

For most of South-East Europe,[1] the closing decade of the twentieth century was a time of sweeping changes and turmoil, including such atrocities as regional and ethnic wars. Today, the majority of states in the sub-region are still in the throes of a radical transformation of their political, social and economic systems set in motion by the fall of the Berlin wall in 1989. One of them, Yugoslavia, has even disintegrated into five new states. For all the countries in transition, the past decade has been marked by economic weakness and grave social problems. Only Slovenia has managed to sail through the transitional period, even succeeding in becoming a Member of the European Union (EU) in May 2004. In a reflection of its new status, Slovenia straddles both the present chapter and that on the EU (see page 87). Greece, for its part, has escaped unscathed from this period of turmoil, thanks to its political stability and membership of the EU.

The science and technology (S&T) systems of the countries in the region have similarly been subjected to far-reaching and unprecedented changes. Economic difficulties have led to chronic underfunding of S&T activities, the collapse of the knowledge-producing system and a gradual disengagement by both governments and society. Prior to the transition period, institutes performing applied research and development (R&D) had enjoyed close ties with local industry; in some cases, they had been part of economic blocs like the former COMECON (Bulgaria and Romania). In the 1990s, these ties were broken. Cooperation with industry ceased for the majority of R&D units, which were incapable of building new relationships. Today, R&D funding comes mainly from government and, more particularly, from one prevailing source, the Ministry of Science. There are no incentives for the private sector to support R&D, since the national economies are import-oriented. A common problem for all countries is an intensive external 'brain drain' and, even more preoccupying, an internal brain drain, phenomena which demoralize researchers and diminish the inflow to science.

Under such unfavourable socio-economic conditions, the role international and intergovernmental organizations and initiatives play in revitalizing and transforming national S&T systems becomes very important. Some of these bodies aim at an overall stabilization of the region, whereas others are more specialized in rebuilding and reintegrating knowledge-producing and innovation systems. These initiatives create favourable conditions for cooperation in research both among the South-East European countries themselves and between them and the rest of Europe. Some of these bodies encompass only some countries of the region; others, like UNESCO with its global mandate, involve them all.

Since the adoption of the Stability Pact for South-East Europe (Cologne, 1999), the role of regional cooperation has been enhanced through multilateral and bilateral agreements and a better economic and political framework for R&D. The main objective of the Stability Pact is to bolster the efforts of countries in South-East Europe to foster peace, democracy, respect for human rights and economic prosperity, in order to achieve stability throughout the region. A comprehensive and coherent approach has been elaborated to achieve these objectives, involving the United Nations, the EU, the Organization for Security and Co-operation in Europe (OSCE), the Council of Europe, the North Atlantic Treaty Organization (NATO) and the Organisation for Economic Co-operation and Development (OECD), among others.

The EU's policy for South-East Europe is anchored in two strategies: accession to the EU, involving Bulgaria, Croatia, Romania and Turkey; and the Stabilization and Association Process for Albania, Bosnia and Herzegovina,

1 The countries in this region are: Albania (area of 28 748 km^2, population of 3.4 million), Bosnia and Herzegovina (52 280 km^2, 4.3 million), Bulgaria (110 993 km^2, 7.9 million), Croatia (56 542 km^2, 4.4 million), Greece (131 940 km^2, 10.9 million), FYR Macedonia (25 713 km^2, 2.0 million), Romania (237 502 km^2, 21.7 million), Serbia and Montenegro (Serbia: 88 361 km^2, 7.5 million (excluding Kosovo: 10 877 km^2, approx. 2 million); Montenegro: 13 812 km^2, 0.7 million), Slovenia (20 273 km^2, 2.0 million), Turkey (814 578 km^2, 67.8 million). All figures are taken from official government webpages in 2004. The aforementioned countries are also referred to as South-East Europe, a region which sometimes includes Hungary and Moldova. In some political documents, Albania and the countries from the former Yugoslavia (listed in Table 2 overleaf) are labelled West Balkan countries.

Serbia and Montenegro, and the Former Yugoslav Republic (FYR) of Macedonia, to prepare for eventual membership of the EU. Formal talks between Croatia and the EU were scheduled to begin in December 2004 and between Turkey and the EU in October 2005.

The Venice Process initiated by UNESCO, the European Science Foundation (ESF) and Academia Europaea in November 2000 consists in rebuilding scientific cooperation both among South-East European countries and between them and the rest of Europe. It has essentially the same goals as the specific actions of the European Commission and its successive Framework Programmes; it does, however, lay greater emphasis on the regional aspect by encouraging the creation of regional networks. The latter approximate to centres of excellence or competence.

In the area of higher education, a pan-European process was launched in 1999 with the adoption of the Bologna Declaration. A pledge by 29 European countries to reform the structure of higher education in their respective countries in a convergent way, the Declaration reflects 'a search for a common European answer to common European problems'. This document launched the Bologna Process to create a European Higher Education Area by 2010. The process has three main goals: to simplify the patchwork of higher education qualifications; to improve mobility within Europe and attract students from around the world; and to ensure high standards.

This chapter looks individually at Croatia, Bosnia and Herzegovina (B&H), Serbia and Montenegro (S&MN) and FYR Macedonia, before studying in turn Bulgaria, Romania, Albania and Turkey. It then takes a closer look at the way in which the EU and other international bodies are bolstering the efforts of the South-East European countries to achieve stability and prosperity through regional and international cooperation.

CROATIA, BOSNIA AND HERZEGOVINA, FYR MACEDONIA, SERBIA AND MONTENEGRO

The social context

Economic and social indicators for Croatia, B&H, S&MN and FYR Macedonia deteriorated from 1989 to 1999, as illustrated in Tables 1 and 2. There have been sweeping demographic changes linked to the drop in the fertility rate and improvements in health. The population under 17 has decreased by 10% in Croatia, FYR Macedonia, S&MN and Slovenia, and by as much as 30% in B&H. The fertility rate in Croatia in 1999 was only 1.38. If, as expected, it drops to 1.15, this will imply a population decrease from 4.5 million today to 3.7 million in 2050.

Issues in human resources

External and internal brain drain is rampant in each of Croatia, B&H, S&MN and FYR Macedonia, with many science and engineering graduates either leaving the

Table 1
ECONOMIC INDICATORS FOR SOUTH-EAST EUROPE, 2002/03
Selected countries

Country	GDP/capita ($PPP[1])	GDP by sector (%) Agriculture	Industry	Services	Inflation (%)	FDI[2] as % of GDP	GDP growth (%)
Bosnia and Herzegovina	1 900	13	41	46	0.4	4.9	3.5
Croatia	8 300	10	33	57	1.5	6.2	5.0
FYR Macedonia	5 100	11	31	58	2.4	1.1	3.0
Serbia and Montenegro	2 200	26	36	38	8.0	3.6	4.0

1 Expressed in Purchasing Power Parity US$
2 Foreign direct investment

Source: CEPS (2004) *Europe South-East Monitor*, Issue 51; Central Intelligence Agency (2003) *World Fact Book:* www.bartleby.com/151

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Table 2
SOCIAL INDICATORS FOR SOUTH-EAST EUROPE
Selected countries

Country	Population (2003)	Employment change 1989–99 (%)	GDP/capita change 1989–99 (%)	Fertility rate* 1989	Fertility rate* 1999	Age structure 2003 (%) 0–14	Age structure 2003 (%) 15–64	Age structure 2003 (%) 65+	Effectiveness of governance on a scale of 0–100 (2003)	Rule of law on a scale of 0–100 (2003)
Bosnia and Herzegovina	3 989 018	–	–	1.88	–	19.4	70.5	10.1	14.9	19.1
Croatia	4 390 751	-13.1	-18.7	1.92	1.38	18.3	66.3	15.4	63.9	58.8
FYR Macedonia	2 063 122	-15.2	-31.2	2.45	1.75	22.0	67.5	10.5	44.8	44.3
Serbia and Montenegro	10 655 774	-10.1	-59.1	2.26	1.67	19.3	65.4	15.3	26.8	16.0
Slovenia	1 988 000	-3.1	+9.7	2.11	1.21	–	–	–	–	–

* Number of children per woman.

Source: Central Intelligence Agency (2003) *World Fact Book*: www.bartleby.com/151; WBI themes (2002): http://info.worldbank.org/governance; UNICEF (2001) *A Decade of Transition. The Monee Report*. Regional Monitoring Report.

country or pursuing a more lucrative career at home outside their field of specialization. Brain waste is even more serious than brain drain because it demoralizes both researchers and those planning to become researchers. As we shall see in a later section of the chapter, other countries in South-East Europe, such as Romania and Albania, are also suffering from this phenomenon.

There are also issues of concern in higher education. Croatia, B&H and S&MN share a high drop-out rate and drawn-out degrees. Each year in Serbia, for instance, 33 000 students enrol but only 12 000 are awarded their first degree. There are also few interdisciplinary and inter-faculty studies. The distribution of students shows a preference for social sciences (30%) and engineering (24%).

The percentage of young people enrolled in higher education varies greatly in the region. It hovers at 25 to 30% in Croatia and S&MN, and at 15 to 20% in B&H and FYR Macedonia, compared with a high of 50% in Slovenia. The number of degree holders in the region is also low. In Serbia and Croatia, for example, only 7% of the population hold a university degree. Given the current low number of degree holders, it is disturbing that efforts to improve adult education are almost non-existent in all four countries.

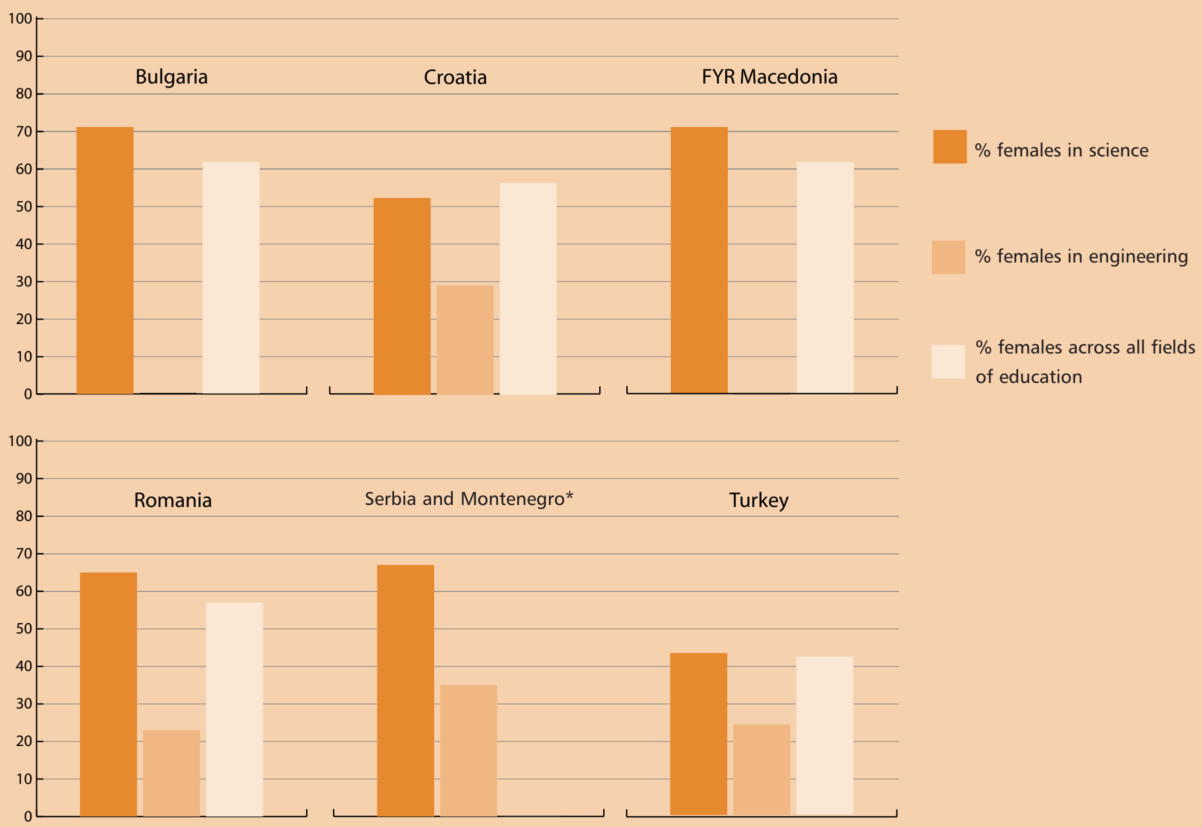
It is interesting to note that a gender balance in higher education prevails throughout the region, with the exception of Turkey (Figure 1). According to Eurostat, Turkish women nevertheless represented 25% of graduates in engineering, manufacturing and construction in 2001 and 44% of graduates in science fields (Table 13). In some countries, there is even a gender imbalance in favour of women; in B&H for example, women made up nearly two-thirds of university graduates between 1998 and 2002, according to the National Agency for Statistics.

Another trend common to many countries of the region is the constant rise in tertiary enrolment, particularly among women.

This rise in tertiary enrolment comes as good news at a time when the research community in South-East Europe is ageing. Of Croatia's 7 433 PhD holders, for example, only 2 600 are younger than 50 (Table 4). Although most of these PhD holders (6 504) are employed as researchers, 16.3% of them did not publish a single paper from 1991 to 1998. The most productive age group in Croatia appears to be those aged 53 to 63. On the more positive side, the great majority of PhDs obtained in 2001 were in the hard sciences. Medicine dominated (26.7%), followed by engineering (22%), natural sciences (20.8%), social sciences (12.5%), the humanities (10.2%) and biotechnology (7.8%). The average age of those receiving doctorates was 40 years.

The strength of the R&D potential in each of the four countries of the former Yugoslavia is currently below the threshold for achieving national priorities. For instance,

Figure 1
FEMALE SCIENCE AND ENGINEERING GRADUATES IN SOUTH-EAST EUROPE, 2001
Selected countries



* Data for Serbia and Montenegro are for 2000.

Source: UNESCO Institute for Statistics.

Croatia's 7 443 PhD holders and 280 000 other graduates fall far below the critical mass needed. The same is true of active researchers: there are currently between 2 000 and 4 000 in Croatia when there is a need for at least 20 000. Nearly half of FYR Macedonia's researchers hold a PhD. Most of these are in engineering (47%), followed by agriculture and the humanities (13%), medicine (11%), social sciences (10%) and natural sciences (6%).

The biggest development problem facing the Serbian province of Kosovo, with its 90% Albanian and 10% Serbian population, is illiteracy. Although primary and secondary education have improved over the past 50 years, Kosovo still lags behind: in 1953, 55% of Kosovo's population aged over ten years was illiterate, 38% male and 72% female. By 1981, illiteracy had shrunk to 18% (9% male and 26% female), with 34% of the population completing primary education, 7% secondary education and 3.3% tertiary education. Although things are slowly improving, even today only 17% of teenagers complete secondary education.

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The Bologna Process

All four countries under study have embraced the Bologna Process, one of the goals of which is to ensure high academic standards in tertiary education throughout Europe.

A law on education reform recognizing the principles and objectives of the Bologna Declaration (1999) was endorsed by the Federation and the smaller Republica Srpska which make up B&H and presented to the Peace Implementation Council in Brussels on 21 November 2002. A majority of higher education institutions in B&H have since adopted the plan of reforms and it is anticipated that, by the year 2010, the Bologna Process will be applied fully in B&H universities. The biggest university in the country – Sarajevo University – has paradoxically also been the slowest to implement the Bologna Process.

In 2000, Croatia initiated a process of reform of its R&D and higher education systems as part of its move towards a knowledge-based society. In May 2001, Croatia joined the Bologna Process and, in turn, passed a law aligning higher education with the Bologna Declaration.

As with Croatia, the Constitution of FYR Macedonia grants autonomy to universities. In FYR Macedonia, there is a quota whereby a certain percentage of university places is allocated to ethnic minorities. FYR Macedonia ratified the Lisbon Convention on the recognition of qualifications in March 2003. All three Macedonian universities have developed programmes that fully implement the Bologna Process.

In February 2001, the Ministry of Education and Sport of the Republic of Serbia defined its mission for establishing a modern higher education system in accordance with the Bologna Process. A special problem in Serbia has been the 1998 law governing universities which cancelled the autonomy of institutions of higher education. That law has resulted in the suspension of Serbian universities from the Association of European Universities. Similarly inadequate laws and practices regulating science in Croatia in the early 1990s have prevented Croatia from being admitted to the European Science Foundation.

The Ministry of Education and Science in Montenegro made an unorthodox decision in 2003 to transfer higher education reform and the drafting of a new law for higher education to the University of Montenegro. Montenegro plans to establish a Bologna Commission for coordinating, supervising and monitoring the reform.

The R&D framework

All four countries have, on several occasions, declared R&D to be a national priority. It must be said, however, that the R&D potential is below the vital threshold for achieving any national priorities. In all but Croatia, where industry supports R&D to the tune of 0.5% of GDP, R&D funding comes from a single source, the Ministry of Science. There are no adequate centres of excellence or adequate support for internationally recognized scientific research, nor for international cooperation, particularly when it comes to participating in major international collaborative projects using international research facilities. Support from the EU and the USA for various collaborative projects in the 1980s was considerably larger than current support through the EU's Fifth (1998–2002) and Sixth (2003–07) Framework Programmes.

In the 1970s, the scientific productivity of Yugoslavia was comparable to that of Hungary, Spain, Ireland, Austria

Table 3
R&D EFFORT IN SOUTH-EAST EUROPE, 2000
Selected countries

	GERD/ GDP ratio (%)	Researchers per million inhabitants
Albania	<0.1	–
Bulgaria	0.49[1]	1167
Croatia	1.00	1187
Romania	0.39[2]	879
Serbia and Montenegro	–	1085
Slovenia	1.52	2258
Turkey	0.64	306

1 2002.
2 2001.

Sources: for GERD/GDP data: OECD; for Croatia: UNESCO Institute for Statistics, 2004; for Albania: Dega (2003); for researchers per million inhabitants: UNESCO Institute for Statistics, 2004.

and Greece. According to the *World Science Report 1998*, Yugoslavian productivity dropped in the 1980s to the point where it was more comparable to that of Portugal, Romania and Bulgaria.

Most R&D is performed by the university sector in each of Croatia, B&H, S&MN and FYR Macedonia. Whereas several universities could once boast of figuring on the list of the world's 500 leading universities, not a single one appears on that list today.

R&D in Bosnia and Herzegovina

There is a separate R&D system for each of the two entities that make up B&H, the larger Federation and the Republica Srpska. The Federation and its cantons invest € 2.7 million in R&D annually, of which € 1 million is set aside for research projects.

In 1990, the population of B&H comprised 18% of the Yugoslavian population and B&H produced 13.6% of Yugoslav GDP, or US$ 10.5 billion. This contribution fell dramatically during the war and only began to recover after 1995. By 2003, GDP had climbed back to 50% of its value 13 years earlier.

Whereas, in the late 1980s, 30% of exports were based on domestic R&D, no company had a single product in this category in January 2002. In 1990, B&H counted about 2 000 researchers who spent annually US$ 43.5 million, or US$ 22 000 each. By the end of the 1990s, there were only 1 300 university professors and lecturers, which translated into 650 full-time equivalent (FTE) researchers. A further 650 researchers were employed in industrial R&D centres. In 1990, B&H spent 1.5% of GDP on civil R&D. The government share represented two-thirds of the total, with industry contributing the remainder. Still part of Yugoslavia at the time, B&H received 40% of the government share from Belgrade and 60% from local government, according to a 2002 science policy report by the Academy of Sciences and Arts of Bosnia and Herzegovina (ANUBiH), which was founded in 1966. Military R&D represented an additional 0.3% of GDP, bringing the total to 1.8% of GDP or US$ 195 million.

The first phase of the policy proposed by ANUBiH argued that the gross domestic expenditure on research and development (GERD) of B&H should reach pre-1990 levels by 2003, with 30% coming from the Federation and 70% from cantons. The same was demanded of the Republika Srpska. It is clear that this has not been achieved. Today, there are 23 research institutes in the natural and social sciences, including an Institute for Genetic Engineering and Biotechnology, an Institute for Materials Science, institutes for history and economics, the industrial institutes of Energoinvest in the city of Sarajevo and the Institute of Metallurgy at Zenica. Research is conducted at centres of ANUBiH.

R&D in Croatia

More than 50% of research in Croatia is performed in the country's universities, of which there are six. The largest of Croatia's 28 public research institutes is the multidisciplinary Rudjer Bošković Institute in Zagreb, founded in 1950, which has 350 PhD holders among its employees and accounts for over 30% of Croatian scientific output. Other major research bodies are the Institutes for Medical Research, Oceanography and Fisheries, and Economics. Each was established

Table 4
AGE STRUCTURE OF RESEARCHERS IN CROATIA, 1991 AND 2001

Age group	1991 number	%	2001 number	%	% change
Under 29	1 071	10.5	713	7.8	-33.4
30–34	1 211	11.8	1 026	11.3	-15.3
35–39	1 326	12.9	1 173	12.9	-11.5
40–49	3 174	31.0	2 220	24.5	-30.1
50–59	2 409	23.5	2 674	29.5	+11.0
>60	1 054	10.3	1 274	14.0	+20.5
Total	10 245	100	9 080	100	-11.4

Source: Prpiç, K. (2002) Size, structure and dynamics of R&D personnel. In: Nada Švob Đokic (ed.), *R&D Policies in the South–East European Countries in Transition.* Zagreb, Croatia.

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more than 50 years ago and employs close to 100 individuals.

The Croatian Academy of Sciences and Arts in Zagreb is a learned society of 150 fellows, with an equal share of foreign fellows. The Academy hosts a research centre employing over 100 researchers (see also international cooperation).

Government expenditure on education in 1998 amounted to US$ 770.5 million, 90% of which covered salaries. The remainder was invested in infrastructure. Support for young researchers in 2003 accounted for 22% of the Ministry of Science's overall budget.

The Croatian Innovative Technological Development Programme launched in 2000 to develop infrastructure has led to the establishment of Croatian Business and Innovation Centres and Technology Centres in Split, Zagreb, Rijeka and Osijek. The TEST and RAZUM programmes fund the pre-commercial R&D of companies on the cutting edge of their field. Of more than 300 projects proposed for TEST funding, just over half have been approved.

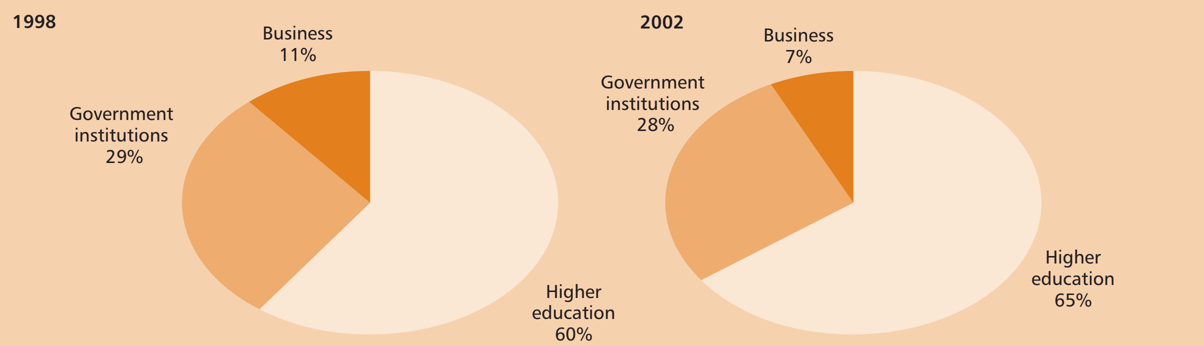
R&D in FYR Macedonia

FYR Macedonia's annual budget for a total of 375 research projects amounts to US$850 000 or the equivalent of 0.025% of GDP. As in Croatia, most research is performed by universities, of which there are three in FYR Macedonia. The number of researchers has declined, from 3 275 in 1998 to 2 838 four years later. In 2002, just under half (1 300) of researchers held a PhD: 47% in engineering, 13% in agriculture, 11% in medicine, 6% in natural sciences and the remainder in the social sciences and the humanities. For the employment of researchers by sector, see Figure 2.

The Macedonian Academy of Sciences and Arts was established in 1967. It comprises Departments of Linguistic and Literary Sciences, Social Sciences, Mathematical and Technical Sciences, Biological and Medical Sciences and the Department of Arts. The Academy also houses five research centres.

FYR Macedonia has 13 scientific institutes in all. National R&D priorities are biotechnology, high-quality food protection, new materials, water resources and management, sustainable development, energy, environment, information and communication technologies (ICTs), health, Earth sciences and engineering. The Institute for Seismology and Earthquake Engineering deserves individual mention, as it is world-renowned.

Figure 2
RESEARCHERS IN FYR MACEDONIA, 1998 AND 2002
By sector



Source: Jordanov, J. Pop (2002) *Short Review of Science and Technology in Republic of Macedonia*, private communication; Angelov, I. *et al.* (2001) Science in Macedonia. In: Proceedings.of conference on Reconstruction of Scientific Cooperation in South-East Europe, UNESCO ROSTE, Venice, pp. 75–8.

SOUTH-EAST EUROPE

R&D in Serbia and Montenegro

The R&D budget in S&MN amounted to just €13 million in 2000. As elsewhere in South-East Europe, R&D is performed mainly by the academic sector; the principal universities in S&MN are those of Belgrade, Novi Sad, Niš, Kragujevac, Montenegro and Pristina. The main body of researchers works at the University of Belgrade and at the largest of the country's research centres, the Vinča Institute for Nuclear Sciences in Belgrade.

Table 5
R&D INSTITUTIONS, PERSONNEL AND PROJECTS IN SERBIA AND MONTENEGRO, 2001

	Number of institutions	Personnel holding tertiary degrees	Completed research projects
Research institutes	55	2 903	1 449
(of which in engineering)	(16)	(1 038)	(499)
Development units	40	945	351
Faculties	77	8 877	1 578
Total	172	12 725	3 378

Sources: Government of Yugoslavia (2003) *Statistical Pocketbook*: www.szs.sv.gov.yu/StatKal3/Komplet.pdf; statistical data from Serbia and Montenegro; Trajkoviç, D. (2001) Encouraging international collaboration in research programmes. In: Proceedings of conference on the Reconstruction of Scientific Cooperation in South-East Europe. UNESCO Regional Bureau for Science in Europe (ROSTE), Venice, p. 117–26.

The TESLA Scientific Centre was founded at the Vinča Institute in 1996. The centre is the realization of a longstanding project for a medium-energy accelerator for nuclear, biomedical and material sciences research, and is a hub for international cooperation, even though the accelerator facility is not yet completed. There are plans to split the Vinča Institute into four separate bodies, one each for: basic research; applied R&D; the TESLA accelerator; and supporting activities.

The Serbian Academy of Sciences and Arts was founded in 1887 and the Montenegro Academy of Sciences and Arts in 1976.

Social impact of science

Major breakthroughs are one measure of the social impact of scientific activity in a country. For example, Croatian scientists have made significant contributions to particle and nuclear physics, in haematopoietic stem cell transplantation; genetic elements in the pathogenesis of cancer; in mineralized tissue and in environmental and marine research. For their part, Macedonian scientists are highly productive in sustainable energy research, environment and earthquake engineering, molecular biology and genetic engineering. Serbian and Montenegrin scientists are making key contributions to

Table 6
NUMBER OF RESEARCHERS IN SERBIA, 2001
By field of competence

	Research institutes	Development units	Universities	Total
Natural sciences	841	70	1 098	2 009
Engineering	1 038	422	2 229	3 689
Agricultural sciences	483	311	713	1 507
Medical sciences	197	85	2 094	2 376
Social sciences	184	8	1 119	1 311
Humanities	160	3	1 442	1 605
Multidisciplinary	–	46	182	228
Total	2 903	945	8 877	12 725

Source: Government of Yugoslavia (2003) *Statistical Pocketbook*: www.szs.sv.gov.yu/StatKal3/Komplet.pdf; statistical data from Serbia and Montenegro; Trajkoviç, D. (2001) Encouraging international collaboration in research programmes. In: Proceedings.of conference on the Reconstruction of Scientific Cooperation in South-East Europe. UNESCO Regional Bureau for Science in Europe (ROSTE), Venice, p. 117–26.

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Table 7
SHARE OF SCIENTIFIC LITERATURE OF SELECTED COUNTRIES IN CEE ZONE*, 1999
Percentages

Country	Medical research	Chemistry	Physics	All fields
Bulgaria	2.8	6.1	6.9	5.5
Czech Republic	7.8	13.1	9.7	11.9
Hungary	12.2	12.3	8.8	12.1
B&H	0.1	0.0	0.1	0.1
Croatia	4.1	3.2	2.9	3.1
FYR Macedonia	0.2	0.3	0.3	0.3
FR Yugoslavia	3.2	3.1	4.5	3.8

Note: the table contains only a selection of countries from the region, which explains why the percentages do not add up to 100%. The data are more useful for assessing the scientific activity in various disciplines within each country than for comparing various countries, since data are not given in relation to the number of inhabitants. For instance, Croatia's share of medical research is higher than its population share in all fields, whereas in the Czech Republic the opposite is the case.

* In the source, the CEE zone comprises Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, FYR Macedonia, Malta, Poland, Romania, Serbia and Montenegro, Slovakia, Slovenia and Turkey.

Source: Central European countries: Institute for Scientific Information Web of Science (2000 and 2004) http://wos.mimas.ac.uk/; for other European countries: Cadiou, Y.; Esterle, L. (2002) *Scientific Profile Activities in Central and Eastern European Countries*. UNESCO Regional Bureau for Science in Europe (ROSTE).

new materials and biotechnology; they have made breakthroughs with regard to the molecular basis of diseases and the development of new diagnostic and therapeutic strategies.

A second measure of scientific productivity is scientific publications in selected journals. The share of several Central, South-East and East European countries in scientific literature is given in Table 7.

The number of biomedical publications per 100 000 inhabitants in 1990 and 2000 is given in Table 8. Most countries show an increase in publications over this period and only B&H shows a significant decline. This trend is to be viewed with some caution, since it should be compared with the total number of publications for the whole of Europe. The data show that Slovenia has made considerable progress, increasing its scientific productivity 2.59 times. It now outperforms Croatia by a factor of 2.96.

An assessment of scientific activities in Central and Eastern Europe prepared for UNESCO in 1999 reveals a grouping of countries according to the number of publications per 10 000 inhabitants. The UK, USA, France, Germany, Japan, Spain and Italy all register between four and nine publications; Slovenia, Greece, Hungary, Estonia and Slovakia between two and four; Portugal, Croatia, Bulgaria, Poland and Cyprus all between one and two. S&MN falls in the 0.5–1 bracket, with B&H and FYR Macedonia both below 0.3.

Table 9 shows scientific activity, as measured by articles published. When related to population, the figures for Hungary and Slovenia are comparable. Finland's scientific productivity is outstanding and it is interesting to note the change there over a single decade: in the late 1970s, scientific activity per capita in Finland was comparable to that of Hungary and Yugoslavia. The scientific activity of Macedonia, which has roughly the same number of inhabitants as Slovenia, is almost a factor of 10 lower. Despite the fact that Croatia has six universities and 28 research institutes spread fairly evenly throughout the country, there is a strong concentration of productivity in just one city, Zagreb, which represents about one-fifth of the population.

The R&D potential of B&H and FYR Macedonia is modest. Moreover, the indicators for these countries, as for

Table 8
BIOMEDICAL PUBLICATIONS PER 100 000 INHABITANTS IN COUNTRIES OF SOUTH-EAST EUROPE, 1990 AND 2000

Country	1990	2000
Bosnia and Herzegovina	1.95	0.61
Croatia	18.40	26.00
FYR Macedonia	2.36	5.24
Serbia	11.92	11.34
Slovenia	29.63	76.84

Source: Fourth International Congress on Peer Review on Biomedical Publications, Barcelona (Spain), September 2001.

Table 9
NUMBER OF ARTICLES PUBLISHED BY SOUTH-EAST EUROPEAN COUNTRIES, 1991–2004
Hungary and Finland are given for comparison

Country	Number of current content* articles, 1993	Number of ISI articles 1991–2004
Slovenia	12 092	14 702
FR Yugoslavia/S&MN	9 639	–
FYR Macedonia	1 397	1 779
Croatia	11 505	14 272
Hungary	40 170	54 721
Finland	83 123	–

* Current content articles are a set of selected journals.

Source: ISI Web of Science (2004) Science Citation Index of Institute for Scientific Information, ISI-Thompson, Philadelphia, USA.

S&MN, are not reliable enough to assess in which research fields they are strongest. A comparison with earlier data on Yugoslavia and current data on Croatia and Slovenia reveals that, in all scientific disciplines, the total scientific productivity in each of the four countries is below the world average. This does not mean that all scientific papers are below the world average – on the contrary, quite a few are above. The impact factor data for Croatia, Slovenia and other countries between 1997 and 2001 are summarized in Table 10. It can be inferred from the impact factor that Croatian science, for example, is strongest in medical and natural sciences and quite weak in social sciences.

From 1992 to the present day, some 11 437 patent applications have been filed in Croatia, 4 340 of which have been filed by residents of Croatia and the remainder by non-residents. Currently, there are 1 780 valid patents in Croatia but only 396 are held by residents and 41 of these belong to two large companies, Pliva (29) and INA (12). Four pharmaceutical transnational companies hold a total of 193 valid patents in Croatia.

Information and communication technology

The number of mobile phones and personal computers is increasing rapidly in B&H, Croatia, FYR Macedonia and S&MN. For example, in Croatia, there were 35 personal computers per 1 000 inhabitants in 1996 but 90 in 2001; in S&MN, the figures are 16 and 23 respectively.

ICT is strongly interconnected with R&D, education, economics, health services and national security. A distributed environment for sharing resources is known as a Grid paradigm. (The Grid (*Globalisation des ressources informatiques et des données*) is a service for sharing computer power and data storage capacity over the Internet, unlike the Web, which is a service for sharing information over the Internet.) The current

Table 10
IMPACT OF SCIENTIFIC RESEARCH IN SOUTH-EAST EUROPE, 1997–2001
Countries outside the region are given for comparison

	Natural sciences	Technical sciences	Medical sciences	Biotechnical sciences	Social sciences
USA	7.02	2.21	7.36	2.66	1.95
Germany	5.77	1.72	5.71	2.00	0.81
Finland	4.97	1.69	5.61	3.03	1.40
Slovenia	2.87	1.17	2.30	1.35	0.43
Croatia	2.28	0.89	2.92	0.83	0.23
Bulgaria	2.05	1.02	2.31	1.43	0.46
Yugoslavia*	1.67	0.70	1.94	0.58	-0.31

* For Yugoslavia, the data are for 1986–1990.

Note: The impact factor is equal to the number of citations received by national scientific publications divided by the number of that nation's publications.

Source: Private communication by Professor Vito Turk based on data from the ISI Web of Science; Institut informacijskih znanosti Maribor (IZUM), September 2002.

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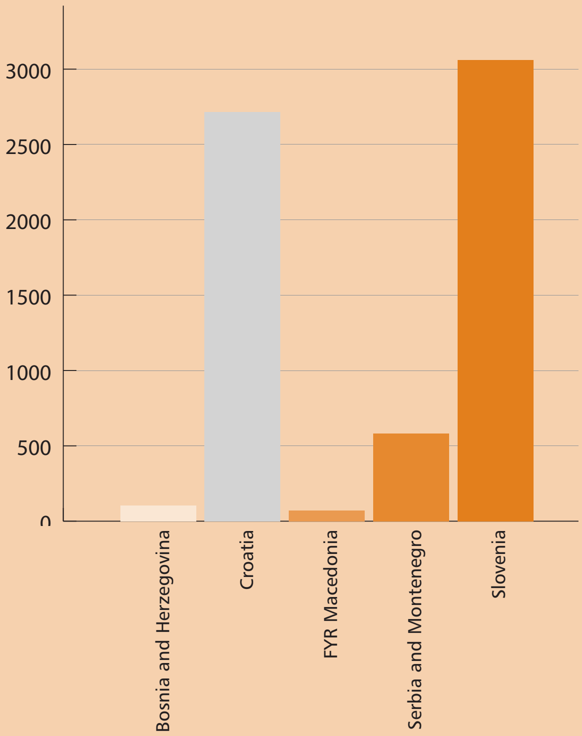
Figure 3
PATENTS GRANTED IN SOUTH-EAST EUROPE, 2004
Selected countries



Source: Advanced patent search, Thomson – Delphion: http://www.delphion.com/advquery

infrastructure in South-East European countries lacks adequate technology. This is why the SEE-GRID project within the EU's Sixth Framework Programme (2003–07) intends to provide support to countries from Croatia to Turkey to enable them to participate in European and worldwide Grid initiatives, thereby easing the digital divide. Known as Enabling Grid & E-Science in Europe, the project employs infrastructure provided by the Gigabit Pan-European Research and Education Network (GEANT) and the South-East European Research and Education Network (SEEREN).

The CRO GRID project, sponsored by the Croatian Ministry of Science and Technology, aims to provide Grid computing throughout the research and educational network in Croatia. It consists of three interlinked projects: CRO GRID Infrastructure, to provide all the necessary infrastructural elements for proper high-speed and high-throughput Grid computing, CRO GRID Middleware, to provide the necessary application organization, distribution, authentication, authorization and billing overlay, and CRO GRID Applications, where real life e-science applications will be developed for solving actual scientific and social problems, like genetics and molecular biology research. The Rudjer Boškoviç Institute in Zagreb is one of the primary initiators of the CRO GRID project and is involved in metacomputing technology, distributed computing test beds, high-speed computing, high-throughput computing, virtual laboratory (teleimmersion), e-science centre and data mining. Presently, the clusters in the Institute's campus GRID attain around 180 GHz Linux PC processing power.

Over the past decade, a variety of research networks have sprung up in the region, some of which have stagnated since their foundation. Slovenia, Croatia, Greece and Hungary all figure among the well-developed examples of the National Research and Education Network (NREN).

In September 1991, the Ministry of Science and Technology established the Croatian Academic and Research Network (CARNet). A year later, the first international Internet link was established, enabling Croatia to access the Internet. Today, some 176 institutions at 263 locations in 31 towns and cities in Croatia are connected via CARNet. All institutions in Croatian science and higher education are linked up at speeds of 2 Mb/s or better. The capacity of the CARNet link with the world is 1.2 Gb/s.

Research networking in B&H, FYR Macedonia and S&MN is on a much lower level. BIHARNet in B&H was set up with the help of the Slovenian ARNES but is still in its infancy.

The national AMREJ network is supported by the Ministry of Science, Technology and Development of S&MN. Connectivity within the country is based on a tar topology network with the Computing Centre of the University of Belgrade and the following centres connected to this node: Novi Sad University, Niš University, University of Montenegro and

University of Kragujevac (2 Mb/s). AMREJ has international connectivity to the Greek network (GRNet) of 2 Mb/s.

FYR Macedonia's Academic and Research Network (MARNet) at Ss. Cyril and Methodius University in Skopje became operational within the NATO Science Programme and GRNet in June 1995 at 64 Kb/s.

BULGARIA

Economic and political reforms in Bulgaria launched in 1990 were delayed throughout the decade by political instability, with a turnover of seven governments and five parliaments between 1990 and 1997 which made for a discontinuity in economic and legislative measures. Reforms in R&D likewise suffered.

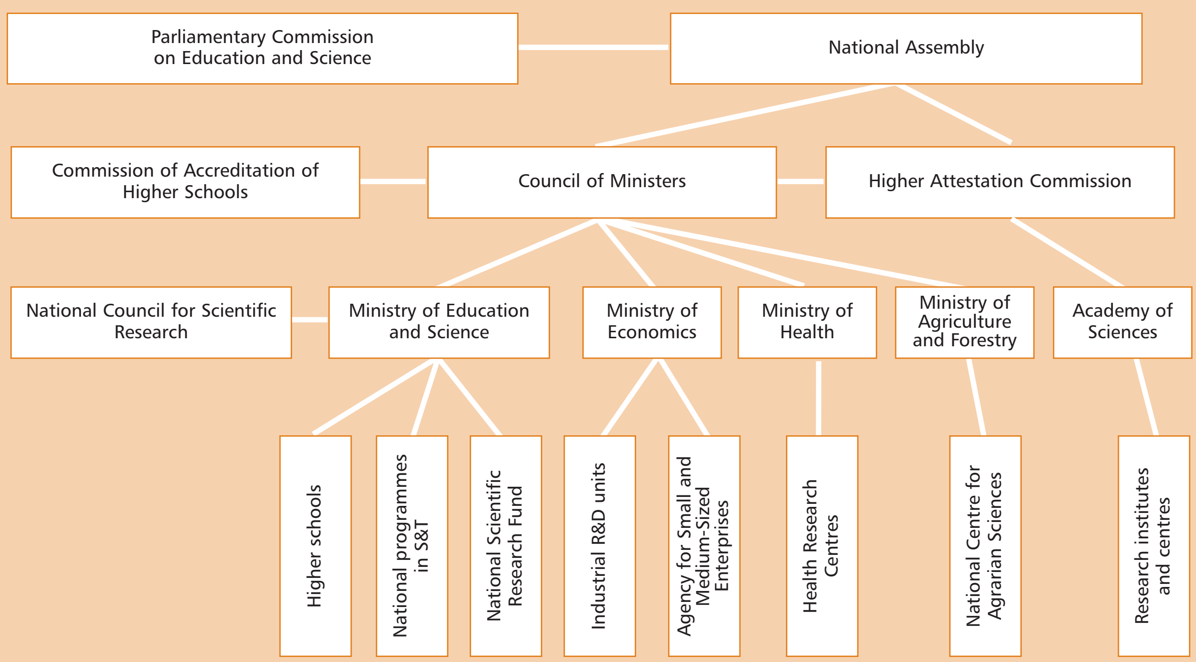
Things began looking up for S&T in 1999. Bulgaria entered a new phase of reform with the introduction of the Currency Board, which brought both financial and political stability. However, the most important factor has been the enlargement of the EU. In 1999, Bulgaria began negotiations to join the EU and to fulfil the requirements for membership; this has had a considerable impact on the country's R&D system.

S&T policy institutions

The first half of the 1990s was characterized by the lack of a comprehensive S&T policy and unstable institutional settings. Frequent changes in the government bodies responsible for S&T have not helped science: first, there was the merger of the Ministry of Science and Education with the Ministry of Culture (1994), followed by the setting up of a Ministry for Education, Science and Technology (MEST) a year later. Then, in 1997, MEST was reorganized into the Ministry for Education and Science, with the state's technology policy reverting to the Ministry of Economics.

The Law for Promotion of Scientific Research (2003) made the Ministry for Education and Science the

Figure 4
INSTITUTIONAL STRUCTURE FOR S&T POLICY MAKING IN BULGARIA



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government institution responsible for S&T policy, in accordance with the National Strategy for Research adopted by Parliament. The Minister of Education and Science is supported by the National Council for Scientific Research (NCSR) in defining and implementing state research policy; the NCSR is chaired by the minister, who appoints its 19 members. The NCSR participates in the elaboration of the national strategy, prepares reports on the state of the art and on the development of research institutions and higher education, and submits analyses and position papers on international cooperation and other research-related issues.

The National Fund for Scientific Research (NFSR) funds R&D on a competitive basis, in line with the National Strategy for Research and national programmes. NFSR is entitled to a share of the interest from bank credits accorded to R&D bodies whenever these credits are used to implement research projects that fall within the national strategy.

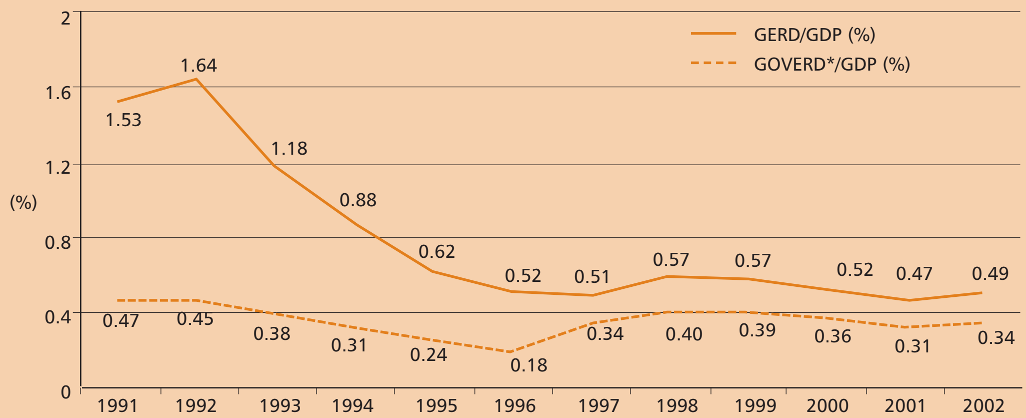
Innovation policy and R&D performed in the enterprise sector fall under the responsibility of the Ministry of Economics. R&D strategy is elaborated and implemented by other ministries: the National Centre for Agrarian Sciences, set up in 1999 after the former Academy for Agriculture was abolished, has been tied to the Ministry of Agriculture and Forestry, and the seven national research centres set up to conduct medical research after the closure of the Medical Academy are attached to the Ministry of Health Care. In preparation of strategic decisions on applied research, the respective ministries are involved.

In January 2003, the government adopted five priority national programmes in S&T. These programmes are each implemented by two or more ministries, with the Ministry for Education and Science being responsible for coordinating implementation. The five programmes are: information society; genomics; nanotechnologies and new materials; Bulgarian society – part of Europe and the world; and space research, science and society, sustainable development, global change and ecosystems[1].

R&D funding

Bulgaria appears to have little prospect of meeting the Barcelona target fixed by the EU of a GERD/GDP ratio of 3% for Member States by 2010. Since the national S&T system first underwent transformation, GERD has dropped in Bulgaria from 2.38% (in 1988) to just 0.49% of GDP (Figure 5). The budget allocation is negligible. The EU, on

Figure 5
GOVERNMENT CONTRIBUTION TO GERD IN BULGARIA, 1990–2002



* GOVERD: Government intramural expenditure on R&D.

Sources: NSI database for respective years.

SOUTH-EAST EUROPE

the other hand, already devotes 1.8% of GDP on average to R&D (see page 87).

According to EUROSTAT, the proportion of business expenditure on R&D (BERD) to total GERD amounted to only 18.6% in 1998. This did not even match the level of BERD in Bulgaria in the 1980s. For the knowledge base of industry to broaden and for an innovation policy to take shape, the share of BERD will need to rise. This does seem to be happening: by 2001 BERD represented 24.4% of total expenditure. For its part, government expenditure dropped over the same period from as much as 76.2% of GERD to 62.2% by 2001.

Human resources

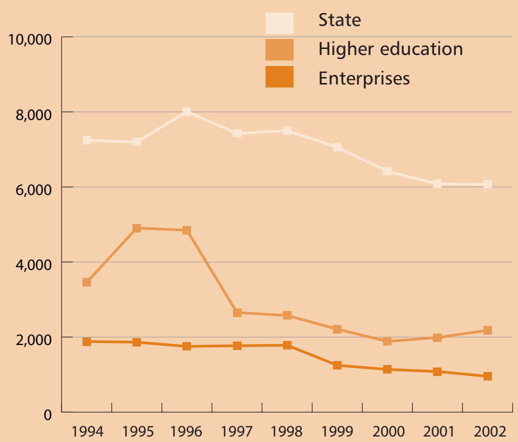
By 1992, the number of R&D personnel had shrunk to 55% of their level at the launch of reforms only two years earlier. The number of scientists decreased by 14% between 1998 and 2002, FTE researchers decreasing by as much as 23% over the same period, from 12 608 to 9 223 (Figure 6). There were 2.68 FTE researchers per 1 000 workers in 2001, representing an average annual drop of 3.0% since 1996. The low social prestige of researchers in Bulgaria is reflected in the R&D expenditure per FTE researcher, which in 2001 was one of the lowest in the current 25-member EU, at € 8 000 (at current values).

The picture is rosier for women researchers. In terms of head count, women represented 45.5% of all Bulgarian researchers in 2001, corresponding to the high end of the scale within the 25-member EU. Bulgaria ranks fourth after Latvia, Lithuania and Portugal. Less positive is the drop in recruitment of women in R&D from 1998 to 2001, which was not in line with EU policy.

The number of PhD students increased by more than 250% to 3 585 between 1995 and 2001 and the number of Bachelor's and Master's degree students quadrupled. This positive trend is mitigated by an average annual decline in PhDs in the science and engineering fields of 2.5% between 1998 and 2001. The number of PhDs per 1 000 inhabitants aged 25 to 34 amounted to only 0.11 in 2001.

The ageing of researchers poses one of the biggest headaches for human resources policy. The outflow of younger researchers to other professions and abroad has created an imbalance in the structure of R&D organizations. Judging from the most recent quinquennial survey by the National Institute of Statistics, however, a career in research is becoming a more attractive prospect again for the young (Figure 7). This image is somewhat tarnished by a 5.1% drop in S&T graduates every year between 1998 and 2001.

Figure 6
RESEARCHERS (FTE) IN BULGARIA, 1994–2002



Note: The fourth category, that of the private non-profit sector, is small in Bulgaria. There were only 23 researchers employed in this category in 1994 and 18 in 2002, with a peak of 145 in 1996.

Source: NSI database for 1996–2002.

Organizations performing R&D

In 2002, there were 361 R&D units in Bulgaria, 26.6% of which were in the enterprise sector, 44.0% in the government sector and 27.4% in higher education. The remainder were confined to the non-profit sector. The total number of R&D institutes decreased by 19.2% between 1998 and 2002. Of the 99 R&D units in the higher education sector, 42 are located in universities, three of

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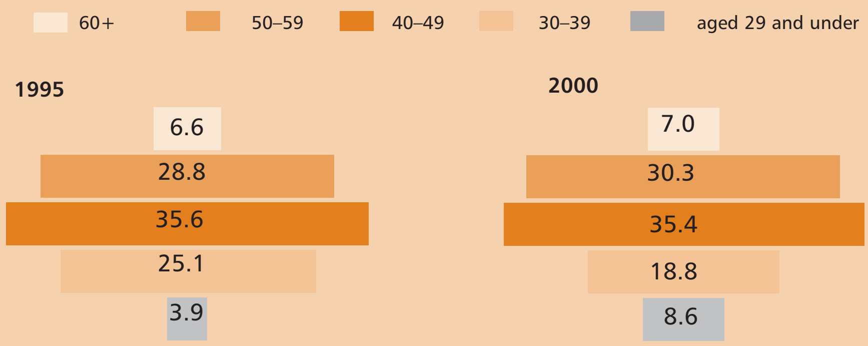
Figure 7
AGE PYRAMID OF BULGARIAN RESEARCHERS, 1995 AND 2000
Percentages



Source: Quinquennial survey by the Bulgarian National Institute of Statistics.

which are privately run and accredited by the National Agency of Accreditation. In the government sector, the majority of R&D units fall under the umbrella of the Bulgarian Academy of Sciences and the Agricultural Academy. Whereas the Bulgarian Academy of Sciences lost only one of its 75 units between 1998 and 2002, the R&D units administered by the Agricultural Academy (now the National Centre for Agrarian Sciences) shrank from 76 to just 28.

Eighteen state government institutions perform R&D for the different state agencies and ministries to which they are attached. These R&D activities relate to the ministries' special missions: foreign policy, security policy, information technology, culture, environmental issues, energy and so on.

Bulgarian Academy of Sciences

The Bulgarian Academy of Sciences was founded in 1869 as a learned society. In its 135-year history, Academy members have had internationally recognized achievements in mathematics, physical chemistry, atomic physics and the life sciences, as well as in some applied research fields such as materials science and geophysics. The Law of the Bulgarian Academy of Sciences (1991) confirmed its status as a centre for national research and its 74 units were given a great deal of autonomy. Between 1990 and 2003, staff numbers were reduced by 6 648 (or 44.8%), including the loss of 1 447 (28.8%) researchers. In recent years, the Academy has seized new opportunities by shifting its focus from basic to more applied research. The nationwide role of the Bulgarian Academy of Sciences is unique in such fields as weather forecasting and geomagnetic prognoses, among others.

The Academy participates in higher education at all levels on the basis of agreements with universities. It is also accredited to supervise PhD students; the Centre for Education was set up for this purpose and to coordinate, monitor and manage teaching by the institutes of the Academy.

The Academy hosts four out of five Bulgarian centres of excellence set up under the EU's INCO 2 programme (see page 132). The fifth centre of excellence, that for Agrobiological Studies, was set up by the National Centre for Agrarian Studies which itself dates from 1999.

The National Centre for Agrarian Sciences (the former Agricultural Academy) is attached to the Ministry of Agriculture and Forestry. It operates 28 research institutes, as well as Centres for the Qualification of Personnel and for

Table 11
BULGARIA'S HIGH-TECH TRADE, 2000

High-tech exports			High-tech imports			
Amount (€ billion)	As % of total exports	Average annual growth rate 1996–2001 (%)	Amount (€ billion)	As % of total imports	Average annual growth rate 1996–2001 (%)	Balance (€ billion)
0.1	1.6	1.6	0.6	8.3	22.3	–0.5

Source: Statistics in Focus, Science and Technology Theme 9 – 2/2004, p.3.

Scientific and Technical Information, and the National Museum of Agriculture.

Research output

The share of Bulgarian authorship in international publications has stabilized to approximately 0.2% of those listed in the SCI database: in 1990 1 407 Bulgarian publications were cited. Eight years later, the number was still comparable but it dropped significantly in 2001. Behind this decline lie the migration of productive researchers and the removal of the one Bulgarian journal that had been on the list used by the Institute for Scientific Information in Philadelphia (USA). Recovery seems to have begun in 2003 when 1 420 Bulgarian publications were cited in the ISI database.

Since 1990, Bulgarian scientists have tended to co-author publications with scientists from Germany, the USA, France and Italy to the detriment of Russia. Russia has fallen from being the primary partner to ranking fifth. The geography of joint publications today extends to new partners such as India, the Republic of Korea, Japan, Canada and Australia. The Bulgarian Academy of Sciences accounts for more than 60% of international publications co-signed by Bulgarian authors.

Bulgaria’s specialization by field of research covers applied physics, physical chemistry, materials science and organic chemistry. Bulgaria’s share in international co-authorship has increased in the biological sciences, physics, chemistry and Earth sciences.

Patent activity has fallen off in the past decade. There was an average of 16.4 patent applications per year to the European Patent Office (EPO) in 1985–89 but this had dropped to 7.2 by 1990–94. The US Patent and Trademark Office (USPTO) granted 27 Bulgarian patents in 1990 but only 1 in 1995. There is, however, a glimmer of hope: patent applications to EPO amounted to 1.0 per million inhabitants in 2000, representing a 5.7% growth rate between1995 and 2000. Less encouraging is the innovation output from R&D, as measured by the high-tech trade balance, which was negative in 2000 (Table 11).

Prospects for the new Innovation Strategy

The future development of S&T is articulated in two recent documents: the *Innovation Strategy of the Republic of Bulgaria*, adopted by the Ministry of Economics in 2004, and the *National Strategy for Science* drafted by the Ministry for Education and Science. The first of these documents articulates the state’s firm commitment to strengthening R&D by 2013, taking into account the strengths and weaknesses of the national innovation system. The financial plan for the ten-year innovation strategy foresees an increase in funding that will lift Bulgaria’s GERD/GDP ratio from 0.49% in 2002 to 1.15% by 2013 and BERD from 0.11% to 0.32% of GDP.

Ten measures are outlined within the Strategy. Four are financial instruments covering the creation of two separate funds, a special provision for job creation for young specialists in small and medium-sized enterprises (SMEs) and, last but not least, support for new or existing centres of competence. The non-financial instruments envisage the optimization of still-fragmented S&T activity by evaluating R&D bodies.

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ROMANIA

The reforms of Romania's science system follow much the same pattern as in the other Central and Eastern European countries. S&T policy has become more active in Romania since 2001 as result of the invitation to negotiate membership of the EU and the adoption of a number of policy documents. These trends reflect the country's acceptance of the *acquis communautaire* about science and research, which itself coincides with the strategic reorganization of a number of government bodies overseeing S&T.

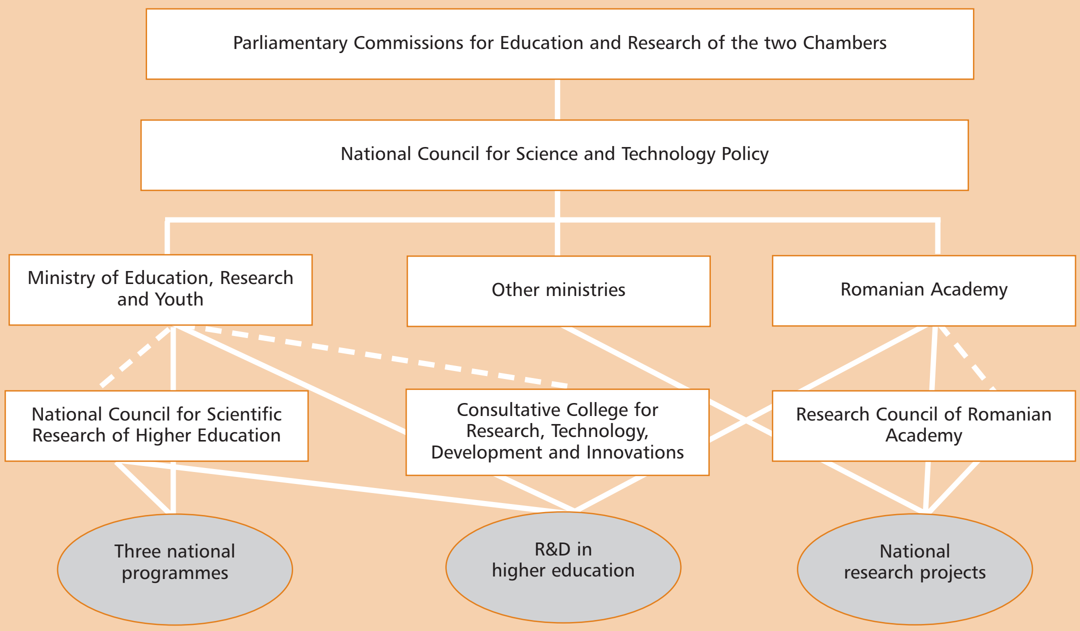
Romania has set six strategic goals for S&T: to intensify the economic and social impact of R&D in the public sector; increase the amount of public and private funds allotted to R&D and innovation; carry out institutional reforms; develop the R&D infrastructure; stimulate enterprise R&D; and integrate Romanian R&D into the European Research Area.

National S&T policy institutions

The Ministry of National Education and the National Agency for Science, Technology and Innovation merged in 2001 to form the Ministry of Education and Research, which was itself renamed the Ministry of Education, Research and Youth (MERY) two years later. The mission of the latter is to elaborate, apply, monitor and evaluate policies for research, development and innovation. The Ministry distributes 71% of the country's total R&D expenditure through three national programmes: the National Plan for R&D, updated in 2001 and extended to 2005 (55% of total MERY funding); the Horizon 2000 Programme, extended to 2002 (40%); and the Grant Programme for Scientific Research (5%).

The latest developments in science are the fruit of two pieces of legislation, the Law on Scientific Research and Technological Development and the Law on the Status of Research and Development Personnel, both adopted in 2002.

Figure 8
INSTITUTIONAL STRUCTURE FOR S&T POLICY MAKING IN ROMANIA



The main government body is the National Council for Science and Technology Policy (CISTI). It is responsible for setting strategic priorities in S&T and defining national R&D policy. Within the new R&D policy, a range of important institutions has been created: the National Centre for Programme Management, subordinated to MERY; the National Council for Research Certification, a unitary system responsible for the country's research institutes and staff evaluation; and, last but not least, the Investment Company for Technological Transfer, an organization mandated to take the risks inherent in marketing the application of research results, in both products and services.

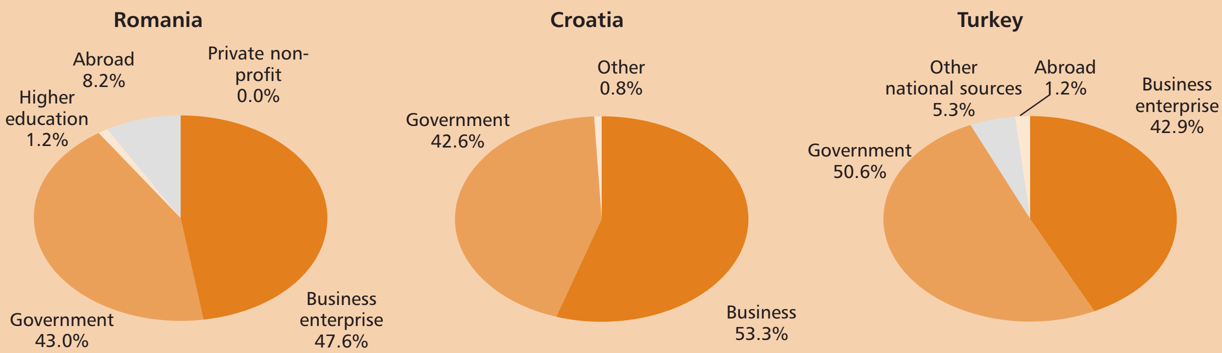
The picture would not be complete without the Romanian Academy, a long-standing body which performs most of the country's basic and applied research. The Academy runs 68 R&D institutes active in natural sciences and mathematics, technical sciences, life sciences, social sciences and humanities. Of the Academy's total staff of approximately 4 000 employees, 2 600 are researchers, including almost 2 000 certified researchers. The Academy's expenditure on R&D represents 18% of GERD. The Romanian Academy coordinates two national programmes: the Priority and Basic Research Projects and the Grant Programme for Scientific Research mentioned earlier.

Institutions performing R&D

In 2002, there were nearly 590 units performing R&D in Romania: 34 national R&D institutes, 18 of which were subordinated to MERY and the remainder to 7 other ministries; 227 public institutions subordinated to MERY, the Romanian Academy and the Academy for Agricultural and Forestry Sciences; 15 R&D institutes operating on the basis of a government decree from 1991, which were being reorganized in 2004; and 310 joint-stock companies, public or private companies with R&D as a main activity.

The sector of applied industrial research has been restructured. From 1995 to 2000, changes in ownership in the industrial R&D units brought about an increase in the private sector's role: private units rose from 64 out of 454 (14%) to 201 out of 439 (46%). By 1999, the private sector accounted for 18.6% of total employment in R&D.

Figure 9
GERD IN SOUTH-EAST EUROPE BY SOURCE OF FUNDS, 2001
Selected countries



Sources: for Croatia, UNESCO Institute for Statistics; for Romania and Turkey, European Commission (2004) *Key Figures 2003–2004.*

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The university sector includes 49 state and 68 private institutions; 18 of the latter are accredited universities.

Funding of R&D

Since 1990, GERD has shrunk in Romania, as in all countries of the region. In 2001, Romania invested €176.5 million in R&D, or the equivalent of 0.39% of GDP. In 1997–2001, R&D fell on average by 9.2% each year. The government budget allocation to R&D represented 0.17% of GERD in 2003, a negligible amount, following annual declines (of 6.0%) between 1997 and 2003.

As in Bulgaria, GERD has declined in absolute terms even as business funds have come to play a greater role in R&D funding (Figure 10). SMEs performed nearly half of all publicly funded R&D in 2001 (47.6%), compared with 42.0% five years earlier. Foreign funds grew over the same period to represent 8.2% of GERD, compared with just 2.6% in 1996. The government share dropped over this period from 54.9% to around 43.0% (Eurostat, 2000).

Human resources in R&D

The number of R&D personnel in Romania has shrivelled since the reform process was launched over a decade ago. This is due to the country's economic decline since the end of the cold war in 1989 and the lack of financial means to fund R&D in both the private and public sectors.

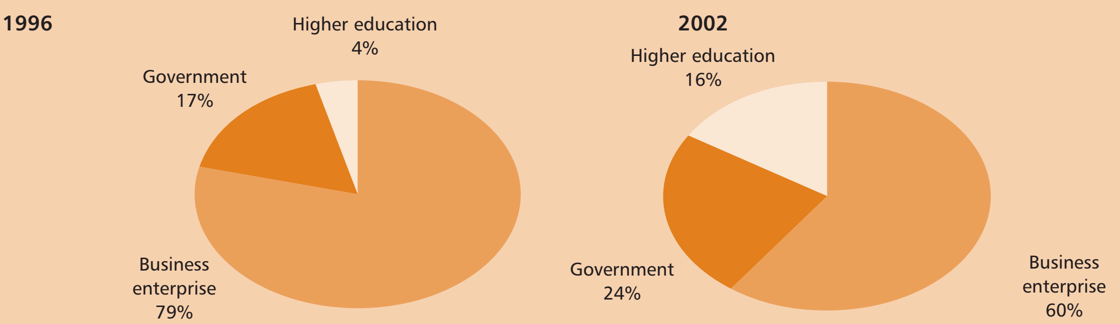
Personnel employed in S&T today represent 18% of the labour force aged 25–64. Between 1996 and 2001, R&D personnel (FTE) dropped by 45.5%, from 59 907 to 32 639. Behind this drop are voluntary departures motivated by low salaries, career uncertainty, migration abroad and a lack of effective recruitment, as well as the laying-off of personnel. By 2001, these factors has brought the number of FTE researchers down to just 1.71 per 1 000 workers. The share of R&D personnel in the business sector also decreased, from 71% to 61%. There are no signs of this trend reversing: a further decline of 11% was recorded in 2002–03. The structure of R&D personnel is shown in Figure 11 and the participation of women in research in Figure 12.

