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Chapter 1

Global Dynamics in Science, Technology and Innovation

This chapter reviews the main trends in science, technology and innovation across the OECD area and the BRICS economies. It examines the latest available data and indicators on the inputs, outputs and impacts of R&D and innovative activity. Where possible, the analysis highlights recent developments, comparing them to longer-term trends. It considers the financing of innovative activity, innovation performance, R&D in key technologies, the scientific and technological outputs of R&D and innovation, the role of globalisation in changing patterns of innovation and human resources for science and technology.

Introduction

Global structures of research and development (R&D), science performance, invention and innovation are in a multidimensional transition process. Although the OECD and other economies continue to be characterised by persistent diversity, strong trends are nevertheless in evidence and are reshaping global patterns of research, technology and innovation.

The main dimensions of change are: the absolute growth of R&D and innovation-related activities; the rise of the BRICS[1] economies in scientific and technological fields; significant globalisation of R&D; more performance of R&D in the services sector and a growing focus on non-technological innovation; widespread policy shifts towards fiscal incentives for R&D; and enhanced internationalisation and mobility of highly skilled people, including greater participation of women in the HRST (human resources for science and technology) labour force across almost all countries.

Among the main elements underpinning these developments have been the increasingly knowledge-driven nature of innovation; the quickly changing organisation of research, driven by informatics, collaboration and the sharing of knowledge; rapidly improving connectivity and the development of platform technologies and standards as globalisation accelerates; and changes in markets, the competition environment and technology.

This chapter uses the latest available data and indicators to view these broad trends and the dimensions of change in the global economy.[2]

Drivers of economic growth

For almost all OECD countries, lower labour productivity levels account for most of the gap in GDP per capita compared to the United States. Data for 2006 show that for the poorer members of the OECD, for example, GDP per hour worked is less than half that in the United States (Figure 1.1). Countries must achieve higher labour productivity levels to improve material living standards, a good proxy for overall well-being.

Achieving higher productivity levels implies strengthening labour productivity growth. Several drivers are important here, notably investment in information and communications technology (ICT) capital and non-ICT capital, which enables labour to work more efficiently, and the contribution of multi-factor productivity, which measures how well labour and capital are used together in production processes and also captures the impact of human capital levels within a country. These factors typically account for a large proportion of growth of GDP in OECD countries. For the G7 countries, for example, multi-factor productivity growth has been a key driver of performance over the past two decades (Figure 1.2).

With limits on the extent to which labour utilisation can be raised in many countries, the contribution of ICT and other investment, in addition to multi-factor productivity, will become increasingly critical for economic performance in OECD countries. This suggests that innovation, human capital and technological change will become central to growth, since it is these factors that underlie improvements in technology and working methods.

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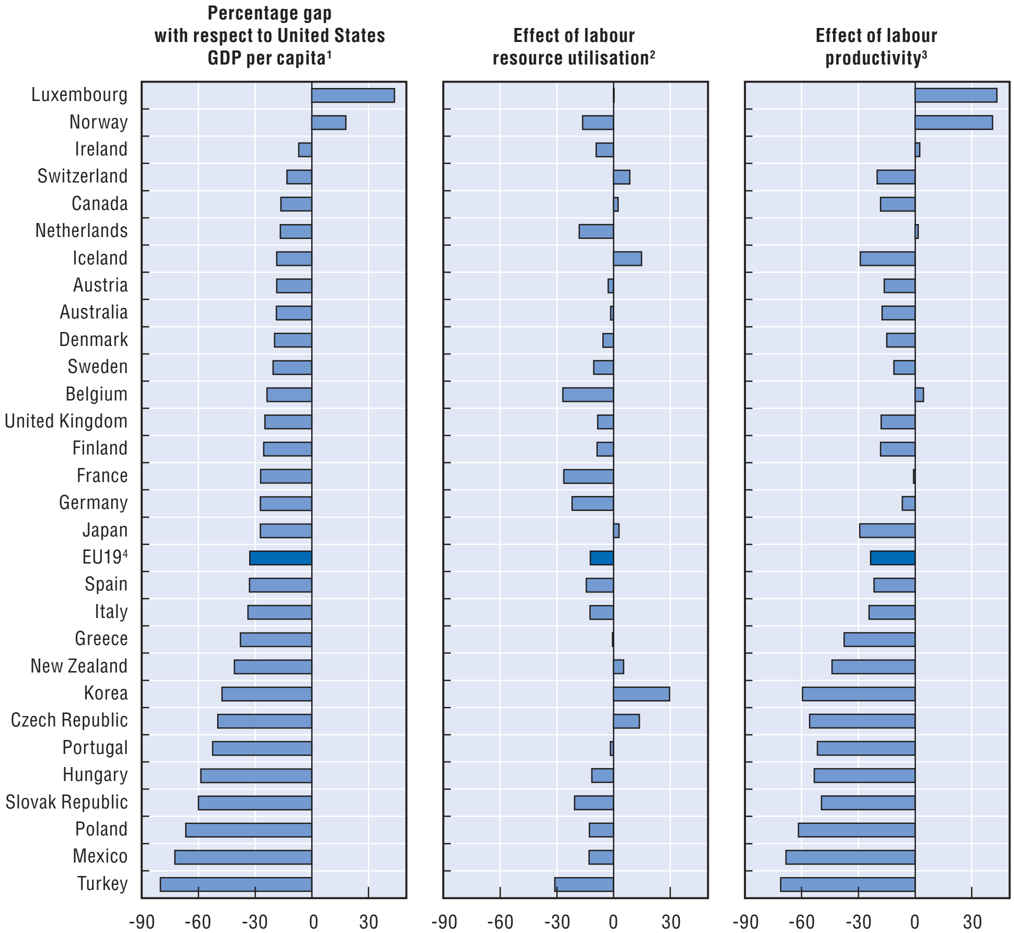
Figure 1.1. **The sources of real income differences, 2006**



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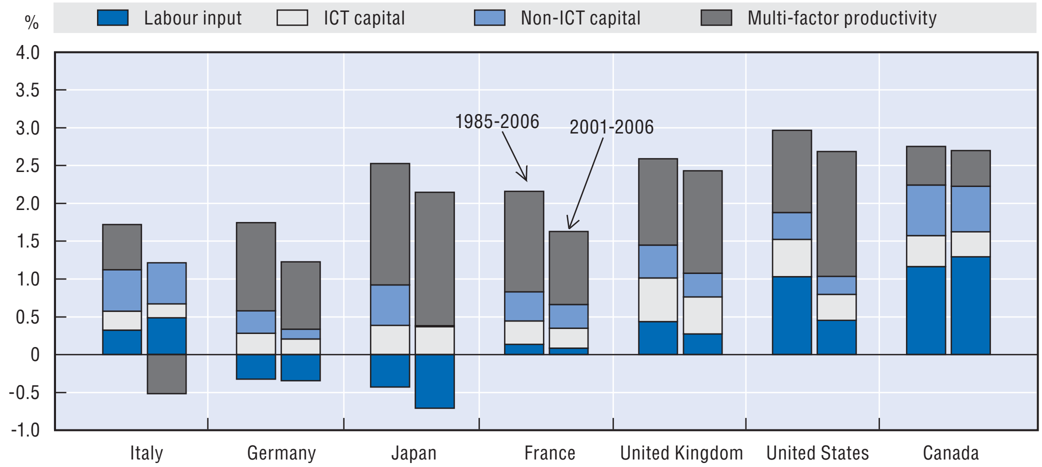
1. Based on 2006 purchasing power parities (PPPs). In the case of Luxembourg, the population is augmented by the number of cross-border workers in order to take into account their contribution to GDP. Data for Greece take into account a 10% upward revision to the level of GDP as agreed by Eurostat in October 2007.
2. Labour resource utilisation is measured as total number of hours worked per capita.
3. Labour productivity is measured as GDP per hour worked.
4. EU19 is an aggregate covering countries that are members of both the European Union and the OECD. These are the EU15 countries plus Czech Republic, Hungary, Poland and Slovak Republic.

Source: OECD, *National Accounts of OECD Countries, 2007*; *OECD Economic Outlook, No. 82*; and *OECD Employment Outlook, 2007*.

In recent years, the macroeconomic context for R&D and science, technology and innovation activities has been favourable. In spite of the current turbulence in financial markets, output growth has been strong across the OECD area in recent years at around 2.7%. In the last four years the United States, the EU and Japan have all grown at faster rates than during the 1994-2003 decade. The BRICS economies, and other major developing economies such as Indonesia, have grown at even faster rates (between 4 and 10%), and this growth is having powerful effects on global trade, flows of foreign direct investment (FDI), and external balances. Within the OECD area, unemployment has fallen slowly but steadily to 5.6% in 2007, and the inflation environment has been stable.