The supply side of human resources in S&T is reflected in the number of participants in tertiary education and new university graduates. In Romania, the former grew by 13.9% annually and the latter by 1.3% between 1998 and 2001.

Performance of R&D

Despite the difficult situation for R&D in Romania, some positive developments have been observed in recent years

Figure 10
R&D IN ROMANIA BY SECTOR OF PERFORMANCE, 1996 AND 2002



Source: OECD (2003) *Main Science and Technology Indicators*, November. OECD, Paris.

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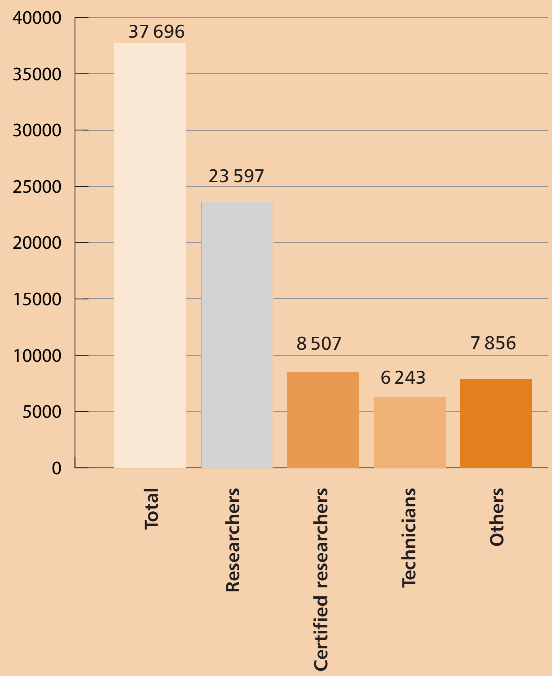
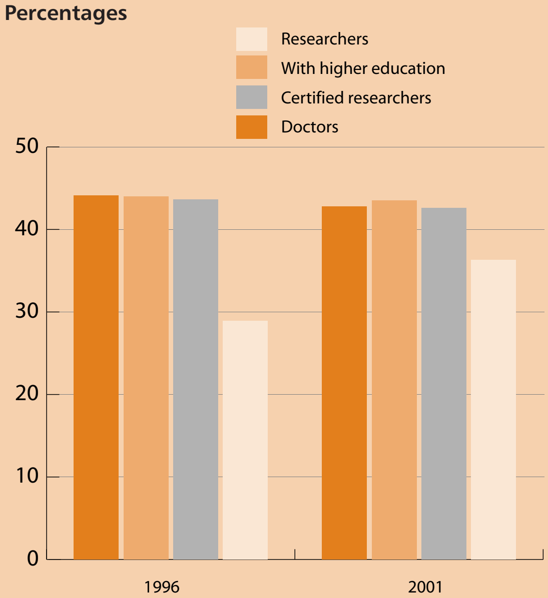
Figure 11
STRUCTURE OF R&D PERSONNEL IN ROMANIA, 2002
In absolute numbers



Source: NIS, *Statistical Bulletin 1/2002*.

Figure 12
SHARE OF ROMANIAN WOMEN IN R&D, 1996 AND 2001
Percentages



Source: NIS, *Statistical Bulletin 1/2002*.

in terms of output. There were 84 scientific publications per million population in 2002, an increase of 5% over 1995. The picture with regard to patents is more complex: although patent applications to the EPO have increased, from 2 in 1990 to 17 in 2002, these dropped back again to 4 in 2003 (half of which were granted), according to the EPO's annual report. In terms of patent applications per million population, the figures are similar for both the EPO (0.3 applications in 2000) and the USPTO (0.2 in 2002). In 2001 high-tech exports netted Romania €0.6 billion, or 5% of revenue from total exports. High-tech exports grew by 29.01% annually from 1996 to 2001, translating into a share of 0.05% of the world market by 2001. Pharmaceuticals and chemical products made up the biggest share of this export category.

ALBANIA

S&T institutions and legislation

In the mid-1990s, the Government of Albania sought the assistance of UNESCO in creating an efficient S&T system capable of integrating Albania into the world economy. UNESCO was asked for advice on four topics: the formulation of a national S&T policy; international relations in S&T; S&T statistics; and the formulation of a science budget for the government. The result was a report to the Albanian Ministry of Education and Science, financed jointly by UNESCO and UNDP, on *The Development of Albanian S&T Policy* (August 1996).

The functions and relations governing Albania's institutions for S&T policy are defined by two principal laws: the Law on Higher Education in the Republic of Albania passed in 1999 and the Law on Science Policy and Technological Development passed in 1994. The latter states that 'scientific and technological activities constitute a national priority' (Article 3). The institutions responsible

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for the elaboration and implementation of Albanian S&T politics are pointed out in the Law and, in conformity with their functions, constitute a structure with three levels: political, strategic and operational (Figure 13).

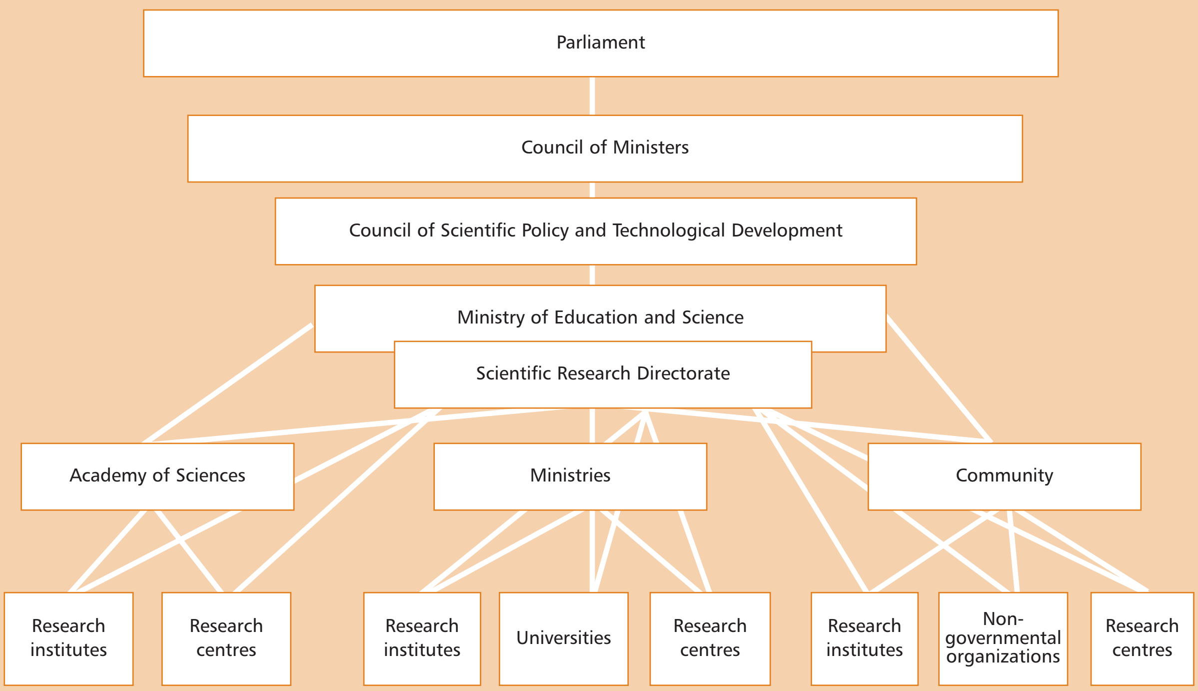
If Parliament approves laws concerning the functioning of the S&T system, budget and appropriation for R&D and higher education, the Law on Science Policy and Technological Development stipulates that the government 'creates the legal and organizational conditions for the S&T activity and supports the activity of relevant state institutions and their personnel'. It is the government that approves the priority research areas, the budget for national R&D programmes and the establishment or closure of public R&D institutes.

The members of the Council of Scientific Policy and Technology Development (CSPTD) are appointed by the Council of Ministers. The CSPTD consists of heads of ministries and central bodies, together with distinguished scientists. The number of members should not exceed 15. The CSPTD approves the orientation and priorities of the S&T policy and R&D programmes. It makes recommendations and proposals concerning draft laws and decisions on S&T activity and on priority research areas.

The Ministry of Education and Science (MoES) wears two hats; it defines S&T policy and plays a coordination role. The MoES has responsibility for administrating national S&T programmes funded through the Public Investment Programme. In this latter role, it supports S&T programmes in other ministries, drafts national S&T policy documents and prepares the total budget for R&D programmes.

The ministries and the Academy of Sciences draft sectoral S&T policy documents, administer the budget for national R&D programmes and approve the financing of their respective institutes. The various scientific institutes come under the umbrella of the central Academy of Sciences. The Academy is entrusted with conducting scientific research, helping to open up new fields for

Figure 13
INSTITUTIONAL STRUCTURE FOR S&T POLICY MAKING IN ALBANIA



scientific research, petitioning the relevant government authorities with important issues related to the situation of R&D and, last but not least, working towards the integration of Albanian science into world science.

Institutional mechanisms for R&D

Article 9 of the Law on Science Policy and Technological Development states that the objectives of the country's S&T policy are to be attained through national R&D programmes. These programmes identify R&D objectives in the relevant field and the institutions and the scientific teams that will be collaborating on the project, including possible foreign partners; necessary improvements in infrastructure; the sources of budgetary and, in some cases, extrabudgetary funding; and expected results and time limits.

R&D activities are financed by the state budget in two complementary ways, institutional and according to the national R&D programmes. Institutional financing is given directly to the central organizations to support the R&D activities of their dependent institutions. Financing for programmes takes place through state budget funds designated for the R&D programmes and given directly to the organizations that manage these programmes, and through funds given to the Ministry of Education and Science to finance different projects in a competitive way following known and standard procedures. The role of national R&D programmes is to finance from the state budget 'bottom-up' initiatives for R&D.

Some of the drawbacks of projects run within the national R&D programmes are that funds are always allocated at the end of a fiscal year, making project management difficult; the national R&D programmes also offer few possibilities to pay in-house human resources.

In the first round (1995–98), 12 national programmes were approved by the CSPTD. For the ensuing four-year period, the list was half as long (Table 12). The six programmes defined for the period 1998–2001 are still ongoing because funding was interrupted in 2001. Institutes of the Academy of Sciences take part in all but the programme for agriculture and food.

Institutes involved in R&D activity are affiliated to the Academy of Sciences or one of the government ministries. Nearly 85% of Albania's 46 research institutes are affiliated to just three bodies. Those not listed in Table 12 are the Ministry of Health (one institute), the Ministry of Culture, Youth and Sports (two) and the Ministry of Construction (two).

The Academy of Sciences

The Academy of Sciences was founded in 1972 as an autonomous institution funded by the state budget. It is the most prestigious scientific institution in Albania. It comprises eminent Albanian scientists (Academicians) and 13 research institutes and centres employing nearly 250 researchers. Institutes are grouped in two sections. The Natural and Technical Section comprises hydraulic research, nuclear physics, informatics and applied mathematics, seismology, biological research, geographical studies and hydrometeorology. The Section of Albanology focuses on archaeology, linguistics and literature, art studies, history and popular culture. One centre is devoted to the Albanian Encyclopaedic Dictionary.

The Academy houses two large libraries: the Library of the Academy of Sciences and the Library of History and Linguistics. The administrative autonomy of research institutes and centres enables these to participate more easily in national and international projects. A considerable proportion of academic researchers work part time as teachers at universities. Besides R&D, some institutes host a total of 80 students for hands-on and speciality training.

The R&D system

The report prepared by UNESCO and the UNDP for the Government of Albania (UNESCO 1996) stated that, 'Although many of the Albanian institutes run by government ministries describe themselves as research institutes, it appears the bulk of their activities are scientific and technical services. Thus, the Albanian national system of innovation is, at present, primarily an S&T services system (as defined by UNESCO).' These institutes have staff that vary from 10 to more than 40 researchers. Only some

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are equipped with computers and not all have local networks. Internet connectivity is mainly dial-up.

In general, R&D suffers from a number of problems in Albania but mostly from a lack of adequate research infrastructure and a shortage of funds. It is estimated that GERD represents less than 0.1% of GDP but there are no precise figures because neither the National Institute of Statistics (INSTAT) nor MoES has collected statistical information about the financing of the S&T system.

The universities are a key element of the S&T system in Albania. There are currently ten of these.

In total, 900 personnel are working in R&D institutes, excluding R&D personnel at the universities and private not-for-profit institutes. A considerable number of highly qualified specialists have left R&D institutions and many have even emigrated abroad. This massive brain drain has been devastating for the S&T system: one researcher estimated that more than 1 000 out of the country's circa 1 600 university teachers had left the higher education system, caused in part by a 'lack of a clear view of the future of the S&T system'.

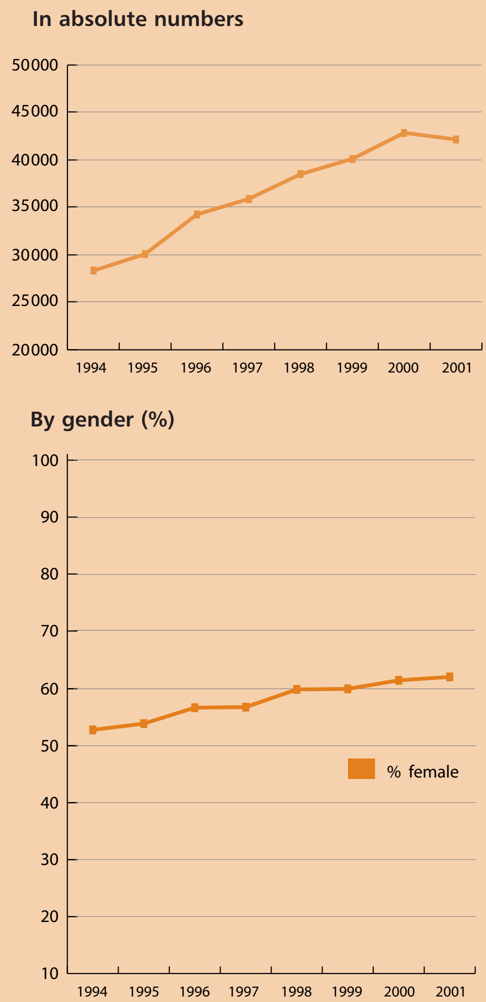
In a recent analysis of the role of the S&T system in development, the developing countries were subdivided into three categories of S&T capacity. First came the scientifically proficient countries which increasingly defined their relations with the scientifically advanced countries on the basis of equality or near equality; second came the scientifically developing countries with pockets of adequate S&T capacity amidst general scarcity of resources; and third came those scientifically lagging countries that lacked capacity almost entirely. Albania was placed in the third category.

Table 12
ALBANIA'S R&D PROGRAMMES, 1998–2001

Programme	Responsible body	Affiliated R&D institutes
1 Agriculture and food	Ministry of Agriculture and Food	14
2 Albanology 3 Natural resources	Academy of Sciences	13
4 Geology, mineral extraction and elaboration	Ministry of Public Economy and Privatization	12
5 Information systems and technology 6 Biotechnology and biodiversity	Ministry of Education and Science	2

Source: www.mash.gov.al/ministria_eng/kerkimi_shkencor/programme2000.html; www.mash.gov.al/ministria_eng/kerkimi_shkencor/institute_qendra.html

Figure 14
UNIVERSITY ENROLMENT IN ALBANIA, 1994–2001



Source: Albanian Institute for Statistics – INSTAT.

Higher education

It is some comfort that the data on higher education paint a more optimistic picture than those for R&D: university enrolment has increased rapidly over the past decade. The same can be said of graduate students, whose numbers have climbed from 3 708 in 1997 to 4 618 in 2001. Interestingly, women now represent close to two-thirds of students, compared with just over half in 1994 (Figure 14).

TURKEY

The S&T policy framework

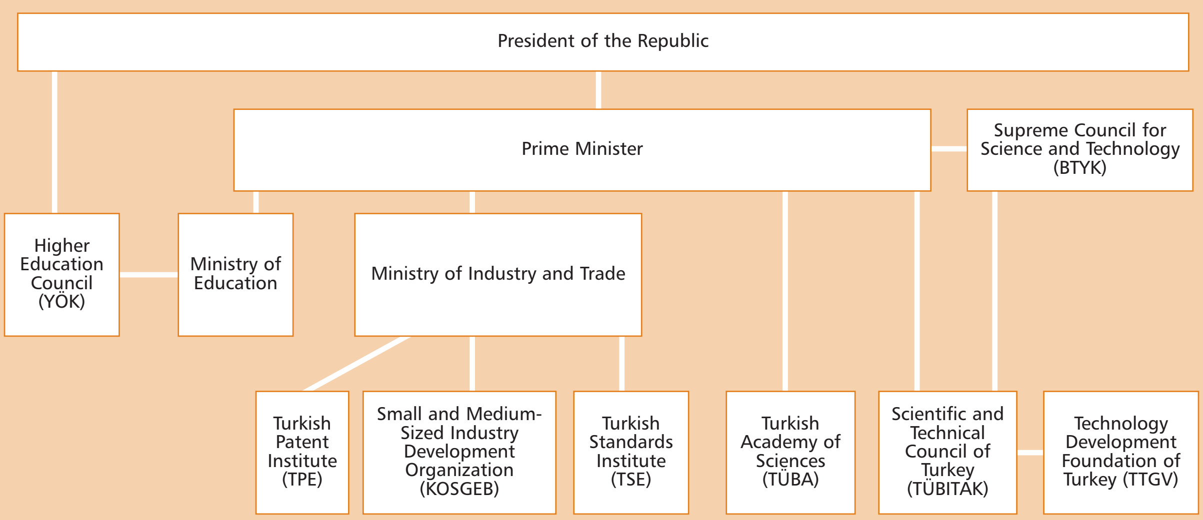
Over the past 20 years, three framework documents have guided S&T policy development in Turkey: *Turkish Science Policy 1983–2003, Turkish Science and Technology Policy 1993–2003* and *Impetus in Science and Technology* (1995).

Institutions that determine and coordinate Turkey's S&T policy are shown in Figure 15. The Supreme Council for Science and Technology (BTYK) was set up in 1983. Chaired by the Prime Minister, it assists the government in determining long-term S&T policies. The Council is made up of cabinet ministers concerned with S&T; the presidents of the Scientific and Technical Council of Turkey (TÜBITAK) and the Higher Education Council (YÖK); undersecretaries of the State Planning Organization, Foreign Trade and the Treasury; the president of the Turkish Atomic Energy Council; the director-general of the Turkish Radio and Television Corporation; and, lastly, the chairman of the Union of Chambers and Commodity Exchange.

In 2002, BTYK began formulating S&T policies for 2003–23 with the elaboration of the project VISION 2023: Science and Technology Strategies. This comprises four sub-projects: National Technology Foresight Project, Technological Capabilities Project, Researchers' Inventory Project and National R&D Infrastructure Project.

The Scientific and Technical Council of Turkey (TÜBITAK) has been in existence since 1963. It is authorized to perform, encourage, organize and coordinate basic and applied R&D; to act as a funding agency for R&D activities; to support promising researchers through scholarships; and to organize international collaboration. Through its department TIDEB (1995) it provides grant support for industrial R&D projects and organizes university–industry joint research centres.

Figure 15
INSTITUTIONAL STRUCTURE FOR S&T POLICY MAKING IN TURKEY



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The Technology Development Foundation of Turkey (TTGV) dates from 1991. A private non-profit organization, its role is to support industrial R&D, facilitate university–industry cooperation and create technoparks and the like. The most active technoparks are METUTECH at the Middle East Technical University and the TÜBITAK-MAM Technopark and Cyberpark at Bilkent University in Ankara.

Since its inception in 1990, the Small and Medium-Sized Industry Development Organization (KOSGEB) has been working to increase the technological capacity of SMEs through training centres, consulting and quality improvement services, common facility workshops and laboratories, and technology development centres. KOSGEB runs 11 incubators for high-tech start-ups jointly with technical universities.

The Turkish Academy of Sciences (TÜBA) was founded in 1993. Its mission consists of improving research standards and orienting youth towards scientific careers. The Turkish Standards Institute (TSE) (1960) and Turkish Patent Institute (TPE), which came into existence in 1960 and 1994 respectively, provide services for the standardization and protection of intellectual property rights; YÖK (1981) is responsible for higher education policies.

R&D institutions

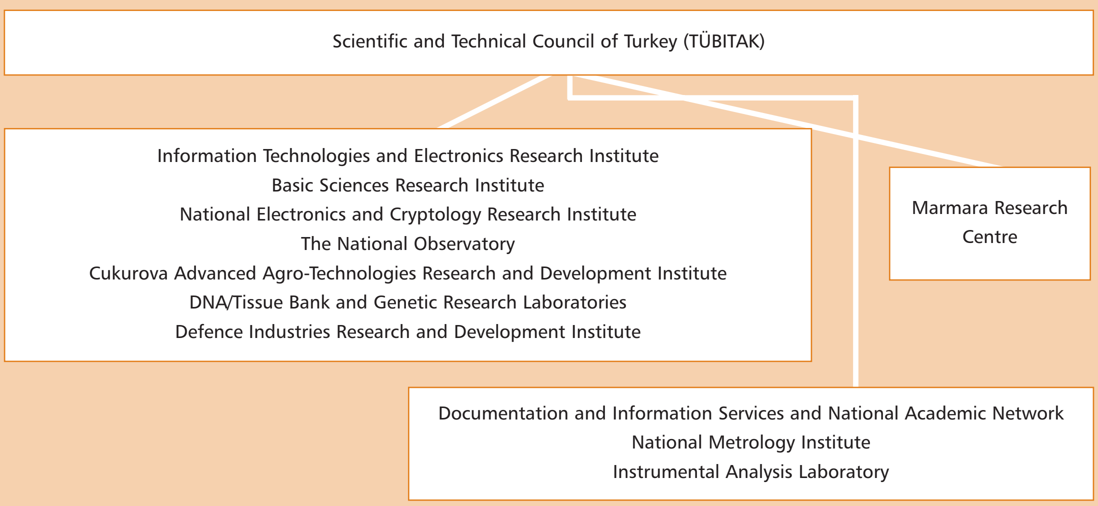
R&D is conducted by public research institutions (nearly 90) and 76 universities (53 state and 23 private). The leading public R&D institutions are affiliated to TÜBITAK.

The Marmara Research Centre set up in 1972 is the main public institution performing research in Turkey. It consists of five institutes and employs about 700 personnel, including 400 researchers.

In the fields of agriculture, forestry and aquaculture, there are 64 research organizations with more than 1 000 researchers. The Public Health Centre leads in health research with around 150 researchers.

The General Directorate of Mineral Exploration and Research is the R&D organization for research in geological sciences, with nearly 1 200 researchers. Nuclear R&D is conducted at the Ankara Nuclear Research and Education Centre, the Çekmece Nuclear Research and Education Centre and the Lalahan Animal Health Nuclear Research

Figure 16
R&D INSTITUTIONS IN TURKEY



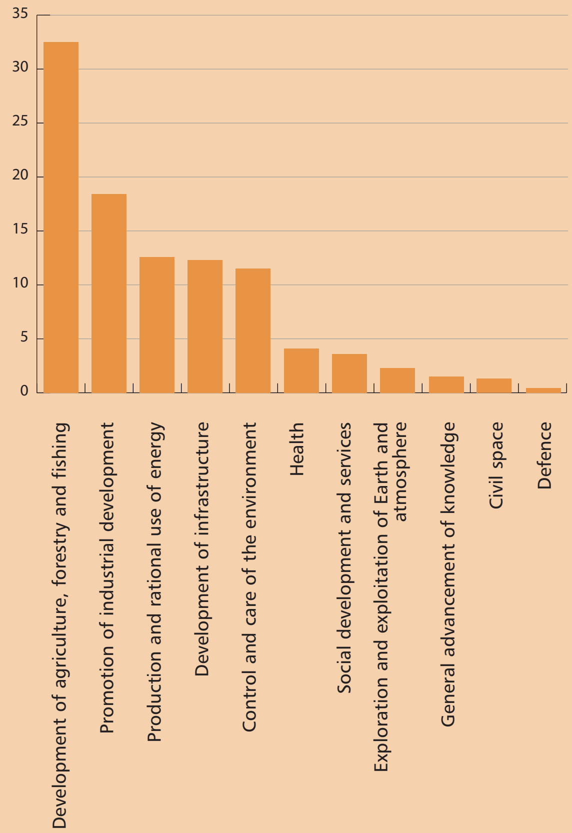
Institute, which are supervised by the Turkish Atomic Energy Commission.

The 12 public research institutes in the industrial sector conduct R&D mainly in the food, machinery, construction and chemistry fields. Three-quarters of universities have technical faculties and research centres engaged in innovation-related services to industry.

R&D funding

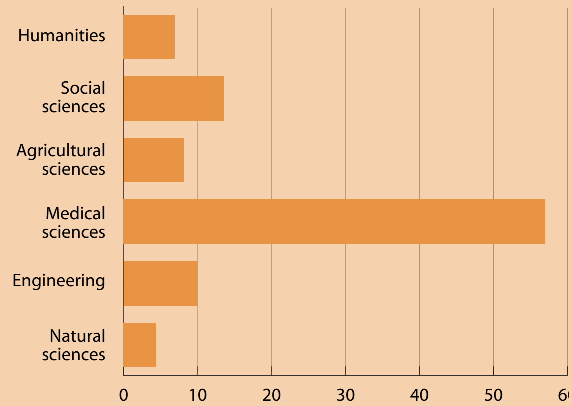
In 2000, GERD represented 0.64% of GDP, almost double the figure a decade earlier. Turkey's relative growth of 9% per annum is one of the better rates in the world. In terms of purchasing power parity (PPP), GERD trebled from US$ 855.6 million in 1990 to US$ 2 749.2 million in 2000.

Figure 17
GOVERNMENT EXPENDITURE ON R&D IN TURKEY, 2000
By socio-economic objective (%)



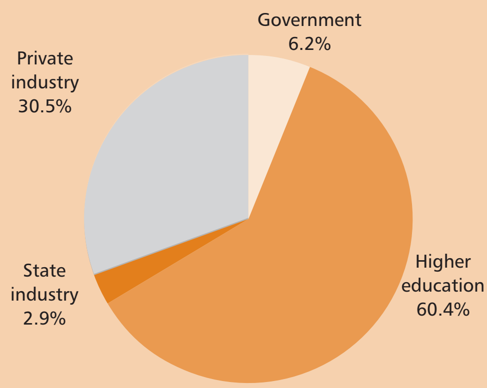
Source: Turkish State Institute of Statistics.

Figure 18
HIGHER EDUCATION EXPENDITURE ON R&D IN TURKEY, 2000
By field of science (%)



Source: Turkish State Institute of Statistics.

Figure 19
R&D IN TURKEY BY SECTOR OF PERFORMANCE, 2000



Source: Turkish State Institute of Statistics.

THE STATE OF SCIENCE IN THE WORLD

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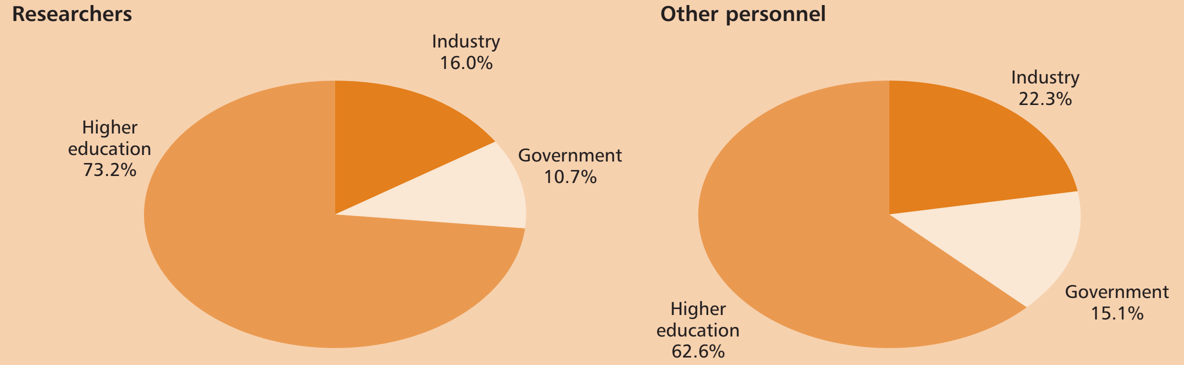
Figure 20
RESEARCHERS AND R&D PERSONNEL IN TURKEY, 2000
By sector



Source: Turkish State Institute of Statistics, *Key Figures 2003–04.*

Figure 19 shows that the main sector performing R&D is higher education. Business expenditure on R&D (BERD) in 2000 was 33.4% of GERD, with an average annual growth rate of 1.2% for the period 1997–2001. Government still plays the leading role in R&D financing, but the business sector's share of total funding is growing, from 31% in 1993 to 43% in 2001.

The distribution of GOVERD and of higher education R&D expenditure (HERD) in 2000 are shown in Figures 17 and 18.

Human resources for R&D

At 15%, average annual growth in R&D personnel was more than twice that of researchers between 1996 and 2001 in Turkey. By 2001, researchers numbered 23 000 and R&D personnel 27 000. Growth followed a similar pattern in the different sectors: 14% in industry, 13% in government and 15.6% in higher education. The distribution of researchers and R&D personnel by sector is shown in Figure 20.

S&T performance

The number of scientific articles published by Turkish scientists in world-renowned journals trebled between 1997 and 2002, as scanned by the SCI, SSCI and AHCI (Figure 21). By 2002, there were 148 scientific publications per million population, representing a spectacular growth

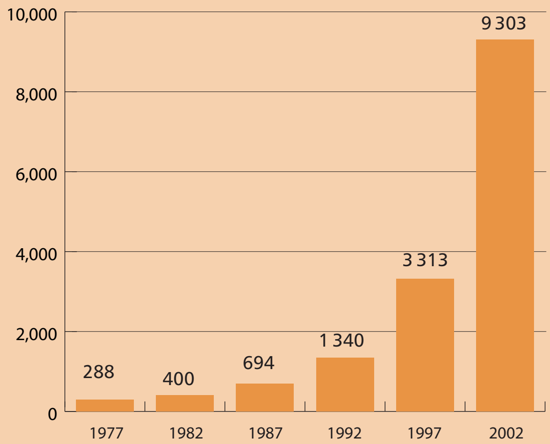
Table 13
TERTIARY GRADUATES AND PhDs IN TURKEY, 2001
By gender and selected fields of study

	In science				In engineering, manufacturing and construction			
	Total	% of total students	AAGR (%) 1998–2001	% women in total	Total	% of total students	AAGR (%) 1998–2001	% women in total
Tertiary graduates	19 961	9.6	11.1	44.4	41 506	20.0	5.8	24.8
PhDs	320	16.1	3.8	44.4	320	16.1	-2.8	32.2

* Annual average growth rate.

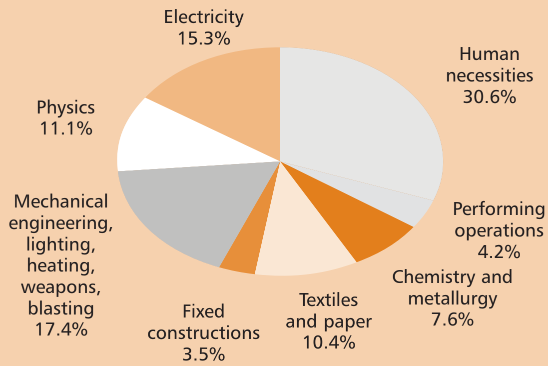
Source: Eurostat.

Figure 21
PUBLICATIONS BY TURKISH SCIENTISTS, 1977–2002
Number in SCI, SSCI and AHCI



Source: Cakir, S. (2003) *National Main Science and Technology Indicators for Turkey*. UNESCO Workshop on Science and Technology Indicators and Statistics for S&T Policy Making in South-East European Countries, 15–18 November 2003. Sofia, Bulgaria. http://seestil.net

Figure 22
TURKEY'S PATENT APPLICATIONS TO THE EPO, 2001
By International Patent Classification



Source: Eurostat.

rate of more than 500% over the decade. As a result, Turkey moved from 37th place in 1992 in world rankings of the most productive nations for scientific publications to 22nd place in 2002.

The growth in patent applications has been similarly encouraging. From just five patent applications to the EPO in 1993, Turkey had progressed to making 82 applications by 2000, although the number did fall back again to 72 a year later. The figure of 72 corresponds to one patent application per million population. Figure 22 shows the distribution of patent applications among the International Patent Classification (IPC) sections.

Turning to high-tech exports, these have grown at a much greater pace than high-tech imports in recent years. The balance is given in Table 14.

The results from the Technological Innovation Activity Surveys carried out by the Turkish State Institute of Statistics (SIS) show that 39% of firms in the service sector and 30% of firms in industry were engaged in innovation from 1998 to 2000.

Table 14
TURKEY'S HIGH-TECH TRADE, 2001
By value and composition

High-tech exports 2001			High-tech imports 2001			
€ billion	As % of total exports	Annual average growth rate 1996–2001 (%)	€ billion	As % of total imports	Annual average growth rate 1996–2001 (%)	Balance (€ billion)
1.1	3.2	43.1	5.4	11.6	16.2	-4.3

Source: Eurostat.

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INTERNATIONAL COOPERATION

The Venice Process

The Venice Process of rebuilding scientific cooperation both among Balkan countries and between them and the rest of Europe has essentially the same goals as the specific actions of the European Commission and its successive Framework Programmes. It does, however, lay greater emphasis on the regional aspect by encouraging the creation of regional networks, which should be centres of excellence or competence. The process was initiated by UNESCO, the ESF and Academia Europaea in November 2000 and officially launched at the Venice Conference of Experts on Reconstruction of Scientific Co-operation in South-East Europe in March 2001.

UNESCO has a long tradition of encouraging cooperation in the world's regions and sub-regions as a method for strengthening security and stimulating development. Applied to the sciences, this approach once again found a concrete expression at the World Conference on Science held in Budapest (Hungary) in 1999. As a follow-up specifically targeting South-East Europe, UNESCO's Regional Bureau for Science in Europe (ROSTE), located in Venice (Italy), launched the 'Venice Process', with support from the Italian government.

The Venice Process was greeted with unanimous approval by the ministers for science and technology of the countries concerned at the Round Table organized on 24 October 2001 within the framework of UNESCO's 31st General Conference bringing together the organization's 188 Member States. High-ranking representatives of EU Member States and many supranational bodies, such as the European Commission, participated, as did international governmental and non-governmental bodies, among them Euroscience. The process was reconfirmed by the ministers or their representatives at the High-level Conference on Strengthening Co-operation with South-East Europe held at UNESCO headquarters on 4–5 April 2002.

Cooperation with the European Union

The EU is by far the largest single donor to the countries of the West Balkans. As already outlined in the introduction to this chapter, the EU's policy for South-East Europe is two-pronged. On the one hand, it aims to prepare the candidate countries of Bulgaria, Croatia, Romania and Turkey for entry into the EU. On the other, the Stabilization and Association Process aims to prepare Albania, B&H, S&MN and FYR Macedonia for eventual membership of the EU. At the Thessaloniki European Council in June 2003, an Agenda for the Western Balkans was adopted, enriching the current Stabilization and Association Process through the provision of new European Integration Partnerships.

All the countries of the western Balkans are involved in the EU's EUREKA, COST, TEMPUS-PHARE and Fifth (1998–2002) and Sixth (2003–07) Framework Programmes (see below for details). They also benefit from the Community Assistance for Reconstruction, Development and Stabilization (CARDS) programme, which provides technical and financial support. In addition, Romania and Turkey are members of the Organization for Black Sea Economic Cooperation.

The principal objective of the EU's West Balkans programme in preparation for the European Research Area in 2010 is to increase the quantity and quality of participation from the countries of the western Balkans in the Sixth Framework Programme.

In July 1999, Romanian collaboration with the EU in R&D entered a new phase with the start of the country's full participation in the Fifth Framework Programme and EURATOM programmes. The report of the Romanian Ministry of Education, Research and Youth (MERY) on the results of the Fifth Framework Programme by the end of 2002 noted that 200 Romanian research institutes had been involved in 187 projects benefiting from European Commission funding in excess of € 18 million. A further 220 contracts had been signed for a total value of € 20 million.

Romanian participation proved greatest in the following thematic programmes: Energy, Environment and Sustainable Development (85 projects), User-Friendly Information Society (76 projects) and Competitive and Sustainable Growth (47 projects). Private firms and research institutes ranked first among the participating bodies. Within these contracts, contacts were established most frequently with France, Germany and the UK. Cooperation with the other EU candidate countries led to 255 collaborations, most of which were established with Poland, Bulgaria and Hungary. In joining the Sixth Framework Programme in 2002, Romania undertook to contribute € 14.3 million (of which € 13.3 million will go to EURATOM).

The special CORINT programme of Romania's MERY National Plan supports the participation of researchers in international programmes. In 2002, the CORINT programme absorbed 7.9% of the budget for Romania's National Plan. The importance attributed by Romania to this programme is also confirmed by an increase in the number of projects funded: from 19 in 2001 to 69 in 2002. The Bulgarian Academy of Science is giving strong priority to participation in the Framework Programmes in the context of integration and the European Research Area. The Academy obtained 125 out of Bulgaria's 255 projects granted by the Fifth Framework Programme, for example. Those 255 projects represent financial support of more than € 7.5 million (2003 data), a sum which has allowed research institutes to perform R&D up to international standards.

Cooperation within INCO

Within the EU's INCO–Copernicus–Balkans programme, which encourages cooperation in areas related to the improvement of living conditions or public health, as well as the development of industrial schemes in the energy, food and information society sectors, Croatia is conducting seven research projects in environmental protection and health care, the latter focusing on post-traumatic stress disorder, a syndrome typically induced by war.

The Bulgarian Academy of Sciences hosts four out of five Bulgarian centres of excellence set up under the EU's INCO 2 programme: the Centre for Sustainable Development and Management of the Black Sea System, the Centre for a Bulgarian Information Society in the 21st Century, the Centre for Portable Energy Sources and the Bulgarian Centre for Solar Energy.

Cooperation within EUREKA

EUREKA was established in 1985 by 17 countries and the EU to encourage a bottom-up approach to technological development and to strengthen the competitive position of European companies on the world market. EUREKA fosters international cooperation between companies, R&D centres and universities of the member countries.

Although Croatia has only been a member of EUREKA since 2000, it has been active in two important projects since their inception: EUROTRAC (air research) and EUROMAR (marine research). Currently Croatia is a coordinator for eight EUREKA projects and cooperates on nine umbrella projects: EUROENVIRON (environmental protection technologies), EUROTOURISM (technologies for tourism), EUROLEARN (e-learning and multimedia), EUROCARE (protection of cultural monuments), EUROAGRI (agricultural technologies), EULASNET (laser use in medicine and industry – Croatia is a founding member of the project), FACTORY (development of technologies for use in manufacturing industries), ITEA (software-intensive systems) and MEDEA (technologies in microelectronics).

In 2003, Serbian researchers were engaged in four EUREKA programmes and 18 projects under the Cooperation in Scientific and Technical Research (COST) programme.

Cooperation within COST

The COST programme is the oldest and widest European intergovernmental network for cooperation in research. Established in 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds. In a bottom-up approach, the initiative of launching a COST action comes from the European scientists themselves.

As a precursor of advanced multidisciplinary research, COST plays an important role in realizing the targeted European Research Area. It complements the activities of the Framework Programmes, constituting a bridge to the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of networks of excellence in many key scientific

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domains such as physics, chemistry, telecommunications and information science, nanotechnologies, meteorology, environment, medicine and health, forests, agriculture and social sciences. It covers basic and more applied research and also addresses issues of a pre-normative nature or of societal importance.

Since 1992, Croatia has been involved in more than 80 COST research projects in oceanography, new materials, environmental protection, meteorology, agriculture and biotechnology, food processing, social sciences, medicine, chemistry, forestry, telecommunication and transport. Some 35 projects are on-going. Bulgaria has participated in COST since 1999, taking part in 74 on-going projects, 40% of which are in the fields of agriculture and biotechnology, telecommunications and information science. Turkey is currently participating in 46 activities within COST.

Cooperation within TEMPUS

TEMPUS is the EU's major instrument for the development and restructuring of higher education. In the past 15 years, it has undergone several different phases (Tempus I, Tempus II and Tempus II bis). Tempus III (2000–06) is focused on the Western Balkans, the partner states in Eastern Europe and Central Asia (so called 'Tacis' countries) and Mediterranean partners.

The EU's TEMPUS-PHARE postgraduate programme in molecular biology and genetic engineering began at the University of Skopje (FYR Macedonia) in 1998. It involves the eight faculties of medicine, pharmacy, veterinary science, natural sciences, agriculture, forestry, technology and electrical engineering. Also participating is the Macedonian Academy, which is collaborating with scientific institutions in several countries of the EU.

The EU provides Bulgaria and Romania with assistance through the budget lines of PHARE, which provides general accession aid in adopting the body of community legislation, as well as through two other programmes providing pre-accession funds: ISPA (transport and environment) and SAPARD (agriculture).

Croatia, B&H, S&MN and FYR Macedonia all participate in the TEMPUS programme.

Cooperation within NATO

Bulgaria is one of the most active partner countries in the NATO Science Programme, having benefited by 2002 from over 280 grants and 350 fellowships.

By the end of 2002, over 200 Romanian research teams had participated in the NATO Science Programme and Romania had received more than 320 fellowships allowing Romanian scientists to study in NATO countries.

In Turkey, TÜBITAK participates actively in NATO. Beyond Europe, Turkey's participation in international bodies also extends to the OECD and the Organization of Islamic States.

Croatian scientists are involved in several research programmes with NATO, particularly those from the Rudjer Bošković Institute.

Cooperation within and beyond Europe

Scientific activity in the former Yugoslavia has always been characterized by intensive international scientific cooperation. For instance, in the 1980s, 300 physicists from Croatia published papers with scientists from 203 institutions: 108 from Western Europe, 35 from the USA and 31 from Eastern Europe. Today, scientists from B&H, S&MN, Croatia and FYR Macedonia are still collaborating with one another and even more intensively with scientists from Europe, the USA, Asia, Australia and Africa.

Noteworthy examples of current scientific cooperation involving the countries of the former Yugoslavia are: the Danube River Environmental Project with the Sava Basin Project, the Coordinated Adriatic Observing System, Mediterranean Sea Pollution Studies, Transport Connection between Baltic and Adriatic Seas, Telemedicine, Eastern European Consortium on Crystallographic Studies of Macromolecules, Central European Studies in Chemistry towards Biology, the Development of a Forensic Osteological Database involving Bulgaria and Croatia with the collaboration of the Smithsonian Institution in the USA, International Cooperation in Humanitarian De-mining and

Securities, Wetland Research, Environmental Hot Spots, projects within UNESCO's Man and the Biosphere programme (MAB), collaborative projects in hydrology, ICT projects and fluidized bed conversion applied to efficient, clean energy production in the sub-region.

All four countries have a considerable number of expatriates working abroad. A project to include them in the national R&D programme was initiated in 1987 in each independent state. Most successful has been Croatia, which has managed to draw several outstanding researchers back home to take up leading positions. However, a joint collaborative project with expatriates is the more frequent pattern, as in the case of the observatory on the island of Hvar, which boasts a high-energy gamma ray telescope on Pelješac and particle physics research.

One of the most comprehensive endeavours involving scientists from all four countries is the International Centre for Sustainable Development hosted by the Jozef Stefan Institute in Ljubljana, Slovenia, where scientists from the Rudjer Boškoviç Institute in Croatia play a crucial role and which involves researchers from B&H, FYR Macedonia, S&MN, Bulgaria, Romania, Italy, Greece and Turkey. For the past three years, the centre has organized an MSc programme. All the countries of the former Yugoslavia, plus Greece, Bulgaria, Romania, Albania and Italy, have proposed that the centre be turned into the Southeast European Institute of Technology under the Sixth Framework Programme, after the pattern of the Massachusetts Institute of Technology or the California Institute of Technology in the USA.

Turkey cooperates bilaterally and multilaterally in S&T through government agreements with the USA, Russia and Hungary. TÜBITAK has agreements with CNR (Italy), the Centre national de recherche scientifique (CNRS, France), the Centre for Scientific and Industrial Research (CSIR, India), the National Science Foundation (USA) and the National Committee for Technological Development (OMFB, Hungary).

Bulgarian institutions of higher learning have improved international cooperation since 1990; a large number of inter-university agreements have been established through the EU's ERASMUS and TEMPUS programmes. The oldest Bulgarian University, St Kl. Ochridski in Sofia, has agreements with 75 universities from 31 countries. An important development is the setting up of a joint department with universities abroad. One example of this new trend is the Technical University in Sofia, which has founded a joint faculty with the University of Karlsruhe and Technical University in Braunschweig (Germany). Moreover, within its membership since 1995 of the Association of French-Speaking Universities, the Technical University in Sofia has also created a French-speaking Department of Electrical Engineering.

The Bulgarian Academy of Sciences has a strong tradition in international cooperation. It remains the most internationally recognized research body in the country, participating in international programmes and bodies which include the European Science Foundation, European Federation of National Academies of Science and Humanities (ALLEA) and EU programmes. By 2003, the Bulgarian Academy of Sciences had concluded 53 bilateral agreements with national academies, research centres, research councils and universities.

The Academy hosts four out of five Bulgarian centres of excellence set up under the EU's INCO 2 programme: the Centre for Sustainable Development and Management of the Black Sea System, the Centre for a Bulgarian Information Society for Education, Science and Technology in the 21st Century, the Centre for Portable Energy Sources and the Bulgarian Centre for Solar Energy. The fifth centre of excellence, that for Agrobiological Studies, has been set up by the National Centre for Agrarian Studies which itself dates from 1999.

The Croatian Academy of Sciences and Arts is a member of the Interacademy Panel, ALLEA, European Science Foundation and International Council of Scientific Unions. It maintains active research collaboration with most of the academies throughout the world and typically 'exchanges' 300 scientists a year.

The Interuniversity Centre (IUC) in Dubrovnik (Croatia) is an international institution for advanced studies founded

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in 1971. It has a membership of over 200 universities and academies throughout the world. More than 50 000 scholars and students have participated in courses and conferences organized by the IUC over the years.

The Romanian Academy has signed more than 42 agreements with institutions from 29 countries and with UNESCO. The Academy is affiliated to about 30 international scientific associations and organizations, among them the International Council for Science, Inter-Academy Panel and ALLEA.

Macedonian scientists are cooperating on seven projects with Slovenia, six with Turkey, two with Italy, one with Greece and another with Albania. They are involved in four multilateral projects, two of which are with NATO (involving Albania, Turkey, Greece, the USA and Italy) and one with the United Nations Food and Agricultural Organization (with Croatia, B&H and S&MN). A fourth is financed by the French *Association des établissements d'enseignement supérieur et de recherche agronomique, agro-alimentaire, horticole et vétérinaire* (AGRENA).

Croatian scientists are involved in six research projects at the European Laboratory for Nuclear Research (CERN): NA49, NOMAD, CMS, ALICE, OPERA and CAST. In the NA49 experiment, for example, scientists recreate conditions of high energy density as they existed at the time of the early Big Bang by bombarding heavy nuclei that are accelerated to near-light velocity onto nuclei in a thin metal foil. NA49 is a large acceptance tracking spectrometer at CERN's SPS lead beam facility.

Croatian scientists are also participating in the work of several international and European research centres: Elletra (Italy); the Paul Scherrer Institute (Switzerland); FOPI and CBA, GSI (Germany); Brookhaven National Laboratory (Upton, New York), TUNL (Durham, NC), Los Alamos and Oak Ridge National Laboratories (USA); and TRIUMF (Canada). Croatian scientists are participating in five projects within the Adriatic–Ionian Initiative, as well as on projects within the Stabilisation and Association Agreement and in cooperation with the Commonwealth of Independent States. A particularly important research project for Croatia is the Adriatic project which includes Croatian R&D institutions and universities working with sister institutions in several European countries.

As stated earlier, the TESLA Scientific Centre at the Vinča Institute of Nuclear Sciences in Belgrade is the realization of a long-standing project for the installation of an accelerator for nuclear, biomedical and materials sciences research. Although not yet completed, it has already become a rendezvous for international cooperation.

One impediment to international cooperation for Serbia has been a 1998 law the country passed cancelling the autonomy of national institutions of higher education. That law has resulted in the suspension of Serbian universities from the Association of European Universities. Similarly inadequate Croatian laws and practices regulating science in the early 1990s have prevented Croatia from being admitted to the European Science Foundation.

A new trend in cooperation is emerging in Romania, as illustrated by the establishment of the Austrian Institute of Timisoara in partnership with the West University of Timisoara, Technical University of Timisoara and RISC Institute of Linz in Austria (2002), which will ultimately become a technological park in the field of information technology. Moreover, Romania's bilateral cooperation at the European level is growing. In a single year from 2001 to 2002, this increased from 148 to 160 projects.

Albania's Law on Science and Technological Development gives ministries, research institutes, the Academy of Sciences and universities the opportunity to sign bilateral agreements with similar institutions in other countries. The Ministry of Education and Science, for example, has signed two bilateral agreements, one each with Italy and Greece. The Academy of Sciences also has a bilateral agreement with Greece and takes part in NATO scientific programmes, the International Atomic Energy Agency (IAEA) programme and INTERREG-2. The University of Tirana has established bilateral agreements and cooperates with around 40 different universities and institutions in Europe and in other parts of the world.

CONCLUSION

Over the past decade, the countries of South-East Europe have followed different paths in the transformation of their S&T systems. Almost all used to be socialist countries with well-developed research systems supported by government. Exposed to new market conditions, they faced financial restrictions, deteriorating infrastructure and the challenge of a competitive market, while professionals working in science and engineering experienced a loss of social prestige. The restructuring of S&T is a painful process with many unanticipated outcomes and problems which every country has to solve in its own way.

Despite the hurdles in recent years, the countries of South-East Europe are all moving towards stabilization and recovery.

The underlying national S&T policies in the region have the goals of harmonization with European legislation and the adoption of international standards and good practices. The countries of the region are at different stages in achieving this. To nurture the aforementioned processes, regional cooperation in S&T will need to be strengthened and transborder programmes developed. Member Nations of the EU and accession countries will be vital to this effort.

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The Russian Federation

INTRODUCTION

Russian science is well known for its achievements in basic and pilot research, in solving important academic and technical problems on both national and international scales. Russian scholars have traditionally based their academic projects on original research of a high intellectual standard.

In the past decade, Russian science has faced serious challenges created by the transformation of the Russian economy following the collapse of the Union of Soviet Socialist Republics (USSR) in 1991. Funding for scientific and technical activities was abruptly and severely reduced. Military funding plummeted.

Despite this adverse environment, Russian science has adjusted to the new socio-economic realities, demonstrating viability and resourcefulness. Science and academic life in the country as a whole has become more open and democratic; international cooperation in the fields of science and technology (S&T) has soared; regulation of academic activity based on ideology has disappeared and administrative regulations have been eased. Sources of funding for academic scientific and technical projects have become more diversified.

Funding is now based on a competitive, merit-based approach with a focus on advanced scientific schools,[1] high-priority fields and research targets, high-calibre scholars and innovative academic and educational centres. Important measures have been introduced in order to integrate institutions of higher learning and centres of basic scientific research, and to attract young people to academia using, along with other incentives, additional financial support for graduate and postgraduate students and scholars.

Besides the chronic problem of insufficient state financing, Russian science faced other serious problems at the end of the twentieth century. These included little demand for S&T-based projects from industry, 'brain drain' to other countries, a low public opinion of the academic professions and rapid ageing of the scholarly community.

In the period between 1990 and 2002, the number of people involved in research and other academic activities decreased by 55.2%. In absolute figures, this means that Russian science lost 1 072 500 skilled people. On a ranking of countries by the proportion of those employed in academic fields, the Russian Federation now rates ninth in the world, after Finland and Iceland.

The number of academics in their most productive years has decreased dramatically. The average age of a professor or lecturer in a Russian tertiary institution is now approximately 60 years, whereas it used to be just 40–45. The highly prestigious image accorded to the academic profession at all levels – a higher status even than in other countries of the world – is no longer true for Russia.

CHANGES IN EDUCATION

It can be argued that the enormous number of newly created universities and other institutions of higher learning represents a loss for Russian science and academia. In general, this growth in institutions has not been accompanied by a higher level of education or scientific activities. In the last few years, 3 200 non-state institutions of higher learning and their branches have begun to operate in the Russian Federation along with new branches of existing state universities. As a result, a disparity has emerged between the real demand in society for a professional, highly qualified workforce and the number of university graduates. The number of students has rocketed in just a few years to 410 students per 10 000 population. The imbalance between supply and demand in higher education and the unpredicted and unpredictable rise of university graduates, often with low-quality education, are detrimental trends.

The situation regarding academic degrees earned through dissertation and thesis preparation has also changed. The number of graduates has risen significantly but

1. 'Scientific schools' were first created under the former Soviet system and still exist today . A 'scientific school' is a group of research scientists working under the leadership of a well-known figure in their field, who has also usually supervised their Candidate of Science degree (the equivalent of a PhD) and higher Doctor of Science degree.

without producing a higher number of completed dissertation theses. More importantly, this development has been accompanied by lower-quality dissertations, reflecting a lower level of basic research. The choice of subject has also changed: in 1991, 71% of the dissertations presented were in hard sciences and 29% in the humanities and social sciences; in 2001, the percentage of PhD dissertations in the humanities and social sciences had risen to 46% compared with 54% in hard sciences. The situation with the second academic degree (Doctor of State) is similar: in 2003, more than 50% of all second academic degree dissertations were in the humanities and social sciences. According to data for the first three months of 2004, two-thirds of the dissertations in the humanities and social sciences were in management and law. In general, in these disciplines, the dissertations have little or no scientific value but are useful to those in the political and business spheres in confirming their status.

OVERSEAS DRIFT

Between 1989 and 2000, more than 20 000 academics previously employed as researchers and research assistants emigrated from Russia. Another 30 000 specialists now work abroad on a contractual basis. A significant part of the latter group does not plan to return to Russia, where academic salaries are far below what can be earned abroad. The Russian scholars who live and work abroad are, in the majority of cases, specialists in the most advanced and science-intensive high-technology fields – mathematics, information technology, physics, biophysics, virusology, genetics, biochemistry – which to a great extent currently determine social and technological progress in society.

Science is, of course, international by its very essence. There have been many instances in history when Russian scholars working in international laboratories or in cooperation with international academic centres have achieved great results and made significant contributions to the development of science, thus enriching and strengthening Russian scientific schools. The first name that springs to mind in this context is Academician Kapitsa (1894–1984), a Nobel laureate for physics: the equipment he brought back with him from Cambridge, along with cutting-edge research topics, determined the development of physics and the creation of science academies in Russia.

A good example of modern cooperation is the work of Russian scholars at CERN – the European Organization for Nuclear Research. At the CERN experimental grounds, about 7 000 specialists representing 500 scientific organizations from 80 countries carry out research and conduct experiments. About 10% of these scientists are Russian. Russian specialists working at CERN feel they are representatives of Russian scientific traditions, conducting science and pursuing the interests of Russian academies. Only a small percentage of Russian scientists have left the country as a result of this cooperation – an example which shows that, when organized in the right way, the work of Russian specialists abroad can be mutually beneficial.

One way to develop the human resources necessary for academic and scientific research in Russia is to maintain relations and enhance cooperation with the Russian academic diaspora. It is especially important to maintain contact with the countries of the Commonwealth of Independent States (CIS), founded after the disintegration of the Soviet Union, by providing opportunities for talented young people from the CIS to receive higher education in Russian universities.

Several positive steps taken by the state have tended to lower the number of people leaving the academies or leaving Russia to pursue their academic careers abroad. The most important initiatives have been the development of foundations for the support of science in the mid-1990s and federal programmes supporting academic research. The latter include President of the Russian Federation postdoctoral grants to support young Russian scholars and their academic advisers (300 per year); President of the Russian Federation grants to support young Doctors of State (100 per year); President of the Russian Federation grants to support young scholars from the leading Russian academies and to support the academies themselves (more than 700 groups of researchers per year); a Russian Foundation for Basic Research programme for young scholars, graduate students and undergraduate students

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(MAs) (2 000 grants of US$ 1 000 each per year); the Federal Programme for Integration of Science and Higher Education for 2002–06; the Foundation for Support of Entrepreneurship in Science and Technics programme; and Ministry of Education and Science of the Russian Federation grants to young scholars (91 million roubles per year, equivalent to US$ 3.2 million).

THE CURRENT SITUATION

Almost 4 000 organizations represent science and research in today's Russia. Among them are more than 400 universities (in all, Russia has over 1 000 institutions of higher learning), 1 200 state research institutions and 450 institutions of the Russian Academy of Sciences. The country's professors and lecturers number 291 800, and researchers and specialists total about 400 000. There are more than 32 000 Doctors of State, over 135 000 PhD holders and around 136 000 graduate students in PhD programmes. It is worth noting that, for more than 300 Russian cities and towns, higher education, science and academia together constitute the main employer and the main intellectual resource and potential for socio-economic development.

In 2002, gross domestic expenditure on research and development (GERD) amounted to around 135 billion roubles. Of this, 58% came from the federal budget, almost 33% from corporate organizations and 0.4% from higher education and non-profit funds. International sources contributed 8% of total research funding. In recent years, a series of memoranda of cooperation have been signed with 53 Subjects (i.e. public and private bodies) of the Russian Federation. The amount of funding for research and other scientific work coming from regional budgets now amounts to 3 billion roubles per year.

Not only has Russian science managed to keep its human resources and its academies but it has also managed to educate and promote modern-style research managers. Organizational forms are being changed. One part of academia is shifting closer to industry; another is becoming more involved in higher education. There is a significant growth of interest in hard S&T disciplines among young people. The Russian Academy of Sciences – the unique S&T centre of the country – has managed to remain intact. A future direction for the institutes within the Russian Academy of Sciences is to integrate them with institutions of higher education in order to create research universities. Such universities would be well-organized, effectively managed academic institutions featuring both quality education and advanced research. The main Russian university – Moscow State University, named after M.V. Lomonosov – is an example of such a classic research university, meeting international standards on almost all criteria.

Issues of state policy in the area of basic and applied science, as well as concerning those involved in training human resources for academic research, have increasingly been the focus of attention of the Russian higher authorities. The meeting of the Council on Science and High Technology under the President of the Russian Federation which took place on 9 February 2004 centred on potential in science. The agenda included a detailed analysis of the situation regarding human resources for S&T in Russia to allow the council to define the main problems and offer specific measures to retain and develop academic potential.

The education system is the starting point for achieving this goal. Russia has a time-proven system of educational institutions organized by educational stages: high schools, higher learning institutions and on-the-job personnel training. There exists a long-standing tradition of selecting talented youth through various intellectual competitions, academic projects involving young people and special boarding schools for gifted high-school students. This work has to be continued and enhanced so that the ever-growing social stratification of Russian society will not impede talented youth – especially those from smaller towns and rural regions – from receiving a good education.

Russian science still has a low rate of innovation. Thus, the development of innovative infrastructure for science, technology and education becomes very important. Such infrastructure should include small enterprises with low start-up financing and high-technology transfer centres based on integrated university and Academy of Sciences research partnerships. It should also include research and development (R&D) parks, 'zones of innovation' surrounding the scientific centres that could obtain the status of free economic zones.

On 24 February 2004, a special joint meeting of the Security Council and the presidium of the State Council of the Russian Federation discussed issues related to developing a national innovation system. Enhancing innovative activities and creating infrastructural and economic conditions for faster implementation of scientific achievements in various sectors of the economy is a high priority for today's Russia. The most important element will be overcoming prejudice in Russian regions, leading to the active support of science as one of the main instruments of innovation.

The modern infrastructure of the innovative R&D centres at the institutions of higher education includes about 1 000 regional centres covering various disciplines and fields (academic and educational centres, observatories, botanic gardens and biological stations, university museums and so on). At the same time, a new system of consulting and engineering companies and ventures oriented exclusively towards the high-tech sphere is being formed.

The infrastructure to encourage innovative science currently comprises 76 research and development parks, 15 education and technology innovation centres based at the universities, 11 centres for technology transfer, 16 regional training centres for innovative management, 12 regional analytical information centres, ten regional innovation centres, 12 regional centres for assistance in development of R&D entrepreneurship and a foundation for assistance in development of innovation in higher education.

FUTURE CHANGES

Russia has begun creating an environment conducive to new types of R&D activities. Gradually, innovative structures capable of both creating new knowledge and working it into commercially attractive projects have emerged. Commercially successful businesses are financing R&D programmes by participating in huge investment projects. Simultaneously, some of the organizations involved in high-technology production are being integrated in the global technology arena.

State policy is also being oriented towards improving the status of science and education, promoting high-technology companies and the export of high-tech products. Such a policy is transforming Russian science to create the basis for a dramatically different model of economic growth.

Russia's main task will be to create a system enabling the development of new knowledge, supported by an inflow of professional personnel, and to find ways to use and implement the results of research into new technology. The main national universities and national R&D centres surrounded by special zones for innovative economic activities should become the basis of this system. These will be the places for joint efforts embracing specialist education and training, high-priority research, implementation in industry and new commercial applications.

This, in turn, will create the conditions for revitalizing and supporting human resources to boost national science and the high-tech industry. Only then will Russia move from the current situation where academic personnel or potentially new research ideas are being exported to one where research results are embodied in high-tech exports. Only then will Russia truly take its place among the developed nations of the world.

VICTOR SADOVNICHY

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CONTEMPORARY HISTORY OF THE APPLIED SCIENCES

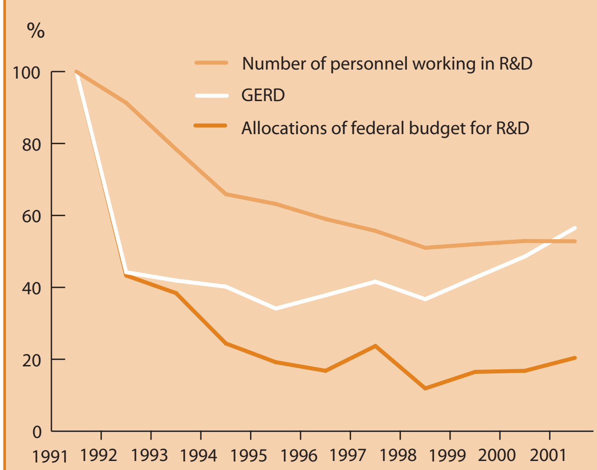
The current state of applied scientific research in the Russian Federation and the way it has developed reflect the deep changes in the country's political and economic structure from 1917 to 1991. Along with its political and economic transformation, Russia has, since 1991, witnessed the overturn of its well-established system of basic and applied R&D. The economic and institutional reform of Russian science from 1991 to 2003 may be described as a three-stage process.

During the first stage (January 1992 to August 1998), the majority of national funding sources were rapidly privatized, prices of goods and services were liberalized and the market economy began to emerge. This resulted in a considerable decline in industrial output and in the value of gross national product (GNP), as well as cutbacks in national budget expenditure. Science funding was reduced accordingly. The subsequent attempt to introduce institutional reforms of science failed because of the difficult economic conditions and social uncertainty.

The second stage began with a significant economic downturn in August 1998, which put a stay on almost all the institutional reforms of Russian science and economics. After 1998, economic recovery began, with some growth in production and an acceleration in industrial technological modernization.

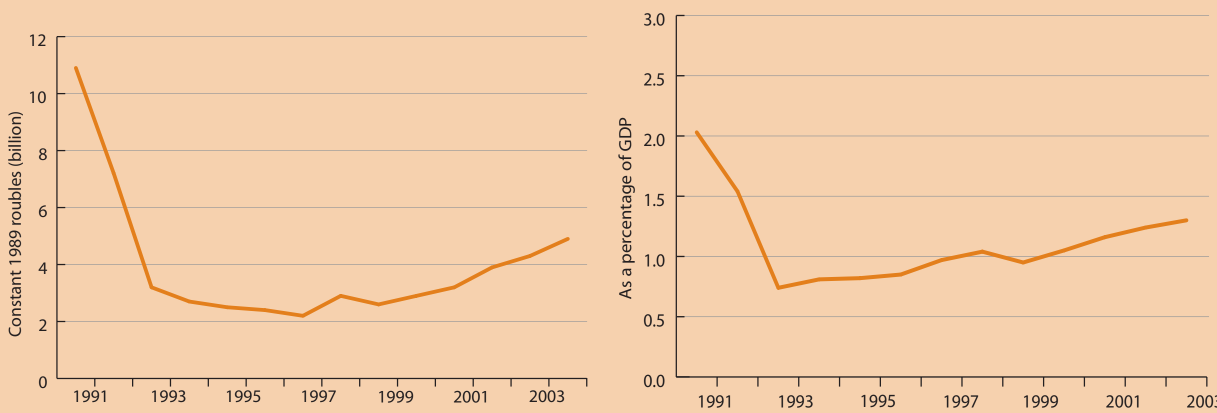
The third stage began with a period of economic growth between 2000 and 2001 which enabled a number of

Figure 1
S&T CAPABILITY IN THE RUSSIAN FEDERATION, 1991–2001 (1991=100)



Source: Kouznetsova, T.U. and Dobretsova, N.I. (eds) (2003) *Scientific Potential and Technical Level of Production: Russia in Figures.* (In Russian)

Figure 2
GERD IN THE RUSSIAN FEDERATION, 1990–2003



Source: K Kouznetsova, T.U. and Dobretsova, N.I. (eds) (2003) *Scientific Potential and Technical Level of Production: Russia in Figures.* (In Russian) enterprises to proceed more actively with technological innovation. Actual reform of basic funding first came about at this stage. During 2003–04, the country has been going through yet another government reorganization, with the system of state science management likewise being reorganized.

REORGANIZATION AND INSTABILITY

A general problem during this latest stage has been the considerable organizational instability in state control over applied R&D. For example, in 1991, the USSR State Committee for Science and Technology was transformed into the State Committee for Science and Engineering. At the beginning of 1992, the Ministry of Science, Higher School and Technical Policy of the Russian Federation was created. As early as February 1993, the Ministry was reorganized into the Ministry of Science and Technology Policy, with control over higher education delegated to a separate government body. In 1996, the Ministry of Science and Technology Policy was transformed into the State Committee of the Russian Federation on Science and Engineering, which in 1997 was reorganized into the Ministry of Science and Engineering of the Russian Federation. In 2000, this ministry was transformed into the Ministry of Industry, Science and Engineering. In 2003–04, within administrative reforms, a new Ministry of Education and Science was created with responsibility for scientific research and education.

Each reorganization of a ministry or a state committee entails considerable changes to its function, inner structure and administration, especially as concerns major executives in charge of structural units of an institution. Changes in the central figures in science administration have been even more frequent than that in other areas. Thus, in 1998 alone, three different ministers supervised scientific research in the Russian Federation.

To further complicate matters, in analysing and interpreting the official statistics that describe changes to applied R&D in the Russian Federation, the imperfections caused by the structural shortcomings of national statistics in Russia in general have to be taken into account. At the end of the 1990s, with the conversion to international standards of statistical observation, certain problems arose that have still not been resolved. According to expert opinion, the available information on the state and development of Russian S&T does not meet the needs of researchers encountering problems in their work, nor can that information serve as an adequate basis for the necessary assessment prior to administrative decisions. Users of statistical data find some difficult to apply and interpret, whereas others appear problematic or contradictory. Specialists of the Russian Scientific Research Institute of Economics, Politics and Law, in the S&T sphere of the Ministry of Industry, Science and Technologies of the Russian Federation focused on this problem in 2003.

It has also been stated that the information available is too simplistic and does not take into account the changes and reforms the country is going through; some important figures are lacking. In fact, the range of science-related national statistics is much narrower than the scope of science outlined in the Federal Law on Science of 1996. The selection and allocation of institutions undertaking R&D within a certain activity segment conforms to international standards but in reality does not reflect the structural peculiarities of Russian science.

All the above hinders objective analysis of this already complicated state of affairs. Nevertheless, there is enough reliable information on the main events and trends in S&T and applied research in the Russian Federation between 1991 and 2003 to make a general evaluation.

A BRIEF APPRAISAL OF RUSSIA'S S&T POTENTIAL IN 1991

The nature of the Russian Federation's historical background has to a great extent determined the development of applied research in the period 1991–2004. The way general science was managed over this period was hugely influenced by the twilight years of the USSR. National spending on science development amounted to 3.8% of national budget expenditure in 1988, 1.99% in 1990 and 1.85% in 1991. Those figures closely corresponded to state funding of scientific research in the leading economically advanced countries. However, the structure of S&T in the USSR from 1917 to 1991, and the way it developed, differed fundamentally from the situation in the USA and other Western countries.

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First, all the institutions engaged in basic and applied research during that period belonged to the state and functioned within the system of government administration, budget funding and a planned national economy. Russian S&T was only able to advance within the limits and rules set by a government that was essentially not accountable to the population for its actions. It is generally acknowledged that the country's leaders considered it a great achievement of the totalitarian state that the government was able to organize R&D in every sphere of basic and applied science – its 'full-scale attack'. Indeed, any country with a market economy and a political system answerable to citizens would not be able to afford such a concentration of resources aimed at solving major S&T problems at the price of a reduction in consumption and tough living conditions for the population. The communist government apparatus, with its forceful (i.e. not economically or scientifically founded) decisions, did not require sanction from its citizens, whose interests were thus effectively disregarded. The system's opponents were not only politically repressed but also physically eliminated by the state security bodies. The USSR's leaders were able to create enormous S&T potential, supported and provided by organized basic and applied research in the main areas of S&T – all in a very short time.

Second, all organizations involved in basic and applied R&D were divided into three self-sufficient sectors: academic, higher education and industrial establishments. Academic institutions were structurally part of the USSR Academy of Sciences and industrial academies of the country. Scientific sections of the higher learning establishments were responsible to the ministerial departments to which each establishment structurally belonged. Industrial scientific research, project development laboratories, engineering and other similar organizations were brought under ministries and other departments in control of various branches of the national economy.

The nation's leaders intended the functions of the three sectors to be different. Academic scientific institutions were to conduct basic research in natural and social sciences (although in reality applied research also played a considerable role in their activities). Higher education science was first and foremost in charge of the educational process; it had inadequate links to industry, was systematically underfunded and did not possess the necessary equipment or experimental and production base. The component parts of higher learning establishments – laboratories, groups of scientists, etc. – were not stand-alone scientific organizations. They conducted basic and applied research on a limited scale.

By contrast, industrial scientific institutions conducted applied scientific research and were also responsible for the application of basic research results. These institutions played the main role in new technological projects as well as providing engineering support for sample production using new techniques. The industrial scientific sector of the USSR included powerful departmental systems of R&D institutes, project design and technology organizations, pilot plants and so on. The sector used to employ 75% of the country's specialists in the field of scientific R&D. Institutions of the industrial scientific sector implemented 80% of the country's scientific research (including almost 25% of basic research), 75% of applied research and about 90% of R&D. Thus, the leading position in the S&T activities of the USSR was occupied by industrial science.

Thirdly, the distribution of scientific institutions in the USSR between certain ministries and departments did not adequately reflect their status and the character of their activities. Applied R&D was also divided into the defence (militaro-technical) and civil sectors. Applied R&D in the area of defence was given top priority. The share of defence constituted more than 60% (80% according to some estimates) of all S&T work in terms of value. Institutions conducting research in defence, whatever department they came under, were strictly classified. They had at their disposal the most qualified and talented staff and the best logistics and maintenance; they spent the major part of Soviet science general funding and commissioned basic research that opened up new perspectives in R&D. Defence employees also received higher salaries and thus were more motivated than those employed in the civil sector of applied science.

All these factors meant that basic and applied research in the militaro-technical field was very efficient. The high level of R&D and scientific support for military engineering placed the USSR in a leading position in the world in many branches of S&T. Soviet industry mass-produced the world's best small arms and artillery. Atomic submarines were built with features as yet unsurpassed. The world's best rockets, nuclear ammunition, means of air defence and military space systems were created. All these types of armaments exemplified the latest achievements of S&T in almost every sphere of S&T progress. Many of them exceeded the best achievements of Western countries. It was for the needs of the defence industry that highly efficient programmable precision machines and many other items of advanced equipment were designed and produced.

Major militaro-technical solutions required new industries to be created when necessary. For example, atomic shipbuilding and aerospace engineering called into existence a large-scale industry to produce titanic alloys and products made from these, which demanded new resources as well as the creation of a new technological cycle from metallurgy to titanic construction welding, etc.

On the other hand, from the end of the 1980s to the beginning of the 1990s, the economic situation in the country became quite paradoxical. The achievements in engineering and technology resulting from basic and applied research conducted in the USSR were not usually taken up by industrial organizations, so they were excluded from the process of the real economic development of the country and the growth of its S&T capability. This was clearly apparent in the civil sectors of the national economy but enterprises in the militaro-industrial complex (MICA) were also often reluctant to adapt to new technologies and equipment. The problem of industry and the economy not responding to S&T progress was never properly resolved throughout the history of the USSR.

The communist government blamed the apparent lack of progress on the inaction of scientists, who were said to be uninterested in practical applications and accused of lack of effort in adapting new scientific achievements for industry. There were frequent statements by party leaders that scientific groups and organizations were only 'thinkers'.

In reality, the root of the problem lay in the little attention paid by some economic leaders to the laws of economic development. Cheap labour, almost-free resources (energy, materials and component items were not acquired at economically justified prices but rather distributed on request among plants and institutions out of available funds), along with complex pricing that did not encourage enterprises to increase labour productivity or the quality of production – all these became serious obstacles to raising the S&T level of production, even though the results of R&D were potentially available and free for industry to use. From 1975 to 1985, the economic efficiency of R&D (measured as the ratio of improvements in knowledge-intensive production to R&D costs) was decreasing on average by 3% per annum. By 1991, it had become urgent to reform the R&D sphere in order to increase efficiency.

Another less obvious but nevertheless fundamental contradiction of the Soviet state was failing motivation among scientific research workers. Apart from economic reasons, lack of elementary civil liberties, ideological suppression of forms of culture undesirable to the government, increasing bureaucratization of science and the absence of creative freedom all had a discouraging effect. The dogmatic ideological directive on the hegemony of the working class in the country's political life did not help to solve the deep contradiction between the actual political and economic status of the country's scientists, on the one hand, and their growing role in creating new knowledge-intensive production on the other. Having accomplished the historical task of catching up on industrialization (albeit at a terrible price), there was no successful transition from an industrial to a post-industrial phase within the repressive political system.

REFORM OF S&T RESEARCH 1992–98

After the collapse of the Soviet Union, the great majority of organizations involved in basic and applied research that had been the central core of the country's S&T potential

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remained within the Russian Federation's borders. Russia retained 70% of the employees of the Soviet economic branch called Science and Scientific Management. From that branch, 445 000 researchers and 80% of its basic funding became 'the Soviet heritage' of the Russian Federation. Some 77% of the general volume of R&D was now performed in post-Soviet Russia, which also held more than 68% of the specialists and more than 90% of the scientific institutions of the Academy of Sciences of the USSR.

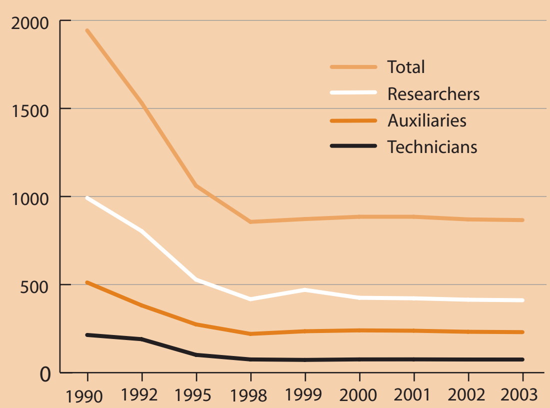
One of the main principles of the Russian government's state policy regarding science (SPGS) in 1991–98 was a recommendation by the Organisation of Economic Co-operation and Development (OECD) for the 'excessive' scientific potential inherited from the USSR to be reduced. That task was expected to be settled in the process of institutional reforms, which were given priority in the early 1990s. The opinion of some experts was that economic growth came only third or fourth on the list of priorities for the development of Russia at that time (Uzyakov, 2000).

In 1992, many Russian scientific research and project-development organizations were privatized and a number of them, in accordance with their owners' wishes, changed to more profitable activities. Some scientific organizations either stopped doing R&D or limited their applied research and took up other activities. A significant motivation in the privatization of the basic state funding used in R&D in Russia was its value. In 1989, the value of this funding, including that for experimental activities, came to 5.1% of the USSR's funding for manufacturing industry, or 25.3 billion roubles (in 1990 prices). This trend did not stop until after the government adopted the Regulations on Privatization of S&T Objects in June 1994, which fixed the rules for selling organizations S&T on a competitive commercial or investment basis.

Nevertheless, contrary to Russian economic reformers' expectations, the transition of R&D funding and organizations to private ownership did not increase efficiency but actually had the opposite effect. After scientific organizations and knowledge-intensive industrial enterprises were privatized, interest in the market-stimulated results of short- and medium-term applied research started growing rapidly. At the same time, investment in long-term basic and applied research with no immediate commercial value declined considerably. Demand for inventions by industrial enterprises fell by more than 85% in five years. In the period 1992–94, the innovation activity of enterprises dropped to two-thirds that of the USSR. The reason was no longer the 'insusceptibility of enterprises to ST progress' typical of the Soviet economy but the enterprises' impoverished circumstances and the lack of means to pay for R&D in a climate where demand for knowledge-intensive production was falling rapidly.

From 1992 to 1996, internal running costs and capital expenditure on R&D fell by three-quarters. During those years, there was a growing tendency to reduce funds allocation from the expenditure part of the federal budget under the heading 'Basic Research and Contribution to S&T Progress', which forced a number of scientific institutions and enterprises to find the money to pay employees' wages by cutting back staff, renting out premises, dismantling and selling expensive equipment and materials, and so on. Rises in the prices of

Figure 3
PERSONNEL WORKING IN R&D IN THE RUSSIAN FEDERATION, 1990–2003
In thousands



Source: Kouznetsova and Dobretsova (2003) *Scientific Potential and Technical Level of Production: Russia in Figures*. (In Russian) goods and services and a restraint on wages became commonplace, leading to a decrease in the number of those involved in scientific R&D.

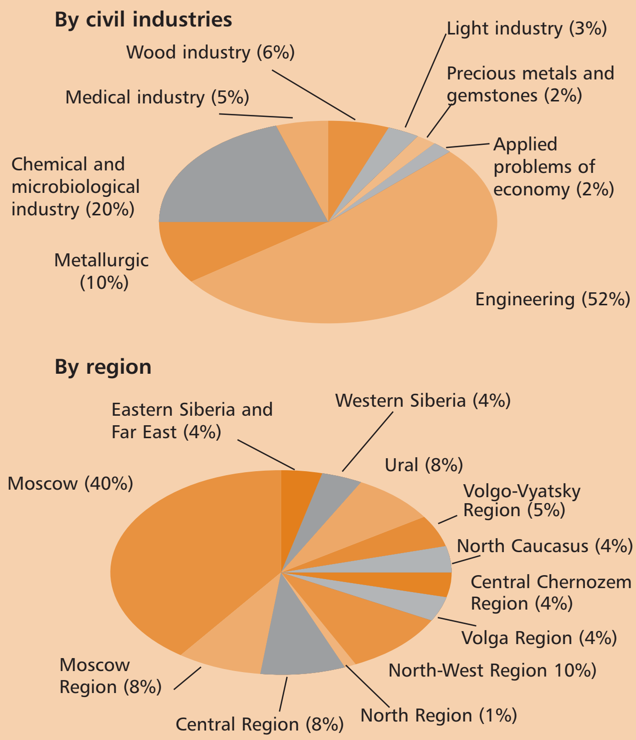
In 1996, the Federal Law on Science and Technology was passed, followed by several governmental decrees that were meant to become the legal foundation for the future reorganization of S&T research and innovation, aimed at improving the competitiveness of production.

To try to preserve the country's S&T base, science and industry executives looked for ways of making applied research and innovation better suited to the market economy. By the end of the 1980s, technoparks – associations of scientific, project and industrial organizations with well-developed information and experimental divisions and highly qualified personnel – had already been introduced. Technoparks proved to be a useful development in the new socio-economic context, as they integrated science, education and production while stimulating more intensive innovation. By 1997, about 60 technoparks had been founded in the Russian Federation.

In 1993, the President of the Russian Federation introduced the status of state scientific centre (SSC) to distinguish a number of advanced scientific institutions and enterprises with unique experimental equipment and highly qualified personnel who had achieved international recognition for their scientific research (Decree No. 939). As a rule, these SSCs, which incorporated over 40% of the country's S&T resources, were founded in large industrial institutes and enterprises functioning successfully under the new economic conditions. From 1994 to 1997, 56 scientific organizations were given SSC

Figure 4
ORGANIZATIONS IMPLEMENTING R&D IN THE RUSSIAN FEDERATION, 1998
By industrial sector and region

Industry	Number of organizations
Mechanical engineering	98
Chemical technologies and chemical industry	71
Electrical engineering	44
Metallurgy	31
General and complex problems of technical and applied sciences and branches of the economy	31
Automatics and telemechanics, computation	29
Medicine and health services	25
Wood and woodworking industry	24
Instrumentation	23
Electronics and radio engineering	20
Mining	18
Light industry	16
Biotechnology	12
Agriculture and forestry	11
Water economy	10
Energetics	9
Atomics	7
Communication	6
Construction and architecture	6
Transport	5



Sources: *Russian Statistics Yearbook* (1998); *Industrial Research in Figures* (1999). (In Russian)

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Table 1
CONTRIBUTION TO GDP OF VARIOUS SECTORS IN THE RUSSIAN FEDERATION, 1998
As a percentage of 1990

	%
Gross domestic product (GDP)	54
Volume of industrial production	45
Metallurgic industry	53
Food industry	49
Light industry	12
Chemistry and petrochemistry	42
Mechanical engineering, wood and woodworking industry, construction materials industry	35
Fuel industry	66
Electric power production	76
Manufacturing industry	40
Extractive industry	70
Consumption of services paid for by population	25
Passenger turnover at public transport	60
Services production	81
Commodities production	45

Source: Kouznetsova and Dobretsova (2003) *Scientific Potential and Technical Level of Production*. (In Russian)

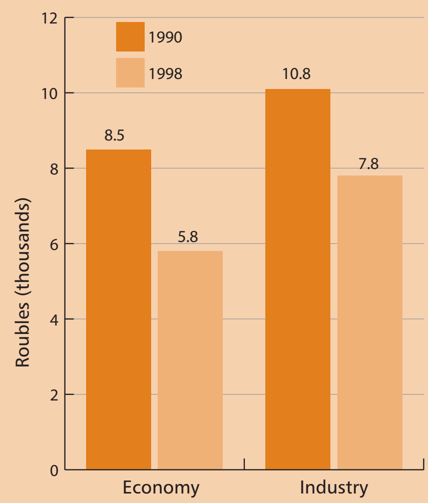
status, reflecting to some extent the priority given in the Russian Federation to different branches of S&T. Among others, the enterprises were in the fields of:

- chemistry and new materials (7)
- aerospace engineering (4)
- shipbuilding, navigation and hydrophysics (6)
- medical science and biology (4)
- oceanology, meteorology, water supply and engineering geohydrology (3)
- computer science and instrumentation (5)
- mechanical engineering (4)
- optical electronics, laser systems, robotics, special chemistry (5)
- agro-industrial complex (4)
- mining metallurgic complex (4)
- construction (1)

The progress being made on innovation encouraged the formation of innovation-technological centres (there were eight in 1997) and especially financial-industrial groups (FIGs). A FIG is an association of legal entities that enters into a contract providing for full or partial consolidation of material and non-material assets for the purpose of technological or economic integration, to implement investment and other projects and programmes, in order to achieve greater competitiveness and further development of markets for goods and services. Creating joint infrastructure in information, banking, insurance, consulting and auditing, supply and sale, transport and personnel results in greater productivity and new jobs. Interregional and transnational FIGs are powerful bodies capable of investing considerable amounts in personnel training, information infrastructure and marketing.

When joining an FIG, an enterprise acquires access to additional investment due to the funding available within FIG financial and loan offices, as well as resources attracted on the security of these offices. Experience has shown that cooperation and differentiation of labour within an FIG allows more efficient use of industrial potential, application of knowledge-intensive and resource-saving highly

Figure 5
GDP PER HEAD OF WORKING POPULATION IN THE RUSSIAN FEDERATION, 1990 AND 1998



Source: *Russian Statistics Yearbook* 1990–99. (In Russian)

THE RUSSIAN FEDERATION

Figure 6
GDP IN THE RUSSIAN FEDERATION, 1997–2003
Percentage change over previous year

Source: Calculated using data from *Russian Statistics Yearbook* 1990–2004. (In Russian)

productive technologies and the growth of productivity, while maintaining the level of personnel. In 1997, there were 72 FIGs listed in the Russian Federation register.

In October 1997, the Russian government approved the Regulations on State Accreditation of Scientific Organizations, which set common standards for scientific institutions and for licensing their activities irrespective of the form of ownership. In 1998, the Russian Ministry of Economic Affairs was responsible for overseeing applied R&D in 250 state and 374 non-governmental scientific organizations functioning within the structure of civil industrial complexes.

Measures taken from 1996 to 1998 were unable to prevent further deep disruption to the technology-transfer mechanism and to the dissemination of forward-looking ideas and developments from the state-funded sphere of basic scientific research to the sphere of R&D and knowledge-intensive production, most of which had taken on new forms of ownership. According to official figures, production fell considerably between 1991 and 1998. The great damage caused to S&T in Russia is hard to estimate and has to the present day still not been repaired.

The economic downturn of August 1998 interrupted implementation of the institutional and economic reforms planned by the legislative and executive bodies. Applied R&D in Russia was stranded in a growing systemic crisis; the institutional reorganization of science would end up being one of the casualties of the economic crisis. A new chapter in the modern history of Russia had begun with the country's economy, as well as its scientific organizations sustaining economic and technical progress, having to adapt to new, even harder conditions to ensure their survival and development.

DEVELOPMENT OF APPLIED SCIENCE, 1999–2003

After seven years of institutional reforms that proceeded regardless of the adverse economic conditions, some indications of recovery began to appear. In 1999, the value of gross domestic product (GDP) halted its decline for the first time since the collapse of the Soviet Union. In 2002, the volume of GDP was 25.8% above the level of 1998.

The number of enterprises actively investing grew by 60% over the same period. By 2001, investment in fixed capital stock had grown by 34% over 1998 levels, with 36% going into new equipment. Foreign investment in 2001 amounted to US$ 703 million, a 357% increase over 1997 levels. The number of newly 'technologized' facilities also increased. The unemployment rate in May 2003 was 37% below May 1999 levels. That resulted in a growth in labour efficiency of 19% in 2001 as against 1999 for the economy as a whole and in growth of 18% in industry.

There is still a long way to go to restore the position lost in 1991 but the country's economy and scientific institutions have been given additional opportunities to adjust to the market. A stronger federal budget has allowed a rise in GERD. In 2001, the Russian Federation still came eighth in terms of GERD among the Group of Eight (G8) countries (Figure 7).

It is generally agreed that human resources are a crucial factor in realizing a country's S&T potential, as well as for its development prospects. The number of those employed in the branch of science and scientific management declined by more than half in 2001 compared with 1990 and represented 1.8% of the total number employed in the Russian economy. Moreover, whereas the number in employment declined by 14% between 1990 and 2001, and by 38% in industry, the number of people employed in

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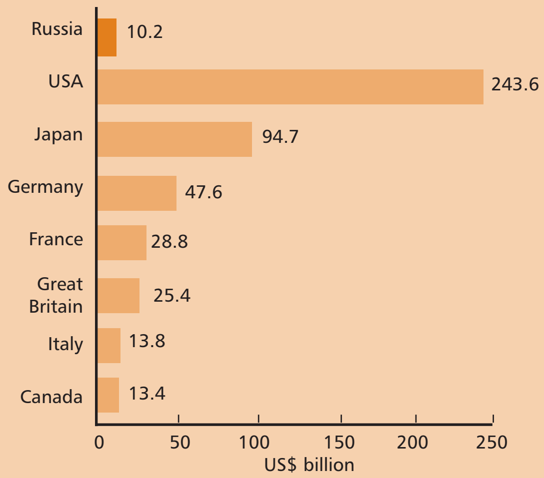
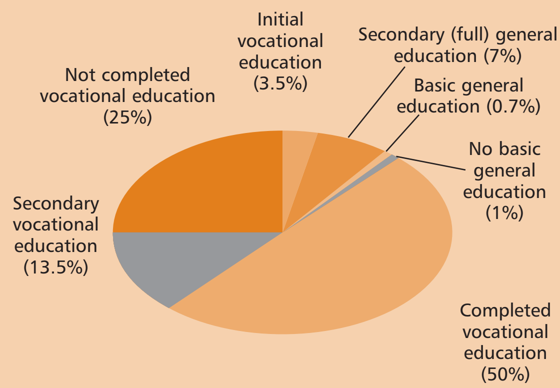
Figure 7
GERD IN G8 COUNTRIES, 2001



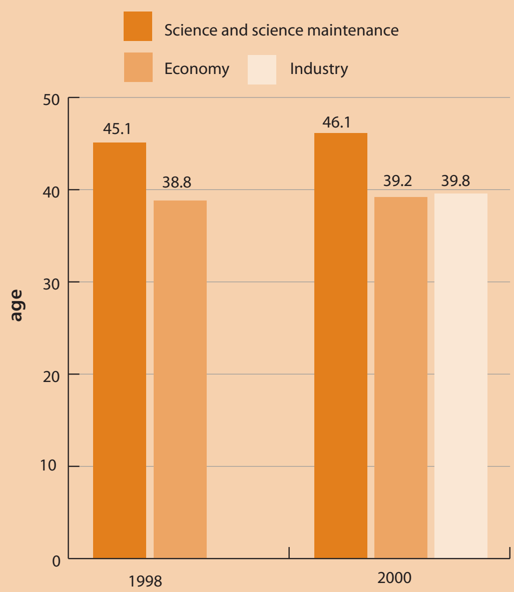
Source: Beketov (2003) *Science in Russia and in the World*. (In Russian)

Figure 9
PERSONNEL IN SCIENCE AND SCIENCE MANAGEMENT IN THE RUSSIAN FEDERATION, 2000
According to educational level (%)



Source: Kouznetsova and Dobretsova (2003) *Scientific Potential and Technical Level of Production, Russian Statistics Yearbook* 2001. (In Russian)

Figure 8
AVERAGE AGE OF PERSONNEL IN SCIENCE AND INDUSTRY IN THE RUSSIAN FEDERATION, 1998 AND 2000



Source: *Russian Statistics Yearbook*. (In Russian)

science declined by 58% over the same period. This was caused both by the ageing of science personnel (Figure 8) and the drift away of the young, coupled with more qualified and creatively active scientists taking up permanent residence abroad.

These trends, which have continued unchecked to the present day, are removing Russia's most precious resource for the country's transition from industrially extensive production to the steady development of knowledge-intensive production. A country's S&T capability stems from a number of long-term factors, such as the activity of several generations of specialists, secondary and higher education and the level of postgraduate training, and is slow to change.

Over the past few years, the Russian Federation system of general, secondary and higher professional education has been going through a process of major reform to adapt it better to the conditions of the market economy and allow it to meet international educational standards. Statistics on the current state of professional training for S&T and engineering personnel (Table 3) illustrate the situation.

Table 2
PERSONNEL IN SCIENCE AND SCIENCE MANAGEMENT IN THE RUSSIAN FEDERATION, 1990, 1995 AND 2001

	1990		1995		2001	
	Men	Women	Men	Women	Men	Women
Number (thousands)	1 332	1 472	827	861	597	590
As % number employed in 1990	100	100	62	58	45	40

Source: Kouznetsova and Dobretsova (2003) *Scientific Potential and Technical Level of Production.* (In Russian)

There are also some interesting figures on trends in training for highly qualified personnel like postgraduate students and candidates[2] (Table 5).

PATENTS AND LICENSING AGREEMENTS

One of the main indicators of technological development is a country's patent and licensing activity. A measure of invention activity is the number of patent applications per 10 000 population; Russia's performance for this indicator in 2000 was 2.6 times higher than that of the Republic of Korea, 4.7 times higher than that of Germany and 5.7 times higher than that of the USA. However, when calculations are made of the ratio of the number of patent applications made abroad to the number of domestic applications, then the figure for the Russian Federation is substantially lower than those of the leading countries in world innovation activity. Thus, the high creative potential of Russian scientists, engineers and inventors is under-developed because of Russia's lack of integration in the world patenting process.

In view of the favourable economic development of the last four years, the President of the Russian Federation has set the strategic goal of doubling GDP in the next eight to ten years while keeping inflation down. However, as economic analysis shows, an increase in GDP of more than 7% a year is not possible if only based on continuing high prices for oil; it will necessitate further development of resource industries and a growth in exports of their products. (Some experts believe the present high oil prices are providing a 6–7% increment to GDP in the Russian Federation.)

Worldwide, significant growth in GDP has been based on expanding exports of competitive knowledge-intensive products. In the 27 countries of the OECD, the GERD/GDP ratio grew between 1992 and 2002 in a trend driven by the private sector. Over these ten years, funding of R&D by

Table 3
TRENDS IN HIGHER EDUCATION IN THE RUSSIAN FEDERATION, 1995 AND 2001*

	Total		State higher-education institutions		Non-state higher-education institutions	
	1995	2001	1995	2001	1995	2001
Number of educational establishments	762	1 008	569	621	193	387
Number of students (thousands)	2 790.7	5 426.9	2 655.2	4 797.4	135.5	629.5

* At the start of the academic year
Source: *Russia in Figures* 1995–2003. (In Russian)

2. The Candidate of Science degree in the Russian higher education system is the second university degree obtained after the initial five-year diploma. It is followed by a Doctor of Science degree. The PhD falls between the Candidate of Science and Doctor of Science degrees.

Table 4
ENROLMENT IN TECHNICAL AND TECHNOLOGICAL SPECIALTIES IN THE RUSSIAN FEDERATION, 1990–2001
In thousands

	1990	1995	1996	1997	1998	1999	2000	2001
Geology and prospecting	0 .9	1.9	1.7	1.5	1.4	1.5	1.7	1.8
Mineral exploitation	4.1	3.2	2.9	2.9	3.5	3.7	4.0	4.9
Energetics and power mechanical engineering	8.8	7.0	6.6	6.8	6.5	7.2	8.3	9.2
Metallurgy	3.9	2.9	2.9	2.8	2.4	2.6	2.8	3.0
Mechanical engineering and material processing	14.0	12.2	11.5	10.4	10.2	10.4	11.1	11.7
Aviation and rocket space-engineering	4.0	4.1	3.4	3.3	2.9	2.8	2.9	3.2
Surface transportation means	7.4	5.3	4.9	5.2	4.7	5.2	6.1	6.6
Technological machines and equipment	10.0	8.8	9.2	8.8	8.4	8.9	9.4	10.2
Electrical engineering	2.8	4.9	4.8	4.5	4.1	4.3	5.0	5.8
Instrumentation	3.9	3.5	3.3	3.0	2.9	2.8	3.2	3.2
Electronics, radiotechnics and communication	14.2	13.1	11.9	10.9	9.0	8.8	9.9	10.8
Automatics and control	10.8	9.8	9.3	8.4	8.2	8.5	9.3	9.8
Computer science and computation	7.1	9.4	8.8	8.7	8.2	8.7	9.3	9.9
Transport exploitation	4.5	4.3	4.9	5.2	5.5	6.2	6.8	7.0
Chemical technology	7.2	4.9	4.6	4.1	4.0	4.3	4.5	4.8
Food technology	8.5	3.9	4.0	4.2	4.4	4.9	5.3	5.8
Commodities technology	8.9	4.5	4.5	4.1	4.1	4.0	4.0	4.3
Construction and architecture	22.6	17.7	18.2	17.5	17.3	18.7	20.2	22.3
Agriculture and fishery	29.7	20.6	21.8	21.6	21.2	22.8	24.8	26.1
Other	6.5	9.1	8.6	8.5	0.3	9.4	12.2	15.3

Source: Kouznetsova, T.U. and Dobretsova, N.I. (eds) (2003) *Scientific Potential and Technical Level of Production: Russia in Figures.* (In Russian)

Table 5
TRAINING OF HIGHLY QUALIFIED S&T PERSONNEL, 1995–2003

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Postgraduate students									
Total in all establishments (at end-year)	62 317	74 944	88 243	98 355	107 031	117 714	128 420	136 242	140 741
In scientific organizations	11 488	12 700	14 508	15 771	15 420	17 502	17 784	18 323	18 959
In higher-education establishments	50 829	62 244	73 735	82 584	91 611	100 212	110 636	117 918	121 762
Postgraduate students by scientific specialty (out of 20)									
Physics and mathematics	5 888	6 599	7 025	7 237	7 360	7 522	7 552	–	7 640
Chemical	1 964	2 263	2 495	2 754	2 951	2 987	3 104	–	3 241
Technical	17 424	21 428	25 407	27 160	28 385	29 058	30 974	–	33 370
Candidates									
Total (at end-year)	2 190	2 554	3 182	3 684	3 993	4 213	4 462	4 546	4 567

Source: *Russian Statistics Yearbook* 1996–2003; *Russia in Figures* 2004. (In Russian) business increased by 50% compared with a rise of only 8% for government funding. The private sector's share of GERD climbed from 57.5% in 1990 to 63.9% in 2002 even as governing funding declined from 39.6% to 28.9%. The contribution of knowledge-intensive industries to GDP rose by a factor of 2.04 to 2.24% on average.

By comparison, only a quarter (27.2%) of entities performing R&D in Russia were privately owned in 2001. Taken together, business and non-profit organizations represented a share of 9.8% of GERD the same year, an increase of just 2.2% over 1995. The federal share of GERD dropped over the same period by 4.3%. These trends are symptomatic of the business sector's lack of interest in investing in long-term scientific R&D. Thus, doubling GDP through knowledge-intensive industries appears impossible without a considerable rise in private investment in this area.

There were some contradictory trends in the development of S&T in the Russian Federation in 1999–2003. Economic growth during those years indicated that the country was recovering from the long recession. Nevertheless, the main qualitative indicators of the country's economic development remained subdued. Continuing economic and institutional reforms have not been reinforced by a fundamental revision of the state S&T policy in a long-term perspective, there have been no essential alterations to the way in which R&D is organized and no solutions have been found for the economic and institutional problems that surfaced between 1992 and 1998 in the process of reorganizing S&T. This allows us to draw the conclusion that the prolonged systemic crisis of basic and applied science in Russia has not yet been overcome.

APPLIED SCIENCE IN RUSSIA: PROBLEMS AND PROSPECTS

The conceptual document, *The Foundation of the Russian Federation Policy in the Field of Science and Technology Development for the Period to 2010 and Further Prospects*,[3]

Table 6
PATENTING AND LICENSING IN THE RUSSIAN FEDERATION, 1995–2001

Indicators of patenting activity	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Resident patent applications per 10 000 population	1.12	1.22	1.03	1.13	1.37	1.61	1.72
Ratio of patent applications made abroad to domestic applications (conveyance)	0.50	0.80	1.16	1.45	–	–	–
Registration of agreements on licence trade and cession of rights on patents							
Total	1 095	1 313	1 521	1 616	1 578	2 114	2 022
By field of technology:							
Construction, construction materials	104	97	111	117	74	89	115
Mechanical engineering, machine-tool construction, materials production	102	260	181	383	197	345	311
Chemistry, petrochemistry	150	171	219	220	223	203	27
Metallurgy	55	63	84	82	95	85	63
Electronics	87	98	125	87	104	78	103
Light industry, food industry	166	179	204	218	271	323	269
Energy, electrical engineering	55	62	71	82	69	150	117
Medicine	230	215	196	171	224	264	131
Oil and gas industry	49	41	97	44	103	224	131
Other	97	127	233	212	218	353	355

Source: *Russian Statistics Yearbook* 1996–2002; Russian Statistics Collection. (In Russian)

3. This was adopted in March 2002 by a joint meeting of the Security Council, the State Council Presidium and the Council by the President of the Russian Federation on Science and High Technologies and approved by presidential decree the same month.

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describes the development of S&T as the top priority for the Russian Federation. The main declared goal of government science policy is to improve innovation; it has listed nine priorities for the future direction of scientific R&D, as well as 52 critical technologies. The main objective for the state in 2004 and up to 2010–15 remains that of creating the right institutional and economic conditions for the transition to sustained development on the basis of competitive high technologies and knowledge-intensive products.

The economic expansion dating from 1999 has been an important achievement of reform. However, first and foremost, the pace of economic expansion has not been sufficient. Second, it has been mostly based on the use of yet-to-be-exhausted S&T reserves and more extensive exploitation of resource industries. Increased exploitation of ever-growing volumes of Russia's non-renewable natural resources may lead to a short-term rise in GDP in favourable world economic conditions but it is contradictory to the long-term interests of the country's population and the declared strategic principles of state S&T policy.

This analysis of the 12 years of S&T reform in the Russian Federation hardly gives grounds for an optimistic prognosis for further development of S&T, even in the mid-term. In 2002, Russia may have ranked third in the world for the number of its scientists and engineers and held ninth place in GDP by volume, but its main indicators of competitive growth were far behind not only those of all the developed countries but also of many developing ones. Russia was 52nd in the innovation activity index and 60th in the level of technologies. As for the General Competitiveness Index (GCI), which defines the ability of a national economy to stabilize growth in the following five years (Figure 10), the Russian Federation occupied 63rd place in the table of world ratings.

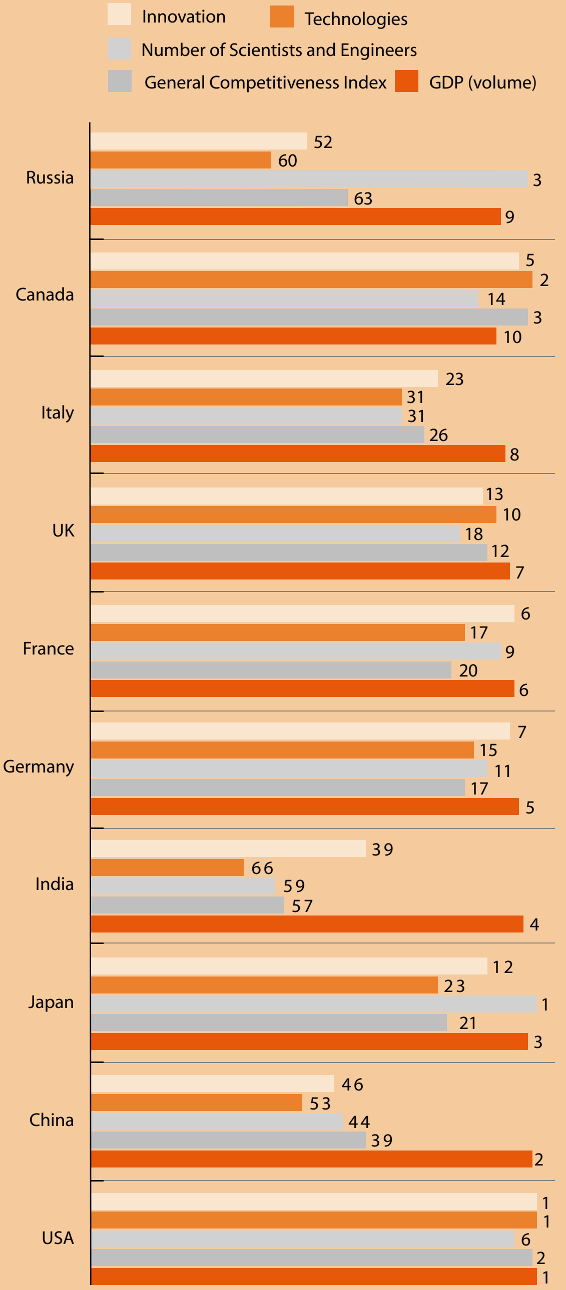
The general reasons for this are obvious. There has been no large-scale improvement in S&T potential. The attempts made so far to create the legislative basis for innovation in science and industry have neglected some core problems: reforming the organization of basic and applied R&D, raising the status of scientists and scientific teams, and intellectual property protection and security for domestic manufacturers of knowledge-intensive products. Economists have pointed to the development of enclaves in the Russian economy. Even with the loosening of the ties between export-oriented economic sectors and industries working for the domestic

Table 7
CLAIMS FOR PATENTS AND ISSUED PATENTS IN THE RUSSIAN FEDERATION, 1993–2003

	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total number of claims for patents	32 216	22 202	23 211	19 992	21 362	24 659	28 688	29 989	29 225	30 651
of which:										
Domestic applicants	28 478	17 551	18 014	15 106	16 454	19 900	23 377	24 777	23 712	24 969
Foreign applicants	3 738	4 651	5 197	4 885	4 908	4 759	5 311	5 212	5 513	5 682
Patents issued										
Total	27 757	31 556	33 574	45 975	23 762	19 508	17 592	16 292	18 114	24 726
New patents	13 214	25 633	19678	29692	23 315	19 508	17 592	16 292	18 114	24 725
New patents issued:										
Foreign applicants	4 276	4 772	3 189	4048	4 100	4 146	3 148	2 513	2 974	4 105
Domestic applicants	8 938	20 861	16 489	25 644	19 215	15 362	14 444	13 779	15 140	20 621
Patents in operation	44 321	76 186	173 081	155 247	173 081	191 129	144 325	149 684	102 568	143 584

Sources: *Russia in Figures 2004* (In Russian); UNESCO Institute for Statistics.

Figure 10
WORLD RATING* OF RUSSIAN FEDERATION IN ECONOMIC DEVELOPMENT AND INNOVATION, 2002
Other countries are given for comparison



* A score of 1 indicates the top country in the world

Source: Beketov, N.V. (2003) *Science in Russia and in the World*. (In Russian)

market, the growth of production in one area does not sufficiently stimulate a rise in the other.

URGENT REFORMS NEEDED

This has resulted in a growing dependence on export-oriented production and world market conditions that is disruptive for the unity of the Russian economy. Hence, the urgent question of the day is whether the Russian Federation can bring about decisive acceleration of reform of the way in which Russian science is organized. Among the top-priority tasks are:

- to create the economic and institutional conditions needed for rapid development of innovation and investment activity in the sphere of science and knowledge-intensive industrial production, with the active participation of the private sector;
- to eliminate once and for all the differentiation of production technology into civil and defence, export and domestic;
- to improve the social and economic status of scientists and scientific groups;
- to complete a reorganization of the system of academic, higher learning and industrial institutions, as well as of the general and professional, secondary and higher-education systems;
- to develop significantly various forms of funding for scientists and groups actively involved in R&D (in particular to facilitate powerful private charitable foundations supporting S&T development);
- to introduce as soon as possible a law on intellectual property relevant to the market economy;
- to substantiate an organizational model of scientific R&D suited to the post-industrial reality and to redefine accordingly the principles and priorities of state S&T policy.

Solutions may be around the corner thanks to a high-level administrative reform being introduced at the time of writing this chapter in 2004. In 2003–04, the Ministry of Education and Science was established to reintegrate science and education management. The structure of the ministry includes the Federal Office on Intellectual

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Property, Patents and Trademarks; the Federal Office of Education and Science Supervision; the Federal Agency on Science; and the Federal Agency on Education.

Within the new government structure, other ministries are also closely linked to applied research and the organization of R&D, as well as to innovation (including scientific research, product development and the application of technology), among them: the Ministry of Economic Development and Trade, the Ministry of Industry and Energy, the Ministry of Transport and the Ministry of Defence, with departments such as the Federal Office in Technical-Military Cooperation, the Federal Office on Defence Contracts and the Federal Office on Technical and Export Control of the Russian Federation.

It is too early to draw conclusions about the efficiency of the new system of state regulation of S&T activity and science and engineering management in Russia, or to evaluate future prospects. Nevertheless, some favourable trends can already be seen: for example, the federal budget for 2004 projects further growth of some indicators of S&T development over 2001, 2002 and 2003. The allocation for science development amounts to 1.74% of general federal budget expenditure. Civil R&D will be allocated 14.9% more than in 2003. Grants will be given to scientific organizations for instrumental base development, unique stand maintenance, development of complex use centres and for the acquisition and maintenance of scientific equipment. Measures taken to redress the consequences of the USSR's differentiation between the S&T and industrial-technological spheres, as well as between the civil and defence sectors, are promising and already appear to be working. The alignment of all manufactured goods on universal, worldwide technical standards will be beneficial and reduce overhead costs.

A current issue for Russia is the development of scientific contacts with the European Union in the area of basic and applied research, which would facilitate the country's integration in the process of globalization. Russian scientists and engineers are already participating in some large-scale international S&T projects. Despite the fact that the Russian economy is still lagging behind those of developed countries, Russia is now entering the world innovation market. All these developments will expedite the recovery of S&T in Russia and help Russia's unique scientific community to advance in a number of directions with the prospects of being a player in global technological progress in the future.

BORIS KOZLOV

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Victor Sadovnichy has been Rector of Moscow State University since 1992. He holds a PhD in physics and mathematics (1974) and is a specialist in informatics and applied mathematics. Among other research projects over the past 30 years, his study of the dynamic simulation of movement control of a spaceship resulted in a world first, the creation of a simulated zero-gravity state under ground conditions. He is also known for being the author of spectral theory, in 1967.

Professor Sadovnichy was appointed Head of the Mathematical Analysis Department of the Faculty of Mechanics and Mathematics at Moscow State University in 1982. In 1994, he was elected President of the principals of almost 700 Russian universities and other tertiary establishments and, the same year, President of the Eurasian Association of Universities. He has been a full member of the Russian Academy of Sciences since 1997. He is also a member of the Standing Committee of European University Rectors and a number of other international institutions.

He was awarded the M.V. Lomonosov Prize in 1973, which rewards outstanding achievements in the natural sciences and humanities. He was also the recipient of the State Prize of the Union of Soviet Socialist Republics in 1989.

Boris Igorevich Kozlov is Professor at the Russian Academy of Sciences. He has been Head of Department at the Academy's Archives since 1993 and is a Fellow of the Russian Academy of Astronautics.

After graduating from the Institute of Military Engineering in 1967, Professor Kozlov took up a position as Head of Laboratory at the Scientific Research Institute of Metrology, before going on to become Deputy-Chief Engineer. In 1976, he was appointed Scientific Researcher at the Institute of the History of Natural and Technical Sciences then later Chief Editor of the Institute's journal, *History of Natural and Technical Sciences*, and Acting Director, a post he occupied until 1993.

Professor Kozlov's research spans a wide spectrum of fields, from the general theory of complex systems to social history and the philosophy of science and engineering, scientific theory and noospherology (a prototype of sustainable development theory). He is the author of two inventions and 150 scientific publications.

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The Arab States

ADNAN BADRAN

Although Arab culture historically has contributed a great deal to the world's scientific development, the region today exhibits poor performance in science and technology (S&T). It is evident that the advances in S&T that have changed our lifestyle have been driven by exciting discoveries made by scientific laboratories in the West. These discoveries have transformed human behaviour by introducing new products, new processes and better services. This progress has been mainly due to the West's commitment to improving both the quality and relevance of education, particularly in basic and applied sciences. The West's investment in human resources has created a wealth of knowledge.

In the meantime, due to political turmoil, low-quality education and inadequate R&D infrastructure, the Arab region has failed to deliver the high-quality scientists it needs to build economic self-reliance and capacity for innovation in the region.

OVERVIEW

The Arab region has by no means a homogeneous social fabric. The region's peoples may share a commonality of language, history and religion, but their societies are at variance when it comes to governance, currency, traditions and socio-economic systems.

The region is home to 295 million people, representing 4.5% of world population, and boasts a workforce of 103 million. Scattered across 22 countries, the Arab region covers 10.2% of the world's land area.

The Arab region has one of the highest fertility rates in the world. It exhibits annual population growth of 2.3%, compared with averages of 0.6% for industrial countries and 1.9% for developing countries. The fertility rate is 3.7 children per woman, whereas the world average is 2.8. As a consequence, the Arab population is expected to reach 315 million by 2015. One feature of Arab demography is that 40% of the population are young people aged 15 or under. This puts growing stress on educational, health and social systems, a trend that may have an impact on economic growth in terms of eroding gains in gross domestic product (GDP) per capita.

Wealth varies greatly from one country to another. In Qatar, for example, GDP per capita is the highest in the world at US$ 29 948. This contrasts strikingly with GDP per capita of only US$ 334 in Mauritania, one of the poorest countries in the world.

The Arab region may be grouped into three categories. The first, characterized by dependence on natural resources, particularly oil, includes the Gulf States of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates – GDP per capita income being highest in Qatar and lowest in Oman (US$ 7 933).

The second category encompasses Algeria, Egypt, Iraq, Jordan, Lebanon, Libya, Morocco, Palestine, Syria and Tunisia, where GDP per capita is highest at US$ 4 552 and lowest at US$ 1 180. Although the countries in this category possess modest natural resources – with the exception of Iraq and Libya, which have considerable oil resources – they are essentially rich in terms of human resources, which are underutilized.

The third group of countries is characterized by scant natural resources and an equally meagre supply of trained human resources. Countries in this category also possess some of the lowest GDP per capita incomes in the world, which classifies them as least developed countries (LDC). They are Djibouti (US$ 819), Mauritania, Somalia, Sudan and Yemen.

Table 1 shows the average GDP per capita of Arab states in 2002 compared with 1995. Some countries have experienced economic growth; others have suffered a recession.

ARAB SCIENCE IN A HISTORICAL PERSPECTIVE

The history of science can be divided into four broadly defined eras. The Greeks made substantial contributions to science between 450 BC and about 200 BC. The Chinese made useful contributions during the period AD 600–700. The Arab golden era of science extends about 350 years, from AD 750 to 1100. Europe and the West come to the fore from AD 1350 onwards.

Between the seventh and fourteenth centuries, the Arab and Islamic region held the banner of civilization, learning,

Table 1
GDP PER CAPITA IN THE ARAB REGION, 1995 AND 2002
In ascending order ($PPP*)

	1995	2002
Mauritania	463	334
Sudan	245	443
Yemen	332	508
Djibouti	858	819
Syria	1 163	1 180
Morocco	1 252	1 250
Egypt	1 053	1 286
Algeria	1 456	1 661
Jordan	1 568	1 744
Tunisia	2 015	2 367
Libya	6 340	3 292
Lebanon	3 178	4 552
Oman	6 477	7 933
Saudi Arabia	7 577	8 053
Bahrain	10 120	11 374
Kuwait	14 118	14 597
United Arab Emirates	17 755	20 509
Qatar	16 642	29 948
Average	**2 144**	**2 430**

* PPP = purchasing power parity.

Source: Arab Fund for Economic and Social Development (2003) *Unified Arab Economic Report 2003.*

science and philosophy. Arabs led the way in mathematics, astronomy, physics, chemistry and medicine, due to their drive and enquiring minds when it came to problem solving and seeking the truth. Luminaries of this era who laid the foundations of modern science include Jaber-bin-Hayan (chemistry), Al-Khawarzmi (mathematics), Al-Razi (chemistry and medicine), Ibn-Sina (medicine), Ibn-Alhaisam (optics) and Al-Bairuni (physics and medicine). It was during this period that an unprecedented unravelling of intellectual mysteries related to nature occurred. The critical and analytical approach that was developed at the time is inherent in today's science.

At the time of Arab greatness, other civilizations remained stagnant. Ekelund and Hébert (1990) wrote that 'The death of the last Roman emperor in AD 475 ushered in a long period of secular decline in the West and a concomitant rise in the fortunes of the East.' By AD 730, the Moslem empire's reach extended from southern France to the borders of China and India, an empire of spectacular strength and grace. Islam led the world in power, organization and extent of government; in social refinements and standards of living; in literature and scholarship. The Arab world acted as a sort of conduit to the West for Hindu wisdom and culture. Cities of the Saracen world like Baghdad, Cairo and Damascus, and Moorish Cordova and Toledo in Spain, were growing centres of Arab civilization and intellectual activity. It was Moslem science that preserved and developed Greek mathematics, physics, chemistry, astronomy and medicine during this half millennium, while Europe sank into what historians commonly call the Dark Ages (AD 500–1100).

Perhaps the most significant single innovation that the eager, inquisitive Arab scholars contributed to the West was their system of writing numbers. This displaced the clumsy Roman numerals of the previous empire with the much more utilitarian Arabic numerals of today. One of the more eccentric Arab mathematicians, Alhazen, founded the modern theory of optics around the year AD 1000. But for our purposes, the most important contribution of Arab culture was its reintroduction of Aristotle to the West.

After the city of Toledo was recaptured from the Moors by Crusaders in 1085, European scholars flocked there in order to translate the ancient classics, from Greek (which Europe had forgotten) into Arabic and Hebrew, then into Latin, making that knowledge accessible to the West. From AD 1100–1350 – during the first half of the European Middle Ages (AD 1100–1543) – the names of a few European scientists appear in scientific literature alongside a string of Muslim scientists, whose numbers include Ibn-Rushd, Tusi and Ibn-Nafis.

In that era, the English scholar Roger Bacon (1214–1292) studied Arabic and Arab sciences. Bacon became an expert on Aristotle at Oxford University and lectured on his teachings both there and at the University

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of Paris, where study of Aristotle had been banned for many years on the grounds that he was not a Christian. Bacon was to introduce the experimental method as the only way to true knowledge.

After AD 1350, the world's scientific honours go mainly to Western scientists. The year 1543, which marked the death of Copernicus – who established a mathematical-astronomical model of the Sun at the centre of the universe, and Earth and other stars rotating around it – was to signal the end of medieval times and superstition, and the dawn of the Renaissance and modern science in Europe.

Robert Briffault states that science arose in Europe as a result of a new spirit of enquiry, new methods of investigation – the experimental method and the use of observation and measurement – the development of mathematics in a form unknown to the Greeks and, last but not least, the introduction of those methods by Arabs into the European world. Since then, European domination of science has become more pronounced with the passage of time.

WHY SCIENCE HAS DECLINED IN THE ARAB REGION

Scientific failing in the Arab region after AD 1350 can be traced to its history of persistent political upheaval caused by loss of empire, subjugation and conflict within countries. Such turmoil led to the disappearance of intellectual activity – an absence of interest in reasoning and a lack of curiosity – and has resulted in the region's current totalitarian and dictatorial political power systems. Arab enquiry and analysis were ultimately replaced by dogma and ignorance, resulting in the erosion of the scientific approach, accompanied by the loss of freedom of expression and thought.

Science grew essentially as a scholarly pursuit in its own right. However, oppression and loss of free thinking as a result of political conflicts, instability and the demise of democratic governance have produced too rigid an environment for the inquisitive mind to study nature. Hence, the last few centuries of scientific innovation completely belong to Europe, and the contribution of Arabs has been close to insignificant.

The current failure of S&T in the Arab region can be attributed to several main factors. One is an overall lack of interest in science by political leaders, who devote minimal funds to education and science compared with those set aside for military expenditure. Another is the deteriorating education system, whose insistence on traditional religious teachings leaves little room for scientific enquiry, much less innovative thinking. These factors, along with the strait-jacket of inadequate infrastructure and R&D support systems, create an environment that is not conducive to research and development. They will be discussed in greater detail below.

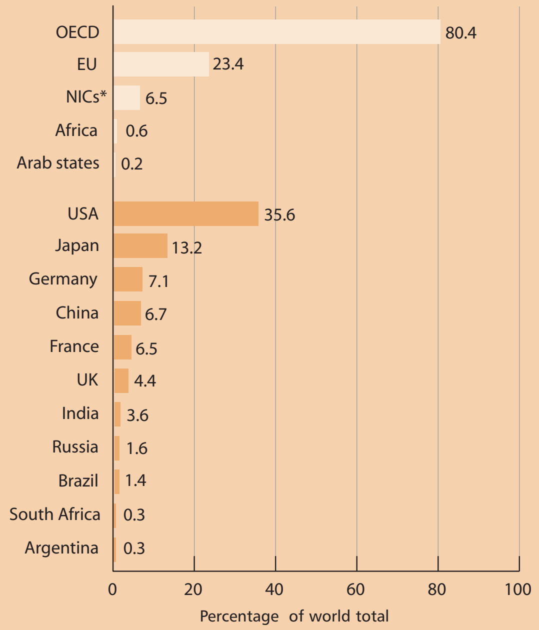
STATUS OF S&T IN THE ARAB REGION

Publications

One indicator of the region's poor performance is its low level of translation and publication of scientific papers. This falls within the general historical trend of few publications and translations in this region. For example, the cumulative total of translated books in the Arab world since the Caliph Maa'moun's time in the ninth century is about 100 000 books – equal to the volume Spain translates in one year (UNDP, 1999). The number of books currently translated into Arabic is about five books for every million Arab people. This compares with 920 books per million people translated into Spanish in Spain. To take another example, some 6 500 books are published by Arab writers every year in the Arab region, compared with 102 000 in North America.

Focusing on active research scientists, an indicator of the dynamism of research is the number of articles cited in reputable journals. The science citation index (SCI) is one measure of this activity. The number of frequently cited scientific papers per million inhabitants amounts to 0.02 in Egypt, 0.07 in Saudi Arabia, 0.01 in Algeria and 0.53 in Kuwait. Other Arab countries frequently have no cited publications to speak of. This compares with 43 in the USA, 80 in Switzerland, 38 in Israel, 0.04 in India and 0.03 in China. On a global level, the number of scientific publications originating in the Arab world does not exceed 1.1% of world production.

Figure 1
GERD IN THE ARAB REGION AS A WORLD SHARE, 2000



* NICs: Newly industrialized countries

Source: UNESCO (2003) *Global Investment in R&D Today.*

Patents

Technology output can be expressed in terms of the number of registered patents. Table 2 indicates the low level of innovative technology produced by the Arab region. Egypt, Kuwait and Saudi Arabia have been the Arab region's main driving forces behind S&T output at the international level.

Investment in S&T

In terms of the ratio between gross domestic expenditure on R&D (GERD) and GDP, investment in the Arab world declined from a world share of 0.4% to 0.2% by 2000. Egypt, Jordan and Kuwait spend the most, devoting 0.4% of GDP to GERD. The figure for the remainder of the Arab region is as low as 0.1%. Total Arab GERD amounts to US$ 1 100 million. As can be seen in Figure 1, the Arab region trails the developing countries in terms of GERD; this can be explained by a number of factors.

First, turnkey technology – which employs assembled products available for immediate use – is favoured in the Arab states to the detriment of endogenous technology, owing to contractual arrangements with foreign suppliers. In the past three decades, the Arab world has spent US$ 1 000 billion on turnkey projects which is more than 20 times the amount spent within the Marshall Plan to

Table 2
PATENTS REGISTERED AT THE USPTO ORIGINATING FROM ARAB STATES, 1995–99
Non-Arab states are given for comparison

Year	1995	1996	1997	1998–99	Total
Bahrain	0	0	1	0	**1**
Egypt	7	6	2	7	**22**
Jordan	0	2	5	4	**11**
Kuwait	2	3	2	15	**22**
Oman	0	0	0	2	**2**
Saudi Arabia	11	12	14	30	**67**
Syria	0	0	0	1	**1**
United Arab Emirates	2	1	2	3	**8**
China	91	78	103	201	**473**
Republic of Korea	1 265	1 603	2 027	5 089	**9 984**
Israel	489	591	653	1 343	**3 076**

Source: United States Patent and Trademark Office: www.uspto.gov

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rebuild Europe after the Second World War. The Arab states' dependence on such technology does nothing to help build domestic S&T capacity. The Arab region has maintained a strong role as a consumer of technology, totally dependent upon advanced countries for its own needs, be it in the form of chemicals, pharmaceuticals, engineering goods, transportation or defence equipment.

Second, S&T is not a priority item on the agenda of Arab political leaders – reflecting an absence of appreciation for the region's science and scientists. This has led to a situation where Arab economies dependent on oil and mineral resources will not be able to sustain development as resources become depleted. In spite of being blessed with 70% of the world's energy resources, the GDP of the entire Arab region is less than that of Italy.

In terms of overall investment, the amount spent in the Arab world on R&D, education and health combined amounts to less than expenditure on military needs imported from abroad (Table 3). Even though spending on defence has fallen recently, it still exceeds spending on education.

Generally speaking, expenditure on R&D by Arab countries is at best one-tenth of that spent in industrialized countries. According to UNESCO's 2003 report entitled *Global Investment in R&D Today*, some countries spend more than 3% of GDP on R&D, as in the case of Israel (4.4%) and Sweden (3.8%). The European Union spends 1.9% of GDP on R&D and has set a target of 3% by 2010. India spent 0.5% of its GDP on R&D in 2000 and has set itself a target of 2% by 2007. India's R&D indicators for 2003 have already shown the country's commitment as GERD has climbed to 1.08% of GDP.

Approximately 1.7% of world GDP was devoted to R&D in 2000, compared with 1.6% in 1997. The OECD reports a 2.4% share of GDP spent on R&D. Latin America spends an average of 0.6% of GDP on R&D, with Brazil and Costa Rica the greatest spenders at 0.9%, closely followed by Cuba at 0.8%. The Arab region remains by far the least R&D-intensive region in the world, devoting only 0.2% of GDP to R&D in 2000.

The low figure recorded by Arab countries again reflects how Arab GDP is inflated by oil production, even though not all Arab states are oil producers. Arab researchers may not reach international standards in either quantity or quality, but their contribution to world R&D at 0.6% of the total is still three times that of the contribution of Arab GERD to world R&D.

Data shown in Figure 3 indicate disparities between developed and developing countries in terms of GERD per capita. In 2002, the Arab region spent US$ 6 per capita on R&D, compared with US$ 953 per capita in the USA, US$ 779 in Japan, US$ 465 in the European Union, US$ 42 in Latin America and US$ 40 per capita in China. The world average is US$ 124 and the ratio of R&D spending by developing countries to that by industrialized countries is 1:15.

Information and communication technologies

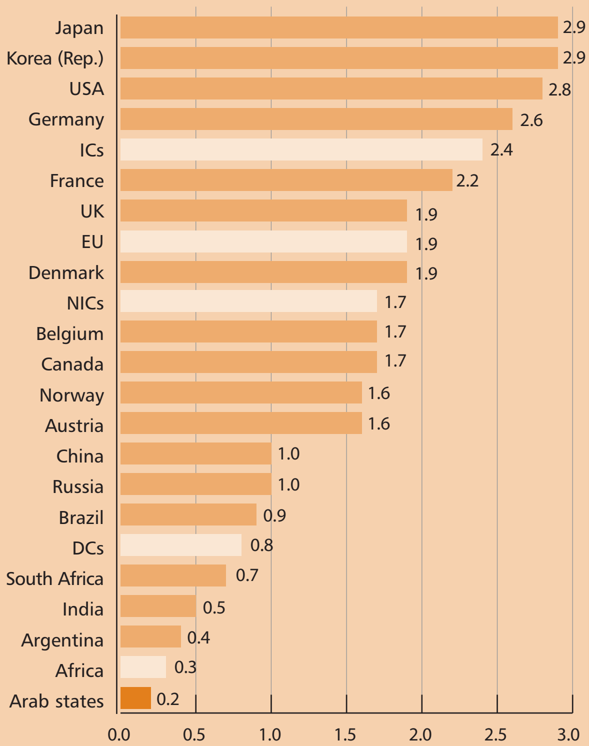
Arab indicators show that S&T is in need of greater attention in terms of resources, institutional arrangements and

Table 3
MILITARY EXPENDITURE IN SELECTED ARAB STATES, 2001
As percentage of GDP, in descending order of GDP per capita

United Arab Emirates	2.5
Kuwait	11.3
Bahrain	4.1
Saudi Arabia	11.3
Oman	12.2
Lebanon	5.5
Tunisia	1.6
Jordan	8.6
Algeria	3.5
Egypt	2.6
Morocco	4.1
Syria	6.2
Djibouti	4.4
Yemen	6.1
Sudan	3.0
Mauritania	2.1

Source: UNDP (2003) *Human Development Report.*

Figure 2
GERD/GDP RATIO IN THE ARAB REGION AS A WORLD SHARE, 2000
Other countries and groupings are given for comparison



ICs: Industrialized countries
DCs: Developing countries
NICs: Newly industrialized countries

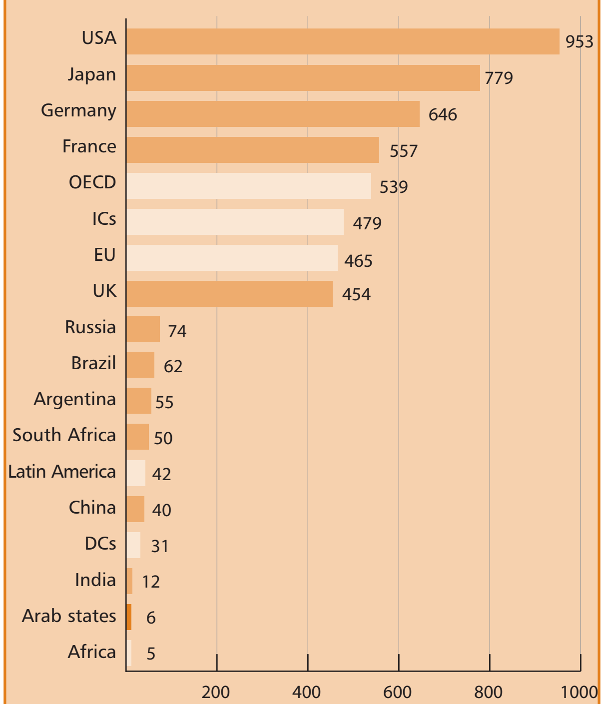
Source: UNESCO (2003) *Global Investment in R&D Today.*

policy support. There are serious inadequacies, particularly where access to new technologies and information is concerned. Figure 4 shows that the Arab region has less than half the number of computers per 1 000 inhabitants than the average for middle-income countries. There are fewer than 25 computers per 1 000 population in the Arab region, compared to a global average of 78.3 (UNDP, 2003a). Similarly, there are only 109 telephone lines per 1 000 inhabitants in the Arab region, in contrast to an average of 561 in developed countries. That translates to one telephone for every ten Arab citizens, against a ratio of one telephone for every 1.7 people in developed countries.