Figure 1.2. **Contribution to growth of GDP, G7 countries, 1985-2006 and 2001-06**[1]

Percentage points



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1. 1991-2006 for Germany; 1985-2004 and 2001-04 for Japan; 1985-2005 and 2001-05 for United Kingdom.

Source: OECD Productivity Database.

These current macroeconomic trends have helped to shape recent developments in science and innovation activity. Particularly in the private sector, R&D and technology-creating activities should be seen in terms of investment, and such investment tends to respond favourably to actual and expected growth. The macroeconomic trends have therefore been positive for R&D performance and other science, technology and innovation related activities.

However, much will depend on the longer-term impacts of financial market instability and on current macroeconomic imbalances. Projections in the *OECD Economic Outlook* (OECD, 2008a) point to weak growth for most OECD countries and headline inflation. This scenario is from the combined outcome of financial market turmoil, cooling housing markets and sharply higher commodity prices. As activity has weakened, employment growth in the OECD area has slowed, particularly in the United States.

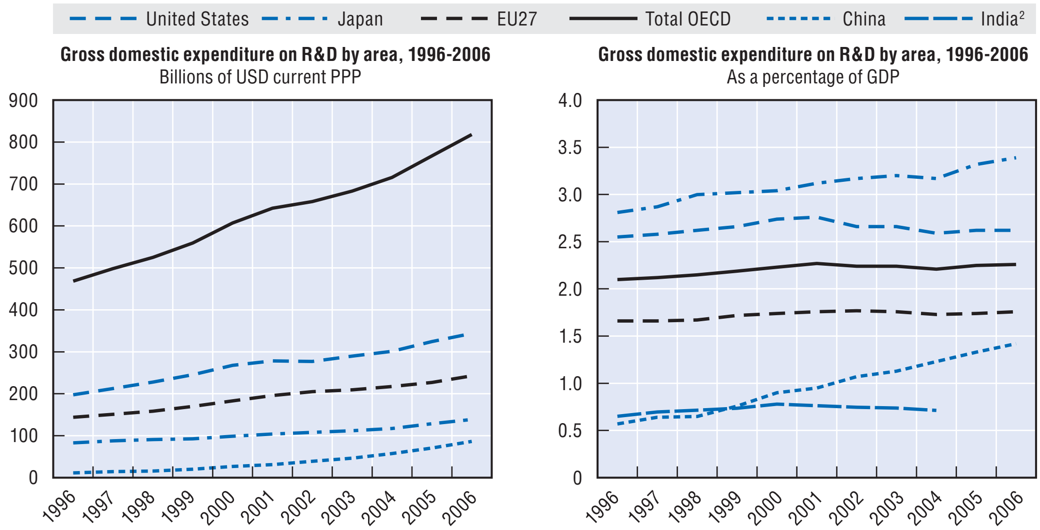
R&D dynamics: the changing landscape

Main R&D trends: intensity slows across the OECD

Except in China, R&D intensities have remained roughly constant or have grown only slowly in recent years. However, since real gross domestic product (GDP) has been growing strongly, broad stability in the ratio of R&D to GDP implies substantial absolute growth in the amount of R&D performed globally. This growth is linked to sustained growth in the employment of researchers and the HRST labour force more generally, with complex impacts on patterns of international mobility.

OECD investment in R&D climbed to USD 817.8 billion in 2006, up from USD 468.2 billion in 1996 (Figure 1.3). Gross domestic expenditure on R&D (GERD) grew by 4.6% annually (in real terms) between 1996 and 2001, but growth slowed to less than 2.5% a year between 2001 and 2006. From 1996 to 2006, R&D spending grew at between 3.2% and 3.4% a year in real terms in the United States, Japan and the EU. In 2006, the shares of total OECD R&D expenditure in the three main OECD regions were around 41% for the United States, 30% for the EU and 17% for Japan. While the EU and Japan have maintained their OECD shares since 2000, that of the United States fell by 2 percentage points.

Figure 1.3. **R&D trends, 1996-2006**



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GERD = gross domestic expenditure on R&D.

Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1*. India: national sources.

Looking from recent trends to the current outlook, both the size and composition of the US budget deficit may have implications for federal R&D spending in the years ahead. Projections for 2008 suggest increases in funding for defence, security and energy research, but real declines in R&D for health, commerce and environmental protection. The present situation in global financial markets, with instability and an uncertain outlook for interest rates following the sub-prime mortgage crisis, may affect R&D spending plans if recessionary trends take hold. So, despite robust recent performance, the short- and medium-term outlook shows some risk of slower R&D growth ahead, and some analysts are forecasting a decline in the real growth rate of R&D in the United States to 1.3% (Battelle Institute, 2008).

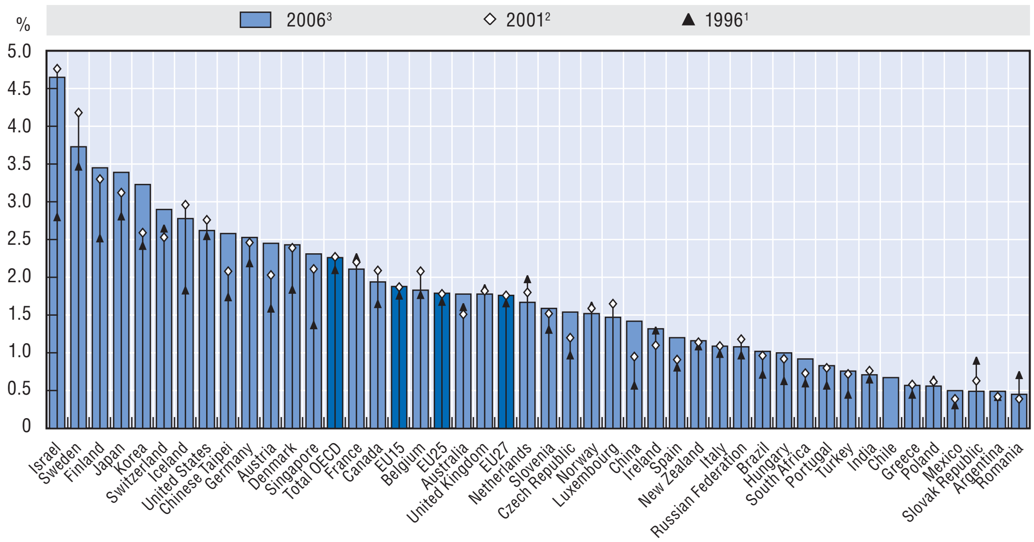
The global distribution of R&D is changing, and some non-OECD economies are becoming important R&D spenders. China's GERD reached USD 86.8 billion in 2006; this was below that of Japan (USD 138.8 billion in 2006) and around one-third of that of the EU (USD 242.8 billion in 2006).[3] China's GERD expanded at around 19% annually in real terms from 2001 to 2006. Investment in R&D increased by 12% in South Africa from 2004 to 2005. Russia's climbed from USD 9 billion in 1996 to USD 20 billion in 2006, and India's reached USD 23.7 billion in 2004. As a result, non-OECD economies account for a sharply growing share of the world's R&D. In 2005, the non-OECD countries for which data are available[4] accounted for 18.4% of the R&D expenditure (expressed in current USD PPP) of OECD and non-OECD economies combined, up from 11.7% in 1996. China made by far the largest contribution, accounting for 41% of the non-OECD share; its share may continue to rise, since China has the ambitious target of raising R&D intensity to 2% by 2010 and to 2.5% or above by 2020.

In 2006, OECD-area R&D intensity reached 2.26%, above its 2005 level of 2.25%, but down from its peak of 2.27% in 2001 (Figure 1.3). In the United States, R&D intensity fell from a peak of 2.76% in 2001 to 2.62% in 2006, whereas in Japan, it reached a high of 3.39% in 2006. R&D intensity in the EU increased modestly from 1.74% in 2005 to 1.76% in 2006, still well short of the 3% of GDP target for 2010.

For the full set of OECD member countries, more varied patterns emerge (Figure 1.4). In Sweden, Finland, Japan and Korea, the R&D to GDP ratio exceeded 3%, and in Finland and Iceland R&D intensity increased by almost 1 percentage point over the past ten years. Several countries, including larger European economies such as France, saw declining levels of R&D intensity from 2005 to 2006, as did Canada and Sweden. The gap between the most R&D-intensive (Sweden) and the least R&D-intensive OECD country (Slovak Republic) was 3.2 percentage points.

Figure 1.4. **GERD Intensity by country, 1996, 2001 and 2006**

As a % of GDP



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1. 1997 instead of 1996 for Greece, Iceland, New Zealand, Norway, Sweden and South Africa.
2. 2000 instead of 2001 for Australia, Luxembourg and Switzerland.
3. 2004 instead of 2006 for Australia, Chile, India and Switzerland; 2005 for Iceland, Italy, Mexico, New Zealand and South Africa.

Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1.*

Growth of business R&D slowing

Businesses account for the majority of R&D performed in most OECD countries and for 69% of total R&D in the OECD area. Business-performed R&D is largely financed by industry, an investment that has grown in recent years. R&D performed by the business sector reached USD 563 billion across the OECD area in 2006 (Figure 1.5). From 1996 to 2001, business enterprise R&D (BERD) expenditure increased by 5.1% annually in real terms, but the pace of growth slowed markedly from 2001 to 2006. Business R&D increased by 1% a year in the United States between 2001 and 2006, by 1.8% in the EU, by 4.4% in Japan and by 23% in China.

Business R&D intensity in the EU27 increased only marginally between 1996 and 2006, from 1.03% to 1.11%. It is therefore unlikely that the EU will meet the Lisbon BERD target of 2% of GDP by 2010. In the United States, business R&D intensity reached 1.84% of GDP in 2006, still short of the peak of 2.05% in 2000, whereas in Japan in 2006 it reached a new high of 2.62%. In China, the BERD to GDP ratio was low in 1996 (0.25%) but increased rapidly, particularly after 2000, and has virtually caught up with the EU intensity, at 1.01% of GDP

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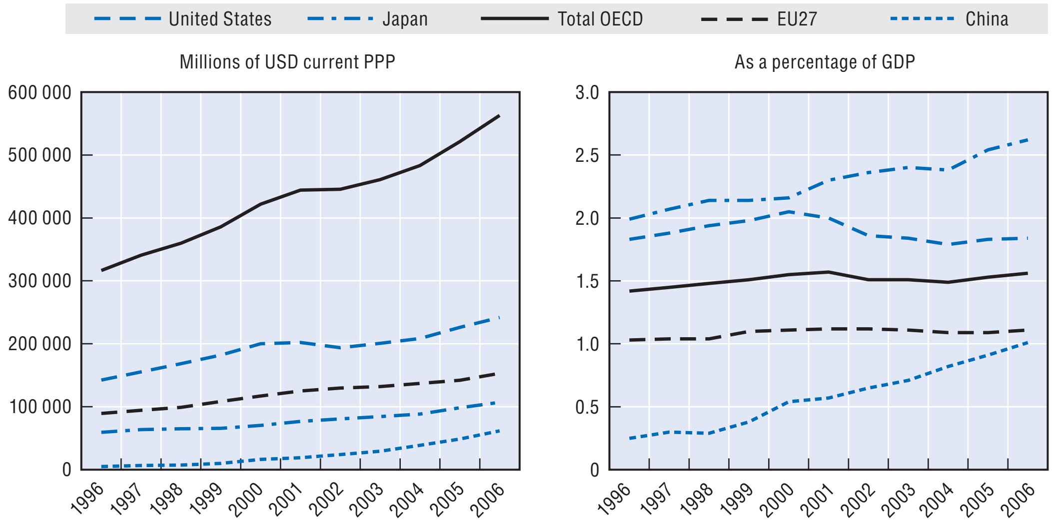
Figure 1.5. **Business R&D spending by area, 1996-2006**



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Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1.*

by 2006. It is important to bear in mind that the intensity of BERD is a ratio, so that larger GDP implies higher absolute R&D expenditure; thus, China remains well short of the EU absolute BERD, although it is gaining rapidly.

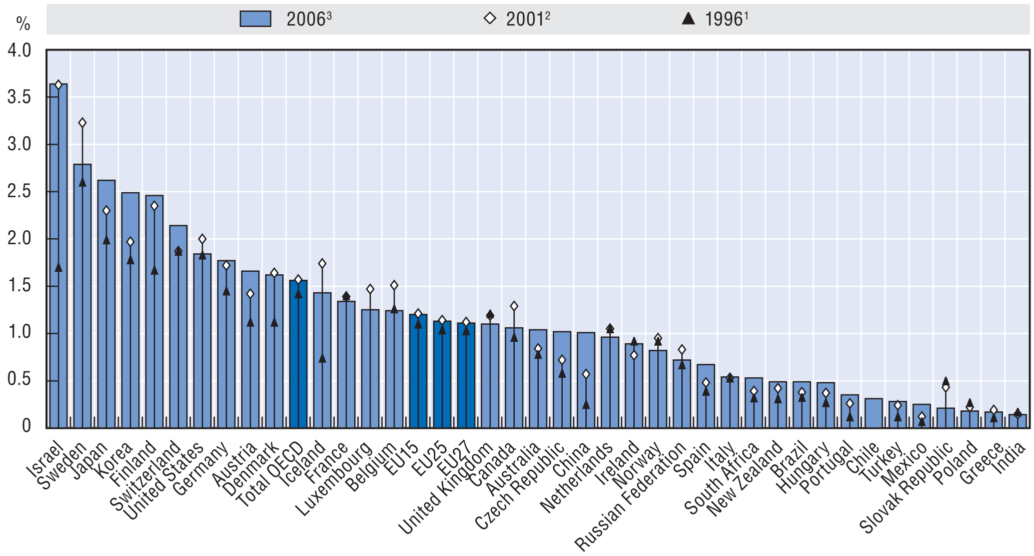
China is not alone is raising business R&D. Over the past decade a number of countries have made substantial gains in BERD intensity. Israel, Finland, China, Korea, Iceland, Japan and Austria have seen gains of more than 0.5 percentage point. That said, growth from 2001 to 2006 was more modest and grew by more than 0.3 percentage point only in Korea, China and Japan. Indeed, in nearly half of the countries shown in Figure 1.6 BERD intensity has fallen in recent years.

It is important to consider what shapes variations in BERD intensity. One factor is industrial specialisation, since some sectors are more R&D-intensive than others (*e.g.* pharmaceuticals is more R&D-intensive than textiles). Another factor is business demographics, since there is a strong relationship between business R&D intensity and the share of large R&D-performing firms in the business population. In most countries with high levels of business R&D intensity, business R&D is concentrated in firms with more than 500 employees (Figure 1.7). More than 70% of business R&D in the Netherlands, Finland, the United Kingdom, Italy, Sweden, France, the United States, Germany, Korea and Japan is undertaken in large businesses. But Figure 1.7 also suggests that a number of smaller OECD economies (the Nordic countries, plus Belgium, Switzerland, Australia, Ireland and New Zealand) perform more business R&D than would be suggested by their large-firm populations, in turn suggesting more BERD-intensive small and medium-sized enterprise (SME) populations.

So even though the bulk of R&D is performed by large businesses in most OECD countries, SMEs are still important players. Firms with fewer than 250 employees account for particularly large shares of business R&D in New Zealand (73%), Greece (53%), Norway (52%), the Slovak Republic (51%) and Ireland (47%). Indeed, in New Zealand, Australia, Norway and Ireland, more than 20% of business R&D is performed in firms with fewer than 50 employees.

Figure 1.6. **BERD intensity by country, 1996, 2001 and 2006**

As a % of GDP



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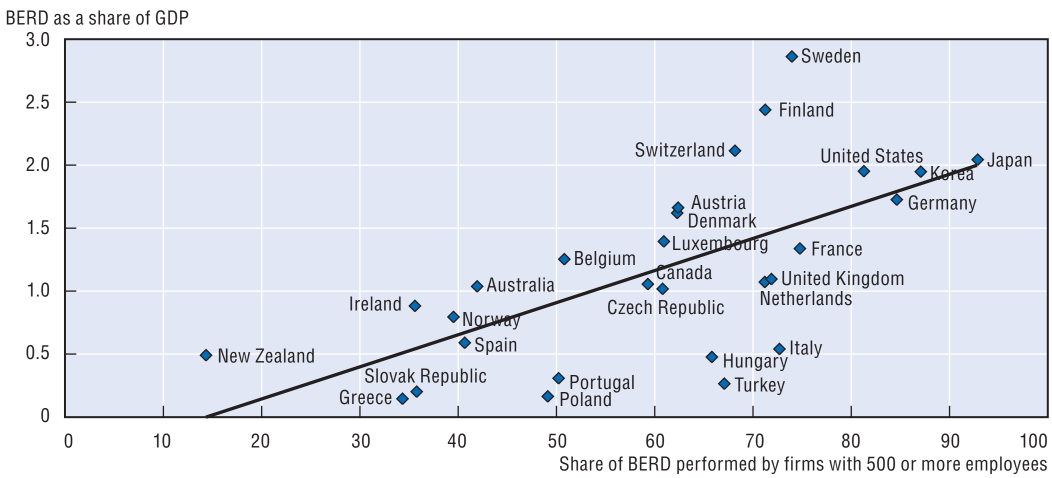
1. 1998 for Austria; 1996 for Switzerland; 1997 for Iceland, New Zealand, Norway, Sweden and South Africa.
2. 2002 instead of 2001 for Austria; 2003 for Luxembourg; 2000 for Switzerland.
3. 2005 for Australia, Iceland, Mexico, New Zealand, and South Africa; 2004 for Chile, India and Switzerland.

Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1*. India: national sources.

Figure 1.7. **Business R&D intensity and share of R&D performed by firms with 500 or more employees, 2005 (or nearest year)**



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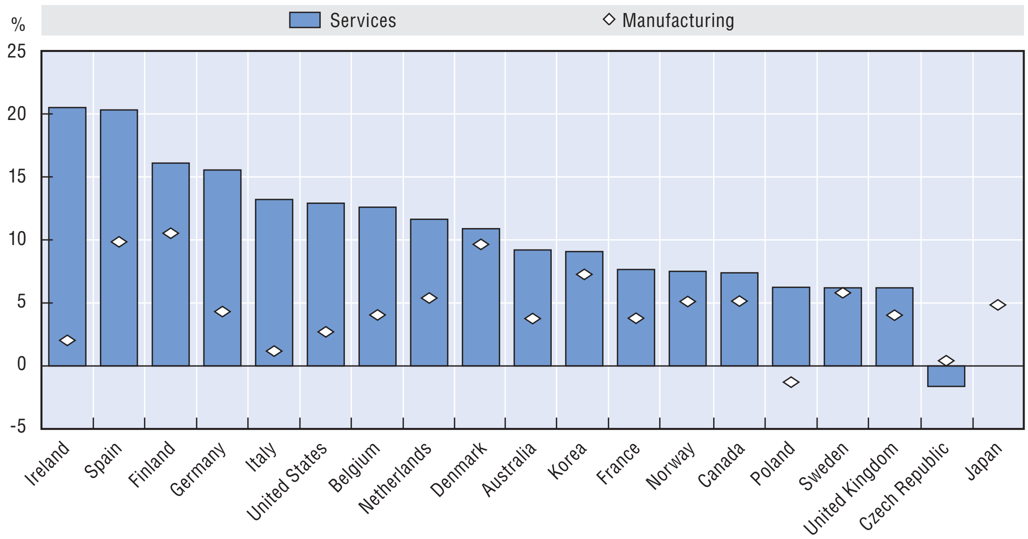
Source: OECD, *R&D Database*, 2007.

An important current trend is that, while the manufacturing sector continues to account for the bulk of business R&D, investment in the services sector is increasing. In several countries, more than one-third of total business R&D is carried out in the services sector: Australia and New Zealand (41% each), the United States (36%), Denmark and Norway (35% each) and the Czech Republic and Ireland (34% each). In Korea, Germany and Japan less than 10% of business R&D is conducted in the services sector, but this may also partly reflect the limited coverage of services in their R&D surveys.

Except in the Czech Republic, business R&D expenditure in the services sector has grown at a faster pace than in the manufacturing sector (Figure 1.8). In Ireland and Spain, the annual growth rate in the services sector was around 20% between 1995 and 2004, while in most other countries it was between 9 and 16%. While some of the growth in services can be explained by better measurement of R&D in this sector and the reclassification of some manufacturing into services, innovation surveys have demonstrated that the services sector is highly innovative. Finland aside, annual growth of business R&D expenditures in manufacturing was less than 10% from 1995 to 2004.

Figure 1.8. **Business R&D expenditures in services and manufacturing, 1995-2004**

Average annual growth rates (%)



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Note: Growth rate in Australia, France, Japan and United States for 1995-2003.

Source: OECD, ANBERD Database, 2006.

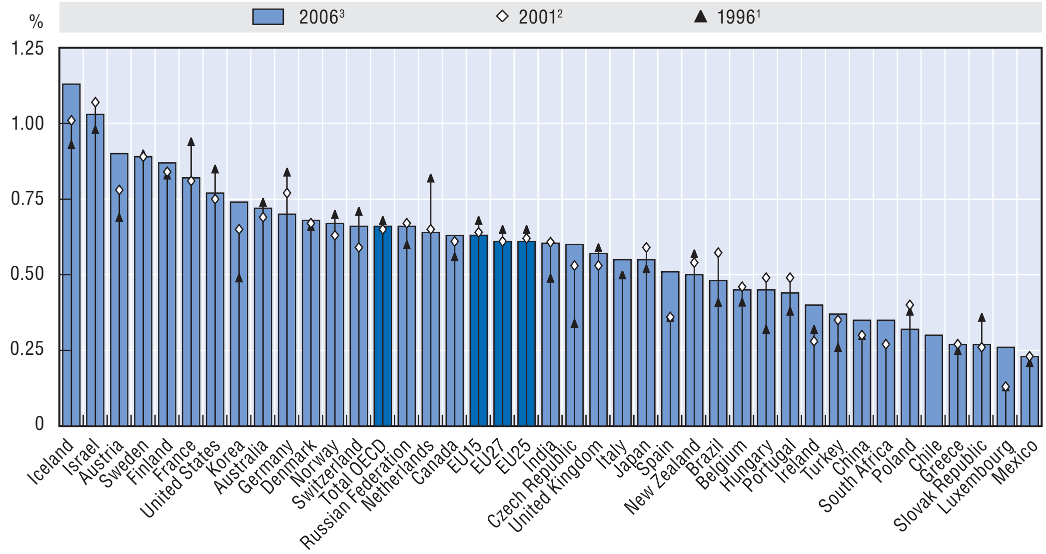
Decline in government support for R&D as a share of GDP

Government financing of R&D (that is, the share of GERD financed by government) also varies across countries, but generally continues to fall. This reflects in part a shift from direct to indirect support of R&D in the business sector (see below). Direct government funding of R&D as a percentage of GDP decreased in the OECD area from 0.68% in 1996 to 0.66% in 2005, slightly above the share in 2001 (0.65%). In Iceland and Israel, government-financed R&D as a percentage of GDP exceeded 1%, but in 13 countries it was below 0.5% in 2006 (Figure 1.9). In Austria, Iceland, Ireland, Luxembourg and Spain, it grew by more than 0.1 percentage point between 2001 and 2006. The largest declines between 2001 and 2006 were in Brazil (0.09 percentage point), followed by Poland and Germany (0.08 and 0.07, respectively). Over the ten-year period, the largest drops were in the Netherlands, Germany and France where government financing declined by more than 0.1 percentage point.

Governments not only finance R&D in various sectors of performance, they also fund the performance of R&D on their own behalf. Government budget appropriations or outlays for R&D (GBAORD) measures the funds committed by federal/central governments for R&D. In aggregate, this has been climbing faster than GDP across the OECD in recent years, but with considerable variation across countries. Since 2001, GBAORD grew by 6.4% annually

Figure 1.9. **Government-financed R&D, 1996, 2001 and 2006**

As a % of GDP



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1. 1997 instead of 1996 for Finland, Greece, Iceland, New Zealand, Norway and Sweden; 2000 for Luxembourg and China; 1995 for India.
2. 2000 instead of 2001 for Australia, China, Luxembourg and Switzerland.
3. 2005 for Belgium, Denmark, France, Germany, Greece, Iceland, Italy, Luxembourg, Mexico, New Zealand, Norway, Portugal, Spain, Sweden, Total OECD, EU27, EU25, EU15 and South Africa; 2004 for Australia, Brazil and Switzerland; 2003 for the Netherlands and Israel; 2002 for India.

Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1*. Chile and India: national sources.