Some Arab countries, however, are catching up with the communications revolution. For example, a fibre-optics cable project covers 27 000km between Saudi Arabia, Egypt, the United Arab Emirates and Jordan. And in 1999, an Internet fair called Dubai Internet City displayed the UAE's progress in integrating information and communication technology (ICT).

In general, however, the lack of computers and limited Internet penetration in the Arab region are serious obstacles to online learning and to gaining access to information and knowledge databases in the vast array of scientific research

Figure 3
GERD PER CAPITA IN THE ARAB REGION, 2000
Other countries and groupings are given for comparison (in $PPP thousands)



ICs: Industrialized countries
DCs: Developing countries
NICs: Newly industrialized countries

Source: UNESCO (2003) *Global Investment in R&D Today.*

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networks, universities, libraries and learning resources throughout the world. Developing into a knowledge society cannot be achieved without the appropriate infrastructure and relaxation of governmental bureaucracy concerning the acquisition of computers and related software technologies. Customs barriers and political protection in Arab countries hinder free communication and access to knowledge through networks.

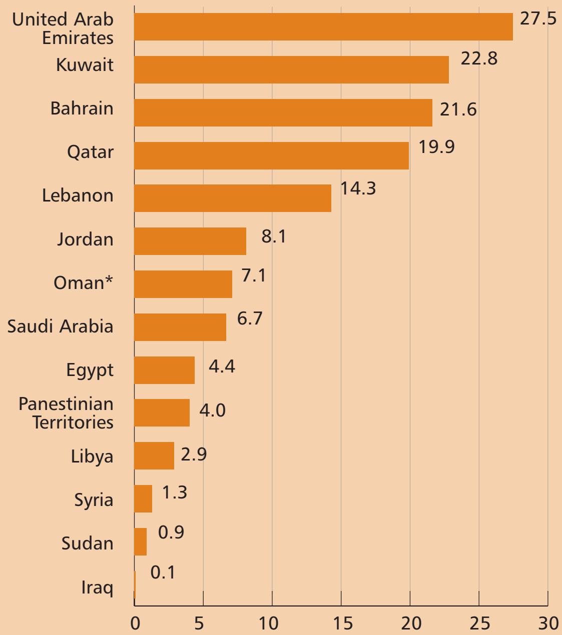
Indicators show there were 4.2 million Arab Internet users in 2000, representing 1.6% of the Arab population (UNDP, 2003a); this figure compares with 30% of the population in the USA. These low numbers are a result both of the factors already mentioned and of the high cost of telephone lines, computers and subscriber fees. The small number of Internet service providers in the Arab region means there is little competition, and costs remain steep.

However, Figure 5 demonstrates that some Arab countries are making considerable progress in Internet penetration. Fibre optics and wireless networks are being established within and between university campuses to help pool resources in teaching, research and access to information. Many Arab universities, particularly in Egypt, Jordan, Lebanon and the Gulf states, have created online education and open university systems to link up to open universities in the UK, as well as to European and American universities. Libraries are also being linked to each other through a National Information Centre (NIC), in order to create an intranet electronic library system and Internet online library.

Increasingly, universities are providing more education in hardware and software technology, in addition to training courses in software programmes. Of all the countries in the region, Jordan has the highest computer literacy, thanks to the implementation of training programmes leading to an inter-national computer driving licence (ICDL). The programme content is supervised by UNESCO and meets European standards.

Table 4 shows the the position of Egypt, Jordan and Tunisia on the Networked Readiness Index (Harvard University, 2003), compared with sample countries from three other

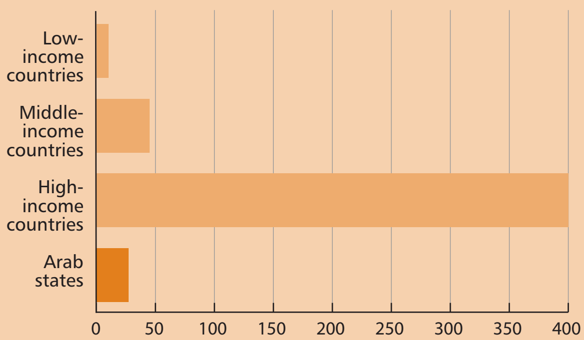
Figure 5
INTERNET PENETRATION IN THE ARAB REGION, 2003
Users as percentage of population



* 2002

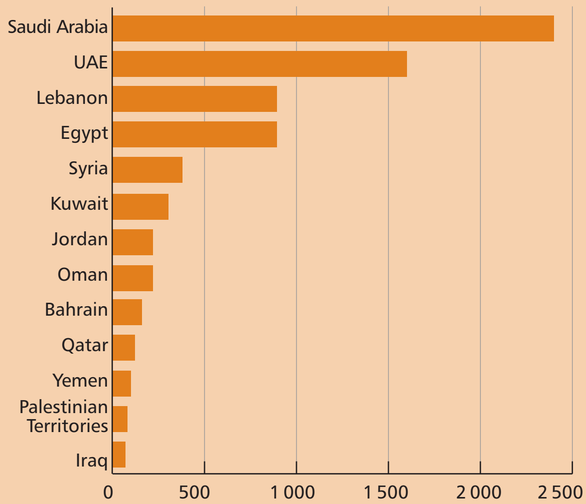
Source: http://unstats.un.org/unsd/mi/mi_series_results.asp?rowID=605

Figure 4
PERSONAL COMPUTERS PER 1000 POPULATION IN THE ARAB REGION, 2001
Other groupings are given for comparison



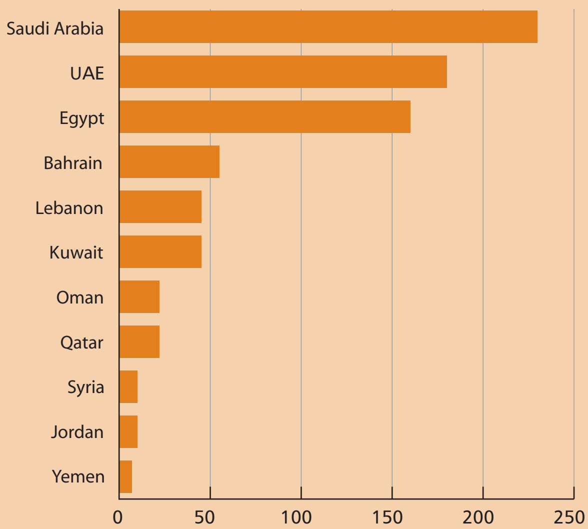
Source: World Bank (2002) *World Development Indicators*; UNDP (2003a) *Arab Human Development Report.*

Figure 6
VALUE OF CONTRACTS INVOLVING TRANSFER IN ICT, SELECTED ARAB STATES AND TERRITORIES, 1992–98
US$ million



Source: *Middle East Economic Digest* (MEED) 1999.

Figure 7
TOTAL VALUE OF CONSULTANCY CONTRACTS IN SELECTED ARAB STATES, 1992–98
In millions of $PPP



Source: *Middle East Economic Digest* (MEED) 1999.

regions. The index ranks countries on their preparedness to participate in the networked world and potential to participate in future. The highest ranking country has the most highly developed ICT networks and greatest potential to exploit them.

The total spent on ICT transfer by Arab countries between 1992 and 1998 amounted to US$ 161.3 million on IT and US$ 6.8 billion on communications. Figure 6 shows the value of contracts involving transfer of ICT over this period.

Consultancy as a tool for technology transfer

Consultancy contracts can be useful as an indicator of how know-how is oriented toward various economic activities, and this information can help in identifying areas for building endogenous S&T institutions that may target the transfer of know-how from contracting bodies to enhance national strategic plans. Figure 7 shows the value of consultancy contracts in S&T concluded by the Arab region from 1992 to 1998 for a total of US$ 726 million. Egypt, Saudi Arabia and the United Arab Emirates account for about 78% of the total. In reality, the transfer of S&T depends largely on how these contracts are managed and what sort of a relationship is established between local teams and the consultants in terms of training, bridging and capacity building.

Table 4
THE DIGITAL DIVIDE IN SELECTED ARAB STATES, 2002
Other countries are given for comparison

	Score	Position in Networked Readiness Index
Tunisia	4.16	34
Turkey	3.57	50
Jordan	3.51	63
Egypt	3.13	64
Finland	5.92	1
Malaysia	4.28	32
Nigeria	2.62	74

Source: Harvard University (2003), *Global Information Technology Report 2002–2003.*

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Arab scientists and engineers

Figure 8 shows that, with 124 full-time equivalent (FTE) research scientists and engineers per million population, the Arab region surpasses only Africa. The Arab figure is far lower than the average of 313 for developing countries.

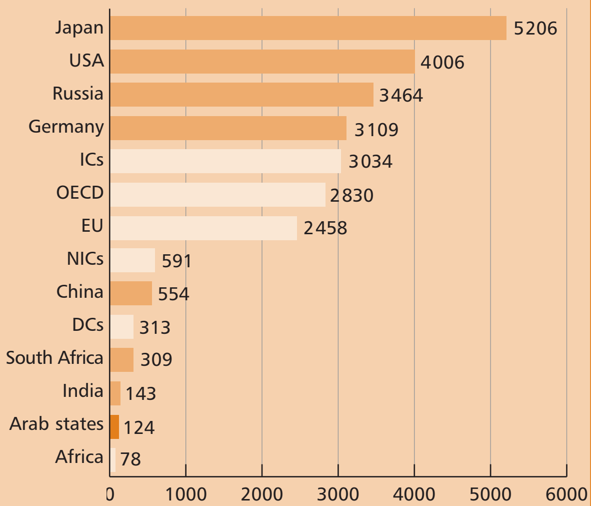
If we compare the Arab region with the Russian Federation, which has a population of a similar size, we find that the number of Arab researchers per million inhabitants amounts to only 0.5% that of the Russian Federation.

GERD per researcher is extremely low in the Arab region (Figure 9). However, owing to the fact that low GERD is spread over fewer researchers, GERD per researcher in the Arab region is actually higher than the corresponding figure in the Russian Federation, despite the fact that total GERD in the Arab region represents only 12% that of the Russian Federation.

Research groups are made up of MSc and PhD holders. Figure 10 gives R&D expenditure per FTE researcher in some Arab countries. It should be interpreted with caution, since the high figures for some countries reflect the fact that GERD is spread over a small pool of researchers. A large amount of GERD is spent on salaries and wages for researchers and support staff. Note also that the Gulf States pay higher salaries to researchers than do other countries.

Of the 20 000 research scientists and engineers in the Arab region, more than half (56%) are found in Egypt (Table 5). Some 66% of Arab researchers work in the public sector (for the government), 31% in the university sector and only 3% in the private sector. Nearly half (44%) of all Arab researchers work in water and agriculture (UNESCO, 1998).

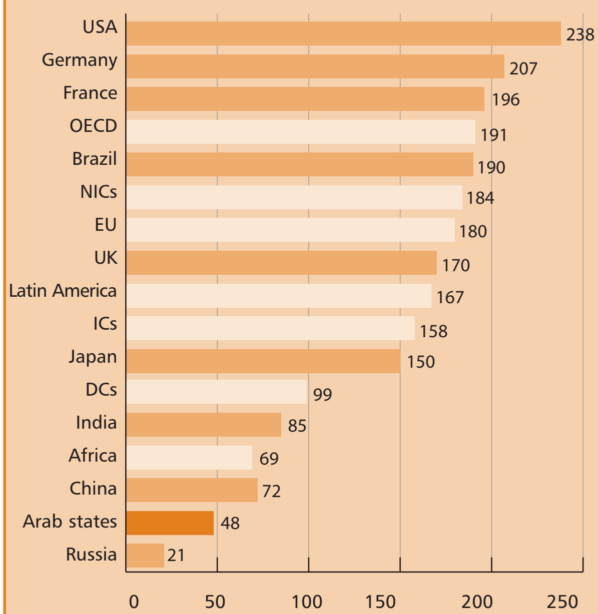
Figure 8
RESEARCHERS PER MILLION INHABITANTS IN THE ARAB REGION, 2000
Other groupings and non-Arab states are given for comparison



ICs: Industrialized countries
NICs: Newly industrialized countries
DCs: Developing countries

Source: UNESCO (2003), *Global Investment in R&D Today.*

Figure 9
GERD PER RESEARCHER IN THE ARAB REGION, 2000
Other groupings and non-Arab states are given for comparison ($PPP thousands)

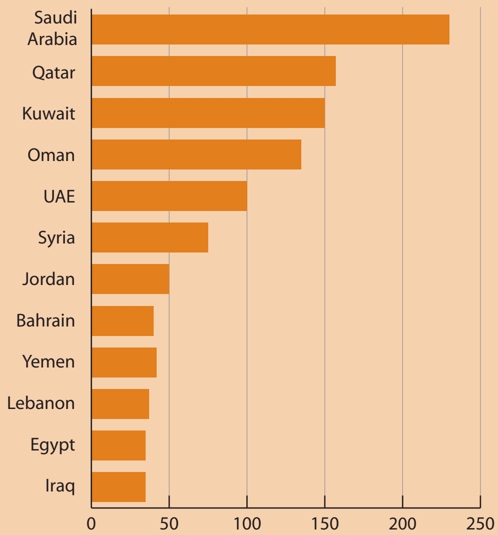


ICs: Industrialized countries
NICs: Newly industrialized countries
DCs: Developing countries

Source: UNESCO (2003), *Global Investment in R&D Today.*

THE ARAB STATES

Figure 10
GERD PER FTE RESEARCHER IN SELECTED ARAB STATES, 1996
US$ thousands



Source: adapted from UNESCO-ESCWA (1998a) *R&D Systems in the Arab States: Development of Science and Technology Indicators.*

Most scientists in the Arab region are working in the agriculture and health sectors, suggesting that they are still concentrating in the area of basic needs in order to secure food and health for their populations. Scientists have not yet been able to leapfrog to the third wave of the brain-intensive knowledge economy but remain in the agricultural and industrial stages. The IT revolution has not yet fully taken place for them.

Who funds what in R&D?

Indicators on who finances R&D reflect how each country deals with problem-oriented research. Many countries are moving towards a model where greater private funding is playing a major role in the performance of R&D. According to UNESCO's report *Global Investment in R&D Today* (2003), 70% of all OECD R&D was performed by the enterprise sector in 2000, compared with 10% by the government sector and 17% by universities. The remaining 3% was carried out by private non-profit institutions. As much as 78% of Sweden's R&D is performed by enterprises; this proportion is matched by Israel and the USA (both at 75%), Switzerland (74%), Japan (72%), the Russian Federation 71% and the Republic of Korea (76%).

Table 5
DISTRIBUTION OF FTE RESEARCHERS IN ESCWA ARAB STATES, 1996–98
By sector of employment

	Public sector			University			Private sector			Total
	PhD	MSc	Total	PhD	MSc	Total	PhD	MSc	Total	
Bahrain	5	22	27	29	30	59	0	0	0	**86**
Egypt	4 708	3 366	8 074	1 627	757	2 384	114	172	286	**10 744**
Iraq	189	540	729	366	296	662	0	0	0	**1 391**
Jordan	86	129	215	98	42	140	15	31	46	**401**
Kuwait	117	217	334	81	2	83	8	15	23	**440**
Lebanon	28	65	93	65	47	112	0	0	0	**205**
Oman	17	39	56	19	7	26	0	0	0	**82**
Qatar	2	2	4	18	12	30	0	0	0	**34**
Saudi Arabia	84	224	308	363	175	538	0	0	0	**846**
Syria	95	115	210	109	37	146	0	0	0	**356**
United Arab Emirates	12	44	56	26	25	51	0	0	0	**107**
Yemen	115	89	204	44	22	66	0	0	0	**270**

Source: ESCWA-UNESCO reports.

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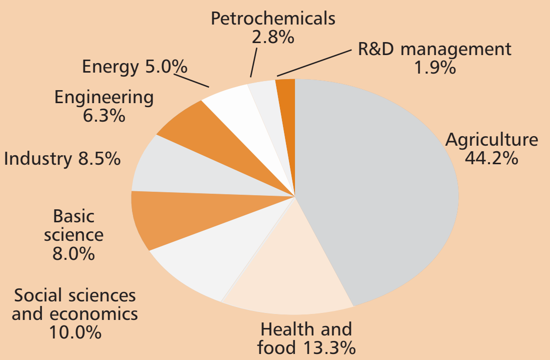
Figure 11
RESEARCHERS IN THE ARAB REGION, 1996
By sector of activity



Source: UNESCO-ESCWA (1998a) *R&D Systems in the Arab States: Development of Science and Technology Indicators.*

Although university research is particularly important in the area of basic research, it corresponds to only 15–20% of the total R&D performed in major economies like France, Germany, Japan, the UK and the USA. It should be noted that only 60% of university research in the USA is financed with federal funds, the remainder stemming from university partnerships with industry.

The largest divergences between national R&D systems in the OECD countries are to be found in the least economically advanced economies, including the former Eastern bloc countries with traditionally agricultural economies and low levels of industrial activity. Here, R&D draws heavily on public expenditure.

Likewise, in the Arab region, most R&D is supported essentially by the public purse, the private sector lacking the appropriate infrastructure and budget to undertake R&D itself. R&D expenditure can be broken down as follows: 1% by enterprises, 30% by universities and the remainder by government.

It could be concluded that the Arab region is dominated by public sector economies. Some countries, however, have recently taken energetic steps to privatize major public sectors. The real obstacle in involving enterprises more in the funding and performance of R&D is a policy question of how to move from 'big government', or the government handling of all economic activities, to 'small government', with greater involvement in R&D by enterprises. Until governments change their policies towards R&D, government incentives could be used in the meantime to achieve some growth among enterprises.

R&D units in the Arab region

In industrial countries, most R&D units belong to enterprises. Even universities and research institutes are contracted by the private sector to conduct R&D on their behalf. In the Arab countries, on the other hand, most R&D units belong to the government and public sectors, and conduct little contractual research work. The distribution of R&D units by sector is shown in Table 6, and it highlights the prevalence of research units specializing in agriculture and related fields.

Of the total of R&D units in the region, 36.3% are in agriculture. The health sector comes second to agriculture, with units specializing in health making up 18.3% of the total. R&D units involved in industry and engineering and related areas such as computer engineering and microelectronics comprise 20.2% of the total, and energy units 8.7%.

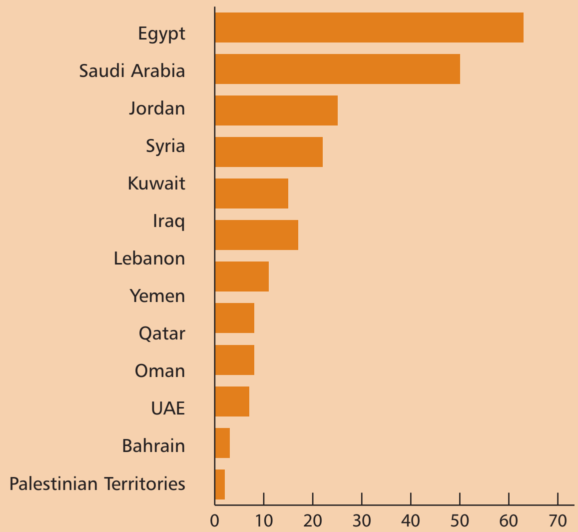
Research in basic sciences is performed by government and universities and represents only 6.2% of the total R&D in the region. This reflects the region's inattention to basic science, which is the backbone of all applied sciences.

Egypt leads the Arab countries within the United Nations Economic and Social Commission for Western Asia (ESCWA) in terms of the number of R&D units, followed by Saudi Arabia and Jordan (Figure 12). Governments fund about 75% of these R&D units. Universities trail far behind with only about 19%, the private sector funding the remainder (Table 6).

HIGHER EDUCATION: DEVELOPMENT OF HUMAN RESOURCES IN S&T

Arab countries have made great strides in expanding higher education. Some 200 Arab universities today have a roll of 3.6 million students taught by 140 000 faculty members. In addition, there are 600 community or intermediate colleges, which award diplomas rather than university degrees,

Figure 12
NUMBER OF R&D UNITS IN SELECTED PARTS OF THE ARAB REGION, 1999



Source: ESCWA (1999) *Science and Technology Policies in the Twenty-first Century.*

distributed throughout the Arab region. With the high population growth rate (2.3%), which means that young people make up a large proportion of Arab populations, it is expected that tertiary enrolment will climb to 5.6 million students by 2015. Teaching such a cohort will require a quarter of a million faculty members, nearly double the current number.

In the Arab region, average government expenditure on higher education per student amounts to about US$ 2 400, far less than that spent on a university student in Spain (US$ 14 200). Table 7 shows average expenditure on education in Arab states from 1996 to 2001, expressed as a percentage of GDP and as a percentage of total public expenditure. There are large variations in expenditure on higher education by Arab governments. Some countries have achieved a rate of expenditure comparable to that of industrialized countries, whereas others have maintained a rate that is lower even than the average for developing countries.

The Arab region spends 5.4% of GDP per year on public universities and colleges, compared with 5.0% in industrialized countries and 3.8% in developing countries. It has been calculated that 20% of Arab total spending on education goes towards public higher education.

Indicators show that tertiary students in the Arab region (including those enrolled in colleges) represent 25% of the eligible population, which is high when compared with developing countries. Table 8 shows that, in the great majority of Arab countries, there is now a gender balance in higher education. In several countries, there is even an

Table 6
R&D UNITS IN THE ARAB REGION, 1996
By economic sector

	Government	University	Private	Total	% of total
Agriculture	97	19	1	**117**	36.3
Health	43	16	0	**59**	18.3
Industry	34	2	16	**52**	16.1
Energy	27	1	0	**28**	8.7
Basic science	12	8	0	**20**	6.2
Social science	13	7	0	**20**	6.2
Petrochemicals	11	2	0	**13**	4.1
Engineering	6	7	0	**13**	4.1
Total	**243**	**62**	**17**	**322**	**100**
% distribution	*75.4*	*19.3*	*5.3*	–	*100*

Source: UNESCO-ESCWA (1998b) *Higher Education in the Arab States: Development of S&T Indicators.*

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Table 7
AVERAGE EXPENDITURE ON EDUCATION IN THE ARAB REGION, 1996–2001

	Expenditure as % of GDP	As % of total expenditure
Saudi Arabia	9.3	22.8
Yemen	7.0	–
Tunisia	6.7	19.9
Egypt	5.2	14.7
Morocco	5.2	20.9
Algeria	5.1	16.4
Jordan	5.1	24.2
Kuwait	4.7	14.0
Mauritania	4.5	19.1
Oman	4.5	9.1
Bahrain	3.7	12.0
Syria	3.5	13.6
Djibouti	3.4	–
Lebanon	1.9	8.2
United Arab Emirates	1.8	16.4
Sudan	0.9	–

Source: UNESCO (1999) *Statistical Yearbook;* Arab Fund for Economic and Social Development (2002) *Unified Arab Economic Report*.

imbalance in favour of women, as in Saudi Arabia and the Gulf States.

Recent data for enrolment in natural sciences in the Arab region are hard to come by, but 2001 data are available for Lebanon and the Palestinian Territories. According to the UNESCO Institute for Statistics, the percentage of young people studying disciplines in the natural sciences is on a par with countries such as Australia, Germany and Mexico, at 15.8% for Lebanon and 13.2% for the Palestinian Territories. Among those studying natural sciences, a high proportion are women in both Lebanon (41.1%) and the Palestinian Territories (46.9%).

Public expenditure on higher education is complemented by the private sector. Jordan and Lebanon, for example, have launched numerous community colleges and universities financed solely by the private sector. This initiative has spread quickly all over the Arab region. Jordan boasts 11 private universities, a figure that is expected to increase within two years; its public universities number only nine. Lebanon has expanded into private colleges and universities, which now number 34. However, 70% of all students at these private institutions are enrolled in disciplines that fall under the humanities and social sciences, and the quality of education has not always lived up to expectations. Indicators show that the education environment is still not sufficiently stimulating to produce entrepreneurs and spark creativity and innovation.

It should be noted that quality education does not depend totally on the availability of financial resources. The results of the Trends in Mathematics and Science Study (TIMSS) – an assessment of primary and secondary pupils in math and sciences around the world – have shown that the quality of education in the Republic of Korea, for example, has surpassed that of the USA, although the latter spends four times as much on education.

Table 8
STUDENT ENROLMENT IN HIGHER EDUCATION IN THE ARAB REGION, 2000
Percentage of age cohort

	Males	Females	Total
Libya	51.7	50.6	**51.2**
Lebanon	35.2	38.2	**36.7**
Jordan	26.8	30.6	**28.6**
Qatar	13.7	46.2	**27.7**
Bahrain	19.6	31.1	**25.2**
Palestinian Territories	29.2	17.9	**24.0**
Egypt	27.1	17.8	**22.4**
Saudi Arabia	19.6	25.4	**22.4**
Kuwait	13.0	30.0	**21.1**
Tunisia	19.6	19.0	**19.3**
Algeria	15.8	11.0	**15.0**
Iraq	17.5	9.5	**13.6**
United Arab Emirates	4.9	20.7	**12.1**
Yemen	16.7	4.6	**10.8**
Morocco	10.6	8.0	**9.3**
Oman	8.8	7.1	**8.0**
Sudan	7.1	6.6	**6.9**
Syria	17.6	12.6	**6.1**
Mauritania	6.6	1.3	**5.6**
Somalia	3.6	1.1	**2.3**
Djibouti	0.4	0.3	**0.4**

Source: Arab Fund for Economic and Social Development (2002) *Unified Arab Economic Report;* Database 2003.

Three Arab countries out of 39 total participants took part in the 1999 edition of the TIMSS. In mathematics, Tunisia was ranked 29nd with 448 points, Jordan was ranked 32nd with 428 points and Morocco came 37th with 337 points (Singapore was top with 604 points). In science, Jordan was ranked 30th with 450 points, Tunisia 34th with 430 points and Morocco 37th with 323 points. Taiwan of China came first on the science list with 564 points. This demonstrates that the quality of education does not depend solely on resources or quantitative

Two Millennium Initiatives in the Arab World

ARAB ACADEMY OF SCIENCES

The Arab Academy of Sciences is domiciled in Beirut, Lebanon. A non-political, non-governmental and non-profit-making scientific organization, the Academy was established by a group of Arab scientists at the initiative of UNESCO in 2002.

The Academy supports and promotes excellence in research by Arab scientists and encourages problem-solving R&D of relevance to the Arab world. The Academy also acts as a consultative body on scientific issues related to the Arab world. In its three years of existence, it has organized two international conferences, the first in Beirut in 2003 on Bioethics: How to Adapt Biotechnology to Culture and Values; and the second, in Amman, Jordan, in 2004 on Drug Biotechnology and Medicinal Plants.

In a drive to create linkages between scientists and governance, the Academy co-organized with UNESCO and ISESCO a meeting on Science, Technology and Innovation Policy: A Parliamentarian Perspective, in Cairo, Egypt, in December 2004. The Academy promotes cooperation both among researchers in Arab countries and between the latter and the international scientific community. Notably, it is a founding member of the Arab Network for Women in Science and Technology.

In a region where there is little scientific awareness, the Academy also promotes public understanding of science and respect for science.

The pet project of the Academy in 2004–05 has been the production of an *Arabic Encyclopedia on Knowledge for Sustainable Development* supported by UNESCO. Once completed, the Encyclopedia will comprise four volumes covering the environmental, social and economic aspects of sustainable development. Contributions from experts in the Arab world were still being sought in 2005.

The Academy's flagship product will be a profile of S&T and higher education in the Arab region. This will be published on-line in 2006 and updated annually.

The Academy is governed by a General Assembly comprising all its members and by an Executive Council headed by Professor Adnan Badran, President of Philadelphia University in Jordan. The Academy's activities are sponsored by international and regional organizations that include UNESCO, the Islamic Educational, Scientific and Cultural Organization (ISESCO), the Arab League Educational, Cultural and Scientific Organization (ALECSO), the Standing Committee on Scientific and Technological Cooperation of the Organization of Islamic Conference (COMSTECH), the Third World Academy of Sciences (TWAS) and the Commission on Science and Technology for Sustainable Development in the South (COMSATS) founded under the aegis of TWAS in 1994.

See: www.arabacas.org or write to: a.academy@unesco.org

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factors, but on the educational process and the means of delivery and evaluation.

Although expanding opportunities in education is essential for an Arab population of 295 million people (Japan, for example, has 1 000 universities – 120 in Tokyo alone – for a population of 127 million), the decline in quality now observed undercuts a basic goal of S&T development, namely that of enhancing the quality of life and moving the Arab region towards a knowledge society.

ARAB SCIENCE AND TECHNOLOGY FOUNDATION

The Arab Science and Technology Foundation (ASTF) was launched in 2000 to enhance the productivity and quality of Arab research by pooling the talents of Arab scientists living in both the Arab region and beyond through the combination of a connectivity network and collaborative research in strategic areas. Although water desalination is an area of obvious interest, for instance, the Solar Water Desalination Project launched by the Foundation in 2004 with funding from the National Bureau of Research and Development in Libya has proved to be the first collaborative research of its kind in the region.

The Foundation provides financial and technical support for innovative research projects in the form of direct grants or fundraising on their behalf. The Foundation's budget originates from various sources, including an annual US$1 million endowment from Abdul Latif Jameel Co., Ltd for scientific research in the Arab world under the supervision of the ASTF.

A founding member of the Arab Union of Venture Capital and of the Gulf Venture Capital Association, the Foundation seeks to forge the missing link in the Arab world between the research community and business. To this end, the Foundation organized the first Investing in Technology Forum in April 2004 and a second six months later. With the slogan of 'Innovating locally, competing globally', the Forum acts as go-between for start-ups within the Arab scientific research community and the corporate business and investment sectors.

The Foundation has also organized three Scientific Research Outlook symposia in 2000, 2002 and 2004, to catalyse and support development-oriented collaborative research among scientists from 22 Arab countries.

In 2003, the ASTF conducted a needs survey among more than 400 scientists in Iraqi universities within 12 sectors of priority importance, namely: health; water resources; environment; engineering; energy; agriculture; veterinary sciences and livestock; biotechnology and genetics; communication; applied material science; basic sciences; and information technology. The findings of the survey were published in a 2004 report entitled *The Priorities of the Iraqi S&T Community*.

The Board of Directors is made up of the ten elected members of the ASTF. All are Arab scientists hailing from the institutional, business and academic sectors of countries in the Arab world, the USA and UK. One of the founders, Dr Abdalla Abdelaziz Alnajjar, is also President of the ASTF, in parallel to his functions as Director of the Research Centre at the University of Sharjah in the United Arab Emirates. A driving force behind the ASTF, his vision became reality thanks to the early financial backing of H.H. Sheik Dr Sultan Bin Mohammed Al Qassimi, ruler of Sharjah.

See: www.astf.net or write to: info@astf.net

Quality of higher education

Many features of higher education in the Arab region contribute to the low academic standards. These are summarized below.

- Universities in the Arab region lack autonomy – the platform of freedom of expression and freedom of thought – and they suffer from political and ideological stress imposed by government. They are controlled both by their national political systems and social systems, whether tribal, ethnic, religious or another.
- Without a clear admissions policy, universities admit students to various disciplines on the basis of criteria other than merit or excellence. For political reasons, there are often higher-than-expected admissions from the provinces, for example.
- The universities lack quality faculty members. Many university professors come from a single university system, having obtained their undergraduate and graduate degrees from the university that employs them. As a consequence, their academic vision in teaching and research often does not extend beyond the university border. Moreover, some faculty members are political appointments forced upon the university without any regard for the requisite qualifications for the post.
- Rigid curricula are unable to meet changing needs in a global knowledge economy. The curriculum is obsolete in some universities, the professors hardly having time to update their skills either in the library or by making use of information networks to structure knowledge derived from new databases on the topics they are teaching. Textbooks are outdated and sometimes unavailable or too expensive for students. Lectures become dull without the help of computer-aided instruction or updated reference material and learning resources.
- There is a shortage of e-learning and distance education. The development of self-learners (teaching people how to learn) and continuous education have not taken hold in Arab universities.
- It is uncommon to see the learning process bridged with professional experience and training in the private and public sectors. This is due to the increasing number of students, which has resulted in a recourse to traditional lecturing as the only way of establishing contact between professor and student.
- There is a lack of an R&D environment on campus. This is the fault of a heavy teaching load for faculty members and a lack of learning resources, equipment and facilities.

Bridging university and industry

The relationship between university research, teaching and industry is a three-way divorce in the Arab States. There is a lack of contractual research between industry and the universities. Although some universities have started up technology incubators and business parks with industrial partners, the majority of universities have yet to follow suit.

National universities are beginning to network among themselves, but they need to expand these efforts to incorporate regional and international cooperation, in order to introduce interactive learning, multimedia and online education.

PROSPECTS FOR THE FUTURE

Over the past three decades, major achievements have been made in the Arab region, primarily in education, food production, pharmaceuticals and health. However, there is a long road ahead.

The Arab region is at a crossroads economically, politically, scientifically and technologically. To thrive, it must become part of the global knowledge and information society. And to do so, it must first invest heavily in improving the quality and relevance of education from primary to tertiary levels.

Educational reform is badly needed to prepare people for the knowledge economy and globalization, which are knowledge-driven and interdependent. It is education which will add value to human capital, allowing the region to strengthen its capacity in science and move from turnkey technology to home-grown innovation.

Such reform will need first to focus on wiping out the

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illiteracy that affects 68 million people in the region – 38% of all Arab adults (2000). The growth of illiteracy is considered to be responsible for the degradation of science and for high population growth. The Arab illiteracy rate is higher than both the average for developing countries (27%) and the world average (25%), and it stands in stark contrast to illiteracy in industrialized countries (1.1%).

Second, education should be science-based, competitive, flexible and relevant and, above all, it should deliver quality output. Reform should emphasize building skills in mathematics, science and IT. Schools should offer training in ethics, teamwork, discipline, dialogue and respect for differences, and they should be places of creativity, innovative thinking and enquiry, and lifelong learning.

Such an education would prepare individuals to absorb the avalanche of information required to construct knowledge. Youth need to be exposed to a challenging educational environment to unleash their creativity in finding novel solutions to difficult problems. They should not be expected to memorize and reproduce facts in examinations without enquiring about scientific principles and their application to real-life situations.

Turning to research, the goal of reform must be to upgrade Arab universities and research centres to the point where they are compatible with centres of excellence of an international standard, in order to develop world-class researchers for the creation of new knowledge. Basic science and basic research should be emphasized to absorb and develop emerging frontier technologies.

The Arab region must draw on its legacy of cultural achievement and reintroduce a system based on merit at all levels to nourish creativity and innovation. It goes without saying that suitable government policies and positive legislation relaxing bureaucracy should be implemented to create a stable, enduring environment for S&T. Confidence must be established between universities and research centres on the one hand, and universities and industry on the other. Last but not least, interaction between scientists and economists would optimize the growth process.

Most crucially, the region needs reforms that will help build societies that promote tolerance, allow freedom of expression, encourage free thinking and respect human rights if the Arab States are to develop fully their potential in S&T.

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Adnan Badran has been Prime Minister of Jordan since April 2005. He first served his country as Minister of Agriculture then as Minister of Education before joining UNESCO in 1990 as Assistant Director-General for Natural Sciences. Six years later, he was named Deputy Director-General of UNESCO, a post he occupied until August 1998.

Adnan Badran received his undergraduate and graduate education in the USA, culminating in a PhD from Michigan State University in 1963. He then spent three years conducting basic research in plant physiology and biochemistry in the USA before returning home to take up the post of Professor of Biology at the University of Jordan. He was later appointed Dean of the Faculty of Sciences of the same university, then founding President of Yarmouk University, also in Jordan, from 1976 to 1986.

In the course of his career, Dr Badran has published several books and articles on the life sciences. He is also the author of articles on science policy and higher education in the Arab region. At the time of his nomination as Prime Minister, he was President of Philadelphia University in Jordan and of the Arab Academy of Sciences in Beirut.

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Africa

JACQUES GAILLARD, MOHAMED HASSAN and ROLAND WAAST
IN COLLABORATION WITH DANIEL SCHAFFER

Africa is a rich continent: rich in biodiversity, rich in mineral resources, rich in precious stones. It is also a continent rich in traditional knowledge, especially knowledge associated with indigenous and medicinal plants. But Africa is also a poor continent; with roughly 13% of the world's population, it enjoys only 1% of the world's wealth. An estimated 50% of Africa's people live in poverty and 40% suffer from malnutrition and hunger. Two-thirds of Africa's land base is degraded and more than half of Africa's population is without safe drinking water. Malaria poses a serious threat in several regions and HIV/AIDS has devastated the youth of many African nations, including Botswana, the Republic of South Africa and Zimbabwe, where an estimated 25% of adults are now afflicted with this deadly disease.

What accounts for Africa's impoverished state? There are many political, socio-economic and environmental factors: centuries of colonialism followed by decades of home-grown authoritarian governments; a chronic lack of transparency in economic transactions, often accompanied by corruption; unsustainable use of natural resources; marginal participation in the global economy. However, there is another factor that may not be as visible or dramatic as those mentioned above but may nevertheless play a central role in the continent's inability to participate at the global economic level, protect its environment and devise sustainable strategies for economic growth. That factor is Africa's woeful shortcomings in science and technology (S&T) (UNESCO, 2000; *Current Science*, 2001).

Setting out from what was, in 1960, a very weak starting point in terms of home-based scientific potential (Eisemon, 1979), Africa went through a stage of rather intensive development of scientific institutions (research institutes and universities) during the 1970s and 1980s (Davis, 1983; Kolinsky, 1985; Gaillard *et al.,* 1997). Associated with this was an enormous increase in the academic population and a steady growth in the number of research scientists (Gaillard and Waast, 1993). This development was underpinned by aid, the amounts varying greatly according to the country involved.[1] Such programmes took on diverse forms: fellowships for training, research grants to individuals and teams, institution building, strengthening and twinning, North/South partnership research programmes and so on (Gaillard, 1999). By the end of 1980, the benefits derived from these investments were modest but tangible.

Since then, the state of S&T has deteriorated substantially in most African countries. Severe cuts in government spending have pushed institutions of higher education and research centres into steep decline. National educational and research coordinating bodies, once the focal points of reform for S&T, have lost much of their political power and influence. Indeed a significant number of these reform-minded bodies have been dissolved. Adding to the decade-long litany of problems that have fractured Africa's S&T infrastructure is the fact that virtually no recruitment took place throughout the 1990s and scientists' salaries are no longer adequate to live on. Recent assessments of African scientific research communities have detailed these prevailing dismal conditions time and again (Dahoun, 1997; Gaillard *et al.*, 1997[2]; Lebeau and Ogunsanya, 1999). Universities that once served as beacons of hope, including the universities of Ibadan in Nigeria, Dakar in Senegal, Dar-es-Salaam in the United Republic of Tanzania and Khartoum in Sudan, have been turned into shells of their former selves. Buildings are poorly maintained, modern laboratory equipment is rarely available, and faculty and staff go underappreciated and sometimes unpaid. Meanwhile, external funding for science and joint research initiatives with universities and research institutes in other nations have often declined. Given such circumstances, it should come as no surprise that the continent's best scientific talent continues to leave in large numbers, creating a chronic 'brain drain' problem.

In addition, official development assistance from the world's richest countries now stands at 0.22% of national gross

1. In some African countries, external 'aid' to research and scientific cooperation came to account for to 75% or more of the national research budget, for example in Senegal (Gaillard *et al.,* 1997).
2. See in particular the chapters on Egypt, Kenya, Nigeria and Senegal.

domestic product, far below the internationally agreed-upon target of 0.7%. No developing region of the world suffers more from this parsimonious level of aid than Africa. At the same time, it is true that the economic development and technology transfer strategies from the 1960s through the 1980s – often encouraged, if not devised, by Northern 'donors' – have not served Africa's interest well. Under these programmes, African nations with weak scientific infrastructures simply did not have the skills to evaluate the appropriateness of the technologies that were being introduced. At the same time, they lacked the critical mass of scientific and engineering talent necessary to add a great deal of economic value to the continent's vast wealth of natural resources by transforming them into products and processes that could command higher prices in the global market place than the unprocessed raw materials themselves.

Despite the unsettling trends resulting from a continuing crisis, there are reasons for hope about the future of S&T in Africa. Foundations and international organizations, for example, have recently launched ambitious programmes in consultation with African countries and institutions to rehabilitate higher education and research systems in a number of countries. Even more promising, initiatives taken by several African governments could boost the development of S&T on the continent. For example, a number of African science institutions have begun to recruit researchers again. Similarly, an increasing number of national research grant schemes have been established in recent years. More specifically, the government of Nigeria, after experiencing a staggering collapse of its scientific production during the last 15 years, has taken some important measures, including the establishment of an international board of science advisers and the granting of US$ 5 million to the African Academy of Sciences endowment fund. These measures could bring about positive developments for both Nigeria and the African continent as a whole.

This chapter of the *UNESCO Science Report 2005*, which examines the status of S&T on the African continent (including North Africa, the Republic of South Africa and the rest of Africa or 'Median Africa'), is divided into three parts. The first part offers a brief historical analysis of S&T development in Africa, a bibliometric panorama of African science through the 1990s and a brief inventory of S&T capacities. The second part analyses the extent to which the process of globalization has fundamentally altered what it means to be a scientist in Africa and changed the very nature of the scientific production. The final part examines perspectives and strategies for strengthening scientific and technological capabilities in Africa.

One of the main difficulties in writing about S&T in Africa is related to a lack of reliable data. This gap has been partially filled by a recent study on science and scientists in Africa at the end of the twentieth century.[3]

THE COLONIAL LEGACY AND THE EMERGENCE OF NATIONAL SCIENCE

The first encounter with modern S&T in Africa was the result of European colonization. Many of the scientific pursuits in the colonies of Africa were confined to exploration, surveys, data collection and the application of techniques mainly to promote colonial economic policies. Nevertheless, the science taking place during this period left an important legacy inside Africa in terms of:

- **knowledge** (detailed inventories and recorded bodies of knowledge);
- **organizational models** (creation of specialized research institutes, full-time researchers employed as civil servants, etc.);
- **strategic choices** (agriculture and health, for example, emerged as research priorities).

This legacy grew even stronger after independence. In the 1960s, it was enriched by the development of national higher education systems. In the 1970s, it was bolstered by the 'nationalization' of research institutes, the 'Africanization' of

3. This study, coordinated by Roland Waast and Jacques Gaillard, and co-funded by the European Commission (DG Research), the French *Institut de Recherche pour le Développement* (IRD) and the French Ministry of Foreign Affairs, includes a comprehensive bibliometric study of science in Africa during the 1990s, country case studies carried out in 14 African countries (Algeria, Burkina Faso, Cameroon, Côte d'Ivoire, Egypt, Madagascar, Morocco, Mozambique, Nigeria, Senegal, Republic of South Africa, Tunisia, United Republic of Tanzania and Zimbabwe) and some 400 interviews with scientists conducted in the same countries.

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staff at both research institutes and universities, the expansion and multiplication of institutions, and the creation of national coordinating bodies mandated to define, implement and monitor national policies. In short, from 1965 to 1985, the African states put considerable efforts into developing national research systems with support from bilateral and multilateral cooperation schemes.

Such widespread trends fostered a mode of scientific development in which the state played a central role. That in turn propelled a new process of scientific production – 'national science' defined by the following principles:

- science is a public good;
- the main funding provider is the state;
- the researchers (and their scientific communities) have a nationalist ethos;
- research scientists are employed as civil servants;
- besides the peer community, the end-users consist principally of public authorities.

The era of national science in Africa resulted in some real success stories. In the mid-1980s, African scientific publications became visible on the international scene; eminent scientific figures emerged; centres of excellence acquired international reputations; and some celebrated innovations originated from home-grown scientific research (see box below).

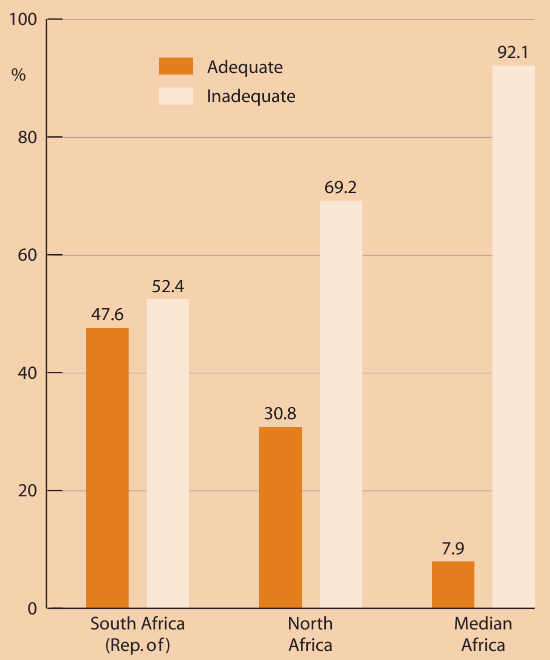
A heterogeneous continent: North, South and Median Africa

When viewed from beyond the continent, there has been a tendency to see S&T in Africa as a single entity of concern. Although there is some truth in this perception, it is

Drugs from medicinal plants in Madagascar

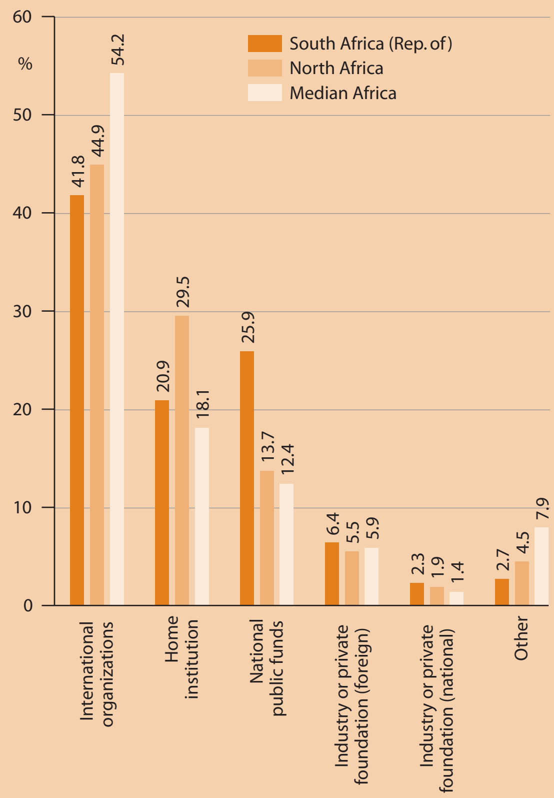
For more than 40 years, the Malagasy Institute of Applied Research, with a staff of 30, has sought to extract agents from indigenous plants to produce effective pharmaceuticals. For example, Madecassol®, derived from active agents of the Malagasy plant *Centella asiatica*, has been used to treat intense burns, leprous wounds and inflamed ulcers for more than a quarter of a century. Royalties earned by the institute for the critical role that its researchers played in the development of Madecassol® have generated thousands of dollars in annual revenues for the institute. The institute, however, does more than research the region's biodiversity for the purposes of developing pharmaceuticals. It also sells the drugs it helps create at subsidized prices to local populations, which allows them to enjoy the same health benefits as citizens residing beyond Madagascar's borders; it manages a health clinic that provides low-cost health care to nearby residents; it oversees a botanical garden to help preserve the region's rich biodiversity; it operates a small production facility that manufactures a variety of drugs for local distribution, including medicines to combat malaria, hepatitis and asthma; and it provides job opportunities to local residents in several different fields, both manual and technical, in a region where steady employment is hard to find. The Malagasy Institute of Applied Research was founded by Albert Rakoto-Ratsimamanga who continued to oversee its operations until his death in 2001. His wife, Suzanne Urverg-Ratsimamagna (an internationally recognized scientist in her own right), now heads the institute. She is expanding the scope and visibility of the husband and wife team's lifetime of work. Taking a long-term view, the institute's future rests on its ability to turn this family affair into a research institution that will continue to function long after its creators leave the scene. It is a challenge faced by many of sub-Saharan Africa's most successful scientific institutions.

Figure 1
ADEQUACY OF SCIENTISTS' SALARIES IN AFRICA, 1999
By region and major country



Source: Gaillard, J.; Furó Tullberg, Anna (2001) *Questionnaire Survey of African Scientists. IFS Grantees and INCO Beneficiaries.*

Figure 2
SOURCES OF RESEARCH FUNDS IN AFRICA, 1999
By region and major country



Source: Gaillard, J.; Furó Tullberg, Anna (2001) *Questionnaire Survey of African Scientists. IFS Grantees and INCO Beneficiaries.*

important to note that real differences exist between North, South and Median Africa in such critical areas as scientific infrastructure, budgeting, training and publication output. Moreover, it is important to keep in mind that not even the division of Africa into three scientific geographical regions conveys the diversity of experience that can be detected when closely examining the situation. For example, Median Africa, which today is the continent's most troubled region, is in itself far from being homogeneous.

A recent Africa-wide questionnaire survey (Gaillard and Furó Tullberg, 2001)[4] illustrates these disparities in relation to several key characteristics, three of which are briefly discussed below: salaries, self-sufficiency for graduate and postgraduate education, and the level and structure of research funding.

While African scientists acknowledge that they enjoy a high degree of job security, they also express strong dissatisfaction – indeed frustration – with their salaries and job benefits. However, scientists in the Republic of South Africa are much less dissatisfied with their salaries (52.4%) than their colleagues in North Africa (69.2%). Not surprisingly, scientists in Median Africa are the most dissatisfied with their salaries. A startling 92% of the survey respondents from this region said they were displeased with their earnings (Figure 1).

The number of students pursuing graduate and postgraduate education in African universities has increased considerably

4. 702 African scientists responded to the questionnaire.

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during the past three decades. Nevertheless, the higher the degree that is sought and ultimately earned, the more likely it is that a student will pursue his or her studies abroad – in Europe (mainly France and the UK) and to a lesser degree in Canada or the USA. While the Republic of South Africa's university system now allows it to be quasi self-sufficient in the awarding of all degrees, the university systems in North Africa and particularly Median Africa continue to depend on foreign institutions of higher education. This trend continues to take place despite recent statistics indicating an increasing number of Master's and Doctorate degrees received at home.

The structure of research funding also varies from region to region (Figure 2). Although international institutions or foreign nations remain the most important source of funding for science throughout Africa, Median Africa's scientific community depends more on outside donors than the Republic of South Africa and North Africa. Similarly, the Republic of South Africa and North Africa enjoy a higher percentage of funding from home-based institutions than Median Africa.

Other characteristics such as the relative importance of and trends in scientific output discussed below also show contrasting developments according to region. What such figures reveal is that there is not one but several Africas and that the scientifically weakest countries are located in Median Africa. All told, we estimate that there are about 10 000 full-time active researchers in Egypt and roughly the same number in Maghreb countries (Algeria, Morocco and Tunisia). Meanwhile, the Republic of South Africa has approximately 13 000 full-time researchers, which is comparable to the number of full-time researchers in the whole of Median Africa (Table 1).

A BIBLIOMETRIC PANORAMA OF THE 1990s[5]

What can we say about scientific productivity in Africa today? An attempt to answer this question has been made by analysing the number of scientific publications in Africa indexed in the PASCAL database from 1991 to 1997.[6]

The PASCAL database shows that in 1991 African scientific production in terms of publications amounted to just 4% of the publications output of European scientists. In 1997, it fell to 3%. At the end of the period covered by the PASCAL database, the Republic of South Africa (the continent's main producer of scientific literature) had an impact comparable to Greece, and Egypt (the continent's second highest producer) had an impact comparable to Portugal.

Not too much significance should be placed on this comparison: Africa's research priorities are often substantially different from those pursued on other continents. Moreover, European researchers, particularly those working in smaller countries, have benefited from increased funding for science in the European Union as a whole. Such trends, which stand in stark contrast to the circumstances of researchers in Africa, have spurred spectacular growth in output among European countries which had previously lagged behind their neighbours. Despite all these qualifications, it is important to note that PASCAL figures for the output of scientific publications in Africa are low (Table 3).

With the Republic of South Africa representing approximately a third of the continent's scientific literature output, statistical analyses of the output of smaller African countries could be misleading and/or subject to substantial fluctuations from year to year. One or two articles could make a big difference. Lastly, the most recent trend (1991–97) shows that countries in North Africa now account for a higher percentage of scientific articles (37%) than the Republic of South Africa.

Countries: the hierarchy

Scientific capacities are unevenly distributed in Africa and not always proportionate to a region's or country's wealth and/or population. Using 1991–97 publication scores as the basis of the analysis (excluding human and social sciences, which are not recorded by PASCAL), five main groupings can be distinguished:

5. This section draws on Arvanitis *et al.* (2000).
6. Despite its limitations discussed elsewhere (Arvanitis and Gaillard, 1992), we consider that the PASCAL database can be used with some degree of confidence to characterize the relative importance of the main science producers and to pinpoint shifts.

Table 1
RESULTS OF THE IRD SURVEY ON RESEARCHERS IN AFRICA, 1999
Selected countries

	Staff in higher education	Researchers full time in the public sector	Researchers full time in the private sector	FTE[1] researchers	Researchers per million inhabitants
Algeria	16 000	1 200	700	3 000	100
Burkina Faso	700	200	0[2]	350	30
Cameroon	1 800	300	0	800	60
Côte d'Ivoire	1 200	500	0	600	55
Egypt	40 000	1 500	0	10 000	230
Kenya	1 800	600	0	1 000	35
Madagascar	900	260	0	300	35
Morocco	10 000	700	500	3 200	120
Mozambique	600	0	0	0	0
Nigeria	14 000	1 300	0	3 000	40
Senegal	1 000	435	0	600	80
South Africa (Rep. of)	17 000	8 500	5 000	13 000	350
Tanzania, United Rep.	1 400	0	0	600	70
Tunisia	9 000	800	400	3 000	350
Zimbabwe	1 100[3]	300	0	600	30

1 Full-time equivalent. 2 0 = negligible. 3 Includes private.

Source: Waast, R. and Gaillard, J. (coord.) (2000) *Science in Africa at the Dawn of the 21st Century*. IRD, Paris.

Group 1: Two countries, Egypt and the Republic of South Africa, together represent half the continent's production (49%). In these countries of 'complete science', all disciplines (in our breakdown, 71 fields) are covered.

Group 2: Four countries account for a quarter (26%) of Africa's publication output: Kenya, Morocco, Nigeria and Tunisia. While these countries enjoyed well-established scientific communities in several fields at the beginning of the study period (1991), they are among those that experienced the most turbulent fortunes between 1991 and 1997.

The remaining 43 countries share 25% of the recorded production. They can be divided into the following groups:

Group 3: Seven countries – Algeria, Côte d'Ivoire, Cameroon, Ethiopia, Senegal, United Republic of Tanzania and Zimbabwe – regularly produce between 70 and 200 papers per year. This output is sustained either by groups or networks of scientists specializing in a few disciplines or by groups of scientists in a handful of cutting-edge institutes. Such people and places represent small pockets of research activity achieving modest levels of accomplishment (ranking seventh to 13th according to the classification).

Group 4: Some 14 other countries publish between 20 and 70 references on average each year: Benin, Burkina Faso, Congo, Gabon, Gambia, Ghana, Madagascar, Malawi, Mali, Niger, Sudan, Togo, Uganda and Zambia. Production in these countries often depends on a few eminent figures of science. As a result, the scientific infrastructure remains extremely fragile, highly sensitive to political change and dependent on external sources of funding.

Group 5: The remainder of the African continent consists of scientifically small countries whose performance in terms of scientific production is erratic and closely tied to a few authors or visiting scientists. This group contains countries that have recently experienced fundamental political change, international isolation, civil war and massive destruction of infrastructure.

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Countries: trends (1991–97)

While different databases provide different perspectives on trends in scientific publication output among African countries over the past decade, they agree at least on one point: in five years (1991–96), compared with Europe or with the rest of the world, Africa has lost 20–25% of its relative capacity to make contributions to world science. Furthermore – and this is the salient point – the paths of different countries have diverged enormously. Whereas in the 1970s and 1980s middle-sized scientific powers had been seen regularly to grow and become established (Groups 2 and 3 as already defined), the 1990s brought abrupt changes in fortune, completely upsetting previous classifications. The main changes are summarized below:

- The continent's two science giants – Egypt and the Republic of South Africa – encountered difficulties in maintaining their previous level of performance. The data from both PASCAL and the Institute for Scientific Information suggest that the relative contribution of both Egypt and the Republic of South Africa remained stationary.

Table 2
SCIENTIFIC ARTICLES PUBLISHED IN AFRICA, 1998
Selected countries

	Number of scientific articles	Articles per million inhabitants	Articles per billion US$ GNP
Algeria	241	8	5.5
Burkina Faso	72	7	26.0
Cameroon	167	12	18.0
Côte d'Ivoire	87	6	8.0
Egypt	1 313	120	17.0
Kenya	506	17	53.0
Madagascar	50	3	13.5
Morocco	510	20	14.5
Nigeria	450	4	14.5
Senegal	106	12	21.0
South Africa (Rep. of)	2 738	72	21.0
Tanzania, United Rep.	196	6	30.0
Tunisia	491	55	26.0
Zimbabwe	176	16	21.0

Source: Science Citation Index (North, South and East Africa); PASCAL (West Africa).

- Scientific output rose among Maghreb countries. In five years, Morocco doubled its score, to become the third-ranking producer on the African continent. Tunisia has also shown a strong surge. Even Algeria managed to improve its performance, despite disruptions caused by civil war and the persecution of its intellectuals. The portion of Africa north of the Sahara (including Egypt) now accounts for more than a third of African publications (catching up and even overtaking the output of South Africa).
- Nigeria experienced a staggering collapse in scientific ranking. In five years, Nigeria's scientific community experienced a 50% decline in output of scientific literature. In the absence of career prospects and faced with the dilapidation of establishments paralysed by large budgetary shortfalls, and with high staff turnover, a large number of research scientists have emigrated or changed profession. Many, while remaining scientists, also devote themselves to other activities.

Among Groups 3 and 4 – countries in which science rests precariously on the shoulders of a few teams of specialists – changes have often been sudden and unpredictable. Here are some noteworthy developments in this classification:

- Among countries experiencing an upswing in scientific output, Cameroon is now the leader of Group 3. While ranked 16th in 1981, it climbed to tenth place in 1987 and eighth in 1996. None of the primary indicators of the state of science in Cameroon (budgets and salaries have remained flat and scientific institutions have actually closed) help to explain these encouraging trends. Similarly, both the United Republic of Tanzania's and Senegal's scientific literature production continues to grow despite severe restrictions in operating budgets and poor working conditions (Gaillard and Waast, 2000).
- The most marked changes in direction are seen in figures recorded for the smallest countries in Africa. Ghana has recovered somewhat. In Malawi and Uganda, aid and cooperation from the USA and, to a lesser extent, the UK have stimulated a revival. The ebb and flow of aid and cooperation schemes can explain the progress of Burkina

Table 3
SCIENTIFIC PRODUCTION IN AFRICA, 1991–97
By main linguistic and geographic area

	Scientific publications	Articles only	% of all scientific publications	% of all articles
English speaking (excl. South Africa)	10 639	9 155	21	22
French speaking (excl. Maghreb)	5 938	4 958	12	12
North Africa	18 906	15 542	37	37
South Africa (Rep. of)	13 997	11 813	28	28
Median Africa	881	759	2	1
Total	**50 361**	**42 227**	**100**	**100**

Source: Publications indexed in PASCAL (1991–97).

Faso, uneven yet one of the most impressive cases. Its science leapt 20 places in ten years, 16 in the course of the past six years. Such an achievement has been possible thanks largely to sound support from government authorities, and the considerable ability of the authorities in charge of science.

- In contrast, Gabon, Mozambique and Niger, which were sustained not long ago by vigorous external support programmes, recently began to sink again into deep recession. The Republic of Congo, which in the 1980s was showing great promise, has slumped since 1994. The Democratic Republic of Congo (formerly Zaire) slips further into the depths of scientific obscurity, although 30 years ago the prowess of its universities would not have augured such a sad fate. It is hardly necessary to mention how insignificant scientific output has become for those countries ravaged by civil war, or confronted with famine, population exodus or obscurantism, such as Angola, Burundi, Liberia, Rwanda or Somalia. Sudan, which at one time occupied a significant position, is in a state of incessant decline.

As a general rule, the scientific performance of other countries is haphazard, subject to the whims of rulers and the instabilities of international cooperation. It would be unwise to comment extensively on their erratic courses. An exception is found in some small countries with an often limited scientific expertise skilfully run or serving as a platform for multinational research. Gambia's Medical Institute in Banjul and the Institute of Geophysics in Djibouti are two bright instances in an otherwise bleak scientific landscape.

GLOBALIZATION: TENSIONS AND REORGANIZATION

Nowhere did globalization alter the ways in which science is structured as much as in Africa. This is no trifling paradox, as such a modification is mainly expected in developed countries and high-technology sectors. After 1980, the signs of a profound change began to emerge. It was, however, by no means confined to Africa. The free market ethos meant that governments everywhere reduced their intervention. The expected source of progress became innovation in private companies and no longer the discoveries of science.

In Median Africa, this disaffection for science (and indeed for education) occurred against a background of severe and enduring economic crisis. Research and higher education, in spite of the growing number of students (up 15% per year before 1990 or 1995), lost their priority. Buildings, facilities and conditions for working deteriorated at an accelerated pace. Budgets from the state were soon to serve only to pay the devalued salaries of S&T personnel.

In parallel, the intellectual professions and the civil service, often regarded as parasites, had their pay reduced. Not only were cuts in salary imposed by emergency economic measures

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(e.g. in Cameroon in 1993), but devaluations and runaway inflation (Madagascar: 20% per year between 1985 and 1996; Nigeria: 34% per year) led to a massive drop in researchers' purchasing power. To avoid humiliation, and a huge downgrading of their social position, many academic figures emigrated. They entered an international market of scientific work, first heading for countries of the industrialized North then, as such opportunities dried up, for other African countries where pay was higher (especially in southern and francophone Africa). Changes of profession without leaving the country are also common. Banks and industrial companies attracted many researchers in the years 1975–85 and international organizations and political positions did so a little later. Informally many teaching staff have a second job, which prevents them from devoting much time to scientific research. According to a recent study carried out in Nigeria, 40% work on farms, and 20% in shops (Lebeau *et al.*, 2000). Through this process of deprofessionalization, the pool of active people in science has significantly decreased in a decade. Parallel jobs are necessary to live decently. Among these, the practice of research can, for some, become an acceptable way of earning a living, provided it is carried out on a consultancy basis.

Many foreign clients – corporations, foundations and international organizations – interested in public health, resource development, nature conservation, population trends and good governance, as well as a wide range of smaller grassroots organizations concerned about such issues as women in development and poverty alleviation, often have job openings for scientifically trained personnel. Few such bodies, however, are interested in science for its own sake. Instead, they seek to use science in ways that have a direct impact on society. While such employment opportunities create valuable career paths for African scientists who have few alternatives, these opportunities often come at the expense of the continent's universities and research centres which are in desperate need of skilled personnel.

All told, the changing nature of scientific work in Africa has spurred professional and institutional crises marked by the following characteristics:

- Policies have become increasingly driven by laissez-faire principles (Waast, 2001).
- Deprived of budget and power, the national coordinating bodies have lost direction and become ineffective.
- Many scientific institutions have floundered. For example, agricultural research institutes, which had become accustomed to reliable earmarked funding, have found it difficult to adjust to a competitive funding environment that requires them to tailor their agendas to donors' expectations and goals. Universities, meanwhile, have failed to meet the challenges posed by dramatic increases in student populations and have failed to respond effectively to policies that have degraded – and in some cases abandoned – higher education's research responsibilities.
- There has been an erosion of academic oversight and direction. As national scientific communities become too impoverished or too small to function effectively, science as a profession has become increasingly individualized.

All these trends suggest that, while scientific research has not disappeared in Africa, in many countries its mode of production has been radically altered. Much closer to development than to investigation, it is less geared towards education and does not much lend itself to publications. In brief, the principles now driving research can be summarized as follows:

- the profession is practised within a system depending on orders for research work and on time-bound contracts (not in the context of a career);
- the activity is exercised in a worldwide network;
- international, not national, demand shapes programmes and objectives;
- benefits and profit, rather than knowledge, define the axioms for action;
- the system is increasingly regulated by the market, not peer assessment.

This cultural revolution is carrying tensions. A rift has opened up between the researchers attached to their old national ethos and researchers open to the market. A certain number of African researchers are hired virtually full-time on

Scientific institutions across Africa

NORTH AFRICA

Egypt has established a strong research apparatus. The country currently has 18 universities (six of them private), with a total enrolment of 1 200 000 students, including 250 000 in the sciences; a national centre and 35 institutes, staffed with full-time researchers and dependent on several ministries (research, agriculture, health, mining); and a few research units maintained by the industrial sector. The Maghreb countries, which developed their national research systems later than Egypt (since the 1970s), now enjoy the highest rate of growth in scientific output on the continent (10% per year since 1980). There are some strong points. Egypt remains the second highest African producer of science, with strong abilities in chemistry and engineering. Meanwhile, the Maghreb countries have developed good capacities in medicine and agriculture, physics and chemistry, and engineering.