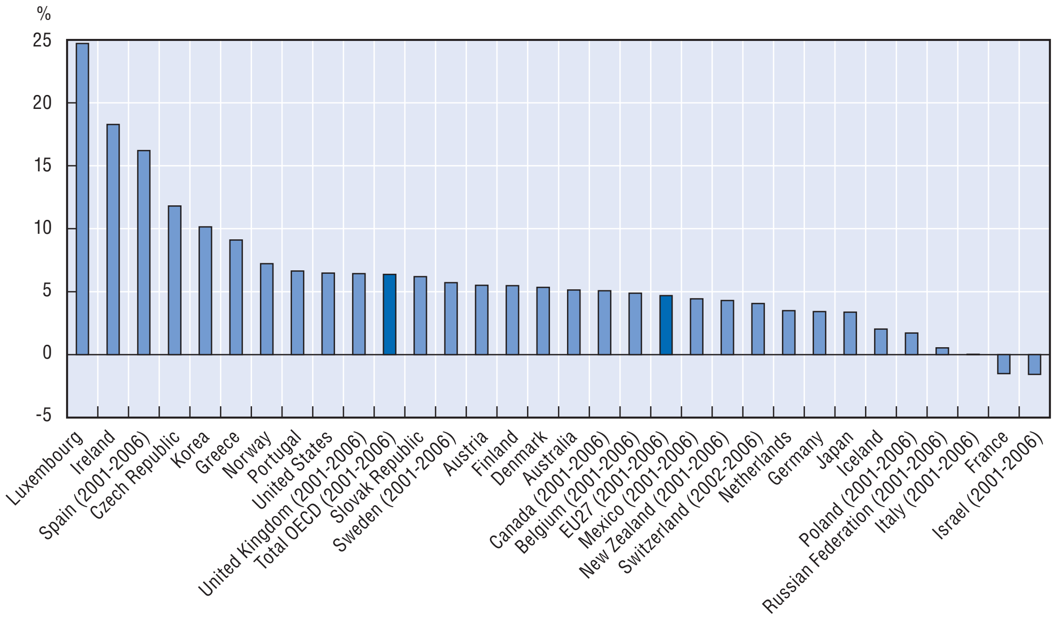
across the OECD, from USD 214 billion in 2001 to USD 291 billion in 2006 (in current PPP USD). The GBAORD to GDP intensity also grew, from 0.76% in 2001 to 0.81% in 2006 for the OECD area. Luxembourg experienced the highest growth at 25%, and Ireland and Spain grew by more than 15% a year (Figure 1.10). GBAORD grew more slowly in the EU27, at almost 5% a year, but it reached 3.4% in Japan and 6.5% in the United States. Israel and France were the only countries in which GBAORD fell. In Italy, the government R&D budget remained flat and in Russia it increased modestly between 2001 and 2006 with an annual increase of 0.5%.

The composition of public investment in R&D also varies considerably across countries. The outstanding feature continues to be the United States' commitment to defence R&D: at 0.6% of GDP in 2007, it continues to have the largest defence R&D budget, double the OECD average of 0.3% of GDP and three times larger than that of France and the United Kingdom which have the second highest ratios in the OECD area (both around 0.2% of GDP in 2005). In Russia, the defence R&D budget was 0.4% of GDP in 2003. These intensities should be seen against the background of the United States' much larger GDP. The United States' very high absolute expenditure on defence R&D accounted for 86% of the overall OECD area budget for defence R&D, and was six times the EU27 total. Finland has the largest civil R&D budget at 0.96% of GDP, followed by Iceland at 0.88%. The OECD average for civil R&D was 0.5% of GDP and the EU27 ratio was marginally higher at 0.6%.

There has been a significant administrative and financial shift in the way that governments support business R&D. In addition to direct support, governments also finance business R&D indirectly through the use of tax incentives, an alternative to direct spending

Figure 1.10. **Change in government R&D budgets, 2002-07 (or latest available years)**

Average annual growth rate of GBAORD



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Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1.*

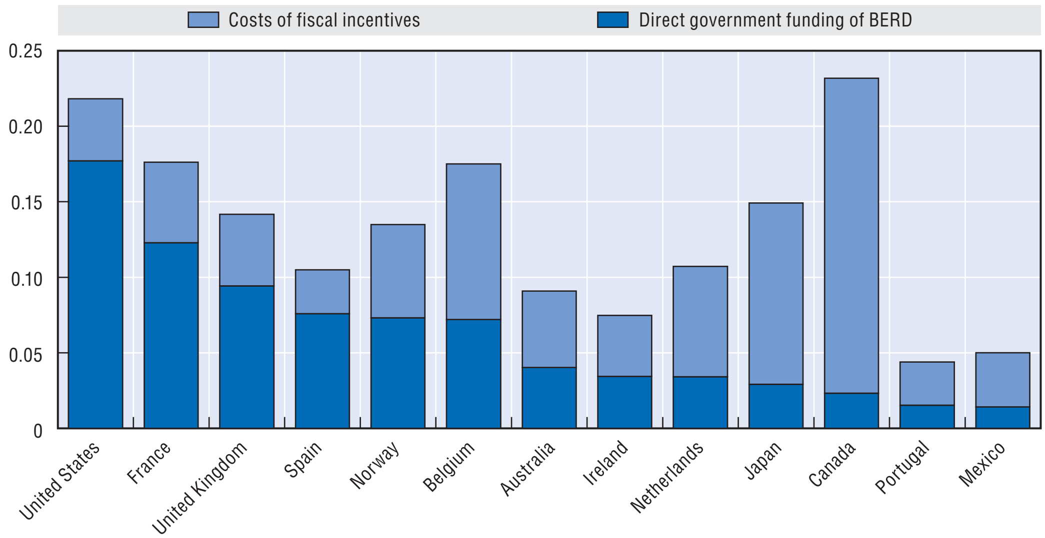
for achieving government policy objectives. The costs of these tax credits, in terms of foregone revenue, do not usually appear as R&D support in government budgets, although they may be significant. As of 2008, 21 OECD countries had tax credits for R&D, up from 12 in 1995 and 20 in 2006. Of the countries that do not currently have R&D tax incentives, Germany, Iceland and Sweden have been considering their introduction (Colecchia, 2007). In addition, five non-OECD member countries – Brazil, China, India, Singapore and South Africa – have a competitive tax environment for investment in R&D (Warda, 2007). Figure 1.11 compares direct and indirect government funding of business R&D and shows that in six countries (Canada, Belgium, Australia, Ireland, Mexico, the Netherlands and Portugal) tax incentives account for a greater proportion of government support for business R&D than direct government funding. Work by the OECD-NESTI Group found that estimated foregone revenue due to R&D tax incentives in 2005 was more than USD 5 billion in the United States, around USD 4.5 billion in Japan, more than USD 2 billion in Canada, over USD 800 million in France and the United Kingdom and between USD 350 and 450 million in the Netherlands, Mexico, Australia, Belgium and Spain. In Norway, Ireland and Portugal foregone revenue was between USD 60 and 140 million (Colecchia, 2007).

Strong R&D spending in the higher education sector

Public sector research organisations (PROs) play an important role in R&D and innovation. Higher education institutions (mainly universities) and government research institutes are key organisations for creating and diffusing scientific and technological knowledge. Many governments are seeking to expand their countries' science and innovation capabilities and have increased funding for public-sector research. Indeed, studies have shown a link between R&D performed in the higher education sector and business R&D (van Pottelsberghe, 2008). In the OECD area, government intramural

Figure 1.11. **Direct and indirect government funding of business R&D and tax incentives for R&D, 2005 (or latest available year)**

As a % of GDP



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Source: OECD, based on national estimates (NESTI R&D tax incentives questionnaire), some of which may be preliminary. The estimates cover the federal research tax credit for the United States; the SR&ED tax credit for Canada; the mixed volume and incremental incentive for France; the refundable research premium for Austria; the tax credit consisting of a reduction of taxes on R&D wages as well as the allowance on profits of R&D self-employed for the Netherlands; the volume measure for the United Kingdom, Mexico and Norway; the mixed volume and incremental measure for Spain (now being phased out); both the tax offset and incentive depreciation for Australia; the incremental tax credit for Ireland; the tax incentives for experimental research plus the special tax depreciation of equipment for developmental research for Japan.

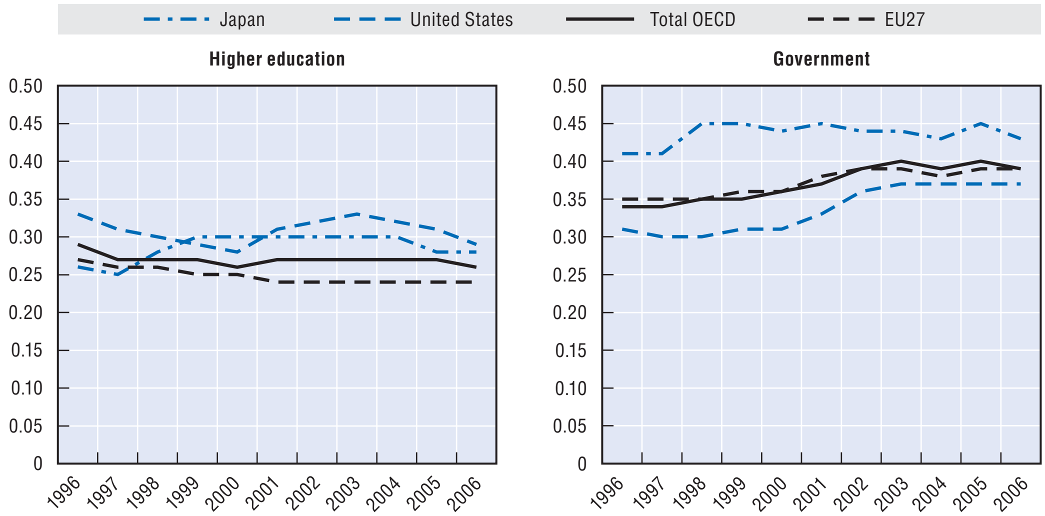
expenditure on R&D rose from USD 63.9 billion in 1996 to USD 93.5 billion in 2006, and higher education R&D (HERD) expenditure nearly doubled from USD 75.8 billion to USD 140.1 billion. As a share of GDP, R&D performed in the public sector (*i.e.* higher education institutions and government research institutes) increased modestly, from 0.64% in 2001 to 0.65% in 2006, with HERD intensity growing more rapidly than government intramural R&D.