MEDIAN AFRICA

Compared with the other two sub-regions, the academic and scientific institutions in Median Africa are of more recent origin. The very first university to be established was the University College of Ibadan in Nigeria where the first science degrees were awarded in 1950. Following independence, in the 1970s and 1980s, the number of scientific institutions, professors and research scientists increased very rapidly. According to our survey (Waast and Gaillard, 2000), in early 2000, out of an estimated total of 13 000 full-time equivalent scientists in Median Africa, 5 000 are in Nigeria, 1 000 in Kenya and 800 in each of Cameroon, Côte d'Ivoire, and the United Republic of Tanzania. The top ten countries contribute some 90% of S&T resources. Efforts bear heavily on medical and agricultural sciences and there is much less work in engineering, social and fundamental sciences.

REPUBLIC OF SOUTH AFRICA

The Republic of South Africa possesses a solid research system, combining 36 universities and teknikons, and seven councils (specialized agencies employing full-time researchers in agriculture, medicine, industry, mining, etc.). The private sector manages its own research units (for research and development), and contributes half of national expenditure on research. The system has wide experience of cooperation schemes between the private and the public sectors and its capabilities range from aeronautics to nuclear engineering, from chemistry to metallurgy, from agriculture and food to specialities at the forefront of medicine. Although it has not yet totally recovered from the fall brought about by an international scientific boycott (during the last years of apartheid), it alone produces approaching a third of the continent's publications and is the leading African country for many disciplines.

a consultancy basis. Some of them have at their disposal research laboratories almost tailor-made for them, equipped and built off the university campus with money from abroad. Others have created simultaneously a non-governmental organization (NGO) for research and another for action. Most researchers are employed more sporadically, by development institutions and small NGOs. A few establishments have been able to adapt themselves; through their quality label, they attract orders and ensure their researchers a continuous flow of work and a share of the profits.

However, the anarchy of a free market satisfies no one. One problem is that it ruins the institutions, and

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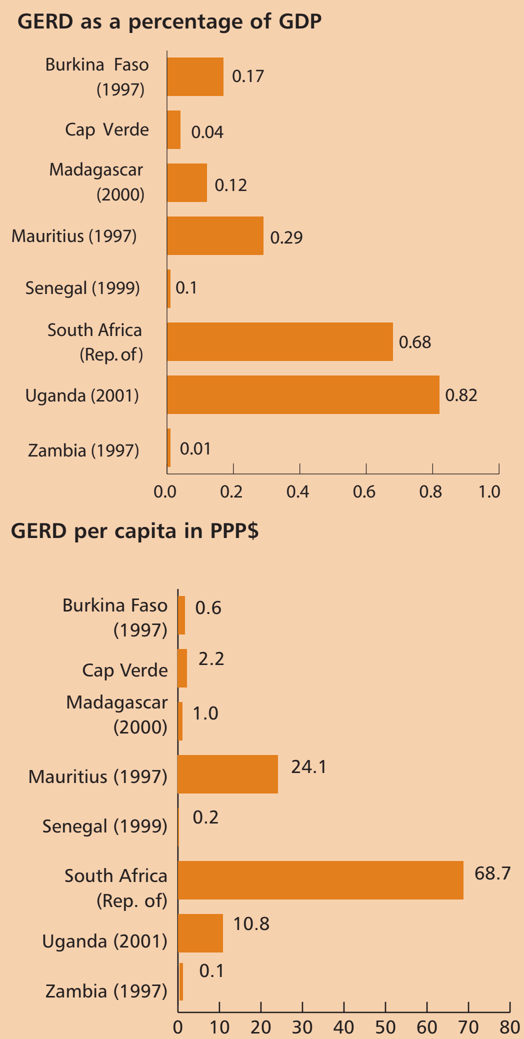
Figure 3
GERD IN AFRICA, 2002 OR CLOSEST YEAR
Selected countries



Source: UNESCO Institute for Statistics.

uses the available talents without ensuring their eventual replacement. Some donors are worried, and offer to support new programmes of capacity or institutional rehabilitation. The hired researchers feel a need for security. As for governments, although they contribute little, they complain of being short-circuited by sponsors, who negotiate directly with the laboratories and individual scientists of their choice. Suppliers and clients alike are therefore seeking new regulatory frameworks and some reconstruction is now under way. The new fledgling institutions are local or regional rather than nationally based.

The Republic of South Africa appears to be poles apart from Median Africa. In spite of the economic crisis, the country remains deeply committed to science and education. Salaries have remained attractive. Facilities and maintenance are generally excellent. But the post-apartheid regime brought a strong thrust of institutional reform to realign research to better serve basic human needs and promote industrial competitiveness. For example, a Council for Innovation, which includes representatives from large corporations, has been set up. The relative decline in research funding (which fell from 1.04% of gross national product (GNP) in 1987 to 0.68% in 1995) has been halted. In 2002, real spending was 0.68% of GDP (Figure 3). In parallel, the nation's system for financing S&T activities has changed radically, towards a competitive system closely linked to strategic goals. Several incentive funds have been established and have tripled in volume in five years. They currently represent a quarter of all public expenditure on research.

In a similar vein, councils (specialized agencies employing full-time researchers in agriculture, medicine, industry, mining, etc.) are instructed to rely more on self-financing. As a result, these agencies have increasingly turned to the provision of products and services (including new services to the poorer populations). A division of labour is also taking shape, between the councils and the private sector (which are involved more with research and development (R&D)) and the universities (active in basic research, but more and more in strategic areas linked to the productive sector). In 1999, 3 000 leading academics categorized their work as one-quarter basic research and three-quarters strategic and/or applied research. Their work was financed 40% by incentive funds, 22% through contracts with industry and government, 25% from cooperation schemes and 12% from their university's core funding (taking into account the number of articles published by the staff in high-ranking journals). The thrust toward innovation now looks like the main concern (Mouton *et al.*, 2000).

Yet other challenges remain. The proportion of 'Africans' between the ages of 20 and 24 attending university is expected to double in coming years. This would entail the creation of 300 000 new places, which is equivalent to the number of students currently attending university in Nigeria. Some councils, moreover, have had difficulties serving new clients (poor farmers, civilian industry) and others manage to do it by remaining in rather traditional fields. Higher salaries in the private sector have made it more and more difficult

Table 4
KEY EDUCATION INDICATORS FOR AFRICA, 1990 AND 2000
Selected countries, in descending order of human development index

	Public expenditure on education as a % of GDP 1990	Public expenditure on education as a % of GDP 2000	Public expenditure on tertiary education (as a % of all levels) 1990	Public expenditure on tertiary education (as a % of all levels) 2000*	Tertiary students enrolled in science, maths and engineering (% of all tertiary students) 1998–2003
South Africa (Rep. of)	6.2	5.7	21.5	14.5	17
Gabon	–	3.9	–	25.5	–
Namibia	7.6	7.9	–	12.0	9
Botswana	6.7	2.1	–	18.6	19
Ghana	3.2	4.1	11.0	–	26
Cameroon	3.2	5.4	29.5	–	–
Togo	5.5	4.8	29.0	17.4	8
Congo	5.0	3.2	–	32.6	11
Lesotho	6.1	10.0	–	16.7	6
Uganda	1.5	2.5	–	–	8
Zimbabwe	–	10.4	12.3	–	–
Kenya	6.7	6.2	21.6	–	29
Madagascar	2.1	2.5	–	11.9	20
Nigeria	0.9	–	–	–	–
Gambia	3.8	2.7	17.8	–	–
Senegal	3.9	3.2	24.0	–	–
Rwanda	–	2.8	16.7	34.7	–
Guinea	–	1.9	–	–	–
Benin	–	3.3	–	16.4	25
Tanzania, United Rep.	3.2	–	–	–	22
Côte d'Ivoire	–	4.6	–	25.1	–
Zambia	2.4	1.9	–	–	30
Malawi	3.3	4.1	20.2	–	33
Angola	3.9	2.8	3.7	–	18
Chad	–	2.0	–	16.6	–
Ethiopia	3.4	4.8	12.1	–	19
Mozambique	3.9	2.4	9.9	–	–
Burundi	3.4	3.6	22.0	26.9	10
Mali	–	2.8	–	14.6	–
Burkina Faso	2.7	–	–	–	–
Niger	3.2	2.3	–	16.2	–

* For some countries, data may be for 1999 or 2001.

Source: Data provided by UNESCO Institute for Statistics in October 2005 and for: UNDP (2004) *Human Development Report*.

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for institutions in the public sector to retain professors, researchers and good students in competitive activities. In higher education, tensions have increased between teaching duties and the necessary research tasks, between top-class, elitist departments (especially if they provide training for specialities in high demand) and others devoted rather to mass education.

Indeed, three distinct groups of institutions are emerging:

- a few councils and five or six elite universities that excel in most areas: these institutions are cultivating a strong research tradition and/or opening up new fields and are eager to forge new partnerships and to market their programmes aggressively;
- some universities and councils of average performance refocusing their activities on several specialities in which they are particularly strong, without excessive risk taking;
- institutions, including most historically disadvantaged universities, which confine themselves to the basics, where there is no tradition of research and where it is sometimes too late to build one up (Mouton *et al.*, 2000).

Other major challenges confronting science in the Republic of South Africa relate to incorporating science in the overall culture and society by addressing problems of illiteracy and scepticism ('Is modern science "white" science?' 'How can "indigenous knowledge" be incorporated?'). Finally, there is a need to establish a new 'contract' between researchers and the state, leaving room for grassroots initiatives and avoiding scientific activity being dissolved in political issues.

Despite the dramatic changes and continuing uncertainties surrounding S&T in the Republic of South Africa, scientific activity is brimming with health and even vibrancy in several sectors, thanks largely to the nation's scientific tradition, solid institutional capacities, a sturdy critical mass of scientists and ample number of centres of excellence. No doubt there has to be added the emphatic support of the government and the backing of socio-cognitive groups (linked to industry and trade unions) which, although not representing all of society, are nevertheless powerful.

Independence in North Africa has stimulated a national-based science, which at first was solidly propped up by the state. However, by the early 1980s, that support began to waver in some countries while picking up momentum in others, leading to an increasingly diverse situation. While some governments banked on the virtues of science (Tunisia since 1990, Morocco since 1996), others did not (e.g. Algeria, Egypt). Cooperation schemes (especially with the USA in Egypt and with France in the Maghreb) have been instrumental in keeping science growing and improving. But the secret of scientific stamina is elsewhere. Ensconced in two distinct professional branches, education and the higher technical civil service, the practice of science became part of respective professional profiles. Scientific activity was divided between two fields: the academic and the technological, maintaining and advocating completely opposed scientific styles. The university system, in no way engaged in the transfer of technology, subordinated research to the tasks of instruction and training. Teaching staff had to publish, but only to further their careers. In the technological camp, the science practised is *for doing*; but concrete demands from local companies are missing.

In spite of its strength and success, the scientific apparatus is now at a crossroads. Its social stance has to be redefined. Modern science, the resulting technology and the way of life it imposes are perceived as 'immoral' and 'foreign' by significant sections of society. Islamism has given the question a highly political significance. Is S&T in conflict with religion? What kind of science do the people need? If social demand remains low, can commercial demand take over? Scientific forces are highly advanced over the concerns of the economic apparatus (based on rents or cheap labour). Only the state can get involved in programmes bolder than commonplace engineering. And the scientists hesitate between academic endeavours, the daring ventures of audacious applied research (such as desalination of sea water, automatic translations into Arabic or agricultural biotechnology) and straightforward projects of technological adaptation, intended to win over the firms that already exist.

Table 5
PATENT APPLICATIONS FILED BY AND GRANTED TO AFRICAN COUNTRIES, 1999

	Applications filed		Patents granted	
	By residents	By non-residents	To residents	To non-residents
Algeria	34	248	0	0
Botswana	0	54	0	26
Egypt	536	1 146	38	372
Ethiopia	0	12	0	1
Gambia	0	7 903	0	26
Ghana	0	80 028	0	17
Kenya	28	80 516	3	91
Lesotho	0	80 315	0	43
Liberia	0	41 120	0	0
Madagascar	9	41 237	6	29
Malawi	1	80 430	0	84
Morocco	0	3 649	0	0
Rwanda	0	4	0	4
Sierra Leone	0	72 449	0	1
South Africa (Rep. of)	116	26 354	0	0
Sudan	2	80 424	0	0
Swaziland	0	40 673	0	57
Tanzania, United Rep.	0	14 467	0	0
Uganda	0	80 421	0	74
Zambia	5	87	0	66
Zimbabwe	1	80 167	0	34

Source: World Intellectual Property Organization.

How these contradictory impulses are sorted out will depend to a large extent on the future course of government policies and on the relationships between science and scientists and the societies in which they live. In Egypt, researchers have poor living conditions and few opportunities to innovate. Export of 'surplus' brain power is structural. In Algeria, education and teaching staff have lost half of their purchasing power during the last 20 years. Since 1991 threats and murders have caused a mass exodus of highly experienced professors, doctors and engineers. The younger generation who take over are lively, but they frequently lack international networks to keep their knowledge up to date.

In other Maghreb countries, the profession has suffered less from recession. In Tunisia, for example, the state has embraced science as a symbol of rationality, competence and modernity. In Morocco, the government has recently praised scientists for their dynamism and is striving to derive maximum benefit from their research. In both cases, government interest is translated into action with great political determination: the creation of an office at secretary-of-state level with real political power; a law that ensures good funding over the medium term; the undertaking to build the whole sector (including universities) into a structure based on laboratories; and encouragement of industrial demand. It has the backing of a new generation of technicians, who wish to promote new tools and areas of research such as transplant medicine, computing, telecommunications and biotechnology.

Thus, some governments in the region are now convinced that globalization, and the prospect of an association with the European market, will require upgrades in their productive system, technical innovation, and a new consensus within their societies of the relationship between science and society. Meanwhile, such considerations are barely on the political agendas of other nations. Not only does this disparity lead to different economic development environments among nations, but it also hampers regionalization and the building of a critical mass of scientists in strategic areas. Science continues to operate under an umbrella of highly nationalist values. The intervention of the state remains necessary, however, both to stimulate demand for research and to reaffirm the legitimacy of science within society. Yet, a leap forward demands tricky reforms to reconcile the two separate fields of academic and technological research, avoiding excessive state control that could antagonize the professionals. The winning cards of governments prepared to enter this challenge lie in the strength of the institutions and the energy (and high skills) of the scientists. Such a wide range of concerns poses serious challenges for both government and the scientific community.

WHAT PROSPECTS FOR AFRICA?

The way scientific research is structured and carried out has changed greatly during the last 30 years. This is as true for Africa as it is for the rest of the world (Krishna *et al.*, 2000). S&T activities are more and more dependent on international

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cooperation. They are part of a global market spurring the mobility of people and knowledge. Furthermore, science, particularly in Median Africa, has lost the hitherto dependable trust of societies and governments. However, S&T is essential for human and technological development, for global trade and for being part of the knowledge society. It is what society depends upon for a sustainable development and future.

Our dependence on S&T for sustainable development necessitates for Africa, and particularly Median Africa, a genuine rehabilitation of activities, including providing future career prospects and compensation for those involved in S&T. African states must reinvest in S&T activities. In part, this necessitates the re-establishment of the people's trust in science. A few African states like Nigeria have recently seized the initiative and are clearly aware of what is at stake (see box on page 192).

While efforts like those in Nigeria are significant and should be applauded, it is important to remember that Africa's shortcomings in S&T remain immense and will not be resolved by six or so isolated measures, however significant each of these measures may be. At a May 2001 workshop on capacity building among science academies in Africa, organized by the Inter-Academy Panel on International Issues (IAP) which is headquartered in Trieste, Italy, participants observed that, of the 53 nations in Africa, only nine had science academies and many of those academies were starved of cash, recognition and influence. A tenth academy has since been launched in Zimbabwe, in October 2004, but it is faced with the same problems. For its first year of operations, the Zimbabwe Academy of Sciences received a government grant of US$ 120 000 but no assurance of future government funding.

The same observations should be applied to other aspects of the continent's scientific enterprise, including the work of individual scientists, the capabilities of scientific institutions and the efforts of scientific ministries.

Six interdependent approaches

In light of these daunting challenges, a clear vision of the necessary steps to take for a sustainable revival is a must. The approaches outlined below may seem utopian and prescriptive, given the present context and conditions. Yet, we feel they are realistic ones, particularly for Median Africa, assuming that the African governments, the scientists, the grassroots actors and the donors can agree on practical measures to ensure a revival.

First, *develop, sustain and utilize local capacities and leadership in efforts to advance S&T.* The truth is that developing scientific and technical capacity is less difficult than sustaining it, and sustaining it is less difficult than utilizing it. That is why it is important for African nations to invest in the education and training of scientists and technologists, and that is why it is important for each nation to develop an economic strategy that offers scientists and technologists employment opportunities once they obtain their degrees. A single talented scientist can make a difference. That is the

The 10 African national academies

Cameroon Academy of Sciences	Cameroon
Academy of Scientific Research and Technology (ASRT)	Egypt
Ghana Academy of Arts and Sciences (GAAS)	Ghana
Kenya National Academy of Sciences (KNAS)	Kenya
Académie Nationale Malgache	Madagascar
Nigerian Academy of Sciences	Nigeria
Académie des Sciences et Techniques du Sénégal (ASTS)	Senegal
Academy of Science of South Africa (ASSAf)	South Africa
The Uganda National Academy of Sciences (UNAS)	Uganda
Zimbabwe Academy of Sciences	Zimbabwe

Science makes a fresh start in Nigeria?

At the request of the Government of Nigeria, an international advisory board for the reform of the country's science, technology and innovation system was established by UNESCO in October 2004. A core activity of the reform programme is a joint review of investment, industry and innovation in Nigeria involving UNESCO, UNCTAD, UNIDO and WIPO. Financed in equal shares by the Government of Nigeria and UNESCO/Japan Funds-in-Trust to the tune of US$ 1 million, the review is part of preparatory work for a donors' conference Nigeria is planning to call to fund implementation of a multi-year plan of action on science, technology and innovation. Other international agencies expected to join the reform programme are the United Nations Economic Commission for Africa, the World Bank and the International Association of Universities.

Could science be making a fresh start in Nigeria? Since the transition to civilian rule in 1999, consolidated in 2003 with the election of the second Obasanjo government, Nigeria has certainly given signs of renewed interest in S&T. In October 2003, it launched a low Earth orbit remote-sensing micro-satellite to monitor the environment and provide information for infrastructure development. This prowess has enabled Nigeria to join a Disaster Monitoring Constellation grouping Algeria, China, the UK and Viet Nam.

President Obasanjo has since announced that his country is establishing, within UNESCO, a US$ 1 million Nigeria Special Funds-in-Trust for Science. This Special Fund will 'not only benefit Nigeria but also assist other African countries in designing project proposals for the reform of their national science systems and in developing managerial capacities', Nigeria's Minister of Science and Technology, Professor Turner T. Isoun stated in October 2004.

Nigeria has considerable human potential. It counts 60 universities, 44 polytechnics and 65 research institutes for a population of 133 million. However, there are also deep-rooted problems; these include insufficient funding of research and development, poor management, inadequate macro-level coordination and a lack of linkages between industry and research institutes or universities.

The need for reform is patent after four decades of military rule marked by state corruption and spiralling foreign debt, following independence in 1960. The rewards of reform could also be immense, for Nigeria is potentially a wealthy country. The world's 13th largest oil producer and the 6th largest in OPEC, Nigeria also has gas reserves which, when fully exploited, will place it among the world's top ten gas producers. However, 'in the 1980s, the country failed to use productively the oil windfall to improve social conditions and encourage the non-oil economic sector', writes the UK Department for International Development (DfID) in its Nigeria Draft Country Assistance Plan (2004). 'Between 1980 and 2000, Nigeria's per capita income plummeted to about US$290, well below the Sub-Saharan average of US$490.'

The reform comes at an auspicious time. After sluggish growth initially following the end of military rule, GDP rose by nearly 10% in 2003, driven by strong oil receipts and agricultural growth of 7%. Public spending has climbed markedly, from 19% of GDP in 1997 to 50% in 2001 (DfID). One aim of the science system reform will be to use this growth to diversify Nigeria's economy, in order to reduce the country's dependence on fluctuating oil prices: oil exports accounted for 95% of foreign earnings in 1998, compared with 58% in 1970 (UNDAF).

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good news. The troubling news is that past experience indicates that educating and retaining scientists and technically skilled workers is much more difficult than it seems. Yet small programmes with relatively limited resources can make a difference (see box below). Two critical prerequisites of sustainability are a vibrant educational system and an enduring, yet flexible, job base (World Bank, 2000).

Second, *mobilize the best and most relevant S&T in Africa and elsewhere to address critical social and economic problems*. The food, health and environmental issues faced by people in poor countries, and especially in the least developed ones, are of a different dimension (and often a different kind) from the food, health and environmental issues faced by people in rich countries. Such differences help to explain why S&T initiatives in developed countries have rarely targeted Africa's most critical problems: those related to poverty, food and energy deficits, inadequate and unsafe drinking water, tropical diseases and the HIV/AIDS pandemic.

As a result, if Africa expects to use S&T to tackle its most pressing problems, it must develop its own scientific and technical capacities. Otherwise, it will be forever beholden to second-hand science that will likely never quite fit the continent's circumstances. For this reason, it is important that the governments of Africa engage the continent's scientific leadership in providing authoritative and independent opinions on current scientific issues of critical importance. That, in turn, means strengthening Africa's scientific academies in those countries where they now exist and establishing new scientific academies in countries where they do not. As stated above, only ten of Africa's 53 countries currently have merit-based science academies. Such numbers indicate that there is much room for improvement on this front.

That is not to say that African nations should turn their backs on research taking place beyond their borders. North–South collaborative efforts have already contributed to strengthening and internationalizing African science. Yet, while they should be continued, care must be taken to recognize inequalities between partners from the start of collaboration so that such inequalities can be addressed and hopefully overcome (Gaillard, 1994). At the same time, Africa should seek to engage the private sector in its efforts to

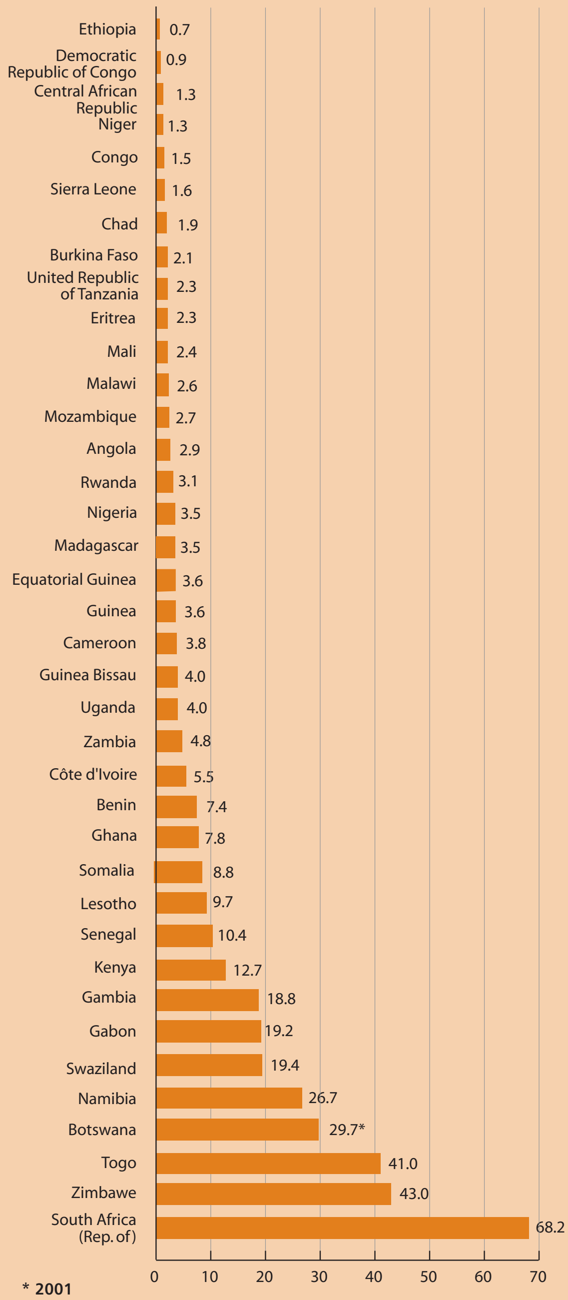
IFS and TWAS support programmes in Africa

The International Foundation for Science (IFS) and the Academy of Sciences for the Developing World (TWAS) have supported many African scientists over recent decades: in sciences related to the management, conservation and sustainable use of natural resources for IFS and in the basic sciences, including biology, physics, chemistry and mathematics, for TWAS. Since 1974, IFS has supported some 1 250 African scientists in most African countries and TWAS close to 1 000 since 1986. As part of the Monitoring and Evaluation System for Impact Assessment (MESIA) being established at IFS, a tracer study of IFS grantees has been conducted in a selected number of countries including Cameroon, Morocco and the United Republic of Tanzania. Paradoxically, very few cases of true brain drain were found in the surveyed population. Out of 262 scientists surveyed some 30 years after the first grant was approved, only four had emigrated permanently to Europe and the USA. Most of the remaining scientists were still active in their respective countries except for the United Republic of Tanzania where some 10% were found to contribute to a regional circulation of scientists in Southern Africa. This shows that support well targeted to young scientists at the beginning of their research careers can be instrumental in retaining them in their national scientific communities.

See www.ifs.se and www.twas.org

AFRICA

Figure 4
SUB-SAHARAN INTERNET USERS PER 1000 POPULATION, 2002



* 2001

Source: http://unstats.un.org/unsd/mi/mi_series_results.asp?rowId=605

boost S&T on the continent. While such efforts may prove difficult to pursue in a climate of political and economic uncertainty, Africa's wealth of natural resources, particularly its treasure trove of indigenous and medicinal plants with potential commercial value, may be particularly attractive to private pharmaceutical firms. The continent's untapped demand for new information technology (barely 1% of Africa's population is currently connected to the Internet compared with 40% in North America) may prove to be another area ripe for public/private partnerships, especially if Africa can nurture a sufficient number of well-trained information technologists allowing African nations to forge balanced partnerships. At the same time, African nations should continue to pursue cooperative projects with constituencies that have special ties to the continent. For example, African scientists should seek to tap the distant yet potentially strong ties that exist between them and expatriate scientists of African origin in the North.

Third, *build a strong case at home and worldwide for supporting indigenous development of S&T.* This is a critical challenge for African scientists given the competing demands that are constantly being exerted on the continent's limited financial resources. African scientists have not only an obligation but a self-serving interest to convince governments of the value of science and the need to support such endeavours. Such efforts must include a willingness to engage the public in discussions on science-based issues, a desire to lobby the government for support and, perhaps most importantly, a commitment to pursue research agendas that focus on critical social and economic problems. The development of national research grant schemes or the strengthening of already existing ones could be a powerful tool to pursue such research agendas. Such efforts will also require serious and sustained investments in education from primary grades through graduate studies at universities. Educational initiatives, in fact, could prove the most productive long-term elements of all governmental S&T strategies.

Fourth, *share innovative and successful experiences in the development and application of S&T.* Africa's successful experiences in the application of S&T for development have all too often been drowned out by the din of dismal news concerning the current state of affairs on the continent. Identification of genetic molecular markers for improved tea harvests in Kenya, ongoing efforts to examine alternative treatments for river blindness in Uganda (see box on page 198), research on sickle-cell anaemia in Ghana, and detailed assessments in Madagascar of the effectiveness of medicinal plants (see box on page 179) are examples of science-based initiatives that deserve greater recognition both within the larger scientific community and among the public (UNDP and TWNSO, 1998 and 2001).

Fifth, *strengthen and build centres of excellence in Africa.* Despite the generally gloomy condition of scientific and technological institutions in Africa, small pockets of strength can be found. For example, such national and regional centres of scientific excellence as the Immunology Laboratories in Cameroon, the African Centre for Meteorological Applications in Niger, the African Centre for Technology in Senegal and the Tanzania Industrial Development Organization could eventually be transformed into international centres of excellence capable of functioning more effectively than they do now. Such a transformation would not only boost science in Africa but could serve as a model for the development of other institutions across the continent. These efforts will likely require both strong political will on the part of Africa's governments and reliable help from bilateral concerted support, regional development organizations such as the African Development Bank and international development organizations such as the European Commission and the World Bank.

Sixth, *strengthen and build regional programmes and networks in Africa.* Many such networks and regional programmes do already exist, particularly in medical and agricultural sciences. In agricultural sciences three sub-regional programmes (*Conseil Ouest et Centre Africain pour la recherche et le développement agricoles* (CORAF), Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), and Southern African Center for Cooperation in Agricultural and Natural Resources Research (SACCAR)) have been established to coordinate activities in the three main sub-regions. While more efforts should be made to strengthen African sub-regional research systems, the legitimate desire of each country to formulate and develop its own research policy should also be taken into account. In any case, a regional strategy can only become truly productive if it is supported by consolidated national systems.

Sustaining biology

The East Africa Regional Programme and Research Network for Biotechnology, Biosafety and Biotechnology Research (Bio-Earn) was founded in 1999 with funding from the Department for Research Cooperation of the Swedish International Development Agency (Sida-SAREC). Four countries – Ethiopia, Kenya, United Republic of Tanzania and Uganda – are members. The organization's principal objectives are to 'build capacity in biotechnology' among its member states and 'to promote appropriate research and related policies'. Equally important, Bio-Earn seeks to foster programmes and policies that enable biotechnology to be used 'in a sustainable manner ... to help improve livelihoods, ensure food security and safeguard the environment'. While biotechnology and genetic engineering may hold great promise for addressing questions of food security in sub-Saharan Africa, applications of these technologies have generated a great deal of controversy and concern. The most critical issues involve questions of property rights, corporate control of the research agenda and the risks posed to non-transgenic crops and the environment. As recent controversies over the distribution of genetically engineered maize in Zimbabwe show, these concerns cannot be ignored in the name of science or even in the name of feeding the hungry.

See www.bio-earn.org

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THE ROAD AHEAD

There is no doubt that the major problems that afflicted Africa during the last 30 years of the twentieth century remain stubbornly in place at the beginning of the twenty-first century. Yet, recent events and discussions suggest that Africa has the best opportunity in the coming decades to break its well-entrenched logjam of problems and make significant advances in scientific capacity building. To seize these opportunities, however, Africa must devise new long-term visions and strategies that enable it to sustain economic

NEPAD

The New Partnership for Africa's Development (NEPAD) was launched in 2001 as a comprehensive, integrated initiative for the revival and sustainable development of Africa. NEPAD is a programme of the African Union grouping 53 countries.

Within NEPAD, African statesmen are calling for greater investment in S&T. Were the target set by NEPAD in 2003 of devoting 1% of GDP to R&D within five years to be realized, it would constitute a mini-revolution for the African continent, where most countries devote less than 0.3% of the public purse to R&D.

It is not the first time that Africa's leading politicians have voiced their 'unflinching' support for such efforts. In 1980, there was the Lagos Plan for Action; in 1987, the Kilimanjaro Declaration; in 1988, the Khartoum Declaration; and, in 1998, the Addis Ababa Declaration. All called on sub-Saharan African nations to turn to S&T as primary sources of economic development.

What makes NEPAD's strategy different? First, the times. A steep decline in many economic and social indicators is a stark reminder that urgent action is needed now more than ever before. Second, the strategy lays heavy emphasis on human resources development as a prerequisite for science-based development and thus takes a long-range view of how progress should be defined and achieved. NEPAD emphasizes sensible goals and makes provisions for on-going evaluations and adjustments. Although the language may not be as dramatic as the statements associated with previous reform efforts, the prospects for success – albeit modest success – are greater. Third, NEPAD views the development of S&T as a tool rather than a goal, directly tying investments in S&T to such immediate needs as poverty elimination, improvements in public health, access to safe drinking water and environmental protection.

NEPAD's plan of action for S&T acknowledges that African science and scientists are currently cut off from the economic system. The plan of action consequently focuses on science policy development and flagship programmes that include biotechnology, indigenous knowledge and technologies, ways of developing university–industry partnerships, technology incubators, innovation hubs and training in science policy. This plan of action was adopted by a ministerial conference in Johannesburg, South Africa, in 2003, which in parallel established a Council of Ministers to serve as NEPAD's policy-making body.

NEPAD is encouraging both a dialogue between stakeholders in S&T and the elaboration of an appropriate regulatory and policy environment to nurture private investment in R&D. Regional centres of excellence are being promoted as a key strategy for boosting African collaboration. At the same time, NEPAD is fostering a genuine spirit of partnership which revolves around South–South and North–South collaboration. The Memorandum of Understanding signed in 2004 between NEPAD and the International Agricultural Research Centres of the CGIAR points in that direction.

See www.nepad.org

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growth and compete in a world where development is becoming increasingly dominated by scientific knowledge and technical skills. In short, African nations must build and sustain their own capacities in modern S&T and then use the knowledge and skills that are acquired through such efforts to devise problem-solving strategies. Such strategies, in turn, must put the best of S&T in Africa and elsewhere to work in ways that will build and sustain local and regional capacities as well as address real-life concerns.

The recent history of Africa has shown that we cannot inject heavy doses of outside technology into the continent and hope that this infusion of external know-how somehow takes hold in the years ahead. Instead, efforts to build S&T capacities in Africa must be driven by a long-term strategy founded on the principle that each country, no matter how poor, needs to develop its own science and, moreover, that scientific knowledge can serve as one of the primary forces behind sustained economic development. Put another way, like speed in sports, there is no substitute for science in development.

All assessments of the state of science in Africa concur that not just the buildings, communication systems and laboratory equipment (that is, the hardware of scientific institutions) are in a desperate condition but so too the teaching and training programmes (that is, the software of scientific institutions). As African nations and outside donors seek to bolster the capacity of the continent's scientific infrastructure, they must devote a great deal of attention not only to the construction and maintenance of physical structures and access to computers and electronic networks, but to a host of basic personnel issues of prime importance to scientists, including the availability

Future harvests today

The Consultative Group of International Agricultural Research (CGIAR) is a worldwide consortium of 15 research organizations, collectively known as the 'Future Harvest' institutions. Four of these research institutions, each with its own history of scientific excellence and specific mandate, are located in sub-Saharan Africa:

- Africa Rice Centre (WARDA), based in Bouakè, Côte d'Ivoire, has pioneered the development of Nerica (New Rice for Africa), which is expected to make Africa self-sufficient for rice by 2010.
- International Livestock Research institute (ILRI), based in Nairobi, Kenya, which works at the crossroads of livestock and poverty, bringing high-quality science and capacity-building to bear on poverty reduction and sustainable development for poor livestock keepers and their communities.
- International Institute for Tropical Agriculture (IITA), based in Ibadan, Nigeria, which focuses on crop management and improvement, especially for such small landholder crops as cassava, cowpea, plantain and yam.
- World Agroforestry Centre, based in Nairobi, Kenya, which conducts research on overcoming land depletion in the smallholder farms of the sub-humid and semi-arid regions of Africa, and searching for alternatives to slash-and-burn agriculture at the margins of the humid tropical forests.

The diverse mandates of these institutions – and the fact that other Future Harvest institutions based elsewhere are also collaborating to help solve some of Africa's agricultural problems – provide a network of scientific excellence. The reach of this network is extended through a host of regional centres distributed throughout sub-Saharan Africa that also assist in disseminating research results and 'best practices' to Africa's farmers.

See www.cgiar.org

of journals and monographs, the timeliness of teaching materials, and adequate pay levels and reasonable opportunities for career advancement.

All of these problems are well known but deserve to be repeated for two reasons.

First, *acknowledging the full range of the problems facing science in Africa is just a first step*. By no means do these expressions of concern ensure that an effective strategy will follow. No region of the world is more cognizant of this fact than Africa, whose problems have been discussed at length for decades without much progress to show for it.

Second, *history indicates that basic bread-and-butter issues often lose out to more glamorous visions of progress*. One reason for the decline of Africa's universities over the past 30 years, after a period of promising steps forward in the 1960s and early 1970s, is the fact that Africa's governments often chose to expand their university systems to new campuses at the expense of adequately supporting their existing institutions of higher education. The reason for this was that clearing and construction in new areas provided more tangible signs of progress. The same 'monu-mentality' helps to explain the persistence of the World Bank's 'bricks and mortar' programme during the post-Second World War era long after library shelves filled with assessment reports largely conveyed a story of failure.

In any circumstances, Africa has to help itself first by its own forces and resources and must remain wary of other people's money no matter how well intentioned and how effective new international funding strategies may prove to be. Donor fatigue, after all, is just another name for human nature.

Even the most diplomatic of ventures, for example, the first (1970–79) and second (1980–89) Industrial Development Decades for Africa, which were sponsored by the United Nations Industrial Development Organization (UNIDO), barely left an imprint, either positive or negative, on the S&T landscape in Africa. And, as much of the literature on economic development has since concluded, the United Nations Conference on Science and Development, held in Vienna in 1979, falsely raised expectations for rapid progress by confidently promising funding mechanisms and follow-up actions that never materialized. The World Conference on Science (WSC) in Budapest in 1999, sponsored by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council for Science

Sighting blindness

Just a decade ago, it was not uncommon for one in every three villages in parts of Burkina Faso, Ghana, Nigeria and other nations of sub-Saharan Africa to be afflicted with river blindness. Today, virtually no villages are. The progress that has been made in combating the disease represents one of the most triumphant public health campaigns ever waged in the developing world. But will this success continue? Nobody is sure. The reason for the concern is that the parasites causing the disease are likely to build resistance over time to the successful drug therapies that have been in put in place. For this reason, Thomas G. Egwang and his colleagues at the Med Biotech Laboratories at Makerere University in Kampala, Uganda, with the help of a grant from the Howard Hughes Foundation, USA, are seeking alternative treatments based on the medical community's rapidly advancing knowledge of molecular biology and, more specifically, biochemical pathways. Such knowledge could help researchers devise carefully targeted strategies designed to disrupt the disease-causing parasites' basic molecular functions. That, in turn, could serve as the basis for undermining the parasites' vitality and disrupting their reproductive cycles.

See www.mblab.or.ug

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(ICSU), was developed with much more modest expectations than its predecessor meeting in Vienna. While follow-up WSC activities on a regional scale have been encouraging, however, the initiatives continue to lack the resources and staffing commitments necessary to make a dramatic difference to the pace of scientific progress in the developing world.

Models and mechanisms

There are, however, models and mechanisms in place to advance the cause of S&T in the developing world. According to the United Nations Development Programme, the Republic of Korea, for instance, recently rose to the ranks of high human development (UNDP, 2001), with an average per-capita income greater than that of the Czech Republic, Hungary and Poland.

Other potential examples include Brazil, China, India and Mexico. None of these nations, except perhaps China, has achieved the spectacular economic success of the Republic of Korea. Nevertheless, each has built a sturdy scientific infrastructure that promises to provide an enduring framework for sustained economic growth.

The strategies that have been pursued by these nations are not difficult to decipher: sustained investment in education at all levels; long-term government commitment to the nation's scientific enterprise; reasonable and reliable funding; the ability to access the most current scientific literature through electronic communications and ample opportunities to interact with the international scientific community; and strong encouragement to compete at the highest levels of excellence in the global scientific community.

These strategies, however mundane they may seem, represent science policy at its best. On the one hand, the strategies provide a clear and coherent blueprint for institutional capacity building based in large part on domestic funding; on the other hand, the strategies offer mechanisms for the development of knowledge and skills by individual scientists. These scientists – at least an increasing number of them – are then given opportunities to apply their talents at home.

Scientific ministries, research centres and universities in Africa would be wise to follow the S&T path laid out by the most successful developing countries. The road map that

African initiative

Launched in 1998 with financial assistance from the World Bank, the Millennium Science Initiative (MSI) strives to build capacity in modern science and technology in developing countries. To date, MSI institutes have been established in Brazil, Chile and Mexico, and have reached the implementation stage in Africa. With the aid of an African MSI task force, organized jointly by the Academy of Sciences for the Developing World (TWAS) and the Science Initiative Group (SIG), an independent non-governmental organization that advises the MSI, three priority areas have been selected: biology and biotechnology; mathematics; and instrumentation and information technology. MSI's strategy involves linking the work of local researchers, teachers and programmes to activities and institutions that are already in place.

Among the institutions acting as focal points for the initiative are Med Biotech Laboratories in Uganda; and the University of Dar es Salaam and the Tanzania Industrial Research and Development Organization (TIRDO), which are the primary nodes for the information technology and instrumentation facilities respectively. In contrast, the mathematics component is 'multi-centred', with hubs in such countries as Benin, Cameroon, Kenya and the Republic of South Africa.

See www.msi-sig.org

they have devised is as likely to advance S&T in Africa as it has in parts of Asia and Central and South America. The bottom line is this: S&T alone cannot save Africa but Africa without S&T cannot be saved. Recent history tells us so.

This chapter was prepared in 2001 and has been partially updated.

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Japan

YOSHIKO OKUBO and SHINICHI KOBAYASHI

The socio-economic issues facing nations today are complex, difficult to define and unlike any that have gone before. No advanced country possesses the best solution. The world is entering the era of the knowledge-based society, in which knowledge is recognized as driving productivity and economic growth. The development of science and technology (S&T) is a *sine qua non* for the creation of new knowledge and international cooperation – both vital for coping with intensifying global competition in the new century. How should the global economy add to, and share, the world's intellectual reservoir? How can knowledge be put to efficient use in resolving pressing national issues? How may S&T be used to create new industries, increase productivity and maintain industrial competitiveness? These are all crucial questions for every nation's economic development.

Japan, like any other country, is striving to find its path in the new era. In the period following the Second World War, the country enjoyed a high-growth economy unparalleled in its history. The national standard of living improved dramatically, and Japanese life expectancy became the highest in the world, with 78.4 years for men and 85.3 years for women. During the last decade of the twentieth century, however, Japan's economy began to stagnate, and the country entered a prolonged structural recession. Now Japan is facing declining demand, and its economic recovery urgently depends on the creation of new industries and markets, as well as the development of systems capable of effectively generating sustainable innovation.

In order to overcome its recession, Japan has made S&T activity a top strategic priority. Its Basic Law on Science and Technology, formulated in November 1995, and its First and Second Basic Plans on Science and Technology, dating from 1996 and 2001 respectively, demonstrate the importance it places on this issue. Likewise, administrative reform launched by the government in 2001 has since been extended to include S&T, which will help build an appropriate innovation system for the new era.

The Science and Technology Agency's *White Paper on Science and Technology 2000: Towards the 21st Century* describes the objective of Japan's S&T policy as the construction of a new relationship between science, technology and society. Japan seeks to become a 'nation capable of long-lasting development' by creating intellectual vitality that will contribute to maintaining the vigour of Japan's economy and improving living standards.

In this chapter, we describe the overall performance of Japan in S&T, starting with a brief history of how the nation acquired modern S&T from the West and constructed its own infrastructure in the nineteenth century. The process of institutionalization and professionalization of S&T systems is depicted, and an overview of national S&T policy since 1950 shows the strategy behind the building of competence in S&T at the government level, as well as the measures taken to achieve this. The state of the art of S&T and its development are shown using S&T indicators and international comparison. We describe the current issues facing the nation's S&T development, the socio-economic problems hindering its expansion and the ongoing reforms to restructure the national system of innovation. We conclude with a view of the future.

A BRIEF HISTORY OF SCIENCE POLICY IN JAPAN

Institutionalization and professionalization of S&T (1868–1945)

In 1868, the Tokugawa Shogunate government collapsed and the new Meiji era began following the proclamation to 'restore imperial government'. This incident put an end not only to the dictatorship of the Tokugawa family and the feudal system, but also to a long isolation policy going back two and a half centuries. Meiji reforms were undertaken by the Emperor Mutsuhito, in the spirit of the Meiji era, Meiji meaning 'luminous reign' in Japanese.

Japan entered the world of modern S&T at this time, beginning an era of openness to Western influences. However, in order to resist attempts by Western countries to colonize Japan, the state gave high priority to building up national wealth and military strength. Administrative and social structures were radically reorganized; peasants acquired the right to own land; universities were set up; the samurai lost their ancient privileges; the government was Westernized and free trade with the outside world was established (1873). The imperial council was replaced by a cabinet based on the Western model (1885), and a constitution was created that provided for a two-chamber parliament, modern judicial system and armed forces. As part of the industrialization process, the first railway was built in 1870.

Entering the new world obliged Japan to become an autonomous state; as a means to this end, Japan made the accumulation of wealth and power a national goal. The country began by analysing the source of Western strength. Western military power was based on industrial power, which in turn had been born of the development of military technology and the Industrial Revolution. The West's underlying strength was its systematic use of S&T. In order to follow the same path, Japan faced the urgent task of constructing the infrastructure needed to acquire S&T knowledge from the West and introduce Western S&T into various sectors of Japanese society. With its strongly centralized administration, the Meiji government was able to play a crucial role in establishing S&T institutions and organizations.

The Ministry of Education was established in 1871 and a comprehensive education system was introduced a year later. Founded in 1877, Tokyo University was later to become (in 1886) the Tokyo Imperial University, the most prominent of the six imperial universities built successively over the half century that followed.

A significant characteristic of the imperial universities was that each one created a department of engineering, demonstrating the Meiji government's view that engineering was equal to science and medicine in importance. This high regard for engineering by a Japanese government stands in sharp contrast to the status accorded the field in Europe and the USA during the same period, where it was regarded as inferior to science, law and medicine. Science and engineering in the West developed in totally separate social and historical contexts. They were institutionalized in accordance with different outlooks and objectives, and developed different methods and approaches, all of which created a hierarchy between the two. The Meiji government reversed this hierarchy. The prestige conferred on engineers not only produced the large quantity of engineers capable of promoting the industrial development that ensued, but also created a tradition of superiority for engineers in the Japanese S&T infrastructure. Today, the country still produces more than five engineers for every scientist, compared with a ratio of 1:1 in other industrialized countries.

At the time it launched construction of its S&T infrastructure, Japan lagged 200 years behind the West in terms of scientific knowledge and the scientific revolution triggered by Galileo and Newton. Japanese industry lagged close to 100 years behind the UK's Industrial Revolution. However, in terms of the professionalization of science – namely, the recognition of science as part of the social system and the ability of scientists to live from their research activity – Japan was no more than 50 years behind France, Germany or the USA. In other words, there was a great time-lag between Japan and the Western world in terms of the institutionalization of S&T, but this was reduced as soon as science took on value in Japan and its benefits were pursued in a systematic way. The creation of engineering as a university department, in particular, facilitated the fusion of science and engineering.

The government followed a unique procedure to introduce S&T from the West. It first selected high-calibre scientists and engineers from around the world, using its embassies and consulates to recruit candidates. These foreign scientists and engineers of diverse specialities were offered posts as professors in the imperial universities. Their best Japanese students were then sent abroad to perfect the knowledge acquired under the tuition of the foreign professors. The returnees contributed to national development as university professors, gradually replacing government-employed foreigners in playing an important role as senior civil servants in their country. The best possible knowledge and expertise available at the time were in this way introduced into Japan from the world's leading scientific countries in the principal fields of industry and learning.

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Japan thus succeeded in nurturing its own industrial revolution with astonishingly little brain drain. The development of S&T continued to reflect the Meiji policy of putting S&T at the top of the nation's priorities. Besides strengthening its industrial base, the country produced scientists of international standing, including Hantaro Nagaoka, Kikunae Ikeda, Ryojin Tawara and Umetaro Suzuki.

The Second World War brought about the total collapse of the Japanese economy, which, after the country's defeat, dropped to pre-Meiji Restoration levels. To survive, Japan needed to reconstruct a nation based on technology. Economic growth once again became top priority and S&T an essential tool.

In pursuit of an independent state (1955–70)

The 1960s were marked by tensions between the USA and the USSR during the formation of Western and Eastern blocs. A decade that had begun with the construction of the Berlin Wall (1961) and the Cuban Missile Crisis (1962) would go on to see the beginning of the Viet Nam War and the Cultural Revolution in China. The era was marked by an ever-intensifying space race between the two superpowers following the USSR's successful launching of the world's first unmanned satellite, *Sputnik I*, in 1957.

In Japan, if the national productive capacity had depended heavily on imports of the latest foreign technology from 1945 to 1959, by the 1960s the archipelago was able to produce its own low-cost, high-quality, internationally competitive products. The pace of economic development in the 1960s took even the government by surprise. The target of its National Income Doubling Plan (1960–70) – to maintain an average annual economic growth rate of 9% in 1961–63 and to double the gross national product (GNP) within ten years – was soon surpassed. National GNP quadrupled, exceeding that of West Germany in 1968, and Japan rose to the rank of second-largest GNP in the 'free world'.

Technological innovation resulted in the rapid development of Japan's industries. The energy revolution, based on petro-thermals, and the materials revolution, based on synthetic resin and textiles, restructured the landscape of national industrial competencies. The first million-vehicle manufacturer appeared in the automotive industry. During the 1960s, domestic pollution issues started heating up. The decade also saw the first international trade frictions, which would only intensify in the decade to follow. As Japan's economy took off, there was a policy switch from 'catching up' with the Western level of S&T to the development of original technology by improving pilot and core technologies, and to enhancing competitiveness within a liberalized economic structure. The promotion of S&T was part and parcel of this plan.

Prior to the Second World War, there had been no policy devoted exclusively to S&T, science policy at the time being considered part of industrial or education policy and thus not formulated independently. In the mid-1950s, plans for constructing a social and economic structure were drawn up. The Science and Technology Agency (STA) was established in May 1956 as a core administrative organization headed by a minister. The advent of the STA symbolized the dawning perception of S&T policy as an important part of the national administration.

In 1959, the Council for Science and Technology (CST) followed. It was entrusted with the mission of fortifying S&T administration and, as the supreme deliberative S&T policy organization, promoting government S&T policies. It was to act as an advisory body to the prime minister, who today still chairs this body and consults the council for basic S&T policy making and when fixing long-term general research objectives. The prime minister first consulted the CST on what measures would be necessary to promote the development of national S&T. *Recommendation Report No. 1*, submitted to the prime minister in October 1960, was to form the basis for Japan's first integrated and systematic S&T strategy.

Japan's economic growth after the Second World War was driven by a large pool of researchers, engineers and technicians. By the late 1950s, however, industry was suffering from a shortage of skilled personnel. In its

Recommendation Report No. 1, the CST predicted a shortage of some 170 000 engineers and skilled workers between 1961 and 1970. The Ministry of Education consequently formulated a plan to increase the number of students to avoid compromising implementation of the aforementioned National Income Doubling Plan. These special enrolment policies channelled an additional 100 000 students into the science and engineering departments of higher-education institutions during the period when the plan was in force.

If competent personnel and adequate facilities and equipment are imperative for research, any development is heavily dependent on the level of investment a nation can make in research, which in turn is determined by the state of the economy. In the late 1950s, the ratio of research investment to national income for France, the UK, the USA and West Germany ranged from 2.7% to 1.5%, compared with a ratio of 0.94% in Japan. This spurred the archipelago to set a target ratio of 2% (near the UK level), a goal thought to be attainable by the turn of the decade.

The construction of the Tsukuba Science City was also planned during the 1960s. The CST recommended relocating national research institutes and laboratories outside overpopulated Tokyo to improve the research environment, accommodate modern facilities and equipment, encourage joint use of facilities and promote interaction and exchange among researchers. In short, the aim was to create an ambience conducive to joint research. A cabinet-level decision in 1963 led to the construction of a science city of international stature in the Tsukuba area, which is still expanding today.

In pursuit of harmonious S&T (1970–80)

Throughout the prosperous 1960s, Japanese society passed from a state of postwar devastation to one of economic expansion. Social demands shifted from a survival-level clamour for food to a thirst for wealth and learning. Technology that was oriented towards material comfort peaked around 1970, by which time 90% of Japanese households were equipped with washing machines and refrigerators. The country entered the 1970s yearning for education more than material satisfaction. Various technologies were developed in order to meet the diverse social demands: technologies in the areas of health and food production such as antibiotics, fertilizers and plant and animal breeding; household electrical appliances, cars and other new material-based technologies; printing and publishing; and telecommunications and broadcasting. This was the period when research and development (R&D) was guided by social needs, a time when consumer goods produced by research began to enter offices and households. Firms began investing in the development of end-products. R&D investment increased most rapidly in electrical and precision machinery, with R&D investment as a proportion of total sales climbing from 2.3% to 3.7%, and 1.6% to 3.0% respectively in these two areas between 1965 and 1980. By contrast, R&D investment in steel remained stable at around 1%, as did such investment in industrial machinery (around 1.7%). The 1970s thus saw a shift from the development of industrial products to that of consumer goods.

The technological gap between Japan and the USA narrowed, with Japan developing its own technology independently of military research. The success of the Japanese approach undermined the hypothesis that only large-scale military or space projects resulted in breakthrough high technologies. A new type of research organization and management based on the Japanese model emerged, whereby development was frequently carried out from the bottom up in the decision-making process, rather than under the leadership of a certain elite.

Thanks to its R&D efforts during the 1970s, Japan was earning 10% of world GNP by the end of the decade. But the country was then, and remains today, heavily dependent on oil. During the oil crises in 1973 and 1979, Japan, then the second-largest consumer of oil in the 'free world', was compelled to seek alternative energy sources. Nuclear energy emerged as one such source. Energy-saving technology was developed alongside this, as were antipollution and energy-saving measures. Meanwhile, social welfare had become a pressing issue, having been neglected during the nation's rush to expand productivity. The postwar

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generation sought intellectual stimulation and harmonious relations between science, technology and society. S&T, however, was primarily driven by material needs at the time, and R&D's emphasis was placed on technology rather than on basic science. Social pressure led to the development of 'comprehensive technology' that combined system technologies and social-science technologies. Under these circumstances, environmental science, behavioural science and the life sciences developed more rapidly than conventional physical technologies during the 1970s.

Recommendation Report No. 5, submitted by the CST in 1971, drew attention to the relationship between S&T and socio-economic, environmental and safety problems. The report encouraged the development of new areas in science, such as software and the life sciences.

In pursuit of greater creativity and internationalization (1980–90)

In the 1980s, Japan's trade surplus soared, its economic power was reinforced and its international influence consolidated. Japan's share of world GNP rose to 11.9% in 1986, and, with external net assets of US$ 18.04 billion, it became the largest creditor country in the world. Japan's consumer product technology and applications for pollution prevention and energy saving became world-class. International competition consequently intensified and relations with Europe and the USA entered a difficult phase.

Economic friction between Japan and the USA increased, and 'Japan bashing' reached new heights when the country was criticized for being 'a free-rider on the back of basic science'. Such criticism was based on the assumption that Japan owed its remarkable economic development to technology built on the scientific knowledge accumulated and made freely available by advanced countries. The message was clear: having profited from existing knowledge, Japan was expected, in turn, to take on the role of creator of knowledge. This 'linear model' was obviously exposed to counter-arguments, but industry itself then took up the model, insisting on the necessity of domestically developed technologies as a means of alleviating trade-based controversy. This proved to be a turning point for Japan's role in world development.

Acknowledging the need to contribute to the world's intellectual stock of basic research, Japan began strengthening its own, and debate intensified on how to foster national creativity. Internationalization – both of the Japanese economy and its S&T – emerged as an important issue. The adoption of the slogan 'internal internationalization' effectively broke with a form of internationalization that had, up until then, been mainly external, with the country sending material, personnel and money overseas. In the future, this would have to be reversed. The key to achieving such a reverse flow was to create a system that would metamorphose such structures as the domestic demand-driven economy, the pattern of scientific mobility that sent Japanese scientists to world centres of excellence but received few in return and the very limited participation of Japan in the creation and management of international programmes. In order for the country to become a centre of excellence itself and attract scientists from different parts of the world, it was essential to improve the conditions of basic R&D in Japan by reforming the research environment, including funds, human resources, facilities and support systems. The CST recommended three courses of action for national policy:

- promotion of creative S&T;
- development of S&T in harmony with society;
- fostering of capabilities to cope with growing internationalization.

The CST also identified three areas of utmost priority for the future development of S&T: new materials, microelectronics and biotechnology. Rather than focusing on socially oriented, problem-solving science as was encouraged by the pollution and energy problems of the previous decade, R&D in the 1980s would attempt to sow the seeds of frontier-breaking fields.

One of numerous measures to promote basic research, the Exploratory Research for Advanced Technology (ERATO) programme, was established in 1981. It presented a new way of organizing a national programme: generous funds were granted to competent and innovative research directors, who were entitled to use the funding as they saw fit and enjoyed a certain freedom in organizing the programme's team of Japanese and foreign researchers. ERATO contributed to the development of research competencies from different sectors, thereby stimulating mobility. In a similar vein, the Frontier Research programme implemented by the Institute of Physical and Chemical Research (RIKEN) in 1989 provided an opportunity for capable young researchers to conduct 'research of their own choosing' with great freedom. The Human Frontier Science Program (HFSP) – whose purpose is to foster basic research on the sophisticated and complex mechanisms of living organisms – was proposed by Japan at the Venice Economic Summit in 1987 as an international scientific cooperation programme, with the objective of increasing the international public assets of basic research and making the research results available to all humankind. HFSP was initiated and financed by Japan but has been organized internationally: its office – the International HFSP Organization – was established in Strasbourg, France, in 1989.

The 1980s also saw advanced research develop through deregulation. In 1986, the Facilitating Governmental Research Exchange Law was passed to remove obstacles to smooth interaction among fields and sectors. Closer cooperation between different scientific fields and among private, academic and government sectors was thus encouraged.

An assessment of the national education system concluded that it was no longer apt to cultivate creativity and individuality. Although it was recognized that early education had the potential to greatly develop creativity, identifying a workable way of achieving this proved more difficult, and the desire for reform was not translated into concrete action.

Expectations of S&T: a more fulfilling life (1990–2003)

The fall of the Berlin Wall and end of the Cold War in 1989 accelerated the construction of a new world order, although the Gulf War in 1990–91 and the terrorist attacks on symbolic US buildings on 11 September 2001 have demonstrated the difficulty of achieving world stability. North–South problems are worsening, aggravating disparities between developing and developed countries as the economic gap widens. Issues of environment, population, natural resources and energy have become global issues, and R&D has moved beyond the traditional framework of bilateral cooperation to complex, mutually dependent relationships between countries.

In only a few decades, Japan has succeeded in developing its economy to the point where the country now accounts for more than 14% of world GNP. The fact that S&T provides possibilities for solving many of the world's problems makes the Japanese feel their country should make a contribution in this area.

In the 1990s, however, Japan was faced with problems of its own, of an economic nature. Manufacturing industry, which had enjoyed a dominant position for decades, began encountering severe global competition. In pursuit of lower labour costs, industry moved its manufacturing offshore, leaving Japan 'hollowed out' – with an absence of industrial activity within the country. Total sales achieved by subsidiaries abroad surpassed total exports by Japan in 1996. Foreign investment in Japan reached a peak that same year, illustrating the development of 'borderless' entrepreneurial activities.

Japan's unemployment rate rose gradually, from 2.1% in 1990 to 5.1% in 2003, its highest level since 1953. The prolonged recession, restructuring of enterprises and overemployment over decades of economic expansion were behind the sharp rise in unemployment. Its worst effects are today being felt by the 15- to 24-year-old age group, 9.2% of whom were unemployed as of October 2003. A series of management fiascos at financial institutions has tainted their credibility in the minds of Japanese citizens. This erosion of confidence, coupled with an unstable employment situation, has had a negative effect on final demand in such areas as consumer spending and investment in production plants, equipment and housing.

The prolonged recession has led households and enterprises to tighten their purse strings. In 1998, the

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government formulated Comprehensive Economic Measures and Urgent Economic Measures in order to stimulate short-term demand. For the medium term, the Industrial Revival Plan was launched in 1999 in an attempt to increase supplier productivity.

In S&T, investment stagnated over two consecutive years (1993–94), with government investment in R&D (as a percentage of total GDP) in the early 1990s failing to rival that of Europe and the USA. In addition, the Japanese R&D system was revealed to be lacking in flexibility and competitiveness.

In recent years, numerous reforms have been implemented to remodel the national R&D system. These are described in the following section.

PRE- AND POST-BASIC LAW ON SCIENCE AND TECHNOLOGY (1995)

Reform I (1990–94)

Against the backdrop of recession brought about by an overvalued yen and 'technology friction' with Europe and the USA in the mid-1980s, Japan began internationalizing its S&T system. The establishment of R&D laboratories abroad by private firms and the increasing employment of foreign researchers in firms, universities and national institutions gave momentum to internationalization. Public policy reinforced this movement by creating fellowships for foreigners.

As for research activities, the goal was to shift from 'catching-up research' to 'original and innovative research'. In the late 1980s, policy documents stressed the promotion of creative research; in the 1990s, their stated objective became to reinforce basic research.

In *Recommendation Report No. 18*, which was entitled *Comprehensive Basic Science and Technology Policy for the New Century* (1992), the CST defined the objectives of S&T as being to:

- contribute to the international community and all of humankind;
- promote basic research.

The need to promote basic research was strongly expressed in the CST's ambitious proposal to double the government R&D budget and foster centres of excellence. The plan to create centres of excellence, which was put into practice in 1993, is expected to raise competence in basic research and improve research facilities and equipment, thereby ensuring that national research institutions merit recognition as centres of international activity. The new policy led the government to increase its R&D budget for 2000, but it also revealed the striking difference between the policy orientation of European and American research and that of Japan in the early 1990s.

In the 1980s, Japanese investment in industrial R&D greatly increased even as investment in universities substantially decreased owing to the financial difficulties encountered by the government, the stagnation of public investment and a reduced budget. By the end of the decade, the lack of research budget was being sorely felt, with the already obsolete and dilapidated state of research worsening and universities in a pitiful state. The universities thus welcomed the CST's 1992 policy recommendation to strengthen basic science, with its promise of a renewal of university facilities and equipment.

The collapse of the 'bubble economy' and the prolonged recession affected Japan's S&T policy. The government was obliged to increase investment, and, paradoxically, the renovation of universities was pushed forward as part of the investment in public utilities. In 1993, a large investment was made in R&D from a supplementary budget established as part of the measures to boost the economy.

Reform II (1995–present)

Under Reform I, a new research environment was constructed within the framework of measures taken to reverse the recession. At that stage, however, scientific research was not necessarily expected to contribute to economic development, as had been the case in some major Western countries. Rather, research facilities and equipment were renewed in Japan as part of public engineering works, in line with an overall orientation formulated by the CST.

The situation changed drastically in 1995. The supplementary budget voted that year included an 'economic frontier budget' to cope with a strong yen. This supplementary budget aimed to develop S&T and activities related to information technology (IT). In order to fully achieve the objective of restructuring economic systems and creating new industries, a policy was designed to support research activities in universities and public research institutes. What is important here is the policy objective to support research activity as a key to future industrial breakthrough technologies. Reform of universities and public institutions had evolved from representing a simple improvement in the research environment into being an important element of the nation's economic development.

The objective of S&T policy thus shifted from promotion of basic science to economic development, a substantial change in orientation. In some European countries and in the USA, S&T policy had been primarily oriented towards stimulating economic development as early as the late 1960s. Japanese S&T policy adopted this concept 30 years after the West.

In parallel, such funding organizations as the Japan Society for the Promotion of Science, the Japan Research and Development Corporation and the New Energy and Industrial Technology Development Organization established competitive R&D allocation systems. Any university or national research institution with the potential for yielding future industrial technologies may respond to the tender. The creation of an R&D allocation system based on tender has revolutionized the university funding system. A multi-funding system has in this way been introduced into the university infrastructure, where previously the only sources of funding were block grant and project funding from the Ministry of Education. Since the introduction of the new system, universities have been able to seek research funds from other ministries and agencies.

The supplementary budget drawn up in 1995 has thus modified conventional S&T policy. This new orientation was embodied in the Basic Law on Science and Technology (1995) and in the Basic Plan on Science and Technology (1996). Both of these are a reflection of the urgent needs of researchers at universities and public institutes for a better research environment. They also reflect the demands of industries in economic difficulty, which had turned to public research for impetus after the 'bubble economy' burst.

As stated in the Basic Law and Basic Plan, the country's expectations of S&T were that they would 'avoid the hollowing out of industry, prevent a decrease in social vitality and in the standard of living and create new industries'.

The government increased its R&D budget from 0.6% of GNP in 1995 to 1.0% five years later, corresponding to an investment of YEN 17 trillion between 1996 and 2000. Included in the budget was a provision for 10 000 postdoctoral students or assistants to researchers in their work, twice the number previously employed.

The Second Basic Plan on Science and Technology covering the period 2001–05 was drawn up in 2001 with less optimism for its success than its predecessor. Japan's deficit had more than doubled in the 1990s, climbing from 59.1% to 125.8% of GDP by 2000, so formulating a comprehensive, strategic S&T policy that ensured maximum efficiency had become an urgent concern of the state. The resultant budget was designed to focus on four determinant fields of science: life science, information technology, environment, nanotechnology and materials sciences. This was coupled with ongoing reforms of the existing S&T structure and an internationalization of Japanese S&T. The amount of 24 trillion yen was allocated to enhancing both basic research driven by scientific curiosity and applied research responsive to socio-economic needs.

The enactment of the Basic Law has proved to be a turning point in Japanese S&T policy. R&D has been reorganized and administrative reform has taken place in a climate of prolonged recession, modifying the S&T system as a result. Some of these changes will be described in the following section.

UNIVERSITY–INDUSTRY RELATIONSHIPS

Interaction between universities and industry was relatively unknown in Japan until 1990. In 1983 there were only 57 joint research projects being hosted by Japan's national universities, with a total of 50 participating firms. By the

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late 1980s, this number had risen sharply to 694 projects with 413 participating firms. This figure doubled to 1 442 projects involving 858 firms in 1995 and nearly tripled again over the following six years. In 2001, 4 190 projects were being conducted with 2151 participating firms. The government's 1987 decision to establish joint research centres in national universities in order to promote such collaboration was partly responsible for this exponential growth. The number of universities hosting these centres had risen to 61 in 2001, compared with only 18 in 1990.

The report entitled *Basic Guidelines for Activating Science and Technology Activities in the Regions*, formulated by the CST in 1995, evoked the importance of university–industry relationships at the regional level. A number of measures were taken to stimulate these relationships. Inspired by the Basic Law on Science and Technology, a law related to the employment of national researchers and university professors under contract was formulated in 1997. The flexibility this law adds to the system of employment is expected to stimulate the mobility of researchers among national institutions, universities and firms. Another law passed the same year relaxed the restriction on national university professors with regard to the holding of additional posts. A university professor is today entitled to supervise a private company's R&D department while maintaining his post at the university. The Law on Strengthening Industrial Technology Competence (2000) enables a public researcher or a national university professor to occupy a seat on the board of directors of a firm where the technology developed by the researcher will be put to practical use.

As for the transfer of technology, the Law on Promoting Technology Transfer from Universities (1998) encourages the transfer of research results from university laboratories to the private sector. As one means of attaining this objective, Technology Licensing Offices (TLOs) were established. By 2002, around 31 TLOs had been institutionalized. Between 2000 and 2002, these processed a total of 3 663 filed patents.

INNOVATION IN THE SMEs

R&D activities in small and medium-sized enterprises (SMEs) became intensive after the 1980s, by which time the SMEs established during the high-growth period of the Japanese economy had reached maturity. Stimulated by the emerging high-tech boom around 1980 and by the necessity to compete with the expanding newly industrialized economies (NIEs) in Asia, SMEs came under pressure to innovate and to produce high technologies. In the 1990s, SMEs became actively involved in innovation by collaborating with the research laboratories in Technopolises and universities. 'Incubators' were also created throughout the country in the 1990s, predominantly towards the end of the decade, and currently number 130.

The Law on Promotion of New Business Creation (1998) led to the setting up of a Japanese Small Business Innovation Research (SBIR) programme, modelled after the SBIR USA.

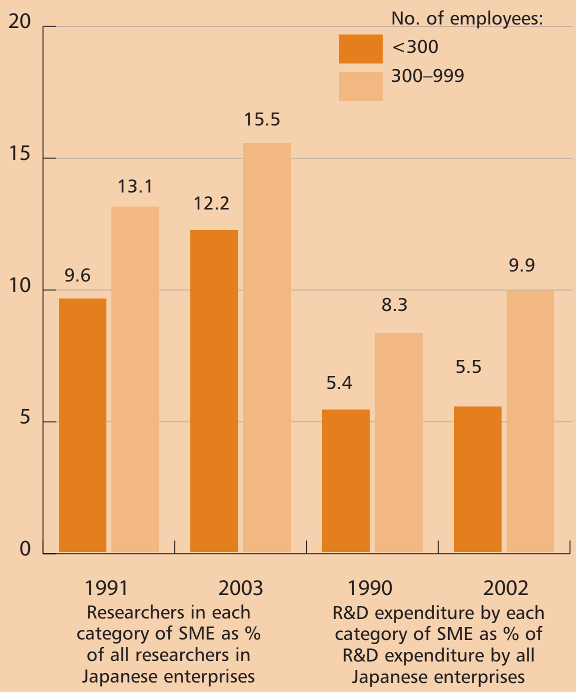
SBIR is a scheme to create new industry and employment, to which high-tech SMEs can greatly contribute. SMEs are now eligible for the contractual projects, subsidies and fiscal incentives the government previously made available mostly to large firms. In 2002, six ministries created 56 special grants-in-aid that will invest YEN 25 billion in SMEs. These are the Ministry of Education, Culture, Sports, Science and Technology (MEXT); the Ministry of the Economy, Trade and Industry (METI); the Ministry of Health, Welfare and Labour; the Ministry of Public Management, Home Affairs, Posts and Telecommunications; the Ministry of Agriculture, Forestry and Fisheries; and, lastly, the Ministry of the Environment. According to the *Report on the Survey of Research and Development*, R&D activities in the SMEs increased in scope during the 1990s (Figure 1).

REGIONALIZATION

The high-growth period of the Japanese economy also led to the development of the regions, since industry built new plants throughout the country. In the 1980s, against the background of the expanding high-tech economy, the spread of high-tech industries, universities and R&D facilities further fostered regionalization.

In the early 1980s, the construction of 'technopolises' was planned as a national strategy. A technopolis is an attempt to concentrate high-tech industry in regions where industries, universities and inhabitants will cooperate to develop l

Figure 1
RESEARCHERS AND R&D EXPENDITURE IN JAPANESE SMEs, 1990/91 AND 2002/03



Note: Researchers are head counts.

Source: Statistics Bureau (2000 and 2004) *Report on the Survey of Research and Development* 1999 and 2003.

leading-edge technologies. Since the mid-1980s, 26 regions have been designated as technopolises. R&D facilities have been constructed in these regions and various core industries established.

Initially, the principal objective of a technopolis was to attract R&D facilities of big enterprises or universities into a region, and a number of measures were taken to promote the technopolis programme. As the technological capabilities of local industries developed, regional R&D networks emerged. In 1998, the law mandating the construction of technopolises was repealed, and these high-tech hubs have now established themselves as the basis for regional development through innovation.

In 1995, in response to an inquiry by the prime minister, the CST submitted *Basic Guidelines for Activating Science and Technology Activities in the Regions*. As a result of the Basic Law that followed, local government is today able to formulate and execute policy to promote regional R&D. The regions are thus becoming important proponents of collaborative research projects involving university, industry and government, as well as of R&D conducted by SMEs.

The new policy formulated in the Second Basic Plan on Science and Technology encourages the creation of 'regional clusters' that would develop R&D resources and potential through the construction of networks and collaborative research between regional universities and industry. Regional clusters include 'knowledge clusters' promoted by MEXT. Whereas the core components of these knowledge clusters consist primarily of universities and public research institutions, the aim of 'industrial clusters' promoted by METI is to create a vast network of human resources in support of technological development, as well as an optimal environment for entrepreneurship. The system has been designed to foster interaction between the original technological 'seed' of the public research organization and the business needs of regional companies, leading eventually to technological innovation and new industries. In 2003, YEN 71.3 billion was allocated to these regional clusters. Currently, ten knowledge clusters in 12 regions and 19 industrial cluster projects are in progress. The 19 projects bring together some 3 800 SMEs and 200 universities.

ADMINISTRATIVE REFORM

In 1997, the Administrative Reform Council decided to restructure the Japanese public administration. The council's final report gave priority to reform of the public administrative bodies and structures related to S&T. Some of the major restructuring projects anticipated were:

- the founding of a Council for Science and Technology Policy (CSTP);
- the fusion of the Ministry of Education, Science, Sport and Culture (Monbusho) with the STA;
- a change in status for national research laboratories and universities.

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Founding of the CSTP

The CST was reorganized into the CSTP in January 2001. With this change, the CST, which had dealt only with the natural sciences, saw its sphere of activity extended to cover all the sciences, including social sciences and humanities. The objective of the reform was to enable the new CSTP to establish comprehensive and strategic S&T policy. The CSTP, which is independent of other ministries, examines the basic orientation of the S&T budget and the allocation of human resources, besides evaluating major national programmes. The CSTP acts as a control tower directing the multifold processes of S&T policy implementation. It is a powerful organization, responsible for deciding the country's overall S&T policy.

Fusion of the Ministry of Education with the STA

Monbusho and the STA merged to form MEXT in January 2001. The two main responsibilities of this ministry are to secure creative and talented human resources and to promote science, technology and culture in an integrated manner. MEXT is charged with drawing up a detailed plan for the execution of the strategic policy formulated by the CSTP for the areas under the Ministry's supervision. Institutionally, MEXT is to assume the role of reinforcing the administration of S&T policy. It was also to act as interministerial coordinator, but this role is essentially now being transferred to the CSTP.

Other ministries were restructured at the same time as part of the government's plan to reduce the number of ministries by nearly half, from 22 to 12, in 2001.

National laboratory reform

In April 2001, national research institutes changed their status to independent administrative institutions (IAIs). Although control will be exercised by the appropriate government body, this reform should facilitate interaction between ministries and agencies and provides for flexibility in R&D, which was problematic under the former system. Pooling resources in a single organization makes for a greater concentration of funding, equipment and researchers.

National university reform

The country's 99 national universities were reorganized in April 2004. Their legal status changed to that of IAI. Three major reforms were implemented to improve their performance. First, decision-making power was transferred from the faculty to the rector of each university. Rectors will be held accountable for the way their institutions are run, obliging them to possess solid managerial skills. Second, an external evaluation system was introduced. Thirdly, the legal status of employees changed from that of civil servant to non-civil servant. With these reforms, universities have gained greater flexibility and autonomy in managing their R&D activities in terms of budget and human resources. They have become key players in industrial development. These are revolutionary reforms in the history of the Japanese university, reforms that are still under way and building momentum.

METI, in a 2001 document entitled *Targeted Plan for the Creation of New Markets and Employment*, fixed itself the ambitious target of creating 1 000 venture companies originating from universities within three years. As it is expected that university research and spin-offs from national research institutions will generate new industries and foster employment via creation of new concepts and breakthroughs, the government considers it vital to stimulate entrepreneurship among researchers and students by promoting venture start-up companies originating in universities. This will entail securing start-up capital and venture development systems, like campus incubators, to nurture an environment conducive to creativity. In parallel, human resources will need to be trained to devise business ventures responsive to social expectations and economic realities. The number of venture companies originating in Japanese universities has been increasing steadily. While these totalled 144 in 1998, the number climbed to 531 in 2002. Changing the status of national universities to IAIs will only deepen this trend.

Moreover, a new programme, Centre of Excellence for the 21st Century, was launched in 2002. Its objective is to concentrate large sums of research funding in a handful of universities. The sum of YEN 100–500 million will be granted for a five-year period. The funding is allocated to 'universities' rather than to 'projects'. This competitive programme compels universities to prepare a solid proposal, which in turn will contribute to an assessment of their activity and strategic R&D policy design.

All in all, institutions in higher education are currently facing both systemic change and a serious survival dilemma. With the population of 18-year-olds expected to plummet from the current 1.51 million to 1.20 million in 2009, there will be a surplus of national and private universities and junior colleges, which currently number 1 220. The ensuing severe competition for students will make it crucial for each institution to design a clear vision of the future that comprises its own unique policy and strategy. At the same time, the reform of the higher-education sector will impose management standards in the research community and make universities increasingly accountable.

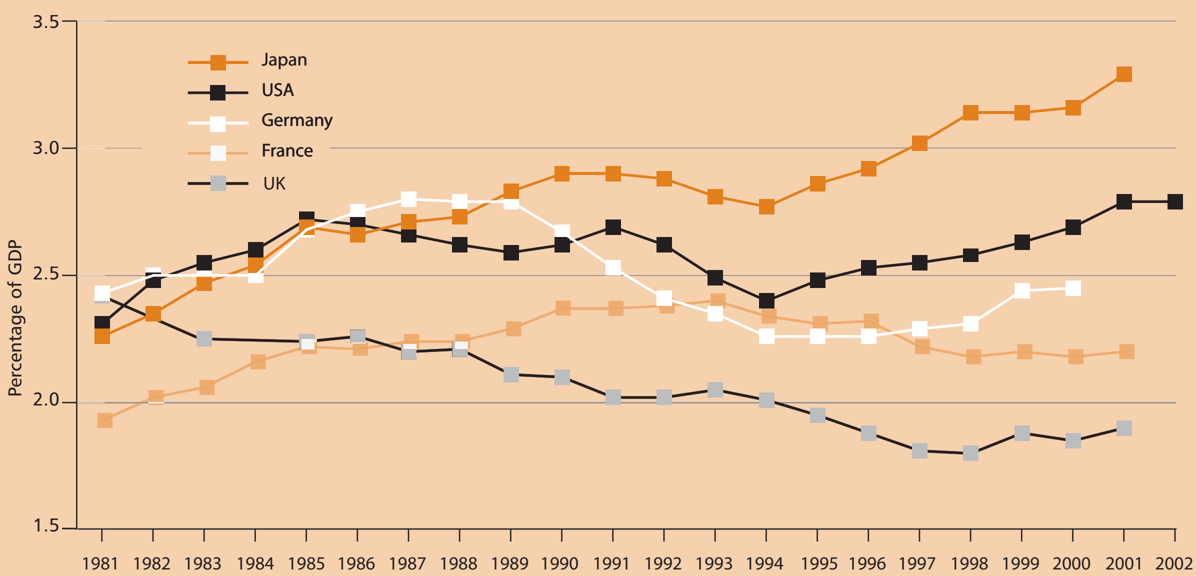
STATE OF THE ART OF JAPANESE S&T

R&D expenditure

Figure 2 indicates a considerable climb in Japan's R&D expenditure growth rate between 1981 and 2002. The CST report on long-term S&T policy, submitted to the prime minister in 1984, stated that both the government and private sector needed to make a greater effort to increase R&D investment to 3.0% of national income in the immediate future, and to 3.5% as a long-term goal, even though Japan's level of investment in R&D at the time was on a par with that of European and North American countries. By 1990, Japan had almost attained the goal of 3.0% and had overtaken its closest rivals in the process. Private-sector investment in R&D has contributed greatly to R&D activities and even tripled between 1981 and 2001.

Over the first half of the 1990s, all countries showed a decline in gross domestic expenditure on R&D (GERD) as a percentage of GDP, but Japan and the USA had recovered

Figure 2
GERD/GDP RATIO IN JAPAN, 1981–2002
Other countries are given for comparison



Source: NISTEP (2004) *Science and Technology Indicators.*

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by 1995. From 1989 on, Japan registered the highest ratio of any of the five countries shown in Figure 2.

In spite of stagnating Japanese GDP and a drop in R&D investment by industry, the R&D share of GDP continued to grow from 1995 onwards; by 2001 it had climbed to 3.29%, the best level Japan has ever achieved.

The share of R&D expenditure in terms of funding and performance by sector is shown in Table 1. The percentage share of R&D expenditure contributed by government may differ from country to country owing to differences in such elements as defence-related research, tax structure and private-sector activities. It can be seen from Table 1 that the government share of R&D funding in Japan is the lowest of the five countries studied, a mere 21.0%. Industrial participation in R&D funding is sizeable for all five countries, but with industry accounting for nearly 70% in Japan, the USA and Germany, these three stand out.

Both in terms of performance and funding, industry accounts for around two-thirds of the total R&D effort in all five selected countries, making industry the driving force behind R&D. The government sector performs the greatest share of R&D in France (18.1%), followed by Germany (13.4%) and the USA (11.0%). While in terms of funding and performance, government participation is lowest in Japan, the contribution of Japanese universities and colleges is the highest of the five in terms of funding, and the second highest (after the UK) in terms of performance.

Trends in the number of researchers

In 2002, Japan accounted for 756 336 researchers. This trend is part of a steady progression over the past 20 years that has seen numbers nearly double between 1981 and 2002 (Figure 3). During this period, numbers of female researchers increased at a faster rate than that of their male counterparts. Female researchers accounted for 11.2% (88 674) of all Japanese researchers in 2003, up from 7.1% (38 000) in 1989 (Figure 4). These numbers are mainly concentrated in the university sector and in social science and humanities.

Table 1
BREAKDOWN OF R&D IN JAPAN AND SELECTED COUNTRIES
By source of funds and sector of performance (%)

Source of funds

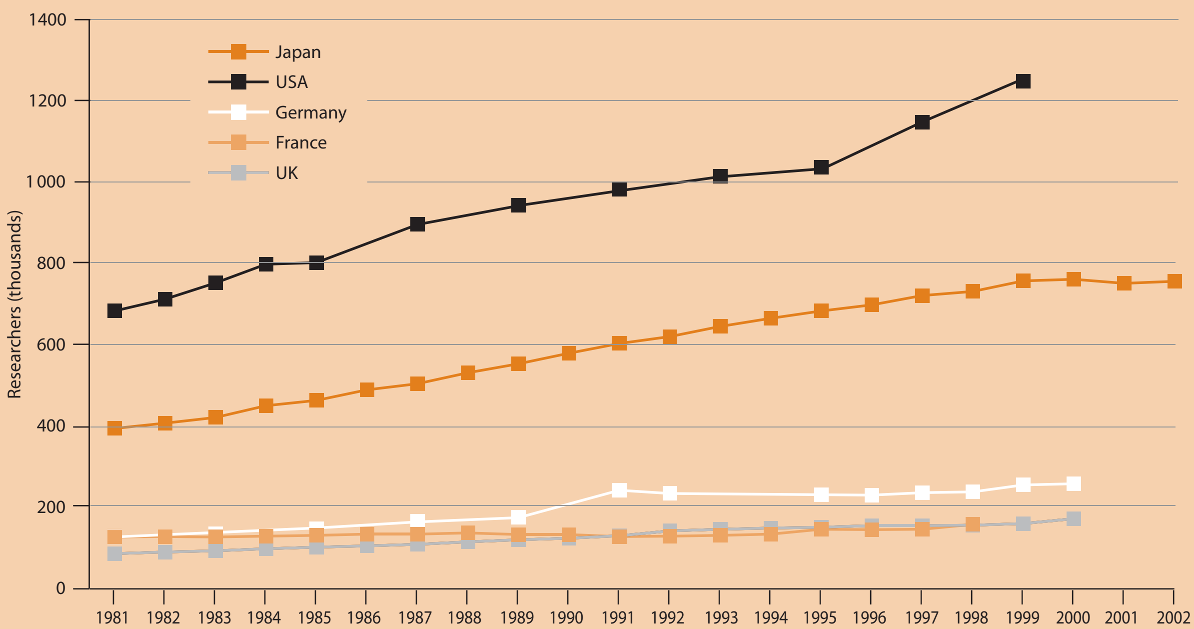
	Government	Universities and colleges	Industry	Private or non-profit research institutions	Abroad
Japan (2001)	**21.0**	**9.0**	**68.9**	**0.7**	**0.4**
USA (2002)	28.6	2.6	66.3	2.5	–
Germany (2000)	32.0	–	65.5	0.4	2.1
UK (2001)	30.2	0.9	46.2	4.7	18.0
France (1999)	36.9	1.0	54.1	0.9	7.0

Sector of performance

	Government	Universities and colleges	Industry	Private or non-profit research institutions	Abroad
Japan (2001)	**9.0**	**19.6**	**69.3**	**2.2**	–
USA (2002)	11.0	12.9	72.3	3.9	–
Germany (2000)	13.4	16.1	70.5	–	–
UK (2001)	9.7	21.4	67.4	1.4	–
France (1999)	18.1	17.2	63.2	1.5	–

Source: Statistics Bureau, *Report on the Survey of Research and Development*; MEXT (2003b) *White Paper on Science and Technology 2003*; NSF, *National Patterns of R&D Resources*; Faktenbericht Forschung; Bundesbericht Forschung; OECD, *Basic Science and Technology Statistics*; Office of National Statistics, *Gross Domestic Expenditure on Research and Development*.

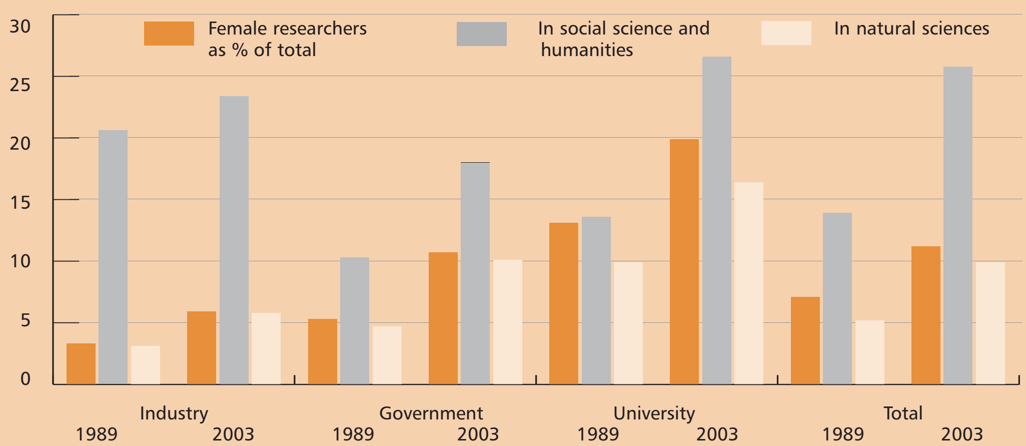
Figure 3
NUMBERS OF RESEARCHERS IN JAPAN, 1981–2002
Other countries are given for comparison



Note: Japanese researchers are head count figures; figures for the other countries are full-time equivalent.

Source: NISTEP (2004) *Science and Technology Indicators.*

Figure 4
FEMALE RESEARCHERS IN JAPAN, 1989 AND 2003
By sector



Source: Statistics Bureau (1989, 2003) *Report on the Survey of Research and Development*.

THE STATE OF SCIENCE IN THE WORLD

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Today, Japan has the largest number of researchers per 10 000 of both population and labour force among the five countries under comparison (Table 2). Some 56.9% work in industry, 37.1% in universities and colleges, 4.5% in public research institutes and 1.5% in private research institutes.

In spite of the growing number of researchers, Japan will at some point be facing a serious shortage. In order to improve basic research activities, it is essential to secure qualified researchers. However, since it is anticipated that the 18-year-old population will be smaller in future (estimates show that the number of young people is likely to decline more drastically in Japan than in the USA and Europe), numbers of high-school graduates going on to enrol in S&T courses in higher education are also sure to decrease.

To attract people to S&T fields, better working conditions and research environments are essential. To produce high-quality researchers, government measures include job flexibility in assignments, increased mobility among sectors and the cultivation of excellent research environments. Measures are also being taken to provide women, senior citizens and foreigners with job possibilities and better working conditions. It will also be important to improve the image of S&T to keep young people interested in S&T-related studies. The enthusiasm engendered by the pleasure of scientific discovery is difficult to convey from one generation to another. Designing a curriculum capable of stimulating such enthusiasm is one of the pressing challenges faced by the education system in Japan.

Scientific publication performance

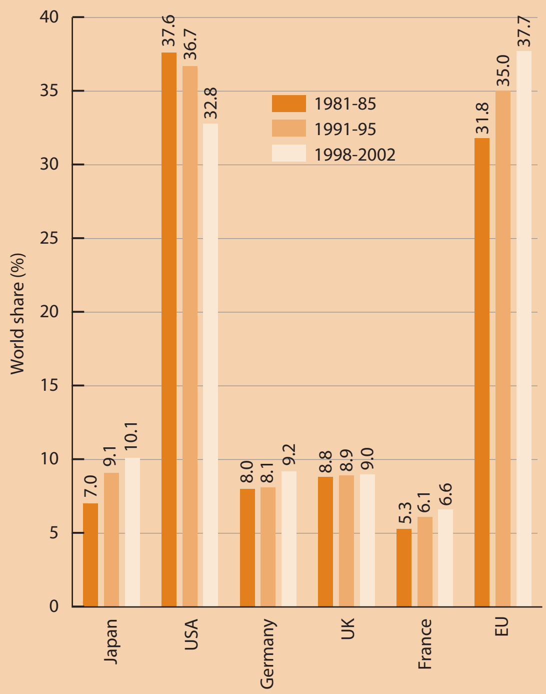
Publications provide a simple and approximate measurement of the quantity and impact of work produced by a nation. The number of world publications recorded in the major scientific journals and retrieved from the database known as the Science Citation Index increased by 160% in the period between 1981–85 and 1998–2002. The USA is today the single most prolific producer of scientific articles, contributing 32.8% of the world share, followed by Japan,

Table 2
JAPANESE RESEARCHERS RELATIVE TO POPULATION AND LABOUR FORCE, 1998–2002
Other countries are given for comparison

	Per 10 000 population	Per 10 000 labour force
Japan (2002)	**53.1**	**100.8**
USA (2000)	45.2	89.6
Germany (2000)	31.4	64.3
UK (2000)	26.6	54.6
France (1998)	28.4	64.8

Source: Statistics Bureau, *Report on the Survey of Research and Development* (annual publication); Statistics Bureau, *Population Estimated Source*; MEXT (2003b) *White Paper on Science and Technology 2003*; OECD, *Main Science and Technology Indicators*.

Figure 5
SCIENTIFIC PUBLICATIONS IN JAPAN AS A WORLD SHARE, 1981–2002
Other countries are given for comparison (%)



Source: NISTEP (2004) *Science and Technology Indicators*, based on the data in *National Science Indicators 1981–2002* (Deluxe version) compiled by the Institute for Scientific Information.

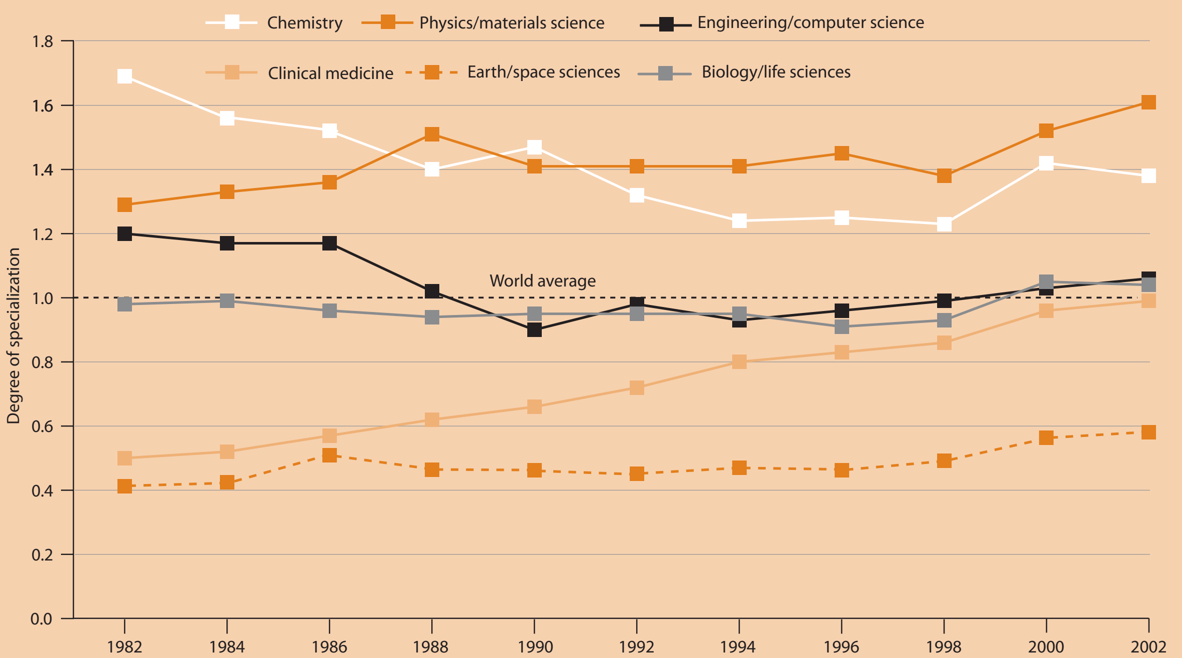
Germany, the UK and France (Figure 5). (Taken together, the countries of the European Union exceed the US share of world publications on the basis of articles in mainstream journals.) All of the countries listed in Figure 5, with the exception of the USA, increased their world share over the period under study.

Japan showed the fastest growth rate (61.1%), moving from fourth-biggest producer of scientific articles in 1981 to the second biggest in 1992. However, while the Japanese share did increase, the number of papers produced per researcher amounted to only 0.09 in 1998, the smallest figure among the five major countries. The other countries produced 0.39 (UK), 0.27 (France) and 0.22 (USA and Germany) papers per researcher, or 2.4 to 4.3 times Japan's rate.

A profile indicator is used to observe the specialization of Japanese science in comparison with the world pattern. A Japanese publication in a given field calculated as a percentage of total Japanese publications is divided by the number of world publications in that field as a percentage of total world publications. If the index score is 1, the country's propensity in that field is approximately the same as average world propensity in the same field. If the indicator value is more than 1, the country is oriented more towards that field than the world average. In this way, the core competencies of a nation and its orientation over time can be measured, thus bringing into view the scientific profile of the country (Figure 6).

Japan's science is strongly oriented towards chemistry and physics/materials science. However, the country's inclination towards chemistry has fluctuated somewhat in recent years, even if in 2002 it still conducted more research in chemistry than the world average (1.38). By contrast, in physics/materials science, Japan showed a sustained strong

Figure 6
PROFILE OF JAPANESE SCIENCE AND ENGINEERING, 1982–2002



Source: NISTEP (2004) *Science and Technology Indicators*, based on the data in *National Science Indicators 1981–2002* (Deluxe version) compiled by the Institute for Scientific Information.

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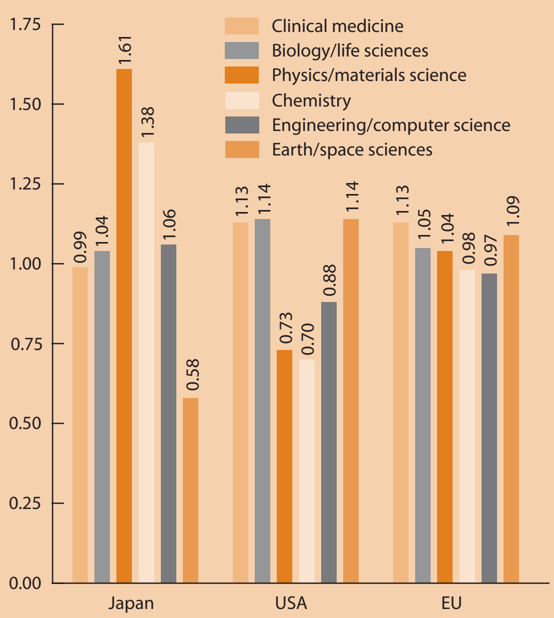
orientation, the profile index remaining around 1.4 to 1.5 throughout the period measured (1982–2002). Despite efforts to improve performance in clinical medicine, Japan had not yet reached the world average by 2002. Earth/space sciences have in the past been, and remain today, Japan's weakest field.

Figure 7 compares Japan's scientific profile with that of the USA and the EU. The USA is Japan's opposite in that it shows a strong leaning towards research in life sciences and Earth/space sciences, according a low priority to physics/materials science and chemistry. For its part, the EU maintains a balance in all six scientific fields.

Citation performance

Citation provides a rough measure of the impact a country's published articles have on the worldwide scientific community. About half of world citations are of US publications (Figure 8). Even if that nation's share slipped slightly between 1981 and 2002, the impact of US science is unquestionable. The UK is cited most after the USA, followed by Germany, Japan and France. The citations share of Japanese articles increased from 6% during 1981–85 to 8.8% during 1998–2002 (Figure 8), and its publications share was rated highest, at 10.1%, over the latter period (Figure 5). The ratio between these two shares amounts to 0.87:1, indicating that the number of citations for Japan was low relative to the volume of publications produced. The impact of Japanese publications is less than might be expected, given Japan's productivity. Citations per paper can also be compared internationally by using the Relative Citation Index (RCI), which divides the number of citations per paper of a given country by the number of citations per paper in the world. During the period between 1998 and 2002, Japan's RCI indicated 0.88, compared with the USA's 1.48, the UK's 1.27, Germany's 1.14 and France's 1.07. Japan's RCI is lower than the world average (1.00) and is the lowest among the five countries studied. Its RCI figure has not changed much since 1981 (0.86), a trend that contrasts with the steady rise for the other four countries over the same period.

Figure 7
SCIENTIFIC PROFILES OF JAPAN, THE USA AND THE EU, 2002



Source: NISTEP (2004) *Science and Technology Indicators*, based on the data in *National Science Indicators 1981–2002* (Deluxe version) compiled by the Institute for Scientific Information.

Patents

Patents are a rough measure of the innovation and technological capacity of a nation. Inventors worldwide apply for patents at the US Patent and Trademark Office (USPTO). Japan accounted for 20.9% of all patents granted by the USPTO in 2002, ahead of Germany (6.8%), France (2.4%) and the UK (2.3%) (Figure 9). Whereas the national share remained relatively stable for other countries, Japan's share of US-granted patents nearly doubled between 1980 and 2002. According to the USPTO, of the top ten institutions granted US patents between 1969 and 1997, three were Japanese firms: Hitachi, Canon and Toshiba. In 1997, of the ten largest institutions to be granted US patents, seven were Japanese firms. Some 6 895 patents were granted to these seven firms that year. According to an analysis by the National Science Foundation (USA), the largest numbers of US patents were granted to

Japan in information-memory devices, copy, video and electronic components and optics.

The Federation of Economic Organizations of Japan conducted a survey on the competitiveness of the major technologies and products of a firm through auto-evaluation. According to this survey, household electrical appliances, non-ferrous metal, semiconductor devices and food technology are the more promising technologies or products, and firms active in these areas assume they will maintain or develop their competitiveness in the future. By contrast, in paper and pulp, software, engineering and medicines, competitiveness is weak and may continue to stagnate in the future. Based on these findings, the Federation issued a proposal entitled *Establishment of Strategic Industrial Technology Policy* in 1998, underlining the necessity of defining a strategic plan for new industrial technologies.

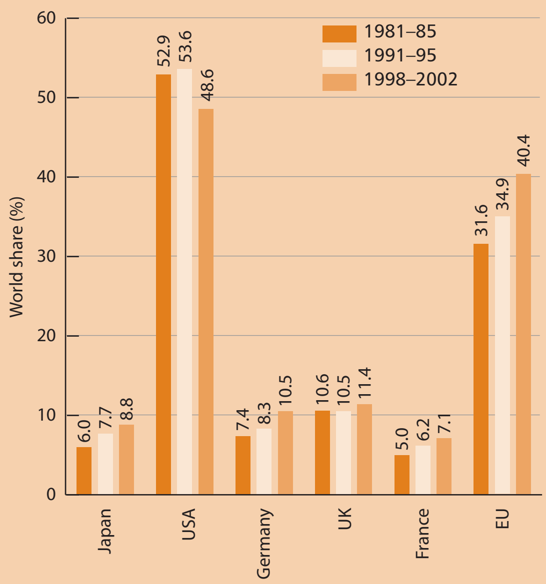
In order to promote R&D in private firms, tax incentives for R&D investment have been implemented, as well as various measures to support R&D in SMEs and new ventures.

OUTLOOK FOR THE FUTURE

As of 2000, Japanese life expectancy had increased to the point where the average Japanese citizen could expect to live a longer and healthier life than citizens of 191 other countries, according to the World Health Organization (WHO, 2000). The WHO has calculated that, by 2020, those over the age of 60 will represent 31% of the total Japanese population. This high percentage will qualify Japan as the most aged country in the world, ahead of Italy, Greece and Switzerland.

This problem of an ageing population is compounded by the fact that Japan also has the third-lowest fertility rate

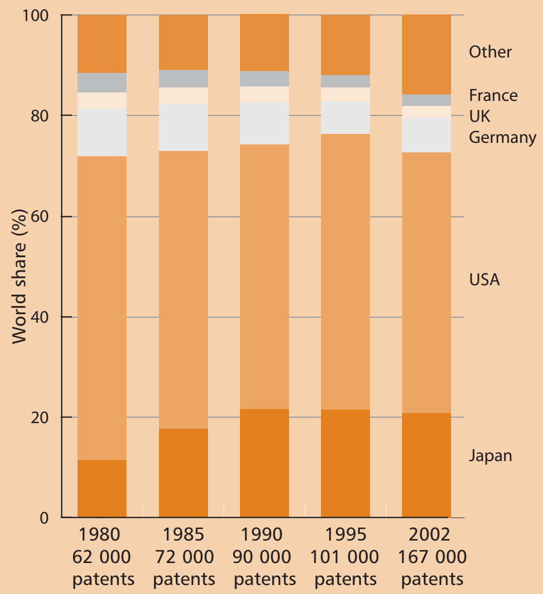
Figure 8
CITATIONS OF JAPANESE PAPERS AS A WORLD SHARE, 1981–2002
Other countries and groupings are given for comparison (%)



Note: Citations are based on five-year windows.

Source: NISTEP (2004) *Science and Technology Indicators*, based on the data in *National Science Indicators 1981–2002* (Deluxe version) compiled by the Institute for Scientific Information.

Figure 9
US-GRANTED PATENTS BY NATIONALITY OF INVENTOR, 1980–2002



Source: NISTEP (2004) *Science and Technology Indicators*, based on the data in *TP2-International Technology Indicators Database for Years 1980–2002* compiled by CHI Research Inc.

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in the world: 1.32 children per woman in 2002, the lowest since 1920. The decrease in population will seriously affect the labour force (those aged 15 to 65), which is expected to drop from 86 million in 2000 to only 55 million in 2050. With the rising number of elderly, not only will national social security payments increase, but so will the burden on the present generation, who will be called upon to assume a greater share of these payments. For the present generation, caring for their elders will be another constraint. Coping with the changing demographic pattern is a pressing national task, one that will involve constructing an S&T system capable of providing solutions for a new way of life. The shrinking labour force cannot be compensated for by an increase in capital investment, but only by a surge in productivity. In order to offset the 36% reduction in the labour force between now and 2050, productivity will need to be multiplied by 1.6, a goal that will only be attainable through technological innovation. Yielding a higher level of national productivity will require the development of revolutionary technologies bearing no resemblance to those produced by conventional concepts, methods or processes.

In order to secure the necessary labour force, its full potential must be exploited by creating a work environment attractive to women and adapted both to the disabled and to seniors. S&T will be needed to create such an environment. For example, information technologies currently under development will free workers from fixed working hours and workplaces, and will provide other forms of flexibility. S&T will be needed to reinforce the physical strength and judgement of the elderly, who will be called upon to work in production, construction or related industries. The aged and disabled will need to be able to go about freely and participate in social and economic activities. To make this possible, cities will need to be planned taking into account safety issues and eliminating obstacles such as stairs, steps and footbridges. Ticket dispensers, for example, will have to be user friendly. There is a growing demand for technologies that create a friendlier environment for those with physical disabilities – for example, a walking stick with an integrated sensor that would signal traffic lights to remain red until the person holding the cane has crossed.

Greater numbers of immigrants could also offset the effects of a declining population. The number of registered foreign residents in Japan has more than doubled in the past 30 years, from 710 000, or 0.58% of the total population, in 1970, to 1.85 million, or 1.45%, in 2002. That said, Japan still has one of the smallest foreign-born populations in the developed world. It is estimated that the mobility of foreigners will increasingly affect the total population of Japan in coming years, implying an important potential labour force. The number of foreigners coming to Japan for research purposes has been increasing at national universities and research institutions. In 2001, there were 30 067 individuals (including short stays) entering the country with this objective. This, however, contrasts starkly with the 103 204 individuals who left Japan that year with the declared objective of 'scientific research and survey'. International mobility may be developing steadily, but, in the case of Japan, it has started from a fairly low level.

Such a trend can also be seen in the level of participation in international collaborative projects. The number of papers co-authored by researchers from different countries has been increasing in Japan, but the ratio of international joint papers to total national publications is lower in Japan than in other developed countries. According to the National Institute for Science and Technology Policy, 20% of all scientific publications in Japan in 2001 were the result of international collaboration, a substantial increase on 1981, when it was only 5%. However, compared with the major Western countries, for which the average figure in 2001 was around 37%, Japan remains a relatively modest player in international scientific activities.

A survey of public attitudes towards S&T published in the *White Paper on Science and Technology* in 1993 and again in 2000 revealed that, while people acknowledge that S&T may foster a more fulfilling life, they strongly feel that it should be used to combat negative aspects of development, such as global environmental problems, the BSE (or 'mad cow') crisis in the 1990s and the ethical problems provoked by genome research. As S&T has permeated modern society, various questions have arisen. It is important that S&T form part of people's lives, but the insecurity and fear that they inspire will need to be eliminated if confidence is to be restored. Raising the social awareness and responsibility of scientists and engineers, establishing clear ethical guidelines, implementing risk and safety management, formulating adequate scientific advice and regulatory policy for risk reduction, and keeping the public informed about S&T activities are all steps in the right direction.

Current globalization and the revolution in information technologies will continue to broaden the activities of enterprises and inevitably lead to increasingly severe competition. The urgency of environmental and socio-economic problems calls for a new system of innovation involving all stakeholders in science. Japan is conscious of its responsibility in building a modern and responsible society capable of adapting to the changes on the horizon. It knows that the system, which dates from the Second World War, is dilapidated and needs to be disassembled so that some parts can be eliminated and others either reformed or recombined. It understands that innovation plays an important role in socio-economic development, and that the demands of society must be clearly articulated so that human, capital and other resources can be allocated efficiently. Japan has undertaken fundamental structural reform to create a more flexible, open and competitive S&T system that takes a strategic and proactive approach to S&T policy.

Since the late 1990s, Japan has implemented various administrative reforms and restructured its S&T system. Guided by the Second Basic Plan on Science and Technology, Japan has undergone a paradigm shift from 'science, technology and society' to 'science and technology for society'.

An S&T system for the new century is still under construction. S&T can offer solutions for revitalizing industry and stimulating competition, constructing a dynamic society that accommodates an ageing population, resolving global-scale issues, improving health and ensuring public safety. Japan's ongoing reforms are a challenge as well as an opportunity to reconfigure the nation's S&T system.

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East and South-East Asia

YU WING-YIN

The East and South-East Asian region is vast and diverse. Rather than attempt a survey of individual countries, this chapter will discuss salient features of the paths taken by countries to develop science and technology (S&T) and highlight issues of common concern. Additional sections give more details about China and compare Hong Kong and Singapore.

PLANNING

All countries in the region have in place institutional mechanisms for S&T policy. In the national planning process, there is generally sufficient recognition of the importance of S&T and planning for S&T in socio-economic objectives. Most countries have explicit plans for S&T development. For the few where S&T objectives may be implicit, there is also definite planning.

A number of countries have earmarked budgets for S&T, whereas others have a development budget alongside the recurrent budget in which funding is allocated for long-term S&T activities. Thus, to a large extent, S&T no longer suffers from incremental budgeting, which has posed a constraint in the past when there was less understanding of the nature and importance of S&T. That is not to say that there are no financial problems: S&T development still suffers from a lack of funding in most countries but it is not a case of governments not being willing to spend on S&T; rather, it is a case of competing priorities when funds are limited.

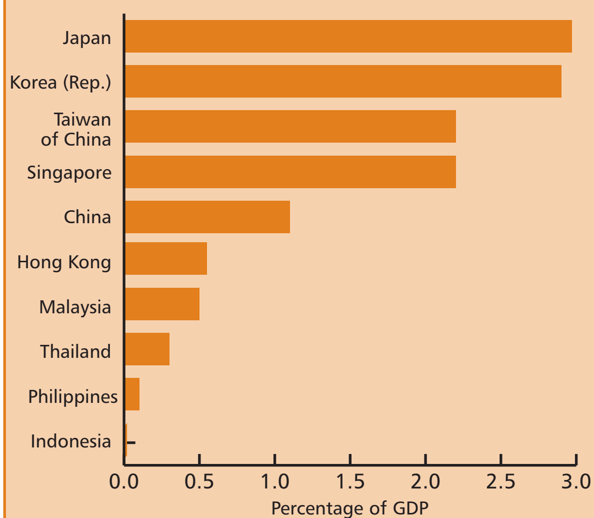
The Republic of Korea, Taiwan of China and Singapore have all broken the 2% barrier in terms of percentage of gross domestic product (GDP) spent on research and development (R&D), while China is on track to reach its target of 1.5%. Meanwhile, Malaysia and Thailand are struggling to keep up their domestic expenditure on R&D (GERD) as a percentage of GDP; their technological capabilities have been catching up despite the apparent lack of improvement in their scores (Figure 1).

TARGETING

In planning for the development of S&T, almost all countries have taken a targeting approach. They have targeted four universal fields: information technology, micro-electronics, new materials and biotechnology. These are so-called universal fields for targeting because all four are generally regarded as being important in the twenty-first century and have been targeted not so much because countries feel they have a strategic advantage in one or more areas but because they realize that they must invest in R&D in these fields in order to acquire the technological capability to make use of advances in the same fields developed in other countries. In addition to the four universal fields, countries in the sub-region also target fields specific to their own strategic advantage, for example, rubber in Malaysia, pharmaceuticals in Thailand and fruits in the Philippines.

In the early stages of development, when the strategies were export-promotion and import-substitution, essentially an industry approach was taken. Later, when technological innovation and development of indigenous capability were emphasized, a technology approach was taken. Countries in the region by and large take a mixture of industry and technology approaches to economic development.

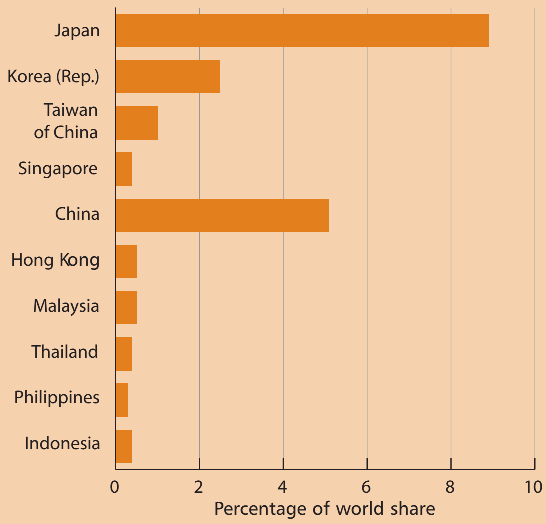
Figure 1
GERD/GDP RATIO IN EAST AND SOUTH-EAST ASIA, 2001*



* Japan 2000, Malaysia 2000, Philippines 1998.

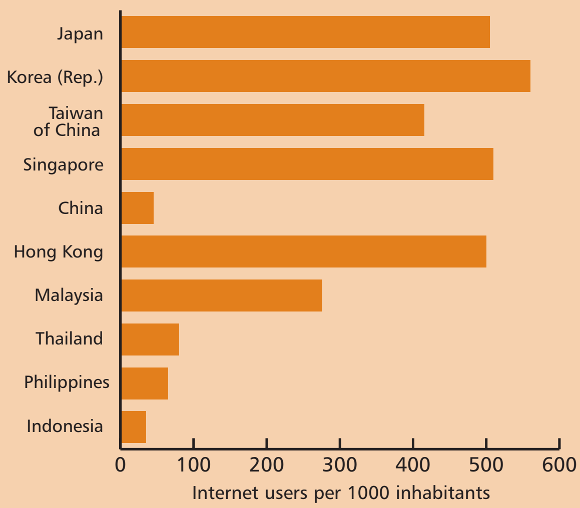
Source: International Institute for Management Development (2003) *World Competitiveness Yearbook 2003.*

Figure 2
COMPUTERS IN USE IN EAST AND SOUTH-EAST ASIA, 2002



Source: Computer Industry Almanac 2002.

Figure 3
INTERNET USERS IN EAST AND SOUTH-EAST ASIA, 2002



Source: Computer Industry Almanac 2002.

INFORMATION TECHNOLOGY

Information technology (IT) has been a great leveller for countries on their paths to S&T development. The Internet has made available a great amount of scientific information and technical data at little or no cost. Hitherto, such information was difficult to come by and this could pose a barrier to S&T development.

Software development requires little equipment and, unlike other forms of technology, can be undertaken without major capital investment and on a small scale. The return cycle is short. Late starters are not necessarily disadvantaged. Because of these factors, most countries in the region have a growing IT industry.

The build-up in IT industry and the general availability of scientific information have strengthened the technological capability of the countries in the region. This is not well reflected in the usual input indicator, GERD as a percentage of GDP, because IT does not necessarily incur large expenditures.

One indicator of the pervasiveness of IT in the region is the number of computers in use. China, with 5.1% of the world share of computers, ranks fourth in the world, which is hardly surprising as China is the most populous country in the world. It is significant that the Republic of Korea, with 2.4%, ranks ninth (Figure 2).

When computers per 1 000 inhabitants are calculated, Singapore and Hong Kong rate higher than the Republic of Korea and Taiwan of China; their statistics are comparable with those of European countries. Malaysia, with 137 computers per 1 000 inhabitants, also qualifies for this league, and is significantly ahead of Thailand's 43 per 1 000 inhabitants.

The Republic of Korea ranks sixth in the world in per capita Internet usage, closely followed by Singapore, Hong Kong, Taiwan of China and Malaysia, all of which have usage comparable to industrialized countries. Further behind is Thailand with 79 Internet users per 1 000 inhabitants, followed by the Philippines, China and Indonesia (Figure 3).

Is there a digital divide in Asia? It is a matter of degree. There is some distance between Malaysia's 269 Internet users per 1 000 inhabitants, which is the lowest of the more

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industrialized countries in Asia, and Thailand's 79 and the Philippines' 57. With regard to computers per 1 000 inhabitants, Malaysia has 137, which is more than three times Thailand's 43. This is a not insignificant difference but Thailand and the Philippines do not appear to be greatly disadvantaged. To some extent, it is a mere size effect because Thailand and the Philippines are more populous countries.

The digital divide may perhaps be seen as an internal problem for the region's two most populous countries, China and Indonesia, where there are great differences in development within the country. The coastal regions of China are much more developed than the western region and the outlying islands of Indonesia are far less developed than the region around Jakarta. Seen in the context of such inevitable differences within a large country, the digital divide does not seem to be significant.

BIOTECHNOLOGY

Biotechnology is a relatively new field and as such may be seen as offering more equal opportunities for newcomers and late-comers such as researchers in Asian countries. There is, however, a formidable threat from the giant pharmaceutical companies. The judicial decision to grant patent rights to genetic codes caused roadblocks to be set up. There is still scope for scientists in Asian countries in this obstacle course. When they lack the funding to pay licence fees to remove the roadblocks, they have to go around them or find a clear path elsewhere. It is, however, difficult for Asian scientists to compete in areas requiring expensive equipment. One factor in their favour is that there is an abundant variety of life forms in the warmer climate of Asian countries.

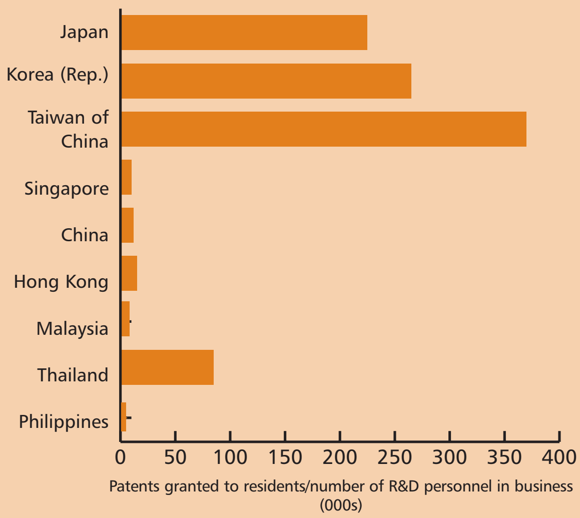
Almost all Asian countries engage in some form of research in biotechnology. Biotechnology is especially significant in Thailand where pharmaceutical research has distinguished itself. In Malaysia, the focus of biotechnology is more on agricultural products. Advances in biotechnology have boosted Thailand's technological capability and narrowed the gap with Malaysia. When the GERD/GDP ratio is considered, Thailand spends only slightly more than half as much as Malaysia: Thailand registered 0.27% and Malaysia 0.49% in 2001. When total GERD is considered, however, due to Thailand's greater size and larger GDP, the difference looks smaller, at US$ 440 million in Malaysia and US$ 306 million in Thailand. Also because of Thailand's larger population, it has more R&D personnel than Malaysia – 20 000 compared with Malaysia's 10 000 – but on the basis of the number of R&D personnel per 1 000 inhabitants, Malaysia is ahead of Thailand at 0.43 compared with 0.33.

Thailand's natural advantage in biotechnology has helped its scientists to secure patents for their research. Thailand's performance in patent productivity has now surpassed that of Malaysia, although it has not quite reached the same level as the Republic of Korea and Taiwan of China (Figure 4).

HIGH-TECH EXPORTS

When it comes to high-tech exports, it is not surprising that China leads the way but it is significant that Malaysia has more high-tech exports than the Republic of Korea and that the Philippines has overtaken Thailand. When high-tech exports are considered as a percentage of manufactured

Figure 4
PATENT PRODUCTIVITY IN EAST AND SOUTH-EAST ASIA, 2000*

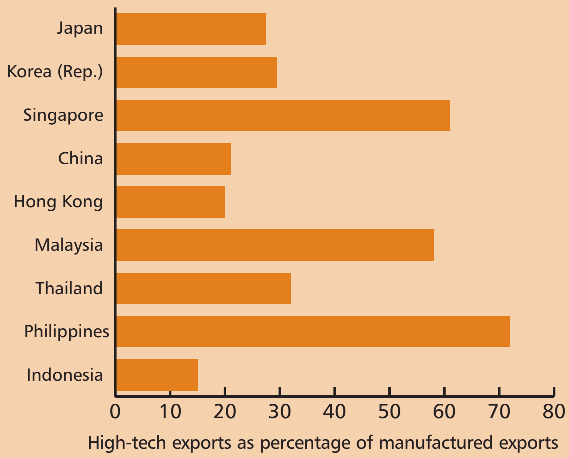


* Japan 1999, Thailand 1997, Philippines 1998.

Source: IIMD (2003) *World Competitiveness Yearbook*.

EAST AND SOUTH-EAST ASIA

Figure 5
HIGH-TECH EXPORTS IN EAST AND SOUTH-EAST ASIA, 2001



Source: World Bank (2003) *World Development Indicators.*

exports, the Philippines leads at 72%, followed by Malaysia with 50% and Thailand with 32%. For China, high-tech exports constitute 21% of manufactured exports (Figure 5).

Multinationals and companies in developed countries have been stepping up original equipment manufacture (OEM) operations in Asian countries; this explains the remarkable level of high-tech exports as a percentage of manufactured exports in the Philippines, Malaysia and Thailand.

INTELLECTUAL PROPERTY PROTECTION

There is generally adequate protection of intellectual property in East and South-East Asian countries. It may be possible to distinguish three elements of intellectual property protection. First is the enactment of adequate legislation. Second is whether the apparatus exists in the country to pursue rigorously infringements of intellectual property. Here, there are two subdivisions. One is whether, and the extent to which, the government assumes its responsibility for enforcing intellectual property legislation – a matter of intention as much as of the effectiveness of measures taken. The other is the process and efficiency through which redress can be provided when an aggrieved party institutes civil proceedings. The third element is the propensity of people in the country to take illegal advantage of protected intellectual property. This is in turn dependent on two factors: the technological capability in the country and the willingness of entrepreneurs to risk litigation.

From this analysis, it can be seen that the first element is generally present in all countries in the region. There is some provision in the second element but it is difficult to assess its adequacy. Governments have generally expressed willingness to pursue intellectual property violations but it is difficult to judge the adequacy or the rigour with which they pursue violators. Similarly, there exist channels and processes for aggrieved parties to seek redress but the efficiency of the process is again difficult to assess.

Often it is the third element which becomes the deciding factor in location decisions of multinational corporations. Consideration of this element would have prompted many companies to set up OEM operations in the Philippines and Thailand. The increase in OEM factories in these countries has resulted in an increase in high-tech exports from these countries.

HUMAN RESOURCES

The region has a generally well-educated workforce. For most countries, more than 30% of the adult population are university graduates (Figure 6), while in the Philippines the proportion is 26% and in Thailand 13%. The most populous countries, China and Indonesia, have a pool of only 5% and 6%, respectively, but it is a not a problem for them. China has the world's second-largest workforce in R&D. In many Asian countries, nearly half of university degrees are obtained in science and engineering; in China nearly three-quarters (74%) are (Figure 7). The exception is Thailand, where the figure is 26%.

There are no serious problems of 'manpower mismatch', something which has caused difficulties in other regions. Worker unions have never been strong in the region, which is a main reason why there is no entrenched resistance to change. Asian workers are pragmatic and flexible; they are

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generally adaptable and willing to learn new skills. However, employers are sometimes reluctant to invest in training employees and would sooner hire new workers with ready-made skills. Thus, while there is little 'manpower mismatch', workers and jobs are not particularly well matched.

In the Republic of Korea, company loyalty is emphasized; in turn, the company is committed to the career development of its employees. This was particularly so in the heyday of the *chaebols*. Since the end of the financial crisis of the late 1990s and the gradual dismantling of the *chaebols*, attitudes have been changing.

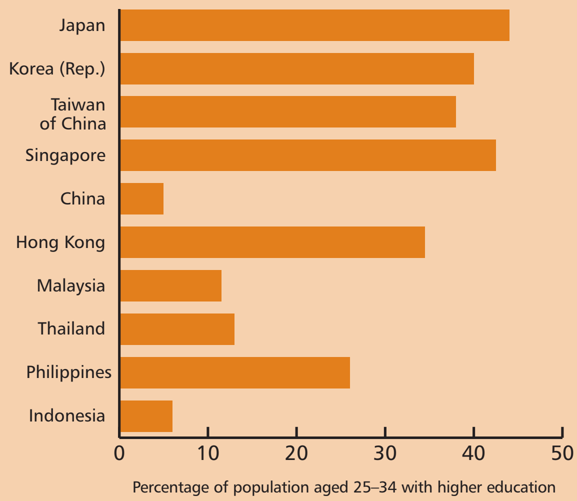
In centrally directed Singapore, there is no fear of 'manpower mismatch'. When the universities were told to step up their output of engineering graduates, there was no concern about employment prospects for the graduates because the government would create jobs for them.

Brain drain

'Brain drain' has been a perennial problem. East and South-East Asia has been a net exporter of talent. It is not clear whether this has been harmful to the region. If there is insufficient opportunity for the personal development of individual talents, it is to the benefit of the individuals to go abroad to find scope for their development. Emigration of talents means fewer human resources are available for national development and, on occasion, countries have found it difficult to recruit local talents to important positions. However, when the country cannot offer sufficient opportunities for the professional development of some of its people, it may be better for the country that these people go overseas to find a meaningful career because they can be useful to the country even while living abroad and may some day return to help the country's development.

China has adopted a liberal policy towards its nationals going abroad. As early as 1978, Deng Xiaopeng said, 'Even if half of those sent abroad would not return, it is better than not sending or sending less.' Now, approximately one-third of those who go abroad are returning to China every year.

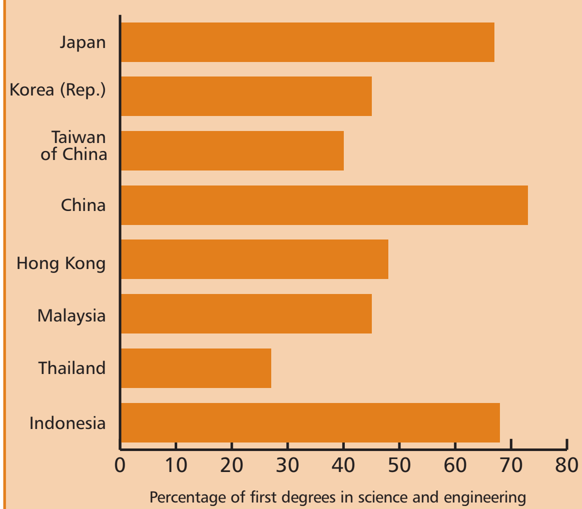
Figure 6
HIGHER EDUCATION ACHIEVEMENT IN EAST AND SOUTH-EAST ASIA, 2001*



* China 1998, Malaysia 1999, Thailand 1999, Philippines 1998, Indonesia 2000

Source: IMD (2003) *World Competitiveness Yearbook.*

Figure 7
SCIENCE AND ENGINEERING EDUCATION IN EAST AND SOUTH-EAST ASIA , 1999



Source: National Science Foundation (2002) *Science and Engineering Indicators*. Washington, DC, USA.

All countries have paid attention to attracting the return of their nationals. The Republic of Korea has appealed to nationalism. Taiwan and China have used high salaries. Singapore still uses a bond system to require nationals going abroad on scholarships to return to Singapore to work for a certain period of time. There is now mounting pressure for Singapore to review or dismantle the bond system.

Policy measures pale in significance compared with the natural attractions of a higher level of development in the home country. By the turn of the twenty-first century, economic development in the region had by and large reached a level such that there were flourishing markets for returning talents. Once they have overcome the sometimes psychological aversion to returning, many soon opt to embrace the new opportunities of their own accord. Indeed, more than ten years ago when the Asian miracle was first mentioned, there was much conjecture about the cause of the miracle. One of the factors was certainly the return of talents who had been trained and gained experience in Western countries.

Their return triggered faster economic growth, which in turn made their countries more attractive for nationals to come back to. Thus, there is a positive feedback loop between returning nationals and economic development. There is also a herding effect: overseas nationals seeing their compatriots returning would sooner consider returning themselves.

INTERMEDIARY INSTITUTIONS

Intermediary institutions were first conceived as bridging the gap between upstream S&T and downstream commercialization. The concept is especially relevant for East and South-East Asia because of the tradition for scholars and scientists to devote themselves to academic research, sometimes with a disdain for commercial applications.

Intermediary institutions were first promulgated by Choi Hyung-Sup, Minister of Science and Technology of the Republic of Korea, in the 1970s. He created the Korean Institute of Science and Technology, which was a mechanism for giving university professors an opportunity to work on the applied problems of industry. He considered the institutional initiative as being necessary because S&T development in Korea at the time was weak. In Western countries, the S&T infrastructure is generally better developed; consequently, there is less need for intermediary institutions and, where they exist, they are not as significant.

The Korean example was widely emulated. A few years later, the Industrial Technology Research Institute was set up in Taiwan of China and, in the past ten years, many more intermediary institutions have sprung up in East and South-East Asian countries, especially in Malaysia.

The institutions function as a half-way house, enabling scientists at universities to spend time working on applied problems then return to their academic work. At the same time, it is a useful opportunity for younger scientists and engineers to learn the workings of industry and is a spawning ground of entrepreneurship. Many young people eventually leave the intermediary institutions to join spin-off companies and they are encouraged to do so. In this way, the intermediary institutions fulfil the role of a conversion mechanism, converting academically trained graduates into useful members of industry. This conversion process is no simple procedure and is not inexpensive.

Without the help of intermediary institutions, entrepreneurs may opt to import ready-made skills from abroad rather than to train up local graduates, as in the case of Hong Kong. There, the situation is exacerbated by the propensity of young graduates to engage in ‘job hopping’; lack of company loyalty means that investments in the development of employees may be lost to the company. Small and medium-sized enterprises (SMEs), which necessarily function with a short time horizon, are hard pressed to invest in staff training. They tend to find the experience of graduates irrelevant to their narrower scope of activities. In an economy where SMEs are predominant, it is difficult for graduates to find appropriate employment and they become branded as inexperienced and unsuitable. Thus, it becomes a vicious cycle. Intermediary institutions are seen as necessary to break this vicious cycle.

Intermediary institutions have now taken on a more general connotation to include entities created to overcome economies of scale or economies of scope for SMEs.

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Thus, the term is taken to embrace science parks, incubators and institutions offering S&T services such as information, management and financing. The term is also taken to include agency roles, as in marketing and sourcing.

There is an important application in the financing of technology, which requires bringing together funds, technical expertise and business acumen. The three attributes seldom come together by themselves. Intermediary institutions function as enabling mechanisms, for example the Korean Technology Development Corporation and the Malaysian Technology Development Corporation.

Another important function of intermediary institutions is to act as bridges in the triangular linkage between government, university and industry. For smaller economies where the level of S&T development is not high, it is especially important to harness the synergy from the triangular linkage.

PUBLIC–PRIVATE CONSULTATIVE MECHANISMS

Public–private consultative mechanisms are a special feature in East and South-East Asia. Their significance stems from the fact that the public sector is the major player in S&T in most countries in the region. With the notable exception of the Republic of Korea, Singapore and Taiwan of China, the public sector generally accounts for more than 50% of total R&D. Companies in the private sector are relatively small. Governments command better resources and have superior access to information. They nevertheless find it wise to tap the market sense of entrepreneurs.

An analogy may be made to power steering. The consultative mechanisms put the entrepreneurs in the driver's seat but their efforts alone, in terms of resources and finances, are insufficient to turn the wheels of the great vehicle of national development. There is a need for the government to supply power, in the form of resources and funding, to enable the steering to take place.

To be successful, the consultative mechanisms must be constituted in such a way as to make it incentive-compatible for entrepreneurs to give advice which is good for the country rather than to advance individual vested interests. This incentive compatibility is not always easy to achieve; it depends on an appropriate *mode d'emploi* of the consultative mechanisms and on a suitable selection of participants.