As shown in Figure 1.12, R&D growth has been strong in the higher education sector. In Japan, higher education R&D expenditure as a share of GDP increased by 2 percentage points between 2004 and 2005 before falling to 0.43% in 2006, whereas it fell 2 percentage points in government research institutes. The United States experienced rapid R&D growth in the higher education sector from 2000 (0.31% of GDP) to 2003 (0.37%), since when it has remained stable. R&D expenditure fell 1 percentage point (or more) a year in US government research institutes between 2003 and 2006. In the EU27, government intramural R&D expenditure remained constant at 0.24% of GDP from 2001 to 2006; in the higher education sector it hovered between 0.38% and 0.39% of GDP. Given that GDP growth has been sound across the OECD (see above) public R&D investment, particularly in the higher education sector, seems largely to have kept pace with economic growth.

Expenditure on HERD across countries is more diverse. In GDP terms, from 2001 to 2006 the largest increases occurred in Denmark, Canada and Ireland with an increase of 0.1 percentage point or more. In Israel, Sweden, Turkey, France, Brazil, Poland, Japan, Italy and South Africa, R&D in higher education institutions declined as a percentage of GDP

Figure 1.12. **R&D performed in higher education and government research institutes by area, 1996-2006**

As a % of GDP



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Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1.*

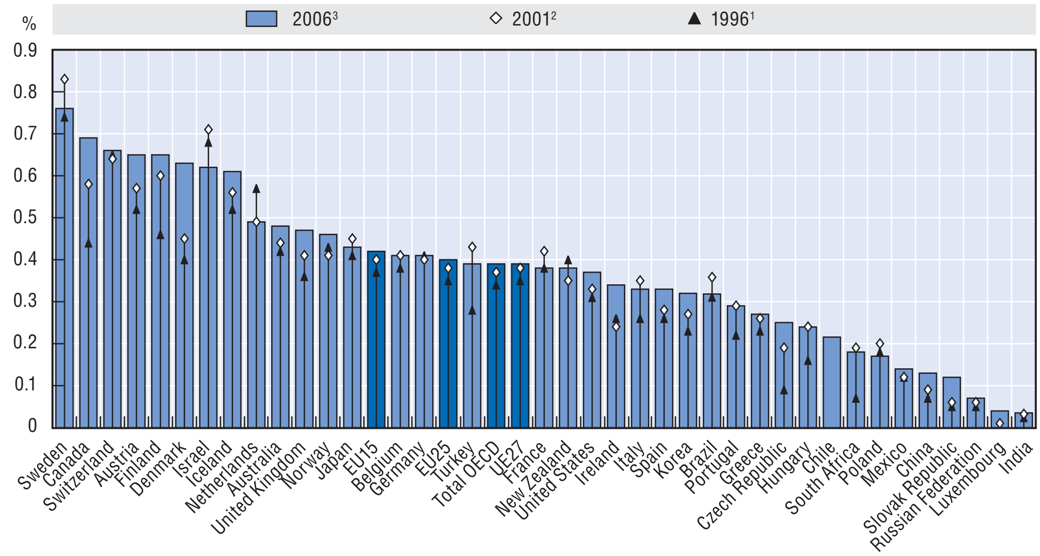
over the past four to five years. However, differences among OECD countries remain large (Figure 1.13). Sweden has the highest ratio of HERD to GDP in the OECD area, at 0.76%, followed by Canada (0.69%), Switzerland (0.66%), Austria and Finland (0.65% each). Most large OECD countries, including Japan, Germany, France and the United States, devote between 0.45 and 0.35% of GDP to R&D in higher education institutions. In the United Kingdom the figure was 0.39% of GDP in 2006.

In absolute terms, spending on R&D in the higher education sector has been strong in recent years. The Slovak Republic experienced the highest real average increase from 2001 to 2006 at 22%, followed by China (17%), Ireland (13%) and the Czech Republic (10%). Luxembourg's annual growth was particularly strong (46%) because it established its first university in 2003. Growth across the OECD area and the EU27 was 3.3% and 2.8%, respectively, between 2001 and 2006, or more than the growth rates in the business and government sectors. This strong growth in the higher education sector may reflect the growing recognition that R&D in higher education institutions is an important stimulus to economic growth and improved social outcomes.

There are significant differences in the fields in which higher education R&D is performed. In Slovenia, Chinese Taipei, Russia and Romania, for example, over 85% of all R&D is carried out in natural sciences, engineering, medical sciences and agricultural sciences, with social sciences and humanities accounting for only a small share (Figure 1.14). In Luxembourg and Israel, however, more than 60% is carried out in social sciences and humanities and in Spain, Mexico and South Africa these fields account for around 35%. The differences may be linked to the specialisation of the science systems in each country. It is important to bear in mind that countries are often specialised in certain scientific or technological areas, and these are likely to have a bearing on policy mechanisms aimed at removing demand gaps. When gaps become acute in the key fields and priority areas of particular countries, policy makers may have to focus on specific fields.

Figure 1.13. **Higher education research and development, 1996, 2001 and 2006**

As a % of GDP



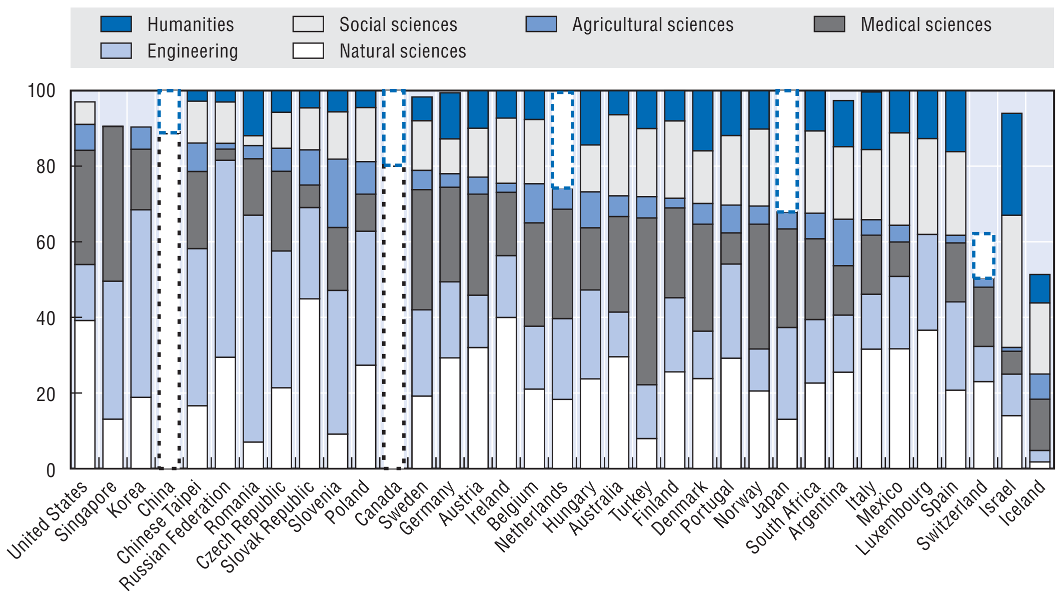
StatLink http://dx.doi.org/10.1787/450636737072

1. 1998 instead of 1996 in Austria; 1997 for Greece, Iceland, India, New Zealand, Norway, Sweden and South Africa.
2. 2002 instead of 2001 in Australia, Austria, India and Switzerland.
3. 2005 for Iceland, Italy, Mexico, New Zealand, Portugal, South Africa; 2004 for Australia, Brazil, Chile, India and Switzerland; 2003 for the Netherlands.

Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1*. Chile and India: national sources.