Malaysia has had notable success with public–private sector consultative institutional mechanisms. Such mechanisms have been very well developed in the Republic of Korea where there is a culture of sacrificing individual benefits to the greater good. In the closely knit society of Singapore, these public–private sector consultative relations become implicit, because communications can be direct. When the key people have many occasions and channels to meet, there is hardly any need to institutionalize explicitly the relationship.

This situation is in contrast to experience in Western countries where the government is not the largest player in R&D. Firms are large and the private sector generally accounts for more than 60% of total national R&D in Organisation for Economic Cooperation and Development (OECD) countries. In Western countries, governments are sometimes considered to be inept and have less access to market information than private firms. The welfare of the country is synonymous with the welfare of the firms in the country. The concept of a national vehicle of development is hardly viable. Rather, when individual firms get to go where they want to go, the firms are happy and that means the country as a whole is happy. In this Western scenario, there is little need for public–private sector consultative mechanisms and, where they exist, they are not considered to be important.

LEAPFROG

Is the region poised to leapfrog? There are favourable conditions. The advent of the Internet has helped to popularize science and has made vast amounts of information and data available at almost no cost, which has been a tremendous boost to under-privileged researchers. At the same time, IT presents a more level playing field for Asian researchers, who will not be severely handicapped by lack of resources.

Biotechnology is a field in which East and South-East Asian countries can have niche advantages. In medical applications, the populous Asian region has a wide range of diseases and large numbers of clinical cases. In pharmaceutical and agricultural applications, the region also has the advantage of a great variety of vegetation and life forms.

Levels of economic and technological development in the region have passed the threshold. Now there will be an increasing number of nationals who have studied and trained abroad returning on their own initiative to take advantage of the new opportunities in the fast developing region. Against this is the region's less than spectacular record for the percentage of GDP spent on R&D. While some Asian countries have risen above 2%, industrialized countries in other regions have passed the 3% mark. But this indicator should be interpreted in the context of increases in GDP in the denominator. Also, input is not the best way to measure technological capability. To conclude, the region is set to look forward to a period of accelerating growth and development in S&T.

S&T COOPERATION

Cooperation in S&T in Asia has not been easy. The region is diverse and countries are spread over vast distances. More languages are spoken than there are countries in the region. Although English is the medium for scientific publications and research communications, most universities teach in the local language. Language is already a barrier to scientific personnel gathering together to overcome critical mass thresholds. But it is not sheer numbers which count; it is complementarity, or mutual reinforcement, which leads to synergy in a cooperation. Such complementarity, concurring with benevolent intentions to cooperate and enabling institutional mechanisms, was difficult to achieve when levels of S&T development in individual countries were not high. By the turn of the century, East and South-East Asian countries have reached capabilities that make S&T cooperation feasible but it is still a daunting task to identify meaningful areas for synergistic collaboration.

It is not in the mainstream for students to go to a neighbouring Asian country for further study; Western countries are preferred by the better qualified or those who command sufficient finances.

As for pooling of resources and sharing of facilities, an institution has to achieve some degree of prominence before it can become a centre of attraction for scientists. Most examples of shared facilities tend to have benefited from the support of countries outside the region.

In the same way that intra-regional trade is less significant than trade with countries in other regions, notably Europe and America, S&T cooperation among countries within the region is less significant than cooperation with industrialized countries outside the region.

APEC

Asia-Pacific Economic Cooperation (APEC) was established in 1989 to enhance economic growth and prosperity for the region and to strengthen the Asia–Pacific community. It is a forum for facilitating cooperation, trade and investment. The Member Economies of APEC together account for one-third of the world's population and about 60% of world GDP. APEC's 21 Member Economies are Australia, Brunei Darussalam, Canada, Chile, China, Hong Kong, Indonesia, Japan, Republic of Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, Peru, Philippines, Russian Federation, Singapore, Taiwan of China, Thailand, USA and Viet Nam.

When China hosted the APEC Economic Leaders' Meeting in Shanghai in 2001, cooperation in S&T was successfully highlighted by way of human capacity-building. Many industrialized countries in APEC were understood not to be keen on S&T, being especially averse to technology transfer. The Fourth APEC Science Ministers' Meeting held in New Zealand in 2004 noted the need to have more and better engagement between the scientific community and society in APEC economies, and recommended a revamp of the Industrial Science and Technology Working Group of APEC.

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ASEAN

The Association of South-East Asian Nations (ASEAN) groups Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Viet Nam. The goals of ASEAN encompass promotion and pursuit of cooperation in the arena of political and security matters, economic integration, as well as cultural and technical cooperation in areas such as social development, S&T, environment, agriculture and forestry, energy, tourism, transport and communications.

The goal for the coming decades, as encapsulated by *ASEAN Vision 2020*, is of 'a technologically competitive ASEAN, competent in strategic and enabling technologies, with an adequate pool of technologically qualified and trained manpower, and strong networks of S&T institutions and centres of excellence'.

The importance of cooperation in S&T has long been recognized. The ASEAN Committee on Science and Technology (COST) was established more than 20 years ago. There are nine COST Sub-Committees, namely: (1) Food science and technology, (2) Meteorology and geophysics, (3) Micro-electronics and information technology, (4) Materials science and technology, (5) Biotechnology, (6) Non-conventional energy research, (7) Marine sciences, (8) Space technology and applications, and (9) S&T infrastructure and resource development. COST maintains an ASEAN Science Fund to provide seed funding for its projects and activities, and also seeks external funding from ASEAN's Dialogue Partners: Australia, Canada, China, the European Union, India, Japan, Republic of Korea, New Zealand, Russia, the USA and the United Nations Development Programme.

Some examples of cooperation projects in 2004 are the China–ASEAN Training Course on Remote Sensing Satellite Technology; ASEAN–Pakistan Cooperation in Composite Materials, with a visit by Pakistani experts to ASEAN countries; a China–ASEAN Workshop on Conservation and Biotechnology Application of Tropical Biological Resources; and ASEAN–India Cooperation on S&T Policy and Technology Management.

The prognosis is for the emergence of internalized forces unifying the region in cooperative efforts. The lead would come from China, the Republic of Korea or Malaysia, or from home-grown Asian multinationals. There will be a diminishing of external influences, which have tended to be divisive. It will be a far cry from the 'ASEAN complementarity' proposed by the Ford Motor Company in the 1970s with its plan for having different parts of a car made in different countries and for the Ford model to be eventually assembled as a so-called ASEAN car. The plan exploited economies of scale by producing large quantities of the same part in one location and made sure no country acquired the technology to make a complete car.

The channels are now open for countries to collaborate on national or regional products. The long period of stagnation in progress towards regional cooperation is coming to an end. After several false starts, institutions for regional development will eventually emerge. For example, a well-justified *raison d'etre* for an Asian Monetary Fund will eventually overcome objections from outside the region. Once regional institutions are in place, there will be additional impetus for cooperation and the region will be able to look forward to a heightened pace of S&T development.

Hong Kong and Singapore: a tale of two cities

Lee Kuan Yew made an allusion to Charles Dickens' novel, *A Tale of Two Cities*, when he compared Singapore and Hong Kong in a speech at the University of Hong Kong in 1992. Although there are similarities between the two island economies, they have taken significantly different paths to S&T development. A point often missed in casual references to Singapore and Hong Kong is that they are both anomalous cases. At times, others might try to emulate Singapore's and Hong Kong's apparent successes. On closer scrutiny, it will be seen that policy actions have been taken to suit the particular circumstances of these two economies, which in most cases are unique, and are scarcely applicable in other countries where conditions differ. With hindsight, it is also not at all clear whether the anomalous policies were desirable.

To set the scene for the comparison, Singapore's total expenditure on research and development as a percentage of GDP (GERD/GDP ratio) stood at 2.1% in 2001, while research scientists and engineers per 10 000 workforce numbered 70 in the same year. For Hong Kong, the GERD/GDP ratio was a meagre 0.6% in 2001 and there were only 10 research scientists and engineers per 10 000 workforce. For all statistical indicators, Hong Kong ranks consistently behind Singapore.

With respect to the institutional structure for S&T, Singapore's provision is deceptively simple. In the closely knit society of Singapore, S&T policy planning is made by a central core of top leaders who bypass formal institutional structures. The National Science and Technology Board was in essence involved only in second-level funding and implementation.

In the case of Hong Kong, which reverted to Chinese sovereignty in 1997, the functions of the former Industry Department have been regrouped to form the Innovation and Technology Commission. The Science Park was eventually set up, almost 10 years after its feasibility study was first undertaken in 1991. The Applied Science and Technology Research Institute was established to fill a void in the S&T infrastructure, into which the Hong Kong Productivity Council has grown, and is now struggling to identify a new role for itself. These are funding and implementation bodies; an adequate policy-making mechanism is lacking.

Singapore has taken bold proactive initiatives to promote S&T. Strenuous efforts combined with very favourable conditions in the form of generous tax and financial benefits have attracted many major technology-intensive manufacturing multinationals to set up operations there. The companies have not brought as much R&D as might have been hoped for but their presence has resulted in a general strengthening of Singapore's technological capability. The challenge now comes from competition from neighbouring Malaysia, Thailand and Viet Nam, where space is abundant and labour is far less expensive. A number of the multinational corporations which have set foot in Singapore are already moving operations to other countries with better natural conditions and many others are now considering their position. In the planned society of Singapore, it has been possible to engineer a decrease in salaries to some extent in order to stay competitive. The space limitation is a fundamental constraint which is difficult for policy action to tackle.

Another controversial policy is that Singapore has nurtured the development of many technology start-ups through favourable government procurement. Many technology-intensive companies are government-owned or -controlled; they help the start-ups by giving them business, such as by procuring their services or technology. This has created a favourable environment for new

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technology companies when it comes to developing and obtaining venture capital financing. A worry is that companies nurtured under such favourable conditions may not be able to compete successfully in the international marketplace. One solution might be to keep these companies within Singapore until they have grown sufficiently strong to be competitive. The question then arises as to whether it is possible to sustain government support long enough for the companies to reach the critical mass beyond which point they can manage by themselves and eventually compete internationally successfully.

Even if some manufacturing operations do eventually leave Singapore, the time they have spent in the country will have helped Singapore to develop its technological capability. The space problem is an essential issue which seems insurmountable. A niche for Singapore lies perhaps in technology-intensive services, drawing on the experiential support of its manufacturing sector and R&D institutes, rather than in technology-intensive manufacturing *per se*. This would capitalize on Singapore's position as a geographical hub.

Hong Kong has been fortunate, or unfortunate, to have avoided earlier pressure to upgrade its technological capability. In the 1980s, when Hong Kong's manufacturing was threatened by the technologically more advanced Republic of Korea, Taiwan of China and Singapore, low-cost labour across the border on the Chinese mainland became available. There has also been the crowding out effect of the real estate sector, before it crashed. The day Hong Kong eventually has to face up to making the transformation to a knowledge-intensive economy, it will be much more painful, like catching measles at a later age.

There are many in Hong Kong who would like to evade the ordeal, arguing that if Hong Kong is not going to excel in S&T, it should not invest in S&T. Given that Hong Kong is a small place and the head-start already taken by neighbours and other countries, Hong Kong does not have an advantage in S&T. This might have been sound comparative advantage thinking, but S&T are not like a commodity or a sector of industry. Like vitamins, S&T are essential to an economy, without which many knowledge-intensive activities become dysfunctional. It is unrealistic to resist the inevitable move towards a knowledge economy.

There is also the thinking that, since Hong Kong will be playing a marketing and sourcing role for the much larger and stronger technological capability on mainland China, there is no need for S&T in Hong Kong. This thinking is fallacious. Hong Kong needs to have an adequate level of technological capability to be able to provide proper marketing and sourcing services to the mainland. The Closer Economic Partnership Arrangement (CEPA) set up between Hong Kong and the mainland in 2003 has been much talked about. An adequate level of S&T capability in Hong Kong is necessary to give substance to closer cooperation and to enable Hong Kong to engage in dialogue at the appropriate level with mainland partners.

The most serious hindrance to S&T development in Hong Kong has been the dogma of non-interventionism, which has plagued Hong Kong for decades. Without proactive government support, Hong Kong's S&T development lags far behind its neighbours. Whereas other countries are actively supporting the competitiveness of their industries, Hong Kong had been cited as an anomalous example of the success of *laissez faire*, until the collapse of the real estate bubble after the financial crisis of the late 1990s led to recession.

Hong Kong boasts of being a most free economy. That freedom is favourable to short-term speculative investments but is irrelevant to long-term and technology-related investments.

Non-interventionism may no longer be government policy but non-interventionist thinking is still widespread among government officials. For the bureaucrats, non-interventionism is a good excuse for non-action, which minimizes the risk of making mistakes. Especially for the generalist who lacks specialist knowledge, non-interventionism is the safest approach. Hong Kong people have for many years been used to making proposals within the confines of non-interventionism; they find it difficult to think out of the box, even now that the restrictions have been officially lifted.

Although the promotion of innovation and technology is now government policy, government officials are still dragging their feet. Hostile attitudes towards S&T trace back to colonial origins. In the United Kingdom, the 1986 report of the House of Lords Select Committee on Science and Technology pointed out that advice from scientists seemed to fall on deaf ears in government because administrative officers were generalists and not in the least sympathetic to S&T or appreciative of their importance. As a British colony, Hong Kong had the same system of administrative officers, who were retained *en masse* in the change of sovereignty.

Hong Kong's niche lies in offering sophisticated and technology-related services to mainland China and the South-East Asian region. There is much potential, as yet undeveloped, for technology-related services; S&T and R&D are needed to provide experiential support to enable technology-related services to be offered. This would take advantage of Hong Kong's position as a geographical hub, like Singapore. Hong Kong has the additional advantage of being a gateway to a large hinterland, mainland China.

However, many championing the cause of S&T in Hong Kong argue that S&T are needed to support manufacturing and that an economy must have manufacturing. There is no doubt that manufacturing needs S&T but it is not true that an economy must have manufacturing. It may be true for a large economy but not for a small economy the size of Hong Kong. It has not helped the cause of S&T at all that proponents use the wrong justification for S&T.

There was some speculation in technology stocks, which proved to be unsound. People had their fingers burnt when the prices of these stocks plunged. This bad experience did not help to promote a positive attitude towards S&T. It was like trying to run before one can walk.

Indeed, Hong Kong needs to leap in order to catch up. One attempt is to use money to buy technological capability. It will be interesting to see the extent to which money can indeed buy technological capability.

CHINA

Present status of S&T

Expenditure on S&T in China totalled 267 billion yuan[1] in 2002. GERD stood at 129 billion yuan, amounting to 1.23% of GDP. R&D expenditure passed the 1% of GDP mark in 2000. In monetary terms, China ranked seventh in the world for GERD in 2001; China has a significant technological capability by virtue of its sheer size.

China had 3.22 million persons engaged in S&T activities in 2002. Of these, 2.2 million (68%) were scientists and engineers. In respect of the total number of R&D personnel, globally China ranked second in 2001, unsurprisingly, since China is the world's most populous country. However, when the number of scientists and engineers engaged in R&D is related to the size of the workforce, China has only 10 per 10 000 workforce (2000), much fewer than the USA at 81 per 10 000 (1997) or Japan at 97 per 10 000 (1999).

1. One Chinese yuan was equivalent to US$ 0.12 in June 2005.

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Government appropriation to S&T has been increasing steadily every year since 1981, taking up to 5.6% of the total government budget; since 1994 however, this percentage share has been gradually slipping and in 2001 amounted to 3.7%. Government expenditure on S&T has not decreased but nor has it kept pace with growth in total government expenditure.

China granted 132 000 patents in 2002, almost twice the number of patents granted in 1998 (67 900). The Chinese patent system distinguishes three categories: invention, utility model and design. In 2001, 95% of the patents granted to local residents pertained to utility model and design, with invention accounting for only 5%. This was in sharp contrast to the distribution of patents granted to foreigners, where invention took up 73% and utility model and design 27%. The rapid increase in the number of patents granted indicates the high growth of innovation, especially by industrial enterprises, which were the main recipients of patents in the categories of utility model and design.

High-tech goods now account for 21% of manufactured exports, with China ranking seventh in the world for the volume of high-tech exports. According to Chinese exports statistics, these fall into the categories of: computers and telecommunications, life sciences, electronics, weaponry, computer-integrated manufacturing, aeronautics and space, opto-electronic technology, nuclear technology, biotechnology and material design.

The launch of China's first astronaut into orbit in the Shenzhou-V spacecraft in October 2003 epitomized China's engineering achievements. Whereas the USA has greatly scaled down its space programme and the Russian effort has essentially stopped, China is forging ahead. Long March rockets have also provided a satellite launching service on a commercial basis for foreign governments and companies.

As a large country, China has taken a balanced approach, engaging in a broad spectrum of S&T fields. In the 10th Five-Year Plan (2001–05), information technology, biotechnology, new materials technology, advanced manufacturing technology, aerospace and aeronautics were listed as fields in which China should aim for breakthroughs. Micro-integrated circuit design and manufacturing, high-performance computers, opto-electric materials and equipment, biotech pharmaceuticals and agricultural bio-engineering were considered strategic areas in which the country needed to increase its independent innovative capacity. Genetics, ecology and earth science were also considered important priority areas.

As mentioned earlier, China has set itself the target of devoting 1.5% of GDP to R&D in the 10th Five-Year Plan. Having increased its GERD ratio by 0.4% in three years from 0.83% in 1999 to 1.23% in 2002, China seems set to reach this target. China's level of S&T development was summarized by the Minister of Science and Technology, Zhu Lilan, in 2003 as having reached the forefront among developing countries.

Technology-related legislation

With regard to technology-related legislation, China enjoys the rare distinction of possessing intellectual property laws a long time before the enactment of company law. In other countries, company law has usually existed well before intellectual property legislation, which is a relatively recent development. In China, the Trademark Law was enacted in 1982, Patent Law in 1984 and Copyright Law in 1990. China acceded to the Berne Convention for the Protection of Literary and Artistic Works in 1992 and joined the World Intellectual Property Organization the same year. On the other hand, China's Company Law was only enacted in 1993. China passed a Technology Contract Law in 1987, quickly following the enactment of intellectual property legislation, but it was not until 1999 that the more general Contract Law was enacted.

Policy-making structure

Alongside a more or less complete set of legislation, China possesses a well-developed national S&T system. An important change in the policy-making institutional structure occurred when the State Science and Technology Commission became the Ministry of Science and Technology in 1999. This change represented a departure from a structure common in centrally planned economies to one more usual in Western countries, a ministry dedicated to the portfolio of S&T.

The Ministry of Science and Technology is apparently less powerful than the former State Science and Technology Commission, which was chaired by a vice premier and state councillor. Is this a downgrading of the portfolio of S&T? One interpretation is that, as the development of S&T matures in China, the state can and should play a lesser role, leaving room for the private and academic sectors. Moreover, as S&T development is on course and progressing well by itself, there may be less need for state direction, and consequently less attention paid at the highest level of government.

The change came amidst the shift of functions from the State Science and Technology Commission to the Academy of Sciences. Technology transfer, relations with enterprises and many service functions were transferred to the Academy. For instance, the Academy now has the power to certify whether a company pertains to high-tech industry. In accordance with the decentralization directive of 1985, the Academy of Sciences has relinquished control of universities and many research institutes. Instead, the Academy has taken on new functions.

Basic science

In 2002, basic research in China received just 5.73% of GERD, compared with 19.2% for applied research and 75.1% for experimental development. The distribution of R&D expenditure among the three categories has been in similar proportions for more than 15 years. Comparison with other countries reveals a trend towards spending more on applied research and experimental development than on basic research, but the share China spent on basic research, 5.73%, was exceptionally small. The only other countries which spent less than 20% on basic research were the USA at 18.1% (2000) and Japan at 12.3% (1999). The level of S&T development is high in both the USA and Japan; business and industry spent more on experimental development, consequently the proportion for basic research appeared less. It is not a case of basic research being allocated less by the government or the academic institutions. China's small allocation to basic research is well out of line with the practice in other countries.

Up till the early 1980s, basic research was very much emphasized, seen as the necessary foundation upon which everything was built. It was during this period that the decision was made to construct the Beijing Electron Positron Collider, a very expensive facility used in experimental investigations of elementary particles.

In 1985, the watershed decision was made to emphasize the commercialization of S&T and to bring the fruits of science to the people. The pendulum then swung all the way from basic science to applied R&D.

Soon after this policy switch, grave doubts were expressed about the health and viability of basic science. In an effort to prevent its deterioration, a group of scientists initiated the '863' programme, so named because it was started in March 1986. The '863' programme ostensibly set out to maintain China's strategic leadership in the eight areas of: laser, space, biotechnology, automation, information, energy, new materials and ocean technology. In the following 15 years, the '863' programme was allocated altogether 10 billion yuan, a small amount compared with the 78 billion yuan invested in the Sparks programme for rural areas; as for the Torch programme, it has launched 52 High-Technology Development Zones all over China.

Basic science did not wither away immediately after the 1985 shift in emphasis because it had previously been very well supported and nourished. Also, the 1985 decision called for the decentralization of resource allocation, with the result that more funding went directly to the universities. Basic research was able to benefit from this increased direct funding to the universities.

The National Natural Science Foundation has been the main lifeline of the basic sciences since its establishment in 1986, although the Foundation spends the majority of its funding on applied research projects. Funding for the National Natural Science Foundation has been increasing at the rate of 20% each year for several years but its annual budget of 20 billion yuan is still a small proportion of the total national expenditure on R&D of 129 billion yuan. With the increase in its budget, the National Natural Science Foundation has also been elevated in status. As it grows into its second-level

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function of funding of S&T activities, it is fast gaining a status on a par with the Academy of Sciences, which has shed many of its first-level policy-making functions.

There is now much debate among the scientific community in China as to whether a more balanced approach should be taken towards the development of basic science *vis-à-vis* applied R&D. Some hold the view that the present imbalance is a factor why no scientist in China has as yet been able to win a Nobel prize.

Commercialization of S&T

Premier Zhu Rongji has stated that enterprises should become the mainstay of S&T. The Minister of Science and Technology, Zhu Lilan, summarized the direction of S&T development in the 10th Five-Year Plan as 'to innovate and commercialize'.

In 2002, 61.2% of R&D was performed by the enterprise sector, a high percentage compared with other developing countries and well in line with the average for OECD countries. China has surpassed Australia, whose enterprise sector performs 47.5% of R&D. China has emphasized commercialization of S&T since 1985 and has gone from almost totally public-sector-dominated S&T activities to the present position.

An extraordinarily low percentage of R&D is performed by the higher education sector, 10.1%. Countries just above this level are the Republic of Korea with 10.4%, Japan with 13.9% and the USA with 16.8%. These are all countries with a high level of S&T activity where the enterprise sector is very active, resulting in a relatively lower proportion for the higher education sector.

The pressure to commercialize has also fuelled a trend to privatize government functions; there have been many instances of part of a government department or agency becoming a company. Privatization involves the conversion of some public services into privately provided services. This usually results in an immediate gain in revenue, particularly when there is a monopoly provider of services, but when the privatized service should properly be publicly provided, there may be a net loss in social welfare in the long term. An example is the S&T information service, where the level of usage of some information may become much less than is optimal for the country because users may not be able to afford to pay.

While privatization may not be the optimal solution, some have argued that the profit incentive ensures that the service will be provided and at a good standard and that it is better than having no service at all. Privatization of services and goods which should properly be publicly provided is not confined to the S&T system and is quite widespread.

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South Asia

V.V. KRISHNA and USHA KRISHNA

South Asia remains one of the world's poor regions in 2005. Harnessing science and technology (S&T) to human development and economic growth over the past decade has proved a difficult task for many countries with a growing population. Even though poverty levels have dropped in India and other countries of the region in the past five years, human development indicators have witnessed only minor improvements for South Asia as a whole. With the possible exception of India, government support for scientific research and development (R&D) has remained relatively low, at between 0.2% and 0.5% of gross domestic product (GDP) for the region as a whole. This compares with gross domestic expenditure on R&D (GERD) of 1.5–2.5% of GDP in East Asian countries during the decade.

For many countries in the region, the main agenda for S&T remains the development of institutions and universities, and the institutionalization and professionalization of science. In many ways, the general underdevelopment of national scientific communities is no more than a reflection of the low priority accorded to investment in S&T for development. It is thus not surprising that biotechnologies, microelectronics, and information and communication technologies (ICTs), among others, have simply bypassed most countries in the region. The ongoing globalization and liberalization processes have compounded these problems. At the global level, access to new and frontier technologies has become both difficult and very expensive on account of intellectual property regimes. Furthermore, growing technological competition has led to market and technology protection in the developed countries, making it even more difficult for developing countries to integrate new technologies.

Although the industrial and service sectors have shown encouraging growth rates over the past five years, contributing an ever greater proportion of GDP, more than 65% of South Asians remain dependent on agriculture and closely related sectors such as food processing, fisheries, animal husbandry and commercial crops. For this reason, building technological capacities in agriculture for food security invariably confers importance on the agricultural and modern biological sciences. The manufacturing and service sectors, which are likely to play a key role in the industrialization and modernization of South Asia, pose additional problems for national innovation systems.

HUMAN DEVELOPMENT SCENE

One of the major social concerns of South Asia is growing poverty. Of the total population of 1.5 billion, some 467.5 million – one-third of South Asians – live below the bread line. The trend towards a reduction in poverty witnessed throughout the region since the 1970s did not survive the 1990s, with the possible exception of India. Poverty has grown in Bangladesh, Nepal, Pakistan and urban Sri Lanka. Even in India, the numbers of the absolute poor, which had remained stable at between 294 and 315 million from 1970 to 1994, hit the 328 million mark in 2000. All but the Maldives are listed after the first 90 countries in the UNDP's Human Development Index assessing 177 nations (the Maldives holds the 84th position) (UNDP, 2004).

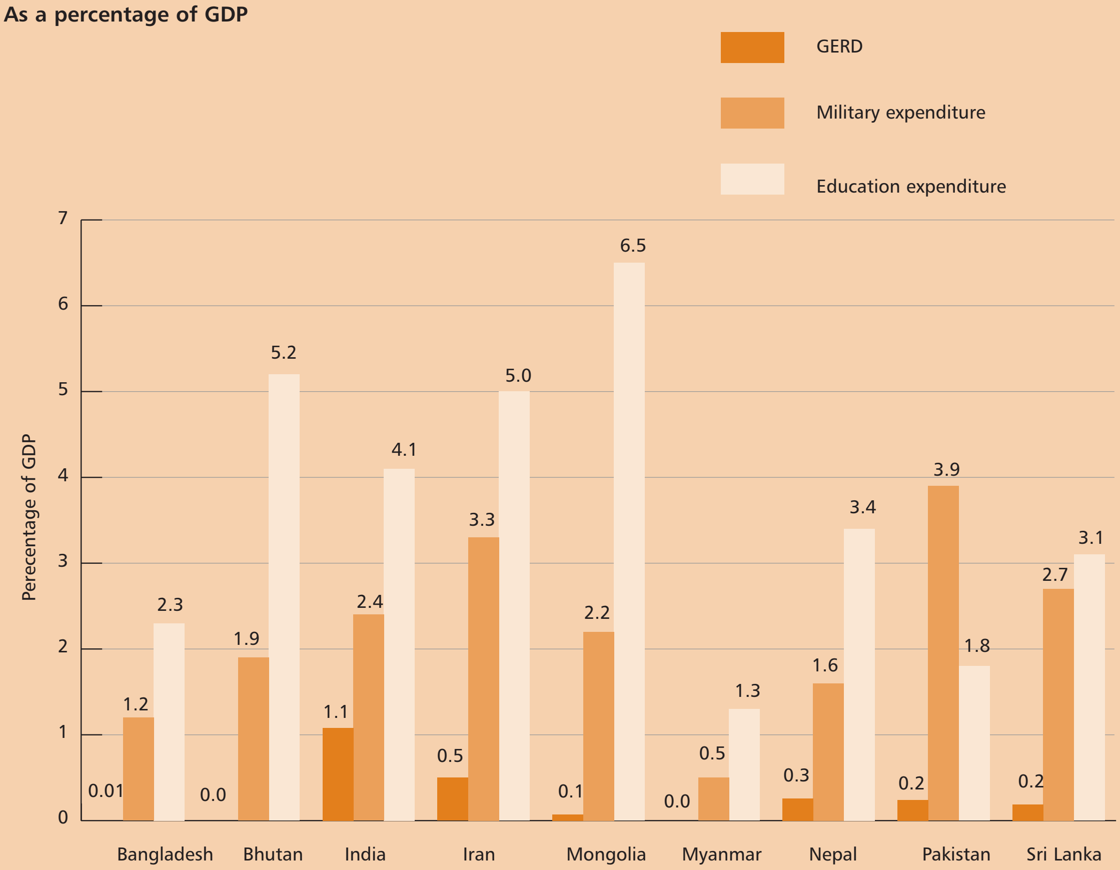
The structure of poverty becomes even more glaring when we take into account other human development indicators. Some 323 million people in South Asia do not have access to health services, 458 million are deprived of safe drinking water and 867 million continue to live without sanitation. With the exception of Iran, these human development problems are deepening in South Asia in the new millennium.

The figures for children (under the age of five) who are underweight for their age speak for themselves: 48% in each of Bangladesh and Nepal, 47% in India, 38% in Pakistan, 29% in Sri Lanka, 19% in Bhutan, 13% in Mongolia and 11% in Iran. One-third of the population in Bangladesh (36%), Nepal (38%) and India (35%) lives on just US$ 1 per day. Extreme poverty is less widespread in Mongolia and Sri Lanka, where 14% and 7% respectively of their populations live below the breadline (UNDP, 2004).

There are however some positive signs. The major human development indicators in health and education reveal that average life expectancy has improved dramatically, from an average 40–44 years in 1960 to 60–64 years in India, Bangladesh and Pakistan and higher in Sri Lanka (73) and Iran (70) in 2001 (UNDP, 2004). Similarly, all countries have made great strides in improving adult literacy over the past three decades, although the task remains enormous for some, particularly with regard to female literacy (the figures for women are in brackets): India 61.3% (breakdown by gender unavailable), Pakistan 41.5% (28.5%), Bangladesh 41.5% (31.4%), and Nepal 44.0% (26.4%) (UNESCO, 2005). The major challenge for improving basic education in South Asia falls to Indian planners, as about 300 million adults in India were still illiterate in 2002–03, out of a total of 402 million illiterates for the entire region. The best indicators of adult literacy in South Asia come from Iran at 76.0% (68.9%), the Maldives at 97.2% (97.2%) and Sri Lanka at 92.1% (89.6%) (UNESCO, 2003; 2005).

Closely associated with adult literacy is the critical indicator of national support for education, reconceptualized as 'human capital' defined as 'the stock

Figure 1
GERD, MILITARY AND EDUCATION EXPENDITURE IN SOUTH ASIA, 2000–04*
As a percentage of GDP



* GERD figures for Iran, Pakistan and India are for 2002; for Bangladesh and Sri Lanka for 2000; for Mongolia 1997; and for Nepal 2004. Myanmar military . expenditure is for 2001.

Sources: for military expenditure as % of GDP for South Asian countries for 2004http://www.photius.com/rankings/military/military_expenditures_percent_of_gdp_2004_1.html; for education expenditure for India, Pakistan, Sri Lanka and Bangladesh for 2001–02,http://www.adb.org/Education/haugh-sin.pdf and http://hdr.undp.org/statistics/data/indic/indic_180_1_1.html; for Nepal, Nepal Academy of Sciences 2004.

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of useful, valuable and relevant knowledge built up in the process of education and training' (Human Development Centre, 1998, p. 25). From such a perspective, a relative stagnation or at best marginal increase (when adjusted for inflation) can be seen in the national education budgets of countries between 1980 and 1996. In India, the decade-long goal of spending 6% of GDP on education has still not been reached, with the education budget witnessing only a modest increase from 3% in 1980 to 4% in 2000–04. Whereas Pakistan has witnessed a marginal decrease in spending on education, from 2% to 1.8%, Nepal has increased spending on education, from 2% to over 3% between 1980 and 2000–04. Over the same period, during the first half of which the Iran–Iraq war was raging, there was a dramatic decline in Iran's education budget, from 7.5% to 5.0% of GDP (Figure 1). Bangladesh and Sri Lanka almost doubled the share of GDP devoted to education over the same period. In Bangladesh, where non-governmental organizations (NGOs) have played an important role, the number of primary schools increased from 47 000 to 63 000 between 1980 and 1996, with a corresponding improvement in the enrolment of pupils (aged 6–10) from 10 million to 14 million (Human Development Centre, 1998, p. 56). Despite drastic cuts in military expenditure, other countries in the region have not managed to raise their education budgets.

THE ECONOMIC CONTEXT

Until the late 1980s, most countries in the region followed a development strategy which promoted industrialization based on import substitution and self-reliance. Since the early 1990s, there has been a shift away from an 'inward looking' policy – with the possible exception of Iran – towards one based on economic liberalization fostering globalization and export. The growth outlook for 2004–05 and beyond is not discouraging, as GDP is expected to grow by 6–7%, the second-fastest rate after China. This has promoted an inflow of capital, technology and partnerships with foreign firms, triggering a shift in the composition of the production structure. As shown by the data from the

Table 1
TRENDS IN ECONOMIC ACTIVITY IN SOUTH ASIA, 1980s–2002

	Sectoral composition of production (% GDP)						**Sectoral share of labour force (% of total)**					
	Agriculture		**Industry**		**Services**		**Agriculture**		**Industry**		**Services**	
	1980	**1995–2002**	**1980**	**1995–2002**	**1980**	**1995–2002**	**1985–86**	**2002**	**1985–86**	**2002**	**1985–86**	**2002**
Bangladesh	49.4	17.6	14.8	27.9	35.8	54.6	56.5	62.0	11.5	10.0	33.7	24.0
Bhutan	56.7	30.3	12.2	39.2	31.1	33.6	–	94.0	–	1.0	–	5.0
India	38.1	23.4	25.9	23.8	36.0	54.9	65.0	67.0	10.0	13.0	26.6	20.0
Iran	18.0	12.0[2]	32.0	39.0[2]	50.0	49.0[2]	36.4	23.0[3]	32.8	32.0	30.8	45.0
Maldives	31.0	7.2	6.0	20.8	63.0	72.0	–	22.0[4]	–	18.0	–	60.0
Mongolia	15.0	33.0[1]	33.0	28.0[1]	52.0	–	39.8	32.0[1]	21.0	23.0[1]	39.2	45.0[1]
Myanmar	47.0	59.0[1]	13.0	10.0[1]	40.0	–	–	63.0	–	21.0	–	16.0
Nepal	61.8	39.2	11.9	20.8	26.3	43.9	93.0	81.0[5]	0.6	3.0[5]	6.4	6.0[5]
Pakistan	30.6	22.3	25.6	21.2	43.8	56.4	49.6	48.0	12.4	18.0	38.0	34.0
Sri Lanka	26.6	21.4	27.2	24.7	46.2	54.0	49.8	42.0	18.8	23.0	32.2	35.0
South Asia	37.8	24.6[1]	25.0	30.2[1]	37.2	55.2[1]	62.8	64.6[1]	10.6	14.8[1]	27.2	18.6[1]

Notes:
1 Data for 1997.
2 Data for 2002 from Encarta.msn.com/encyclopedia–761567300_3/Iran.html
3 Data for 1996.
4 www.mapquest/com/atlas/main.adp?/region=maldives
5 Data for 1999, source as 4 above.

Other sources: UNESCO (1998) *World Science Report 1998*; RIS (2003) *SAARC Survey of Development and Cooperation 2002–2003*; Asian Survey (1999) *Asian Survey* 39(1) p.115–69; for 1997 GDP in India see *Economic Times*, 27 January 2000, New Delhi; for 1997 GDP in Iran see PBO/UN (1999) *Human Development Report of the Islamic Republic of Iran.*

seven-nation South Asian Association of Regional Cooperation (SAARC), where the share of agriculture in GDP declined between 1980 and 2002, there was a corresponding increase in the shares of industry and services (Table 1). The services sector has emerged as the main motor of development in the region, contributing more than half of economic growth as a whole in South Asia. Despite this shift, South Asia remains an agrarian economy, with around 64% of the labour force and population being dependent on agriculture.

The industry and services sectors of the SAARC region witnessed steady growth from 1981 to 1999. Whereas agriculture grew at an average rate of 2.3% over this period, the industrial and services sectors registered average growth of about 6%, making South Asia one of the fastest-growing regions in the world. The services sector is likely to assume considerable importance in the region, which has performed quite impressively in the past decade with an average growth rate of 6.9%. It is something of a paradox that, even though the services sector's composition of GDP increased considerably between 1986 and 2002, its share of the labour force registered a decline. This indicates that modernization processes are not creating employment in this sector at a pace with population growth. The transformation from an economy based on agriculture to one based on industry and services seems likely to persist in the years to come but what is also evident is the significant role played by the small and medium-scale manufacturing sectors, as opposed to engineering and heavy industry.

Despite the slowdown in the share of the labour force employed in industry and services between 1986 and 2002 for South Asia as a whole, there has been a remarkable shift in the composition of GDP in industry and services. With the exception of Bhutan and Nepal, the contribution of the services sector to GDP in South Asian countries has crossed the 50% threshold. Dramatic changes in the services sector can be seen above all in India, thanks mainly to the Indian information technology (IT) industry, which recorded a compound annual growth rate of more than 41% from 1994 to 1999 before sliding back to around 32% by 2004. The IT market crossed the US$ 19 billion mark in 2004 and is expected to reach US$ 50 billion by 2008. The future looks promising: a source in the Ministry for Information Technology indicates that, by 2008, some 35% of India's total foreign exchange earnings are likely to come from software exports, providing employment opportunities for 2.2 million people and a market capitalization of US$ 225 billion (Kumar, 2000).

In Iran between 1995 and 1998, agriculture registered average growth of 3.6%, manufacturing 2.4% and services 5.4%. Iran used to rely heavily on revenue generated by oil exports but, after years of declining oil revenues from 1975 onwards, development plans began to focus on manufacturing and industry in the late 1990s. Long-standing protection policies continue to place a heavy burden on economic dynamism, particularly on the inflow of foreign direct investment and technology. Growth in engineering and high technology is severely hampered by

Table 2
SCIENTISTS AND ENGINEERS IN SOUTH ASIA, 2000–04

Country	Total population (millions) 2003	Scientists and engineers per million population*
Bangladesh	138	51
Bhutan	2	–
India	1 064	157
Iran	67	590
Mongolia	3	1 370
Myanmar	48	–
Nepal	25	40
Pakistan	148	69
Sri Lanka	19	191

* Full-time equivalent.

Source: for population data: www.worldbank.org/data/databytopic/sas-wdi.pdf and www.sarid.net/development/index.htm#statistics; for scientists and engineers: World Bank (2002, 2003) *World Development Report*; National Science Foundation, Colombo; Pakistan Council for Science and Technology, Islamabad; Department of Science and Technology, New Delhi; BANSDOC, Dhaka; Ministry of Science and Technology, Education and Culture of Mongolia; PBO (Iran 1400 Committee), IROST, Iran.

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the concentration of industry in the state sector. These 'inward-looking' policies have prevented both competition and the dynamic growth of the private industrial sector (PBO/UN, 1999).

S&T EFFORT

The consideration of S&T and higher education as a crucial factor in the processes of development, modernization and industrialization is clearly evident from the national plans of individual governments in South Asia. Each country has created a Ministry of Science and Technology, often included in the portfolio of education. On the surface, this indicates that importance is being assigned to S&T. Unfortunately however, there is a continuing gulf between appearances and reality. The formal importance given to S&T policies has not translated into real investment. The 'historic' figure of devoting 1% of GDP to R&D for developing countries, advocated by numerous international and national agencies since the 1979 Vienna Conference on Science and Technology for Development, is still a pipe dream for most countries in South Asia.

COUNTRY PROFILES

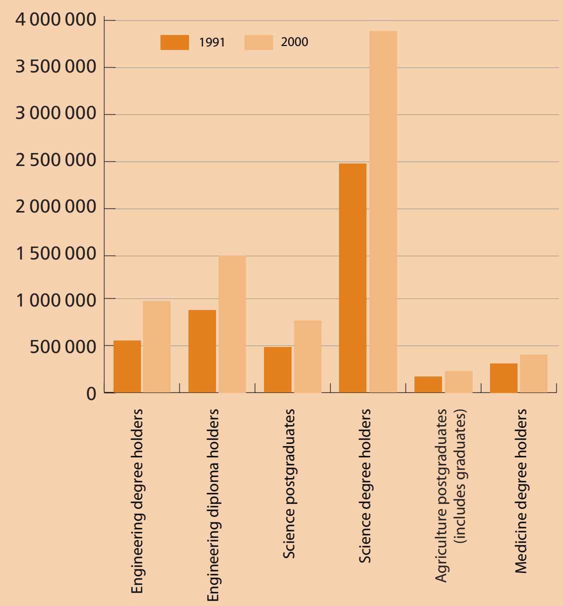
India

Among its South Asian neighbours, India stands out in terms of national investment in R&D and endowment of S&T human resources; it also maintains the lead in S&T publications. S&T policies in India have always stressed the development of human resources. As Figure 2 shows, all categories of S&T personnel have increased over the past decade. The number of universities has also grown substantially, from 209 in 1990 to more than 300 in 2005, thanks to the decision of the University Grants Commission to authorize several private universities. Moreover, seven Indian universities figure prominently in the list of Asia's top 20 universities in 2000 (Table 3).

In terms of S&T publications, even though India maintains a big lead in the South Asian region, the past 15 years have witnessed a notable decline, particularly between 2000 and 2004 (Figure 4). It is interesting to note that, whereas resident Chinese authored fewer than one-third of the number of papers Indian scientists published in the mid-1980s (3 238 compared to India's 11 222 in 1985), China has now overtaken India, with a remarkable 22 061 publications now registered in the Science Citation Index (SCI) of the Institute of Scientific Information in Philadelphia (USA), compared with India's 12 127 (Arunachalam, 2002). Even though S&T policy has focused on intellectual property management favourable to patents in the past five years, the relative stagnation and decline in S&T output, as measured in terms of papers, has generated debate in Indian S&T circles.

However, the most notable development for India has been the crossing of the historic threshold of 1% for the GERD/GDP ratio in 2004 (matching the achievement of China). India had always given high priority to S&T and

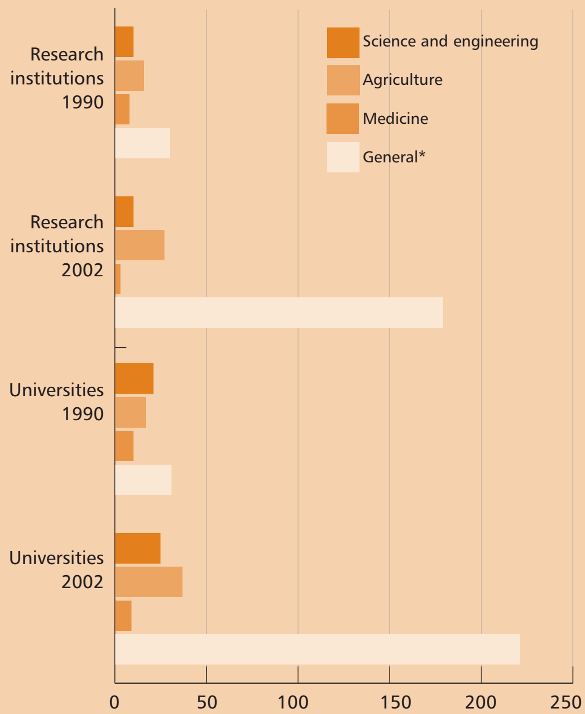
Figure 2
HUMAN RESOURCES IN S&T IN INDIA, 1991 AND 2000
By degree and field of study



Source: Department of Science and Technology, Government of India, 1999; 2002.

SOUTH ASIA

Figure 3
RESEARCH INSTITUTIONS AND UNIVERSITIES IN INDIA, 1990 AND 2002
By field



* Indicates major universities and other institutions teaching science, engineering, technology, medical and social sciences.

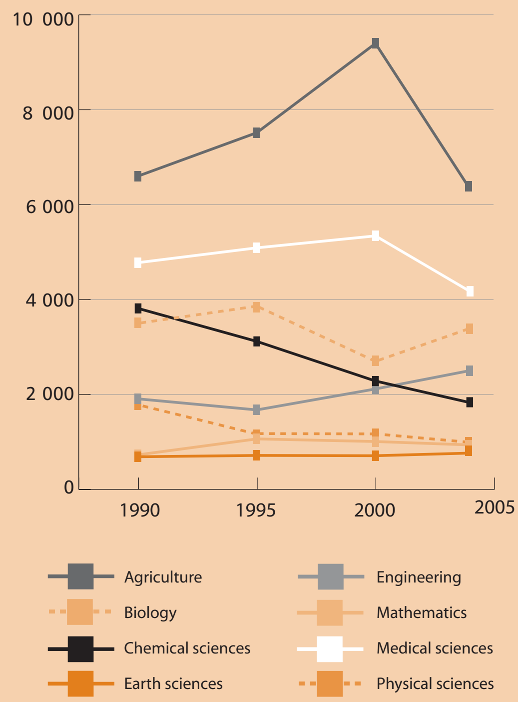
Sources: *Universities Hand Book*, New Delhi; Association of Indian Universities, 2002.

higher education, a trend set by Jawaharlal Nehru, India's first Prime Minister. In line with this tradition, the current Indian Prime Minister, Manmohan Singh, underlined government's commitment to S&T policy at the 92nd session of the Indian Science Congress at Ahmedabad in 2005. Among the important policy commitments, the following are noteworthy:

- development of basic science, applied science and the promotion of excellence;
- rebuilding the science base in universities;
- fostering public–private partnerships;
- debureaucratization of S&T institutions and preservation of academic autonomy; and
- creation of exciting career opportunities for scientists to keep talent at home and to sustain it through the expansion of a dozen main centres of excellence, such as the Indian Institute of Science in Bangalore, one of the country's oldest institutions of learning and research (dating from 1909).

Other recent government initiatives of note include the launch of the Nanoscience and Technology Initiative, with funding of billion Rupees (Rs)[1]; a budgetary allocation of

Figure 4
INDIAN SCIENTIFIC OUTPUT IN TERMS OF PUBLICATIONS, 1990–2004
By field



Note: Agriculture includes animal husbandry, forestry and fisheries; biology includes botany and zoology.

Source: INSDC, *Indian Science Abstracts*, 1965–2000. New Delhi: Indian National Scientific Documentation Centre. (Various issues for respective years.)

1. 43 Indian Rupees (Rs) were equivalent to US$ 1 in June 2005.

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Rs 1 000 million to the Indian Institute of Science in Bangalore to bring its science base up to a par with the best in the world; new Millennium Indian Technology Leadership Initiatives to boost the capacity for innovation in new technologies of the Council for Scientific and Industrial Research (CSIR); a National Innovation Foundation to be run by the Department of Science and Technology (DST); and two major schemes devised by the DST to promote the commercialization of research results and provide venture capital for economically viable technologies and R&D processes developed in national laboratories.

Indian efforts to promote S&T over the past decade have contributed to the country's emergence as an important 'knowledge power' in the global economy. While inaugurating a ceremony to celebrate India's prestigious Shanti Swarup Bhatnagar Awards in New Delhi in 2004, the prime minister proudly observed that India ranked 24th out of 192 (Rand Corporation Classified) scientifically proficient nations. Much of this is due to achievements in the four main science-based knowledge sectors: space technologies (including aerospace); ICT software; biotechnology; and drugs and pharmaceuticals.

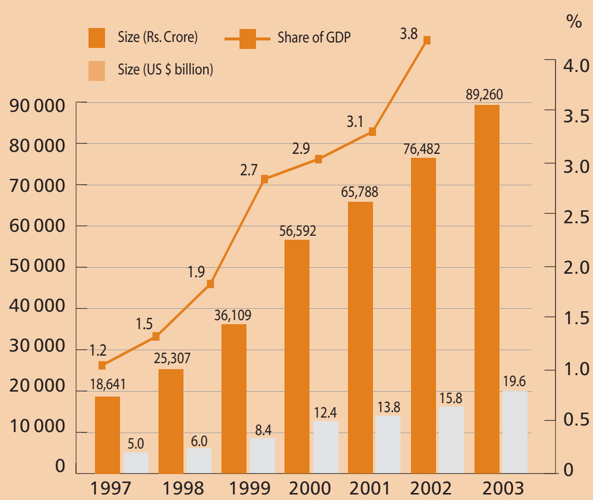
The heyday of Indian space research can be traced back to the launch of the Indian National Satellite System (INSAT) in the early 1980s with a unique system combining telecommunications, TV broadcasting, meteorology and disaster warning. Today, INSAT has become one of the largest satellite systems in the world. Over the years, India has developed sophisticated, high-tech capabilities endogenously in the design and construction of satellites, ground stations, rockets and satellite launch platforms, as well as in software and hardware electronics and telecommunications. In 2000, India launched the third generation INSAT 3B satellite; in 2001, the Polar Satellite Launch Vehicle (PSLV), capable of launching satellites of 1 000–1 200 kg into the 820km polar sun-synchronous orbit; and, from 2001 onwards, the Geosynchronous Satellite Launch Vehicle (GSLV), which can put satellites into approximately 180 x 32 155km geo-synchronous transfer orbit. The PSLV-C2 version has launched two small satellites, one off the Republic of Korea and another off Germany, along with India's IRS-P4 in May 1999. Among other significant launches mention may be made of the educational network satellite (EDUSAT) successfully launched on 20 September 2004 from the GSLV platform at Sriharikota, and the CARTOSAT-1 and HAMSAT satellites for mapping and radio networks launched successfully from the PSLV platform at Sriharikota on 5 May 2005.

India's **space research** in the past five years has come to play a major social and economic role: 85% of India's 1 billion plus population now has access to television via the INSAT system. INSAT can also track weather patterns and contribute to early warning of natural disasters. The INSAT system has become an important educational tool for addressing the mass illiteracy problem by offering *in situ* training for industrial workers and agricultural farmers. Space research systems are contributing to natural resource management and to tracking groundwater and mineral resources. India is now set to lend its space technological capabilities to the commercial launching of satellites. Already, it is playing an important role in the region through its commercial wing, the ANTRIX Corporation Ltd. This provides telemetry, tracking and command (TTC) support services, in-orbit test and support services, specialized training and various other types of services and technical consultancy related to space systems, technology and applications. The company made steady, significant progress over the years in terms of financial performance, with sales turnover exceeding Rs 3 billion.

Closely related to space technology is aerospace research and innovation. The launch of the endogenously built civilian aircraft model, SARAS, and light combat aircraft in the past three years offers further testimony to progress in this field.

The second sector to have changed the image of India abroad in recent years is ICT, and specifically the **software** sector. It is no accident that the *New Scientist* refers to India in its issue of 19 February 2005 as emerging as 'the next knowledge superpower', drawing much of its evidence from the ICT software sector. Whereas more than 100 of the Fortune 500 firms have already set up R&D antennae in ICT and other high technology areas in India in the past five years, Indian software companies in 2005 are providing all kinds of IT services (known as business process outsourcing and IT-enabled services) to 400 of these premier global firms. Currently, about 3 000 IT companies are exporting to over 150 countries around the world. As Figure 5 shows, India's software market has quadrupled in six years to US$ 20 billion in 2004, accounting for about 3.82% of India's GDP, compared with 1.22% in 1998. India's software exports are estimated to rise from the current US$ 12.5 billion to US$ 30 billion by 2008. Contrary to common wisdom about the Indian software sector, which is viewed as being driven solely by global production networks and exports, these figures clearly indicate the rapid evolution of India's domestic IT market. The market is undoubtedly a key factor in the development and growth of the IT software sector but government efforts and those of non-governmental organizations (NGOs) to bridge the digital divide have generated encouraging results in the past decade.

Figure 5
INDIA'S IT INDUSTRY AND MARKET, 1997–2003



Source: NASSCOM.

The M.S. Swaminathan Foundation in Chennai has developed a model for a 'bio-village', where information technology is introduced to help rural people develop communication skills and add value through knowledge to agricultural systems, bio-resource and biotechnology. Among other important developments, some of the most recent are the development and commercialization of SIMPUTER, an Indian-made simple, cost-effective computer which can be held in the palm of the hand and which is priced at less than $US 150; a second example is a laptop with a purchase price of less than US$ 200. These products are the result of public–private partnerships in ICT to help the poor access and benefit from the information revolution.

The domestic IT market in India owes its rapid growth to big e-governance projects launched by both the central government and various state governments; these have been designed to computerize revenue and taxation, land records, motor vehicle registration and the issue of licences, payrolls and salary disbursements, transport networks and so on. Further, as R.A. Mashelkar, FRS, the Director-General of CSIR, observed in an interview with Gurusonline TV in February 2005, 'in the last three years, Indian exports have increased tremendously not only because of the cost advantage but mainly due to quality aspects. India's basic strength arises from the quality of its human resources'. There are about 4 000 IT training centres (1 700 of which are privately owned) and 1 208 engineering colleges imparting education in IT and related engineering fields. Currently, about 290 000 engineering professionals are employed in firms and institutions in India. According to a survey published by the *India Times* News Network on 16 June 2005, the IT industry has witnessed rapid growth of other software and service employees, whose numbers tripled to 697 000 between 2001 and 2004.

The third sector to have drawn sharp attention in the last five years is the Indian **pharmaceutical industry**, which is said to be the fifth largest in the world after those of the USA, Japan, Europe and China in terms of the volume of production; the Indian pharmaceutical industry accounts for 8% of

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the world total (Lalitha, 2002). Some 350 of the 550 bulk drugs are currently produced in India and the country is self-sufficient in every essential drug. One important indicator for the success of this sector can be seen from the trend in exports. The industry moved from a negative balance of trade in the late 1980s to a positive balance of trade of Rs 39 060 million by the late 1990s and Rs 65 000 million in the year 2003, according to the Indian Drugs Manufacturing Association. In a large measure, the relative success of this sector can be attributed to the uniqueness of the Indian Patent Act of 1971, which until 2005 (see page 252) had given protection to process patents for seven years (compared with the product-based 20-year period of patent protection elsewhere) to encourage what is known as 'reverse engineering' (see also Lalitha, 2002; Ramani, 2002). This enabled the country to indigenize almost all the essential drugs by building S&T capabilities in chemical and drug research in government research laboratories and firms; meanwhile, the requisite human resources were gleaned from the expansion of higher education.

One important feature of the Indian pharmaceutical sector has been the evolution of technological capabilities. These have passed through the successive stages of technology support, technology development (based on reverse engineering), building up capabilities for drug discovery, and the exploitation of the innovation base for the purposes of commercialization. If Indian-invented US patents and Patent Cooperation Treaty (PCT) applications are taken as one key indicator of success in recent years, it is edifying to learn that more than 70% of the 300 US patents in pharmaceuticals granted from the 1990s to 2002 were issued to Indian firms and institutions. On the other hand, the number of PCT applications doubled from 1 099 in 1998 to over 2 000 for the period 2000 to 2003 (see also Lalitha, 2002; Hirwani, 2004). More than half of these patents and PCT applications are accounted for by government laboratories, a sign of the crucial role played by public research in the Indian context. The most important development in the past decade has been the emergence of over a dozen Indian pharmaceutical and biopharmaceutical firms. These are involved in R&D activities, as demonstrated by their patenting and drug manufacturing activities showing increasing technological sophistication. For instance, an Indian company recently offered an anti-HIV 'cocktail' for the price of US$ 300, compared with US$ 10 000 in the marketplace.

The fourth sector of note is one that is increasingly meshing with the drugs and pharmaceuticals industry, namely **biotechnology**. In many ways the biotechnology industry follows the development of new software. Created in the early 1980s, the Department of Biotechnology (DBT) has been the main driver of the biotechnology sector in that it has been at the forefront of efforts to develop human resources and generate public funds for research. Government funding for the sector increased about fourfold between the late 1990s and 2004. Currently, more than 60 universities offer postgraduate courses in biotechnology and related programmes and about half of these are funded by the DBT through the creation of specialized chairs and infrastructural facilities for research. In addition to this, the DBT supports doctoral and postdoctoral fellowships for students in India and studying at foreign universities, mostly in the USA, as part of its support to frontiers in biotechnology.

The DBT has given top priority to developing the human resources base in biotechnology. The Vision Document published by the DBT in 2001 underlines the importance of training 1 000 additional professionals per year for the next ten years to generate a professional workforce of 15 000 to 20 000, in order to meet the growing demands of the sector. Between 1991 and 2002, the number of research publications and patents in the biotechnology sector doubled (Kumar *et al.*, 2004; TIFAC, 2004). Over the same period, the government budgetary allocation to DBT increased almost fourfold, from Rs 740 million in 1991 to about Rs 2 800 million in 2004 (Department of Biotechnology, New Delhi).

Other science agencies, such as the CSIR, Indian Council of Medical Research, Indian Council of Agricultural Research, DST and Ministry of Forests and Environment, are supporting

Indian Institutes of Technology

India boasts seven Indian Institutes of Technology (IITs), in Kharagpur, Mumbai (Bombay), Chennai (Madras), Kanpur, New Delhi, Guwahati and Roorke. The IITs run departments offering programmes of study in both engineering and pure sciences to ensure that future engineers acquire a thorough grounding in the basic sciences. Programmes are also proposed in interdisciplinary areas. All seven IITs conduct sponsored basic and applied research and offer industrial consultancy services to the public and private sectors, including a number of multinational companies. They also engage in collaborative research with leading domestic and foreign universities (including institutions in Bangladesh, Canada, Germany and the UK). Examples of research centres run by the IITs are the Centre for Robotics, Centre for Laser Technology and Advanced Centre for Materials Science (IIT Kanpur), and the Composites Technology Centre and Biotechnology Research Centre (IIT Chennai).

The IITs concentrate some of the most promising talent in the country. Fewer than 1% of the 250 000 hopefuls obtain a place each year, an acceptance rate that excludes all but the most excellent students and explains why US universities are so eager to recruit IIT students for their own campuses. In comparison, the acceptance rate is more than 10% for the best US universities (Rajghatta, 1999).

The information revolution has made millionaires of many former IIT students. It has also earned them an international reputation for excellence. In 2000, IITs occupied five of the first eight places in a survey by *Asiaweek* magazine of S&T universities in Asia (Table 3).

IIT graduates are today the object of intense courtship by US universities, which woo them with the lure of scholarships, a housing allowance or a paid internship in an American company. The strategy would appear to be working: an estimated 20 000 IIT graduates are living in the USA alone, about 20% of all graduates produced by the institutes since their inception 50 years ago. According to *Businessweek* magazine published in the USA, as many as 30% of IIT Madras graduates headed for the USA in 1998. This brain drain is now being counterbalanced by the return of professionals to India (a form of brain gain and brain circulation) to surf the on-going revolutions in ICT and biotechnologies. According to one estimate (interview with a professor at the IIT Delhi, 5 July 2005), these professionals together with Indian-owned companies from Silicon Valley, USA, are reported to have created approximately about 200 small- and medium-sized start-up businesses in Bangalore, Hyderabad, Pune, Delhi and other Indian cities.

There are plans to inject US$ 1 billion into the IITs to improve their infrastructure and the quality of research. This is the amount considered necessary to extend the reach of the IITs to a greater number of hopefuls and bring faculties up to the standard of the best universities in the USA, such as Harvard and the Massachusetts Institute of Technology (MIT). Partial funding is expected to come from IIT alumni in the USA and elsewhere. Although this may be a novel approach for the IITs, it is common practice for Harvard and the MIT, which have long since discovered that wealthy alumni make generous benefactors (Goel, 2000).

At the first Global IIT Alumni Conference in January 2003, organized in the heart of Silicon Valley in the state of California (USA), Bill Gates, Chairman of Microsoft Corporation, gave the inaugural address. The second Global IIT Alumni Conference is also scheduled to take place in the USA, in Washington, DC in May 2005. The

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declared goal of the conference is to foster joint research between the IITs and US industry, academia and government, promote networking among alumni and 'to help IITians give back to their communities' (see www.iit2005.org).

Table 3
THE TOP 20 S&T UNIVERSITIES IN ASIA, 2000

Ranking	Country/ territory	University
1	Republic of Korea	Korea Advanced Institute of Science and Technology
2	Republic of Korea	Pohang University of Science and Technology
3	India	Indian Institute of Technology, Bombay
4	India	Indian Institute of Technology, Delhi
5	India	Indian Institute of Technology, Madras
6	Japan	Tokyo Institute of Technology
7	India	Indian Institute of Technology, Kanpur
8	India	Indian Institute of Technology, Kharagpur
9	Singapore	Nanyang Technological University
10	Taiwan of China	Taiwan University of Science and Technology
11	Japan	Science University of Tokyo
12	Hong Kong	Hong Kong Polytechnic University
13	Japan	Nagoya Institute of Technology
14	India	University of Roorkee
15	China	University of Science and Technology of China
16	Japan	Muroran Institute of Technology
17	China	Beijing University of Posts and Communications
18	China	Huazhong University of Science and Technology
19	India	Birla Institute of Technology and Science
20	Pakistan	National University of Sciences and Technology

Note: Universities were assessed by *Asiaweek* magazine according to five criteria: academic reputation, student selectivity, faculty resources, research and financial resources. *Asiaweek* discontinued publication after 2000.

Source: *Asiaweek*: http://www.asiaweek.com/asiaweek/features/universities2000/index.html

various biotechnology-based programmes in agriculture, medical, environment and other related areas which, in budgetary terms, double the amount invested in S&T via the DBT. In the past five years, the most significant development in the biotechnology sector has been the evolution of three main high-technology knowledge-based 'biotech clusters', in Bangalore, Hyderabad (known as Genome Valley) and Delhi. Here, public–private partnerships have given rise to biotechnology venture funds to develop these clusters. India's major universities and government-supported laboratories are located in these cities, all of which have initiated long-term R&D programmes in all fields of biotechnology.

The development of biotechnology clusters reflects a 'Triple Helix', that is, a tripartite partnership between government, university and industry, in this case to foster innovation in biotechnology and thereby advance both scientific and social goals. Whereas D. Balasubramanian, India's leading biologist, characterizes Hyderabad as 'the hub of biotechnology activity' (*Asia-Pacific Biotech News*, 21 February 2000), the founder CEO of Biocon Inc. in Bangalore, Kiran Mazumdar-Shaw, underlines the fact that 'the combination of Karnataka's entrepreneurship and the Andhra government's vision, strategic direction and support give India a very strong profile' in biotechnology (*BioSpectrum*, December 2003). (Karnataka is a state of southern India.)

India's biotechnology market is estimated to be worth around US$ 2.5 billion currently and could quadruple by 2010, creating one million jobs in the process. According to one estimate, there were about 25 000 biotech workers in India in 2005 (*Yahoo! India News*, 11 July 2005). The DBT-supported Biotechnology Consortium of India (BCI) groups 176 biotechnology firms, 49% of which are active in agriculture, 25% in health and 26% in environmental biotechnology; this qualifies the Indian biotechnology sector as one of the most prominent in the Asia–Pacific region, together with those of Australia and China/Hong Kong (Ernst & Young, 2004). India's biotechnology industry is however not confined to the market end of the S&T spectrum: it is also strongly oriented by health and welfare needs.

India's new patent ordinance

The new ordinance amending the Indian Patents Act of 1970 came into effect on 1 January 2005. India now conforms to the Trade-Related Intellectual Property Rights (TRIPS) Agreement of the World Trade Organization (WTO). India's previous Patent Act had not allowed product patents in drugs, food and chemicals but only process patents in these fields for up to seven years. The most significant changes brought about by the new ordinance are as follows:

- It extends product patents for all fields of technology, including medicine, food and chemicals, offering 20 years' protection. The ordinance eliminates exclusive marketing rights (EMRs), which were providing patent-like protection without the grant of patents. It also allows for the patenting of software that has a technical application; thus, embedded software can now be patented.
- It provides that 'mere new use' for a known substance cannot be patented.
- It also strengthens patent opposition proceedings by allowing for both pre-grant and post-grant opposition. The processing time limits for examination of patents have also been reduced from 48 months to 36 months.
- It has a provision for granting compulsory licences for export of medicines to countries that have insufficient or no manufacturing capacity, to meet emergent public health situations (in accordance with the Doha Declaration on TRIPS and Public Health). This means that Indian companies will be able to produce and export AIDS drugs to African and South-East Asian countries.
- Another modification is the introduction of a provision making patent rights for mailbox applications available only from the date of granting the patent and not retrospectively from the date of publication. This will save many Indian companies from being attacked for infringement of patent law by multinational companies which might otherwise have obtained patents for drugs that Indian companies had already put on the market.
- There is also concern that domestic pharmaceutical and agricultural sectors will be affected, as the new ordinance will make it possible for multinational corporations (MNCs) to dominate the Indian economy. However, 97% of all drugs manufactured in India are off-patent and so will remain unaffected. These include all life-saving drugs, as well as medicines for daily use to treat common aliments.
- The ordinance also has a provision for outright acquisition of the patent to meet national requirements.

The ordinance will encourage Indian pharmaceutical companies to emphasize R&D-based innovative growth. The Indian pharmaceutical and biotech industry offers huge scope for the outsourcing of research. Now with the right legal framework in place for the protection of the results of that research, India could become a global research hub.

Source:
http://iplg.com/resources/articles/india_new_patent_ordinance.html

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Much of the impact of India's recent efforts in biotechnology can be seen in the medical sphere. Indian biotechnology attracted global attention recently when a group of public science institutions which included CSIR laboratories and private firms (Shanta Biotechnics in Hyderabad, Bharat Biotech and the Serum Institute of India) developed three vaccines for hepatitis B in 2000–01 to bring down the price of the imported vaccine from US$ 16 per dose to US$ 0.50 in India (Kumar *et al.*, 2004). This followed the commercialization of an anti-leprosy vaccine in 1997–98.

The strength of the Indian biotechnology programme in the area of health has been quite remarkable. Eight other vaccines are currently under development and at various stages of clinical trials. These vaccines target cholera, fertility in humans and animals, rota-viral diarrhoea, Japanese encephalitis, rabies, tuberculosis, malaria and, most significantly, HIV AIDS. These vaccines are likely to be commercialized by 2006–07, according to the DBT in New Delhi.

Other successful examples of the biotechnology programme for health are the development by private firms of recombinant therapeutics for anaemia, diabetes, visceral leishamaniasis, cancer and cardiovascular diseases. In the area of diagnostics, kits have been developed for HIV-1, HIV-2, hepatitis C and neurocysticercosis.

Pakistan

Much of R&D in Pakistan is undertaken by the country's 37 public universities and 110 research institutes. GERD is invested mostly by the government, the private sector playing only a residual role. In Pakistan, S&T has witnessed unprecedented support from government in the form of growing R&D budgets since President Musharraf took the reins in 2000. S&T has been legitimized primarily through the recommendations of the National Commission for Science and Technology, organized in May 2000 under the executive authority of the President. This commission by and large endorsed the priorities for S&T laid down earlier in the country's Ninth Five-Year Plan covering 1998–2003 (Naim, 2005). For instance, between 1999 and 2004, while overall S&T expenditure climbed from 0.28% to 0.51% of GDP, GERD more than doubled, from 0.11% to 0.24% of GDP. The most notable increase was in R&D expenditure on higher education, which grew nearly fourfold from around 530 to 2 000 million Rupees (PKR).[2] In this connection, it is interesting to note that Pakistan's National University for Science and Technology figured in the top 20 Asian universities in 2000 (Table 3).

As Table 5 shows, support since the arrival of the new regime has focused on four areas: agriculture, health, engineering and defence and industrial research. Even though Pakistan's support for R&D and higher education has improved considerably in the past five years, it still has one of the lowest ratios of scientists and engineers (69) per million inhabitants, after Bangladesh (51) and Nepal (40) (Table 2). Even though these figures relate to 2000, the situation remains unchanged in 2005. It is for this reason that the government has accorded top priority to higher education, as revealed by the recent budget increase and by the initiation of four major programmes by the Ministry of Science and Technology in 2001 to increase enrolment in the full spectrum of scientific disciplines from 60 to 700

Table 4
CENTRES OF EXCELLENCE IN PAKISTAN, 2004
By field

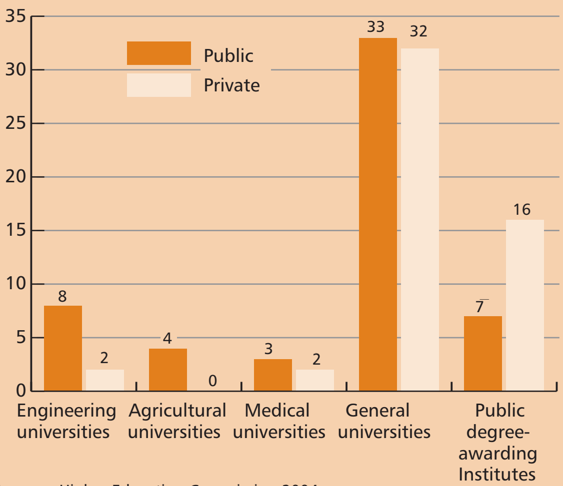
Subject	University
Analytical chemistry	Sindh
Mineralogy	Balochistan
Geology	Peshawar
Marine biology	Karachi
Solid-state physics	Punjab
Water resource engineering	Engineering and Technology
Psychology	Quaid-I-Azam
Physical chemistry	Peshawar
Advanced molecular biology	Punjab

Source: Pakistan Council for Science and Technology (PCST).

2. 59 Pakistan Rupees (PKR) were equivalent to US$1 in June 2005.

SOUTH ASIA

Figure 6
UNIVERSITIES AND DEGREE-AWARDING INSTITUTES IN PAKISTAN, 2004
By broad field

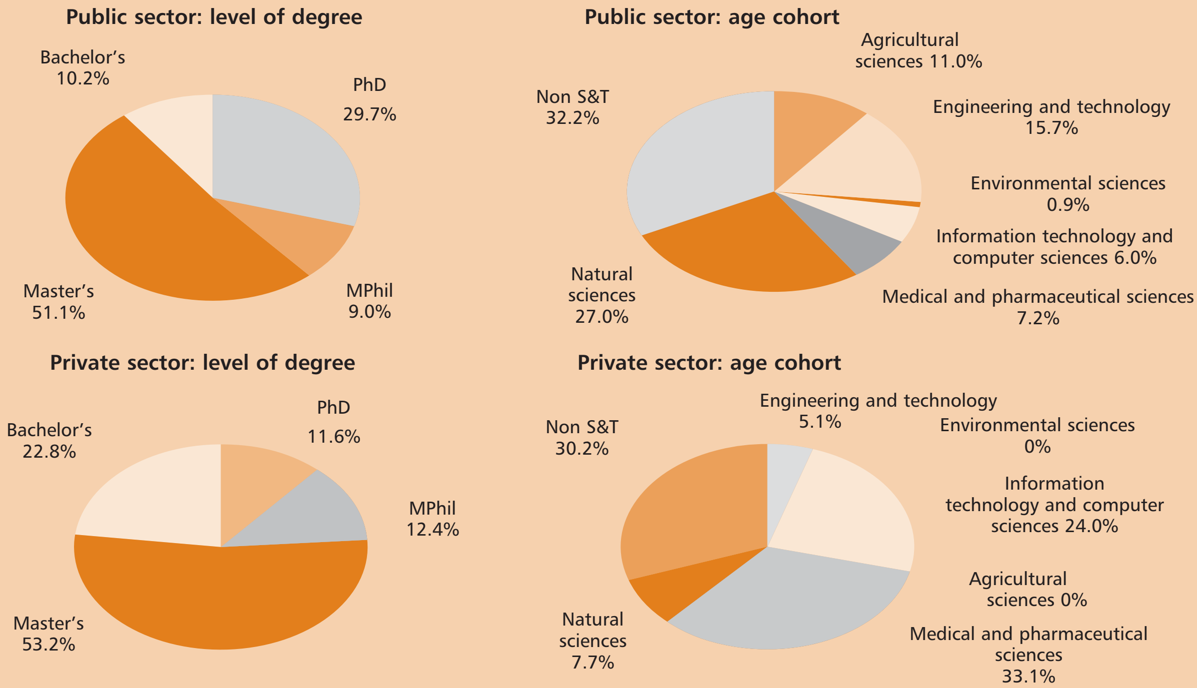


Source: Higher Education Commission 2004 http//www.hec.gov/htmls/hei/collunilist.htm as given by PCST.

PhD candidates per year. Another sign of the priority accorded higher education can be seen in the growth in the number of universities, particularly private universities, from 33 in 1997 to 107 in 2004 (Naim, 2005).

Apart from higher education, the major focus of the government's S&T policy in the past five years has been centred on three main fields: biotechnology, IT and engineering. In the field of modern biological sciences, two national laboratories have been set up in the past few years, the National Institute of Biotechnology and Genetic Engineering (NIBGE) and the Biomedical and Genetic Engineering Laboratories (BGEL). These join the existing Centre for Advanced Molecular Biology at the University of Punjab, dating back to 1981 (Table 4). The NIBGE has accomplished the major achievement of finding a solution via biotechnology for eliminating cotton leaf-curl virus, which plagued the cotton industry. The NIBGE has also successfully used microbes to detoxify

Figure 7
HUMAN RESOURCES IN S&T IN PAKISTAN, 2004



Source: Higher Education Commission 2004: http//www.hec.gov/htmls/hei/collunilist.htm and PCST, Islamabad, Pakistan.

THE STATE OF SCIENCE IN THE WORLD

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Table 5
GERD IN PAKISTAN BY FIELD, 1998 AND 2001
In millions of rupees

Field	1998	2001
Agriculture, Livestock and Fisheries	1 368.44	1 766.81
Health	113.04	126.26
Engineering and Technology	77.18	185.49
Industrial Research	244.14	531.76
Forestry	52.94	58.31
Telecommunications	21.29	21.50
Housing and Works	83.51	26.45
Earth Sciences	28.88	39.45
Energy	38.81	41.36
Irrigation and Water Resources	28.75	27.78
S&T Services	10.20	22.20
Science Promotion	11.75	17.27
S&T Policy	6.31	36.50
Defence	95.47	161.27
Transport and Communications	11.09	14.73
Meteorological Sciences	3.93	4.37
Ocean Resources and Marine Sciences	12.23	13.75
Total	**2 207.97**	**3 095.23**

Source: PCST.

effluent and manage waste and to tackle problems related to dyes and chemicals. For its part, the BGEL has identified 20 genetic loci responsible for blindness, deafness and other disorders and perfected DNA-based typing of transplantation antigens for organ transplants. The reputation of the BGEL has been further enhanced by the high citation rate of its papers in international journals (Naim, 2005).

Sri Lanka

According to an R&D survey conducted by the National Science Foundation in Colombo, GERD amounted to $US18.1 million, or 0.19% of GDP, in 2000. This figure was no different in either 1996 or 2004, indicating a relative stagnation of the country's R&D effort. The continuing civil war, coupled with the tsunami disaster in December 2004, has prevented Sri Lanka from making any marked progress in S&T over the past five years. Even though Sri Lanka counts an impressive number of scientists by South Asian standards (191 per million inhabitants in 2004, see Table 2), this figure has again remained static since 1996.

The stagnation in R&D budgets is clearly reflected in the hesitation among students to enrol in postgraduate programmes at university. Whereas the number of science postgraduates more than doubled, progressing from 181 to 439, between 1999 and 2003, the field of engineering experienced ups and downs over the same period, including a massive decline in a single year from 313 to 32, in 2002–03 (Table 6). The situation is more contrasted when we examine the number of graduates between 1995 and 2001: growth in science (from 844 to 1 264), engineering (458 to 548) and medicine (442 to 904) but relative stagnation or even decline in the dental, veterinary and agricultural fields.

The main signs of progress in S&T in Sri Lanka over the past five years are the growing numbers of PhD holders working in universities (719) and R&D institutes (180) and the international publications coming out of Sri Lanka. According to the aforementioned National Survey on R&D, the country published 120 papers in all S&T fields in 1994 which had dropped to 87 by 1996 but picked up again to 164 by the year 2000 (Samarajeewa, 2003; Wickremasinghe and Krishna, 2005).

Table 7 lists the leading R&D institutes in Sri Lanka. As this table shows, more than 60% of these 19 institutions are engaged in agriculture and related areas of research. This figure assumes importance when one considers that 42% of Sri Lankan GDP is derived from agriculture. Despite the importance of biotechnology and modern biological sciences for agriculture and medical research, Sri Lanka has not managed to bolster these leading institutions over the past decade. This is reflected both in staffing levels and in the current R&D expenditure of these institutions. The response of a leading Sri Lankan molecular biologist interviewed in 1999 still holds good six years later; he observed that 'the record of postgraduate research degree programmes in local universities appears indeed dismal'.

The overall picture that emerges from the data is that 'Sri Lanka does not possess the critical mass of

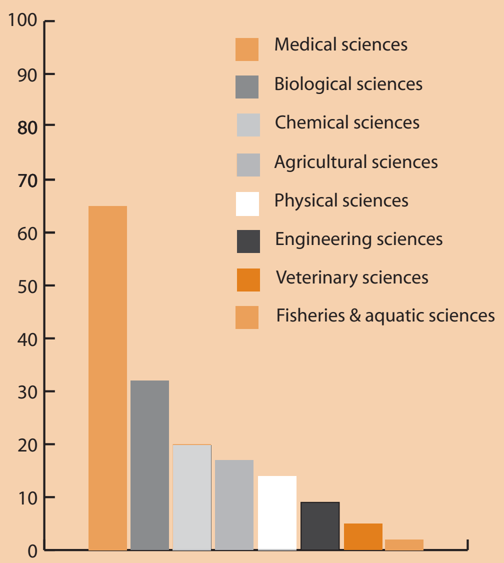
Table 6
ENROLMENT OF POSTGRADUATE UNIVERSITY STUDENTS IN SRI LANKA, 1999–2003

Year	Science	Agriculture	Engineering	Architecture	Medicine	Dental	Veterinary	Total
1999	181	0	115	76	102	2	0	476
2001	286	55	168	0	14	0	0	523
2003	439	41	32	27	43	1	1	584

Source: University Grants Commission (2004) *Sri Lanka University Year Book 2003/2004*. Colombo; National Science Foundation (NSF), Colombo.

bio-science/biotechnology personnel with adequate levels of training to engage in productive R&D activity in biotechnology' (Karunanayake, 1999, p. 306). There are just two or three research groups in modern biology at the University of Colombo and other institutions running postgraduate programmes. The lack of an adequate science and innovation base for this frontier area of biology in half of the leading research institutes is likely to have serious

Figure 8
INTERNATIONAL CO-PUBLICATIONS INVOLVING SRI LANKAN AUTHORS, 2000
By subject area, in numbers



Source: National Science Foundation (2000) *National Survey on R&D*. NSF, Colombo

Table 7
LEADING PUBLIC R&D INSTITUTIONS IN SRI LANKA, 2004

Name of institution	Scientists/ engineers	R&D expenditure (Rs million)*
Horticultural Research & Development Institute	64	0.4
Farm Crops Research & Development Institute	36	34.1
Rice Research & Development Institute	17	23.8
Regional Agricultural Research Centre	13	6.2
Rubber Research Institute	38	100.0
Tea Research Institute	46	154.4
Coconut Research Institute	34	110.0
Sugarcane Research Institute	19	–
Institute of Post Harvest Technology	12	10.2
Hector Kobbekaduwa Agrarian Research Institute	30	48.0
Veterinary Research Institute	29	40.4
National Engineering Research & Development Centre	47	101.7
Arthur C. Clarke Institute of Modern Technology	22	13.4
National Building Research Organization	52	12.1
Institute of Fundamental Studies	31	40.2
Industrial Technology Institute	67	80.0
Ceramic Research & Development Centre	7	4.6
Medical Research institute	20	2.8
Bandaranaike Memorial Ayrvedic Research Institute	17	44.7
Total	**601**	**827.0**

* 100 Sri Lanka Rupees were equivalent to US$1 in June 2005.

Source: NSF, Colombo.

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repercussions for the relevance of such institutions to the Sri Lankan economy, dependent as it is on plantations and connected industries.

In the area of industrial research, the scene is dominated by the Industrial Technology Institute (ITI, created in 1955 as the Ceylon Institute of Scientific and Industrial Research) and the National Engineering Research and Development Centre (NERDC). In 2004, the ITI and NERDC together employed 124 scientists and engineers. The institute's major problem has been the lack of highly trained scientists with postgraduate degrees. The work of these institutions relates mainly to small industries and quality control, testing and industrial trouble-shooting. It is this latter component, which has grown over the past few years, that is worrying, in that it is driving the ITI and NERDC away from R&D programmes. According to the National Intellectual Property Office of Sri Lanka, the number of patents granted annually to residents between 1995 and 2002 remained stable at about 55–62 on average. A recent study shows that, whereas individual inventors claimed 72% of patents and private institutions 22% in 2000, just 6% went to public institutions. Moreover, the same study demonstrates that the majority of patents were granted for small technologies (Amaradasa and de Silva, 2002).

Bangladesh

The S&T effort of Bangladesh has been quite dismal in the decade to 2004, with a GERD/GDP ratio of just 0.01%. However, some confusion surrounds this figure, the one cited in international data bases and national sources. The official figure is disputed by a leading technology management expert from Bangladesh who puts it at 0.22% in 2005. Much of the country's strength in S&T derives from 21 universities and a handful of leading science agencies, such as the Bangladesh Rice Research Institute (BRRI) and Bangladesh Council for Scientific and Industrial Research (BCSIR).

Among the 21 universities in Bangladesh, 16 are devoted mainly to teaching, the remainder being considered as both teaching and research universities. According to output data available for 11 universities for 2003, there were over 16 000 graduate students from fields that included the natural, engineering and social sciences. Of these, 3 000 had obtained their degree in engineering and medical sciences. There were an estimated 1 368 postgraduates in S&T fields coming out of universities in 2003 (Islam, 2005).

In Bangladesh, the main strength of R&D has been in the 14 leading R&D institutions shown in Table 8. They employ 2 785 scientists and engineers. A consequence of the low level of R&D funding available for public research is that the proportion of PhD holders in the total S&T human resource base has been declining quite rapidly. For instance, the BCSIR employed 7.5% of PhD holders in 1986 but only 3.71% in 2004, a state of affairs only too familiar to other R&D organizations.

Table 8
LEADING PUBLIC R&D INSTITUTIONS IN BANGLADESH, 2003

Name of institution	No of scientists/ engineers	No. of technicians
Bangladesh Agricultural Institute	780	84
Bangladesh Jute Research Institute	280	189
Soil Resources Development Institute	125	19
Bangladesh Tea Research Institute	45	19
Bangladesh Space Research and Remote Sensing Organisation	60	39
Bangladesh Forest Research Institute	125	79
Bangladesh Livestock Research Institute	120	67
Institute of Postgraduate Medicine and Research	280	400
International Centre for Diarrhoeal Research	226	150
Atomic Energy Research Establishment	287	204
Bangladesh Council for Scientific and Industrial Research	345	320
Bangladesh National Scientific Documentation Centre	14	12
Institute for Nuclear Medicine	35	9
River Research Institute	63	80
Total	**2 785**	**1 671**

Source: BANSDOC, Dhaka and from individual institutions.

Among science bodies, the role of the BRRI has been central to Bangladeshi agriculture. The BRRI has developed and released 31 modern varieties of rice in the past two decades. Annual rice production (the main staple food) more than doubled between 1970 and 2002, from 10.8 million metric tonnes to 24.3 million metric tonnes. Without the BRRI's modern varieties, rice production would have increased by just 10% over this period. The contribution of modern rice varieties developed by BRRI has therefore been substantial and today accounts for 65% of total rice production.

The BCSIR is a major civil R&D institute; it patented 280 processes between 1972 and 1995 but could only transfer 40 of these to industry. There is a problem with commercializing technology developed by the BCSIR, caused by a lack of perceived need in industry, a small market size and inadequate upscaling from the point of commercial success. Domestic research efforts have mainly contributed to cottage and small industries. Even here, their implementation suffers from the absence of linkages among research institutions on the one hand and between research institutions and entrepreneurs on the other (Islam and Haque, 1994, p. 208). The BCSIR's work is often confined to trouble-shooting industrial work (Haque and Islam, 1997). There are no long-term R&D programmes and the BCSIR's links with universities are almost non-existent. As the recent study by Islam (2005) shows, these problems still persist in the case of BCSIR and current investment in R&D by the government is hardly sufficient to develop any worthwhile technology-based programmes. The major weakness is reported to be an acute shortage of human resources coupled with the lack of a policy strategy to revamp the R&D sector with an infusion of funds commensurable with the growing demands of industry.

Nepal

In Nepal, there are an estimated 12–15 000 working scientists and engineers but R&D remains a marginal activity (Bajracharya and Bhuju, 2000). S&T has yet to receive the priority it deserves in government policies and programmes. The establishment of a Ministry of Science and Technology in 1996 was cause for lively public debate, with some commentators considering the separate ministry a luxury that Nepal could not afford. The government stood its ground, enabling the Ministry of Science and Technology to join the ranks of the Royal Nepal Academy of Science (RONAST, established in 1982) and the Ministry of Population and Environment (1995).

Other recent institutions are Kathmandu University, the Centre for Renewable Energy, the Nepal Health Research Council and the Agricultural Research Council (all dating from 1991), the Environmental Protection Council (1992), Nepal Engineering College and Manipal College of Medical Sciences (1994), the Kathmandu, Nepal and Nepalgunj Medical Colleges (1997) and, since 1998, Kantipur Engineering College (Bajracharya and Bhuju, 2000). In 1998, RONAST and the Ministry of Science and Technology began preparing a 20-year plan for the development of S&T in Nepal.

The Ninth Plan (1997–2002) recognizes, more than earlier government pronouncements, the importance for the country's S&T effort of new technologies, particularly biotechnology and IT, and of increasing productivity through the application of S&T in various sectors. In 2000, Nepal formulated its Information Technology Policy: 2057, with the main objectives of making IT accessible to people at large and creating employment; building a knowledge-based society; and establishing knowledge-based industries. In a primarily agrarian economy, S&T policies have also stressed the application of biotechnology to agriculture and animal husbandry.

Given the agrarian base, in 2003–04, efforts to articulate national biotechnology policy gained currency. Despite the positive S&T policy discourse at the national level, the country had not witnessed any significant increase in the GERD/GDP ratio in the 1990s. This has all changed in recent years, however, with expenditure at a record high of 0.26% of GDP by 2004 (double the figure in 1985).

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This level of R&D funding is much higher than that of 0.01% for Bangladesh.

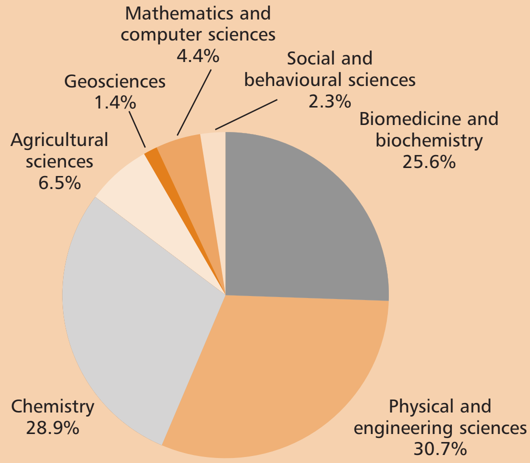
Iran

With oil representing a major source of national wealth in Iran, S&T has only recently been placed high on the agenda for industrial development. The first development plan (1988–93) was a focused attempt to build local S&T infrastructure and implement strategic projects in agriculture and oil industry-related areas. This support for S&T has been pursued in the government's Third Socio-Economic Development Plan 2000–04. One of the major outcomes of this plan is the establishment of a Ministry of Science and Technology.

The GERD/GDP ratio has more than tripled in Iran in recent years, from 0.15% in 1985 to 0.50% in 2002. Much of this has gone on building up local technical capacity and engineering education. The 61 tertiary institutions in the country also incorporate the medical faculties in the main universities. The growing S&T effort in the past decade and particularly in the last Five Year Plan mentioned above has enabled the country to make its presence felt in the international sphere, as depicted in Table 9 and Figure 9. The number of SCI-based publications by Iranian scientists has witnessed a more than threefold increase in just five years, from 400 in 1995 to 1 400 in 2000. More than 80% of these publications are distributed equally among the three broad fields of biomedicine and biochemistry, physical and engineering sciences and chemistry. There are several factors responsible for the notable increase in the number of science publications in recent years: the war's end, better economic conditions, the recent changes in the government's policy for research funding, basic changes in the political environment brought about by the reformers, expansion of the Iranian presses for national journals and the recent return of a large number of students trained overseas on government scholarships. External factors also account for the increased productivity, such as the acceptance of three Iranian source journals by the SCI; greater access to international databases through the Internet; and better electronic communication facilities for international collaboration (Osareh and Wilson, 2002).

Iran has had its ups and downs in terms of scientific endeavour. The main problems hampering the growth of national scientific communities are the lack of recognition of science as a social institution requiring a certain degree of autonomy and a space for critical discourse; the lack of international mobility for scientists; and a sense among scientists

Figure 9
SCIENTIFIC PUBLICATIONS IN IRAN, 1995–99
By field



Source: based on Osareh and Wilson (2002).

Table 9
IRANIAN PUBLICATIONS CITED IN SCI*, 1978–2000

Year	Number of publications
1978	610
1985	180+
1995	400
1998	1000+
2000	1400

*Science Citation Index of Institute of Scientific Information (ISI-Thomson) in Philadelphia, USA.

Source: based on Osareh and Wilson (2002).

SOUTH ASIA

of isolation. As one Iranian scientist put it at a recent seminar:

> *'Iran's failure is all the more surprising in view of its vast oil revenues. Given the speed, complexity and ever-increasing costs of modern S&T research in the world, countries like Iran are in danger of getting totally marginalized in the race that will determine the fate of the coming century. ... Iran has never grasped the importance of a modern scientific world view and systemic changes that allow critical and experimental thought to replace – no matter at what cost – submission to higher authority. Great intellectual and political courage is needed to break away from these ancient frames of mind. Iran's problem in any case is not technology transfer but those conditions that prevent the propagation of scientific thought, modern rationality and technology creation.'*
>
> (Mahadavy, 1999, p. 30)

Even though the reforms in Iranian society have been progressing quite rapidly in recent years, Mahadavy's words take on fresh relevance with the election of the new president in June 2005.

Mongolia

The Mongolian science system reflects a structure dominated by government, be it in terms of the pattern of funding or output. In the private sector, the technical capacity is very weak and establishing linkages with science agencies and institutions in the public sector remains a major challenge (Turpin and Bulgaa, 2004). According to a WIPO source, Mongolian residents registered 63 applications for industrial design patents in 2000, which is said to be double that in 1999, indicating the growing strength of the technology system. Some 60 patents were granted in 2000 (WIPO Technical Report, 2000).

From the 1960s to the 1990s, it was the Mongolian Academy of Sciences (MAS), established in 1961, and the National University of Mongolia (1942) which provided a platform for the development of universities in agriculture, medicine, engineering and the humanities. MAS was reformed in 1996 and research institutes and universities were reorganized the same year with the creation of the National Council of Science and Technology (NCST). Two years later, a new state policy on S&T was introduced and a National Science and Technology Fund created.

Mongolia's efforts to foster both S&T and education in the 1990s are bearing fruit. Mongolia could boast 1 370 scientists and engineers per million inhabitants (Table 2) in 2002, a figure which surpasses that of all other South Asian countries. The government devoted Tugrik 3.5 billion[3] to R&D in 1997 (about 0.28% of total government expenditure). Universities are essentially self-financing.

In the past decade, the country has given precedence to education in management and IT by establishing two major institutions, the Computer Science and Management Institute (1991) and the School of Information Technology (1994). These institutions had a combined student roll of 950 in 1998 and employed 146 faculty members. Since emerging from the influence of the former Soviet Union in 1991, Mongolia has moved towards a market economy and economic liberalization. This has had a direct bearing on the S&T system; the government has developed R&D capacities to market new technologies which compete with those of fledgling private firms. The last five years have witnessed significant change in the research environment. The thirst for scientific knowledge is growing as Mongolia struggles to compete in an increasingly knowledge-intensive global economy. The government is conscious of the need to confront these challenges and is consequently turning to international cooperation to strengthen the country's S&T capacities. It is according considerable importance to an unhindered flow of information and to the exchange of experience and expertise on S&T matters. In the past five years, ICTs have been seen as a dynamic sector in Mongolia. Foreign investment, technical assistance and cooperation with technically advanced nations in ICT development have all grown. It is noteworthy that the prime minister himself

3. 1,120 Mongolian Tugrik (MNT) were equivalent to US$ 1 in June 2005.

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heads the National ICT Committee. A national ICT Vision – 2010 lays out the government's principal strategies for ICT development.

CIVIL VERSUS MILITARY R&D EXPENDITURE

When adjusted for inflation, the GERD/GDP ratio over the past decade has either stagnated or declined for the countries of the region, with the notable exception of Nepal. Although India spends much more on R&D than other South Asian countries, it witnessed only a small increase from 0.83% to 1.08% between 1997 and 2004; moreover, this masks negative growth once the figures are adjusted for inflation. If, in absolute terms, GERD has increased in India, it has not kept pace with rising GNP figures. India has set itself the target of devoting 2% of GDP to R&D by 2007. The target was first unveiled in *Science and Technology Policy 2003* by then Prime Minister Atal Bihari Vaijapee and has since been endorsed by current Prime Minister Dr Manmohan Singh.

The proportion of Indian R&D expenditure devoted to civilian R&D hovers between 50% and 60% of the total, with the rest consumed by the defence and strategic sector R&D agencies (atomic energy, defence and space research). Research into non-conventional energy sources has been one of the casualties of strong growth in the atomic energy research budget. In the absence of any significant spin-offs for the civilian sector (except in the case of space research) and in light of the relative decrease in the S&T budget in the 1990s over earlier years – a decrease which did not adversely affect the defence and strategic sector – policy planners are now mobilizing private industry's support for R&D in 2003–04. The private sector performs 23% of R&D in India. This is low by Asian standards, the average for the Newly Industrialized Asian economies being close to 72%. The Indian figure is more comparable with that for Brazil (37%) (OST, 2004).

The situation is even more alarming for the civilian sectors of R&D in Pakistan, which spends just 0.24% of GDP on R&D as a whole (Figure 1). Whereas military expenditure as a percentage of GDP dropped for India from 3.0% to 2.4% between 1985 and 2000–04, the relative decrease for Pakistan's military expenditure was from 6.9% in 1985 to 3.9% for 2000–04. With the peace initiatives gaining momentum in both countries in the past five years, the military burden is likely to further come down in the coming years, which will enable these countries to invest more in education and science and technology. The military burden can be seen in other countries too. Whereas Bangladesh and Nepal are spending around 1.5% of their GDP on military expenditure, Sri Lanka devotes just 0.27% of GDP to this purpose. In the case of Iran, although military expenditure dropped by a third (from 3.6% to 2.7% of GDP) between 1985 and 1996, it climbed back to 3.3% in 2004. It is important to note that the heavy military burden in South Asia has prevented many countries in the region from devoting the resources to R&D and S&T that they deserve.

STATUS OF NATIONAL SCIENTIFIC COMMUNITIES

With low levels of R&D expenditure over the decade, South Asian countries are still struggling to establish infrastructure in S&T and higher education. As this process has become more and more capital-intensive, the long neglect of S&T has led to serious crises both in the institutionalization of S&T domains and in the professionalization of national scientific communities. The concept of scientific communities does not encompass mere numbers, infrastructure and money. Although these elements are essential, it takes time to establish highly professional and effective scientific communities in specialized fields of research. Some basic indicators refer to a steady production of basic and applied S&T knowledge in specialized fields of research; constitution of new disciplines, specialties and areas of research; university chairs and postgraduate programmes; systems of national recognition and rewards; full-time specialized research institutes in critical areas of national importance; networks of S&T research and national communication patterns with corresponding journals and professional academies, bodies and so on; social and political legitimacy for science with steady state support in the initial stages; and above all the existence of an intellectual climate where individual scientists within national boundaries do not experience a sense of isolation.

If endogenous capacities in S&T, including agriculture, are to be created in the countries of South Asia, there is no shortcut to establishing national scientific communities in the sociological sense of the term (Gaillard, Krisha and Waast, 1997). Oriented basic research, scientific communities and PhD programmes in universities are interlinked complementarities and should be considered as crucial elements for generating local technical capacities. This is because what is known as 'codified knowledge' (such as published papers, patents or copyright designs) can be transferred from one place to another but very often the essential component of 'tacit knowledge', which is embodied in a person and mastered through a lengthy process of 'learning by doing' cannot easily be transferred (Krishna, Waast and Gaillard, 1998).

PhD training at universities and research laboratories in S&T is the main source of tacit knowledge. In varying forms, this knowledge is also interlinked with the 'core competencies' of institutions and organizations which evolve through time and effort, and which cannot easily be traded and transplanted from one place to another. With the increasing importance of intellectual property regimes and globalization, conventional forms of technology transfer are unlikely to persist into the future. Even if they do, they will prove to be much more expensive than creating local, national capacities with a long-term perspective. In agricultural and biological sciences, both of critical importance for agrarian South Asian countries, the status of national scientific communities will determine the strengths of local technological capacities in generating wealth from knowledge. This holds true even for the expanding manufacturing and services sectors, which in the last decade have become more and more knowledge-intensive and interdisciplinary.

Creating a national base in science has indeed become crucial to developing countries where the transnational corporations (TNCs) have set off a competitive race to lay claim to specific biological knowledge. World sales of modern medicines derived from plants discovered by indigenous people in developing countries are estimated at US$ 43 billion (World Bank, 1999, p. 146). Biodiversity is of great economic value to drug development and pharmaceutical TNCs and it is estimated that developing countries are the major source (about 90%) of the world store of biological resources. The USA-based multinational, Eli Lilly, made US$ 100 million by developing anti-cancer drugs from the rosy periwinkle found in Madagascar. The country is reported to have received nothing from this economic gain (UNDP, 1999, p. 70).

Developing countries can only benefit from their biodiversity and the rare germplasm found in their land provided they develop, protect (through intellectual property regimes) and apply modern biological knowledge. At the same time, appropriate policy provisions must be made to protect the interests of the indigenous communities in developing countries who are the cultivators and protectors of plants, as well as the repositories of knowledge about plant-based remedies accumulated over generations. Without an endogenous base in S&T, no country can take advantage of its rightful resources. South Asian countries, with the exception of India, are still in the process of institutionalizing S&T systems. With the low level of government support for science, there are serious crises in the training and promotion of research in new fields such as micro-electronics, biotechnology and molecular biology and ICTs.

There are severe problems involved in the constitution and growth of scientific communities across crucial areas of research in Bhutan, Iran, Myanmar, Bangladesh, Sri Lanka, Nepal and Pakistan. It should however be noted that the status of national scientific communities as a factor of socio-economic development varies quite remarkably between small countries like Bhutan, the Maldives and Mongolia and the rest of South Asia. Although it is difficult to speak of developed national scientific communities, there are specialist groups and communities in some sectors: agriculture in Bangladesh, Myanmar, Nepal and Sri Lanka; and physical and chemical sciences in Iran and

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Pakistan. India has well-developed S&T systems and national scientific communities. Having gone through a first phase of initial professionalization, India's problem lies in its 'second order' professionalization; this consists of forging linkages with industrial and societal sectors on the one hand and developing technological capability to compete at the global level on the other.

SOCIAL ORGANIZATION OF SCIENTISTS

One problem underlying the constitution and growth of scientific communities in South Asia relates to the professional climate and social organization of scientists in R&D institutions and universities, coupled with brain drain. A sense of isolation prevails among scientists in the absence of relevant professional groups of researchers, scientific elites and frequent professional meetings. There are national science academies in each country but their activities are generally confined to holding annual meetings. There are few activities among professional bodies to catalyse the intellectual atmosphere. Lack of peer evaluation systems for the advancement of scientific careers in laboratories and publication in journals is a serious problem cited by scientists in Bangladesh, India, Iran and Sri Lanka. For instance, scientists in Bangladesh are evaluated on the basis of a colonial system of confidential reporting and the seniority principle applies rather than an open merit-based system. Further, according to scientists interviewed, as senior-level positions in the laboratories are limited to around 10–20% of the total, there is hardly any motivation to do creative research.

In a South Asian research system dominated by government funding, there are several bureaucratic problems relating to the organization and pursuit of scientific research. For instance, as a leading Indian scientist observes, 'for research funding to be truly efficacious, you have to have the best people, best material infrastructure and minimal bureaucracy. These three components are not optimal and hence research output is not proportionate to the funding' (Ratnasamy, 1999). Given the continuing bureaucratic problems in Indian science, it is not surprising that the prime minister reiterated his government's commitment to de-bureaucratize S&T institutions while addressing a meeting of the Indian Science Congress on 3 January 2005.

Closely related is the major issue of strengthening scientific excellence and academic standards, attracting the best teachers in S&T disciplines and promoting basic research and professionalization of science in academia. Another serious problem not confined to South Asian countries is the problem of attracting the best students to science at the undergraduate and postgraduate levels. Serious concerns in relation to these issues are recurrently being debated in India (Rao, 1999; Krishna, 2001; Lakhotia, 2005). This said, such problems are of a much more severe nature in South Asian countries. Whereas most developed countries are spending 25–30% of their total R&D budget in the university sector, the South Asian average is estimated to be less than 8–10%.

Since the early 1990s, liberalization and privatization policies have led to enormous salary differences between government and private agencies, further impoverishing the material conditions of scientists. Whereas the salary levels for public researchers in South Asia have witnessed only a moderate increase (the current average ranges from US$ 250 to US$ 600 per month equivalent), the salary package in the private sector (for engineers and technologists, software professionals and business executive classes) has increased four- or fivefold. For instance, in the 'silicon valley' of India (Bangalore), in MNCs and private firms, middle-level executives, scientists, engineers and management professionals earn as much as their counterparts in Europe and the USA. This is driving away the best talent from public-funded research institutions and university positions. From an overall perspective, as a Sri Lankan biologist observed, 'once the needed scientific infrastructure is strongly laid and the basics of comfortable living for these scientists are sorted out, their intellectual capacity and innovative ideas can be developed into products of human consumption and utility and also of commercial value' (Karunanayake, 1999, p. 310). Further, as Lakhotia (2005) rightly observes, 'a teaching job at a college or a university is not preferred by brighter PhDs. Many happen to be teaching in colleges or universities because they could not find other jobs.'

BRAIN DRAIN

A sense of isolation, lack of incentives and poor motivation to do research, combined with a low pay structure in laboratories, have led to both internal and external brain drain in South Asia. Internal brain drain in a limited way refers to loss of core competencies due to a critical mass of professionals leaving the public institutions within a country for private employers. It also refers to engineers, doctors and professionals trained in S&T opting for management and administrative positions offering better pay and working conditions. India is a good example for both of these reference points as publicly funded R&D agencies have experienced a good deal of internal brain drain in the past five years: over 70% of the best Indian engineers from the Indian Institutes of Technology (IITs, see also box) prefer management and marketing positions to 'hard core' engineering professions (Krishna and Khadria, 1997; Khadria, 1999). Similar trends are to be observed in Bangladesh, Iran, Nepal, Pakistan and Sri Lanka.

External brain drain refers to emigrating professionals whose departure causes potential loss to the economy. The USA is the most favoured destination: estimates of South Asian migration to the USA till 2003 are of 1 million of which 20% were Indian and 20% were from other Asian countries. Even if we assume that only 20% of this (non-Indian) Asian figure covers South Asia – including Iran where there is a 90% state subsidy for higher education – one can imagine the loss incurred by these countries. For instance, according to the Overseas Employment Corporation in Pakistan, 36 000 professionals, including doctors, engineers and teachers, have migrated to other countries over the past three decades (Human Development Centre, 1998, p. 43). India has become the world's major exporter of doctors to the USA. There were 38 000 Indian doctors in the USA in 2004. It is estimated that there is one Indian doctor in the USA for every 1 325 Americans, compared with one Indian doctor in India for every 2 400 Indians. Studies in India have shown that, on average, 25–30% of engineers from the world-class IITs and as many as 56% of medical graduates from the All India Institute of Medical Sciences (AIIMS) migrate, mostly to the USA (Khadria, 1999, p. 112).

When we examine the problem of brain drain in the larger context of Asia, taking examples from countries such as the Republic of Korea and China, we see that these countries have turned the problem of brain drain into brain gain on an immense scale by attracting their scientists back home through various national policies and institutional mechanisms (see also the chapter on East Asia). To tap the knowledge frontiers in the industrially advanced nations, these countries have adopted conscious policies to export professionals in large numbers – even to the point of opening R&D institutional units in the USA. At the same time, they have promoted the professionalization of science and improved the social organization of scientists both to make the research climate attractive to potential returnees and to arrest potential migration.

India has adopted similar professional mechanisms in the area of biotechnology since the government established the Department of Biotechnology (DBT) in the early 1980s. Over the last two decades, the DBT has catalysed the growth of the biotechnology community in India by promoting 40 advanced research and higher training departments in universities and establishing four top-ranking modern biological laboratories. A source on NASSCOM indicates that in the past three years about 25 000 IT-related professionals have returned to India and about 200 start-up companies in IT have been established by returnees. In any case, India is in a somewhat better position now to absorb the temporary shocks generated by professional brain drain but it is indeed a serious problem and a strategic issue for S&T policy in small South Asian countries.

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THE NEIGHBOURHOOD EFFECT

A subject of considerable importance and concern in the South Asian context is the 'neighbourhood effect' science, technology and higher educational (STE) institutions are having on the transformation of rural society and industry through knowledge and innovation. The forces of modernization and S&T-based industrialization have so far benefited the needs of the urban population. Traditional technology and skills which dominate the rural industrial sector in terms of small and medium-scale enterprises (SMEs) and industrial clusters, concentrated around the districts, have been largely neglected by STE institutions. This is of great concern in India in particular, which accounts for approximately 65% of the region's population. It is estimated that there are 2 000 small industrial clusters and 300 large consolidated clusters in India, most of which are based on traditional and low technologies. The focus here is on industrial districts and the extent to which the STE institutions located in their immediate neighbourhood could participate in their transformation.

In Meerut, for example, neither its university nor its 20-odd colleges and institutes have any relevant courses on publishing and printing, nor any specialized training related to the design and production of sports goods which could cater to the local industrial clusters in these fields. Similarly, in Agra, the local university and 40 colleges and research institutions have very little to do with training and research programmes concerned with shoe manufacturing or the city's industrial pollution. Although one of India's best engineering institutes (an Indian Institute of Technology) is located in Kanpur, the immediate neighbourhood effect is minimal for the leather industrial clusters in the district. The rate at which the pace of global connectivity of research institutions is increasing seems to be inversely proportional to their immediate neighbourhood concerns.

With 300 universities and more than 1 100 research institutions spread over the country in close proximity to industrial clusters, STE institutions can play a crucial role in the rural innovation system. Unlike earlier concerns relating to the development of small-scale industries and manufacturing schemes, this perspective of the neighbourhood effect of STE institutions draws attention to the importance of building new knowledge networks and regional innovation systems that incorporate the concepts of 'flexible specialization' in technology and 'technology blending' (Bhalla, 1996) at the level of industrial districts.

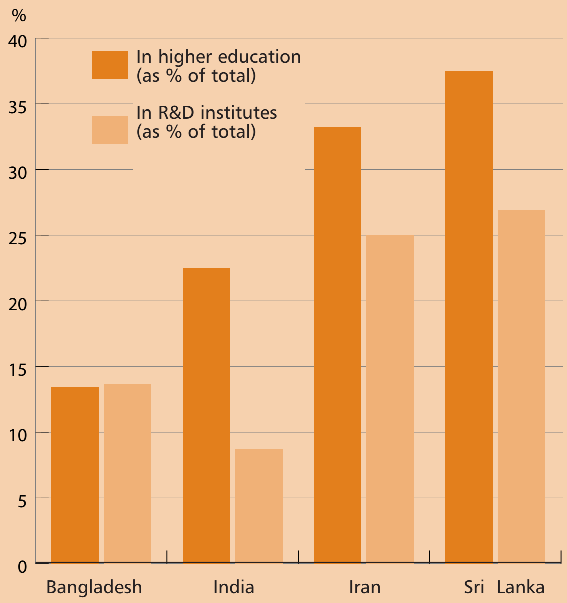
NGO institutions such as Barefoot College in Tilonia, M. S. Swaminathan Foundation in Chennai, the Centre for Technology Development and Development Alternatives in New Delhi, Gonoshasthaya Kendra – The People's Health Centre in Dhaka, CAPART – Public Institution in New Delhi, SEWA, the Honey Bee Network, and the National Innovation Foundation in Ahmedabad are success stories involved in rural innovation and development. However, universities and S&T institutions – the main sources of new knowledge – can take a lead role in partnerships with district-level governments and civil society towards formulating S&T-based solutions and perspectives in aiding industrial clusters to confront the economic and skill challenges posed by the forces of globalization. There is a need to revamp the policies of small industries to turn these into regional innovation systems without losing sight of the local-traditional production systems. The discussion here emanates from the Indian experience but is also highly relevant to other developing countries.

THE GENDER SITUATION

S&T has led to economic growth and material wealth in general but as Hill (2004) points out in the Asian and Pacific context, 'the impact of S&T on society has not been achieved for gender equity. Cultural attitudes and gender stereotyping are impediments to education leading to more men than women in S&T careers and in decision-making positions with increasing inequity and inequality.'

In South Asia women constitute 26.6% of the total S&T student population in higher education but only 18.6% of researchers in R&D organizations (Figure 10). In the case of India, whereas the representation of women in higher education (22.5%) is closer to the South Asian average, the proportion of women in the workforce (8.7%) is much lower than the South Asian average. Interestingly, the situation of women in

Figure 10
WOMEN IN HIGHER EDUCATION AND R&D INSTITUTES IN SOUTH ASIA, LATE 1990s
Selected countries (%)



Source: Institute for Research and Planning in Higher Education, Tehran; DST (1999) *R&D Statistics*, New Delhi; BANSDOC (1997) *Survey of R&D Activities in Bangladesh*. Dhaka; NARESA (1998) *National Survey of R&D in Sri Lanka*. Colombo.

Iran and Sri Lanka is comparable to that of women in the USA, where they represent 38% of total graduate enrolment and 22% of the science and engineering workforce (NSF, 1998, p. 2–22). The proportion of women in S&T higher education in the Asia/Pacific region more than doubled from some 15% to 33% between 1970 and 1990 (Harding and McGregor, 1996, p. 312). In South Asia, this progress may be attributed to the remarkable improvements in female literacy between 1970 and 1995. It is also interesting to note the gradual closing of the gender gap in primary enrolment: 35 percentage points for the South Asian region in 1960 compared to 23 percentage points some 30 years later (Human Development Centre, 1998, p. 86–7). The low status of women in South Asian society relates to patriarchal systems and values with deep historical roots. Added to this is the factor of widespread poverty, still a major constraint in tackling the problems of female literacy and education. Patriarchal values pose a different set of problems for women scientists who enter the workforce.

By 2002, most South Asian countries had instituted varying institutional research programmes and mechanisms to promote women in the science, technology and higher education sectors. In India, the Department of Science and Technology instituted two studies (DST, 1992, 1998) on women scientists and engineers, which together surveyed more than 3 500 respondents spread over different parts of India. These studies have shown different notions of 'inequality' in terms of rewards, recognition, participation in decision making and other aspects referred to earlier by Hill (2004). Recognizing the notion of 'inequality in science', the Indian DST has been running a scheme called S&T for Women since 1981 and in the 1990s created special awards and incentive schemes to encourage women scientists. Similarly Nepal, Mongolia and Sri Lanka have taken some institutional measures in their respective ministries to promote women in science and education.

At the regional level, international agencies such as the ILO, UNDP and UNESCO have initiated various action plans and launched concrete projects following the 1995 Beijing Conference. One such programme involving India, Nepal and Mongolia is the Asian-Pacific Gender Equity Network (APGEN), set up by UNESCO's regional bureau for science in Jakarta, Indonesia. The areas and projects promoted by APGEN over the past five years include biotechnology and green health, renewable energy, water and sanitation, and IT. APGEN has been undertaking policy and social analysis research at three levels: gender equity in S&T; the provision of technical assistance to pilot projects in the region; and the dissemination of results and lessons of experience obtained through research and field experience across the region.

SAARC AND REGIONAL COOPERATION IN S&T

In terms of regional cooperation, the South Asian countries – including Iran – are more a geographical entity than an

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economic bloc along the lines of the European Union or the Association of South-East Asian Nations (ASEAN). The South Asian Association of Regional Cooperation (SAARC), which has seven members (Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka) and dates back to 1985, accounts for 22% of the world population but only 1.65% of world GDP and 1.12% of global trade. Even including Afghanistan, Iran, Mongolia and Myanmar in the equation does not change this economic reality to any large measure.

What is more glaring is the fact that, despite the existence of SAARC for more than 15 years, there is hardly any significant intra-SAARC trade: it represented only 4.25% of total SAARC exports in 1996 and declined to 4% in 2003–04. Furthermore, the main trading partners are Europe and the USA, whose share of SAARC exports increased modestly from 46% in 1990 to 49% in 1996, compared with about 22% for Asian countries, with the exception of Japan. Over the same period, SAARC imports from Europe and the USA rose more steeply, from 53% to 65% (RIS, 1999). This trend continued even in the 2000–04 period. The existing South Asian Preferential Trading Arrangement (SAPTA), which was to catalyse South Asian free trade, has yet to show any noticeable results, indicating a shift away from the present trend.

Another important development in recent years has been the emergence of two sub-regional cooperation groupings. The first consists of Bangladesh, Bhutan, India and Nepal, which have come together to form a Growth Quadrangle called BBIN-GQ. The main objective of this formation is to create a climate for rapid development through the implementation of cooperation projects in communications, transport, energy and natural resource management on a regional basis. The second important sub-regional formation is the initiative taken by Thailand in 1994 to establish Bangladesh–India–Sri Lanka–Thailand Economic Cooperation (BIST-EC). In 1997, Myanmar was admitted to this grouping and it was renamed as BIMST-EC, which paved the way for linking up South Asia with ASEAN economies. Notwithstanding the slow economic start by various groupings and network committees, considerable optimism has been exhibited by various SAARC meetings in recent years.

The major challenge for South Asian countries is thus to enhance their economic and trade ties. Here, regional cooperation should be deemed much more important than that with other partners in so far as various products traded by Asian countries are affected. For instance, economists estimate that Sri Lanka lost approximately US$ 266 million (36% of the actual import bill) and that Pakistan lost US$ 511 million (28% of the actual import bill) in 1994 by not importing goods from SAARC (RIS, 1999). The region's vertically integrated networks in technology, division of labour, production, trade and exports provide enormous scope for the expanding manufacturing and services sector within SAARC. With the Indian information technology sector emerging as an important global player with considerable human capital, there is tremendous potential for cooperation in this high-technology area.

One of the main objectives of regional cooperation as laid down in SAARC's charter is 'to promote active collaboration and mutual assistance in the economic, social, cultural, technical and scientific fields'. It was envisaged that cooperation, over time, would significantly strengthen the region's collective self-reliance. In 1982, through its Technical Committee on Science and Technology (TCST), SAARC identified 14 areas for cooperation ranging from science policy to information. Since 1983, 15 meetings of the TCST have taken place, resulting in a directory of S&T activities in the region; 26 seminars, expert group meetings and workshops; seven training courses; and feasibility studies for the development of specific sectors of cooperation. The other outcome of TCST meetings has been a proposal to create the SAARC Biotechnology Council for developing biotechnology and bioresource policies and to formulate joint technology development programmes, including the establishment of a consultative committee on intellectual property regimes (RIS, 1999).

The 12th SAARC Summit held in Islamabad from 4 to 6 January 2004 reaffirmed that:

'strengthening of scientific and technological co-operation across the region is fundamental to accelerating the pace of

economic and social development. Sharing of scientific and technological expertise, joint research and development and industrial application of higher technology should be encouraged and facilitated.'

Very low or insignificant intra-SAARC trade is by and large reflected in the levels of S&T cooperation within SAARC, in the sense that no long-term R&D programmes with real partnerships have evolved so far. With the easing of tension between India and Pakistan in the last few years, the S&T sub-committee component of SAARC could play a major part in fostering the mobility of professionals through exchange programmes in universities. Being a large country, India could take a lead in the form of SAARC fellowship programmes for greater exchange of students between India and other South Asian countries in areas where India has developed high-class research infrastructure in space, ICT, agriculture, chemical and drugs among other areas of science including S&T policies.

CONCLUDING REMARKS

The triple challenges facing all South Asian countries are:

- agriculture and health security coupled with tackling the problems of poverty and unemployment among growing population;
- coping with the rapid transformations underway due to scientific and technological revolutions unleashed by the developments in ICT, biotechnologies and other fields;
- managing the transition from agriculture-based economies to industrial and knowledge-based service economies, addressing the issue of good governance.

In our view, the three basic elements of a response agenda to the prevailing challenges in S&T, including the educational implications, are:

- expansion of educational opportunities at all levels, particularly the primary and middle levels, looking to reach a sustained level of education expenditure around 5–6% of GDP;
- an increase in government or national expenditure on R&D to a minimum level of 1% of GDP and expenditure on S&T activities to at least 2–3% of GDP, with a focus on creating employment in small- and medium-scale enterprises;
- concrete steps in tackling corruption, decentralization of developmental processes and giving effect to good governance.

Unfortunately, most countries have failed to pay adequate attention to these challenges in their policies during the last decade. With the exception of India, most countries in the region are spending an average of less than 0.5% of GDP on R&D. The major achievement during this period has been in the area of agricultural research, which has contributed to agricultural productivity and hence provided food security in many countries of the region. However, with a 2% average population growth rate, the ongoing task confronting the agricultural scientific communities is to accomplish what is known as the 'Second Green Revolution'.

As a result of the low level of support given to S&T sectors and education, South Asian countries are experiencing a serious crisis in science education and teaching. General sciences, except medicine and engineering, are no longer perceived as attractive career prospects by secondary school students. Eminent scientists who were once role models are being replaced with new ones from areas such as business or information technology. While there is an urgent need for innovation in science teaching to make it more attractive to young students, good science and mathematics teachers are becoming scarce, with many potential teachers being lost to more lucrative occupations. Science now has to compete with other rapidly growing occupations and sectors catalysed by liberalization and globalization, such as economics, business, information technology, fashion design, tourism and leisure. A major effort by both the state and NGOs is needed to rescue science before it loses its shine.

Despite improving trends over the last decade, the major challenge for the gender situation in S&T for the region as a whole remains female education and literacy programmes. Whereas male literacy for the region is

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62%, female literacy is a low 36%. The region entered the new millennium with more than 250 million illiterate women, according to Human Development reports in 2003. The focus on female education demands unprecedented policy attention in the coming decades as the new technologies – such as ICTs, biotechnologies and agricultural S&T networks involving research, education and extension – are all knowledge-intensive domains. Apart from the afore-mentioned common challenges and responses, which nevertheless vary across the region, several countries are also embedded in a contextual matrix concerning the role of S&T for development.

In India, S&T policies have by and large concentrated on the input side of the R&D spectrum, while the structures of linkage and diffusion end of the R&D domain remain quite weak and are left to the natural play of different actors in the national innovation system. One major positive consequence of such policies has been to evolve an S&T human resources base. However, from the perspective of national innovation systems (NIS), India needs to graduate urgently from the existing S&T policy regimes to a regime of national innovation policies as is done in Japan and South Korea. Such a perspective entails not only strengthening the main actors of NIS (the academic sector, the S&T and R&D systems, industry sectors and government agencies responsible for good governance) but forging linkages between these actors and the socio-economic system as a whole.

Given the size and economy of China as a competing neighbour, there is a need to increase the existing R&D budget level of 1.08% of GDP to the government-committed level of 2% in the coming three years and to commit 6% of GDP to education. To this end there is a need to increase private industrial R&D. The existing tax R&D incentive schemes lack penal underpinning and this needs to be addressed adequately by the Department of Science and Technology.

The university sector is the most neglected sector, claiming a bare 8–10% of national R&D spend, and the new innovation policies need to balance appropriately the distribution of resources between different actors in the NIS. The future human resources base, the innovation success of new technologies (nanotechnology, biotechnology, bioinformatics and material sciences) and the economic potential of knowledge-based industries including telecommunications are entirely dependent on the strength of higher education and research in the university sector. Moreover, the academic science sector in India needs a very big boost to arrest the current stagnating and declining trends of SCI-based S&T publications at the world level. Defence and strategic-related R&D systems in India have been quite dynamic and attained very high technological capabilities. The future challenge however lies in converting the defence and strategic technological capability (as in the case of space) into useful market-based innovation in the civilian sectors.

Iran, despite considerable oil revenues and a relatively developed educational infrastructure, has failed to make S&T a major factor in the economy. Excessive economic restrictions and a seemingly inward-looking policy over the years have been very telling on the S&T system. A country with a long historical scientific tradition, Iran has experienced a serious setback in the growth of national scientific communities over the last two decades. The lack of autonomy for science as a social system has been one of the serious challenges confronting the scientific community. However, a favourable attitude to science, rationality and development among the general public is catalysing a new social movement in science and development, which is in an embryonic phase.

The major weakness of the Iranian S&T system lies in the area of technological development. Here again, the prevailing situation which prevented foreign investment and technology, alongside an over-concentration of industry in the state sector, has led to serious problems for technological dynamism. The weak R&D system of both public and private enterprise, coupled with poor linkages with the university sector, have failed to catalyse the absorption and assimilation of foreign and high technology. In recognition of the prevailing problems and to keep up with the wave of globalization and liberalization taking place in other countries, restructuring of the R&D system is under way. The well-developed university educational sector and relatively high proportion of educated citizens give Iran an advantage in the race to catch up with the knowledge and information technology industries.

In Nepal, Sri Lanka and Bangladesh, the major stumbling block for the dynamic development of endogenous scientific and technological capabilities is the low level of state support for R&D (0.26% for Nepal, 0.19% for Sri Lanka and only 0.01% of GDP in 2000–04 for Bangladesh). The lack of highly trained professionals in R&D organizations, the underdevelopment of higher education and the science base in the universities, dependence on foreign training in specialized areas of S&T and lack of adequate merit-based professional incentives are problems common to the research systems of these countries. While Bangladesh is yet to come to the level of R&D funding of other countries in the region, the situation is rapidly improving in the case of Pakistan and Nepal which have almost doubled their government support to R&D in the last five years.

A common feature relevant to Pakistan, Bangladesh and Sri Lanka is the existence of more than three-decades-old national R&D organizations such as ITI and NERDC in Sri Lanka, PCSIR in Pakistan and BCSIR in Bangladesh. These can play an important role in the development of national- and firm-level technological capabilities. For instance, the success achieved by the textile and garments sectors in Bangladesh and Sri Lanka recently can be further consolidated and extended to other manufacturing sectors by connecting their needs and demands to R&D institutions. A low level of R&D effort with short-term goals coupled with thin funding spread over a large number of projects seems to be the main problem indicated at BCSIR and ITI. A lack of R&D downstream and design and engineering facilities to upscale technology developed in national laboratories and transfer it to industry, coupled with a lack of state-supported venture capital mechanisms, has led to gross underutilization of the technological capacity of these R&D institutions. The laboratories of the ITI and BCSIR are located in close proximity to the leading universities of Colombo and Dhaka respectively, but there is little mobility and interaction between scientists and academic personnel.

There is a need to develop such linkages between universities and research agencies on the one hand and with industry on the other. Given the low level of R&D funding, in many of these countries including India, there is a need to optimize research efforts in new R&D fields through mobility of professionals, sharing of sophisticated and costly scientific equipment, joint projects and even through the creation of joint laboratories shared by universities and national laboratories as in the case of France. More than 80% of CNRS laboratories have moved during the last decade to operate jointly with French universities.

Strengthening the science base in the universities with an expansion in PhD and R&D programmes, coupled with peer review and standards of excellence, have become pre-requisites in creating a reasonable national innovation base. This takes considerable time. In a way these tasks have become an essential factor in the process of attaining national technological capabilities, particularly in agriculture, bio-resource and health, because these are the fields closely related to basic sciences and academic research capabilities. Another important reason to support universities is for the human resource base. In all these countries including Iran, the realization that the academic sector could emerge as a major source of S&T innovations in the current decade has as yet been very slow to attract the attention of S&T policy planners in South Asia.

Pakistan has provisions for venture capital and for established institutions, such as the Scientific and Technological Development Corporation, to transfer technology developed in the national laboratories to industry. With a considerable number of universities and R&D institutions, including those under PCSIR, there is however a problem of linkages between different sectors. SMEs in engineering products, textiles and chemicals are

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the fastest-growing sectors of the economy and require R&D support to become competitive through technological means rather than cheap labour. This holds good for other countries in the region.

A considerable achievement in Bangladesh has been the role of the NGOs, catalysed by the collaboration of state agencies, in developing micro-credit institutions, rural health and artisanal innovations and education. Grameen Bank, Gonoshasthaya Kendra (GK), Bangladesh Rural Advancement Committee, Dhaka Ahsania Mission, Proshika and the Underprivileged Children's Educational Programme are among the most notable (see box below). As far as S&T policy is concerned, the role of Gonoshasthaya Kendra – the People's Health Centre, Dhaka (which produces the most essential drugs in its antibiotic factory) – in the formulation of the country's drug policy is most notable.

Micro-credit projects in Bangladesh

Micro-credit finance institutions sponsored by the government and NGOs which have the specific aim of developing the poor sections of society in Bangladesh are beginning to yield significant results in education and information diffusion.

Grameen Bank was set up by Muhammad Yunus in 1983 to make tiny collateral-free loans to the poor to help them set up micro-businesses. As of August 2004, it had disbursed US$ 4.6 billion in loans to 3.8 million borrowers. The Bank provides services in 53 000 villages in Bangladesh (over 70% of the total), lending about US$ 2 million a day in loans of US$ 200 on average. Some 96% of borrowers are women. The bank concentrates on women because they tend to plan for the longer term and be good at repaying loans (99% of Grameen Bank loans are repaid); women also spend more of the business profits on their family than do men, using the profits to send their children to school.

The Grameen Bank's expansion has brought about a phenomenal growth in the number of schools supported by borrowers. Beginning with a modest investment of less than 1 billion takas* annually in 1986, the Grameen Bank had disbursed over 9 billion takas supporting 16 000 schools just eight years later.

Like the Grameen Bank, the Grameen Phone project promotes women's empowerment and information diffusion in rural areas through a credit scheme. Grameen Phone, a nationwide mobile telephone company, enables poor women in villages to market telephone services to their entire village or to individual clients. Besides empowering women, the project connects villages to markets in cities. Villages also benefit in terms of education, health and other informational needs. To date, Grameen Phone has distributed more than 2 000 mobile phones to 'phone ladies' in as many villages.

The founder of the Grameen Bank is currently working with Hewlett-Packard to bring Internet kiosks to villages. These Grameen Digital Centres will be designed so that even illiterate villagers can operate them using touch screens and voice commands.

Another multifaceted project is the Bangladesh Rural Advancement Committee (BRAC). This institution combines training with credit by imparting skills to promote micro-enterprises in such activities as vegetable growing, silk production, livestock, fisheries and forestry. More than 280 000 clients have benefited from these activities and learned about their legal rights with regard to family and business.

See also: www.grameen-info.org/bank/

* In June 2005, 100 Bangladeshi takas were equivalent to US$ 1.57.

Bhutan and Myanmar are still building infrastructure in S&T while they are in the process of institutionalizing science. The major challenge for these countries (the group includes Nepal, Sri Lanka and Bangladesh) in the coming decade is to create viable science communities which will play a key role in the development of agriculture (including animal husbandry, milk production, animal health and veterinary services) and in realizing the economic potential of local biological diversity. Agricultural processing, including dairy and milk processing, textiles, ready-made garments and chemicals are important areas in the manufacturing value added in these countries. Wood products in Myanmar and Bhutan and tourism in Nepal are other specific sectors. The future growth of the manufacturing sector will increasingly depend on the extent to which these countries develop and deploy professional engineering and technical skills to improve the existing 'flexible specialization'. They are crucial for absorbing the imported technology and developing local technical capabilities.

As a large proportion of the labour force (about 94% in Bhutan and Nepal and 73% in Myanmar) is still dependent on agriculture, strategies to manage the transition from agriculture to industry and services calls for a major educational effort in vocational and technical skills. In small countries, retaining the trained scientists and engineers is becoming much more important than training itself. Studies indicate that providing incentives and creating a professional climate are likely to arrest the process of brain drain. S&T policies directed to arrest brain drain and foster brain gain are likely to assume unprecedented importance in the near future because of the shortage of skills in the industrially developed countries in Europe, North America and Australia.

The Maldives, with a population of 0.25 million, is one of the smallest countries in the world. The country has the highest adult literacy and primary enrolment rates in the region (97% and 100% respectively) but still lacks a tertiary institution. The major challenge for the country is to establish such an institution, which will network with neighbouring countries to draw on knowledge and information.

In Mongolia, the S&T structure is still undergoing a transformation to keep up with the new policies towards a market economy and liberalization. With the limitation of a small economy and population, the major challenge in technological innovation is to attain international competitiveness. With a relatively high proportion of scientists and engineers per million of the population, the country has the potential for integrating and commercializing new and high technology. But this will depend on the extent to which new S&T policies introduced in 1997 will be able to forge fruitful partnerships in university/industry relations.

South Asian countries are predominantly agrarian and are likely to experience rapid transformation in the coming decade. From an overall perspective, a cursory look into the pattern of technology trade since the 1970s reveals an important lesson for these countries. Between 1976 and 1996, the shares of resource-based primary products and low-technology goods in total international trade came down from 45% and 21% to 24% and 18% respectively; and the shares of high- and medium-technology goods went up from 11% and 22% to 22% and 32% respectively (World Bank, 1999, p. 28). This trend continued for 2000–04 as indicated by the increasing share of the service sector. In other words, natural resource endowments and low-skilled cheap labour are unlikely to give a comparative advantage to our economies in the future. It is value addition through new skills, technological change and knowledge, coupled with appropriate institutional and organizational innovations, that will play a key role in the comparative advantage of South Asian countries.

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