Figure 1.14. **Higher education research and development expenditure by field of study, 2005**

As a % of total higher education R&D expenditure



StatLink http://dx.doi.org/10.1787/450642538230

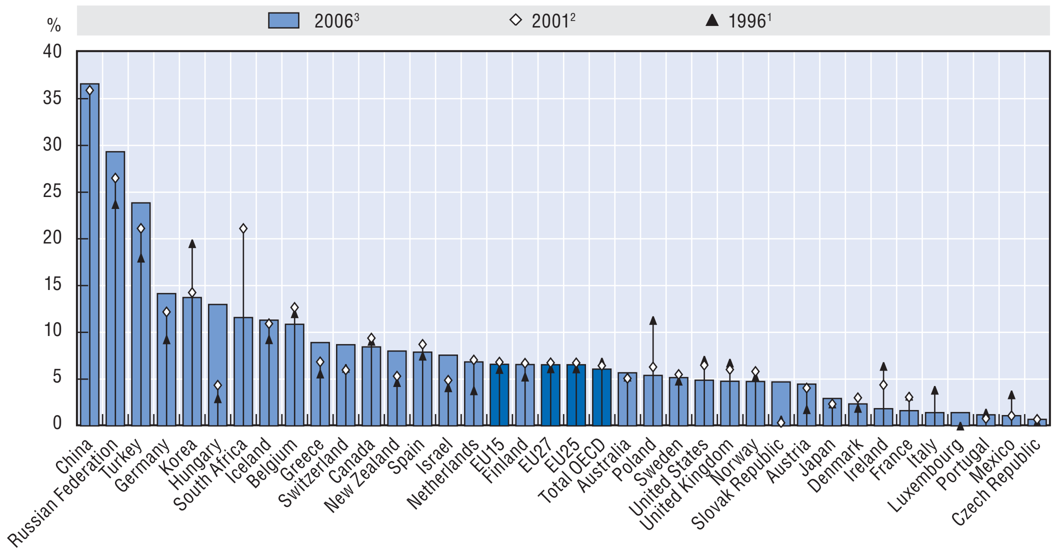
Note: 2001 instead of 2005 for the United States, 2002 for the Netherlands, 2003 for Mexico and 2004 for Australia and Austria. In Canada and China, sciences and engineering are combined. In Canada, China, Japan, the Netherlands and Switzerland, social sciences and the humanities are combined. In Argentina, Germany, Iceland, Israel, Korea, Singapore, Sweden, Switzerland and the United States, some fields are not classified; therefore the sum does not reach 100%.

Source: OECD, *R&D Database*, 2007.

Not all R&D performed in the higher education sector is funded by government. Figure 1.15 shows the share of HERD financed by industry, which provides an indicator of the links between these sectors. The proportions vary, ranging from 37% in China to 0.7% in the Czech Republic. For the OECD area, industry-financed R&D in higher education institutions reached 6.1% in 2005, slightly below the share in 2001 (6.4%). Nevertheless, since 1990, the share has remained fairly constant at around 6 to 7%. In Hungary, industry financing grew the most, by 8.6 percentage points between 2001 and 2006. Conversely, in the United States, Belgium and Ireland, it dropped by more than 1.5 percentage point in each and in South Africa it fell by 9.5 percentage points.

Figure 1.15. **Share of higher education R&D financed by industry, 1996, 2001 and 2006**

As a % of total higher education R&D



StatLink http://dx.doi.org/10.1787/450731005724

1. 1998 for Austria; 1997 for Finland, Greece, Iceland, New Zealand and Norway.
2. 2002 instead of 2001 for Australia, Austria and Switzerland; 2003 for China.
3. 2005 for Belgium, Denmark, France, Germany, Greece, Iceland, Italy, Luxembourg, Mexico, New Zealand, Norway, Portugal, Sweden and the United Kingdom; 2004 for Australia, Austria and Switzerland; 2003 for the Netherlands and Israel.

Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1.*

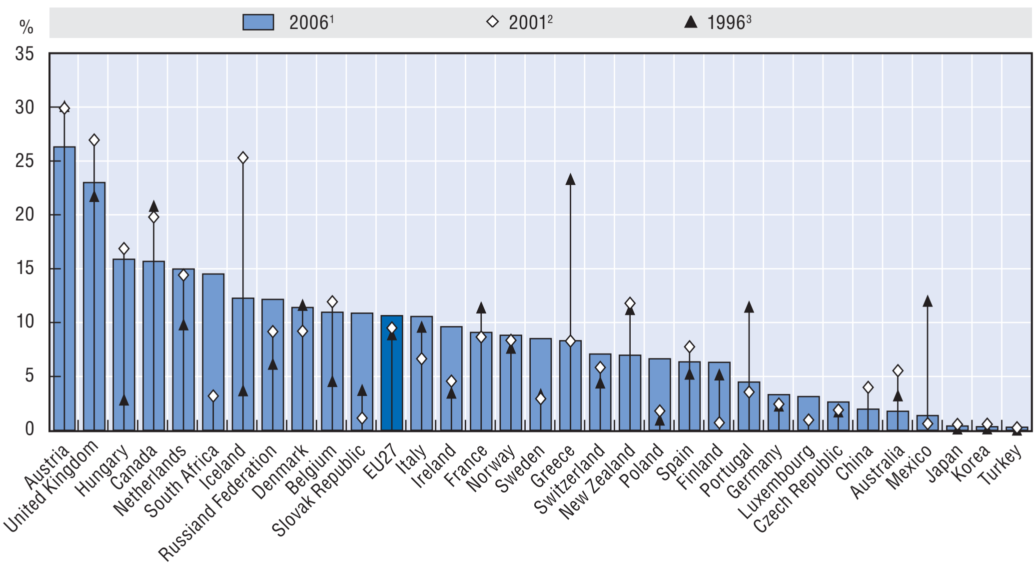
The internationalisation of R&D is spreading

The internationalisation of R&D is not a new phenomenon, but it is occurring at a much faster pace today. Moreover, it is spreading more widely, including to emerging economies. Much of this is linked to the changing motivations for outward investment in R&D. In the past, cross-border R&D was largely aimed at adapting products and services to the needs of host countries; it was carried out close to “lead users” in order to adapt products and processes to local conditions. It also supported the local manufacturing operations of multinational enterprises (MNEs). At present, MNEs seek not only to exploit knowledge generated at home and in other countries, but also to source technology internationally and tap into centres of increasingly multidisciplinary knowledge worldwide. However, the distinction between adaptive and innovative R&D centres is not entirely clear. A range of studies indicate that both demand and supply motivate the location of R&D activities in host countries, but that technology sourcing is on the rise (OECD, 2008b; OECD 2006a).

The changing landscape of global R&D can be observed in the growth of R&D sourced from abroad (through private business, public institutions or international organisations). These sources are quite important in the funding of business R&D. In most countries, the financing of business enterprise R&D from abroad primarily comes from other business enterprises, notably other MNEs. In the EU27, finance from abroad represented on average around 11% of total business R&D in 2005 (Figure 1.16). Austria had the highest share (26%), followed by the United Kingdom (23%). During the past five years or so, South Africa and the Slovak Republic reported the largest increases (around 10 percentage points each), and the share in both Finland and Sweden grew by nearly 6 percentage points. Business R&D finance from abroad fell sharply in Greece and Mexico between 1996 and 2006.

Figure 1.16. **R&D funds from abroad, 1996, 2001 and 2006**

As a % of business enterprise R&D



StatLink http://dx.doi.org/10.1787/450736732060

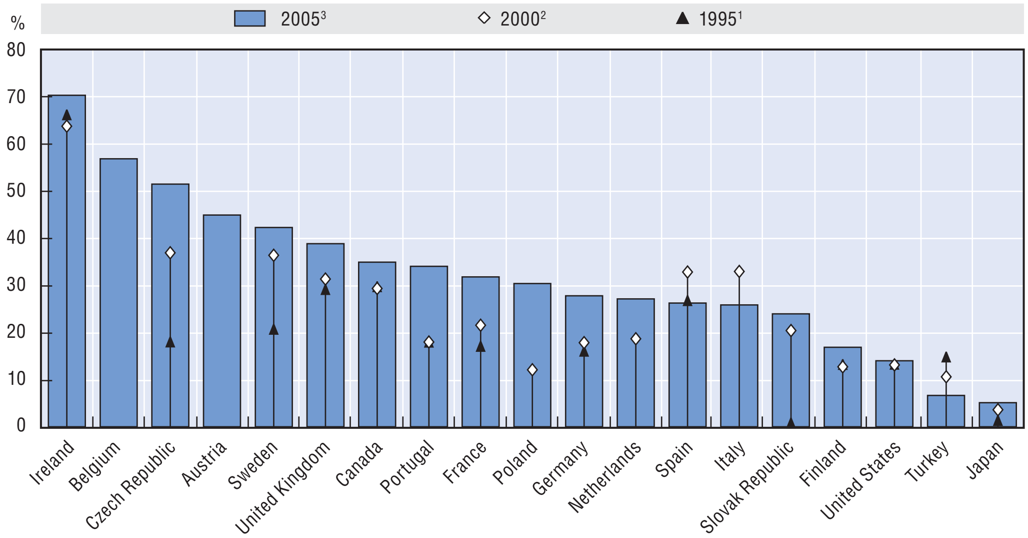
1. 1997 instead of 1996 for Finland, Iceland, New Zealand, Norway and Sweden; 1998 for Austria.
2. 2000 for China, Luxembourg and Switzerland; 2002 for Austria.
3. 2005 for Australia, Denmark, France, Greece, Iceland, Luxembourg, Mexico, New Zealand, Portugal, South Africa, Sweden, EU27; 2004 for Austria and Switzerland; 2003 for the Netherlands.

Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1.*

In most OECD countries, the share of foreign affiliates in industry R&D is growing as foreign firms acquire local R&D-performing firms (*e.g.* through mergers and acquisitions) or establish new subsidiaries. Smaller countries such as Ireland typically report higher shares of R&D expenditures by foreign affiliates. Among the larger European economies, the share of R&D performed in foreign affiliates ranged from a high of 39% in the United Kingdom to a low of 26% in Italy (Figure 1.17). Japan has the smallest share of R&D in foreign affiliates at just 5% of total enterprise R&D, although the share has increased since 1995. In the Czech Republic and the Slovak Republic the share leapt from 18 to 52% and 0.8 to 24%, respectively, from the mid 1990s to 2005.

Figure 1.17. **R&D expenditure of foreign affiliates, 1995, 2000 and 2005**

As a % of R&D expenditures of enterprises



StatLink http://dx.doi.org/10.1787/450765572046

1. 1996 for the Czech Republic; 1997 for Finland and Turkey; 1999 for Portugal.
2. 1998 for Hungary; 1999 for Australia, Germany, Greece and Ireland; 2001 for France, Italy, Portugal, Spain, Sweden.
3. 2004 for Austria, Canada, Italy, Japan; 2003 for the Netherlands; 2002 for Turkey.

Source: OECD, *Main Science and Technology Indicators (MSTI) Database 2008/1.*

International co-operation is a further aspect of the globalisation of research activities. The internationalisation of R&D is demonstrated not only through R&D expenditure on the input side but also through patents. The world share of patents involving international co-invention increased from 4.6% in 1992-94 to 7.3% in 2002-04 (see Figure 1.29). In addition, international co-authorship of scientific articles has grown rapidly over the past decade. In 2005, 20.6% of scientific articles in the natural sciences involved international co-authorship, a figure three times higher than in 1985 (OECD, 2007a, p. 171).

Innovation in key technologies

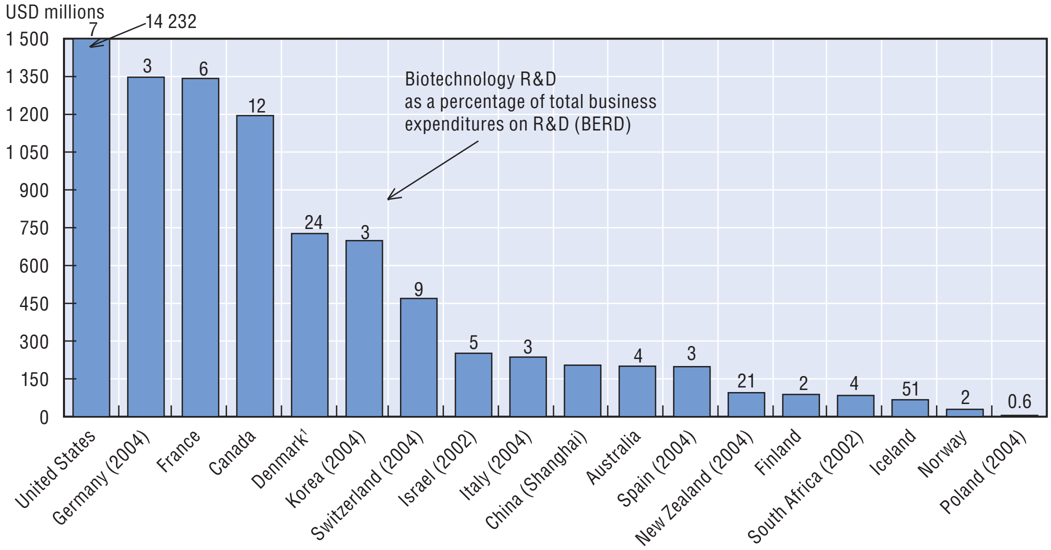
In OECD countries, there is considerable policy interest in a range of new technologies that promise growth opportunities or solutions to pressing social and economic problems. These include most notably biotechnology and general life sciences, nanotechnology, and environmental sciences and technologies. However, although many countries see these broad areas as priorities, there is considerable diversity in their expenditures and outcomes. There are also sharp distinctions in their prominence, as indicated by R&D and patent data. The United States is the clear leader in biotechnology R&D, though less so in patenting, and is also the leader in nanotechnology patenting. In environmental sciences and technologies the United States leads, by a small margin, in scientific publications, but significantly lags the EU25 in environmental technology patenting.

Biotechnology has some particular features. First, it involves large numbers of small firms. Across the OECD area, more than 60% of biotechnology-active firms have fewer than 50 employees; the EU has more than 3 000 biotechnology-active firms, and the United States more than 2 000.[5] Second, many of these firms are linked to universities (via co-operation or shared personnel), so that there is a close link between university funding and biotechnology research and outcomes.

In terms of expenditure on R&D by biotechnology-active firms, the United States stands far ahead, as its R&D expenditure of just over USD 14 billion is considerably more than that of all other countries combined (Figure 1.18). However, a number of smaller economies have higher proportions of biotechnology R&D in total BERD. In Denmark, which is very active in health-related biotechnology, and in New Zealand, Canada and Iceland, very high shares of BERD go to biotechnology. It is worth noting that although biotechnology potentially has a wide range of application areas (*e.g.* health, agri-food, environmental and industrial processes) data available by field of application indicate that the expenditure overwhelmingly is for health.

Figure 1.18. **Total expenditure on biotechnology R&D by biotechnology-active firms, 2003 (or latest available year)**

Millions of USD PPP (current)



StatLink http://dx.doi.org/10.1787/450768474045

1. Results for Denmark may overestimate biotechnology R&D because a few health biotechnology firms did not give the percentage of total R&D allocated to biotechnology. For these firms, all R&D was assigned to biotechnology.

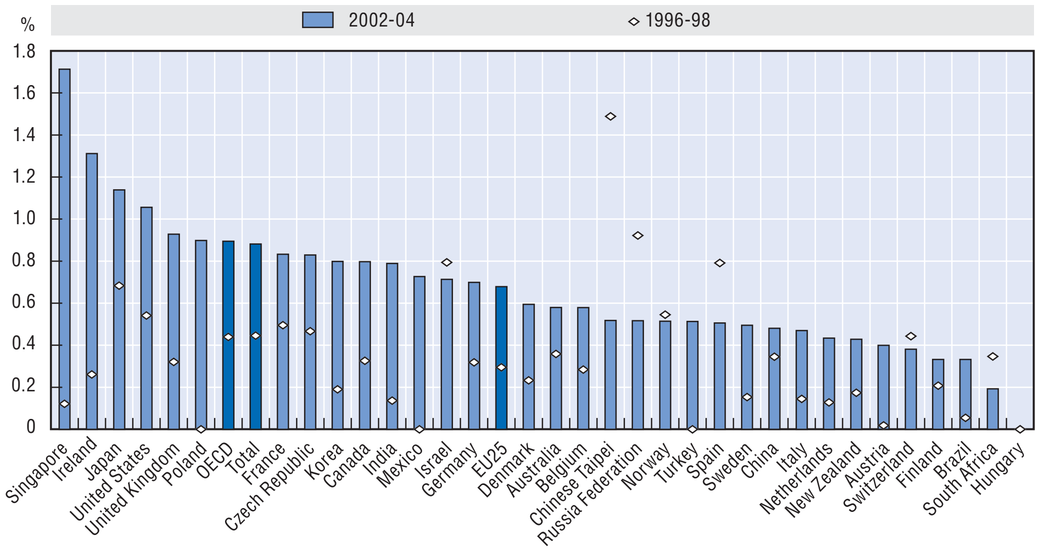
Source: OECD Biotechnology Statistics 2006.

Although biotechnology is widely considered a key R&D priority in many countries, this is not necessarily reflected in budget allocations. Only four countries have a share of public biotechnology R&D in total public R&D of around 10% or more: New Zealand (24.2%), Korea (15.3%). Canada (12.4%) and Denmark (9.9%). These countries, plus Norway, Spain and Finland, also have high shares of public-sector biotechnology R&D in total biotechnology R&D (OECD, 2007a, p. 145).

Biotechnology patenting is less unevenly distributed than biotechnology R&D. The United States is still the clear leader, with nearly 40% of all Patent Co-operation Treaty (PCT) filings, but the gap with the EU25 is much smaller, and the United States has no lead over all other countries combined (OECD, 2007a, p. 150).

Nanotechnology is a multidisciplinary technology at the atomic or molecular scale encompassing a number of technological fields relating to chemical synthesis, computing, and materials and devices at that scale. Internationally comparable data on nanotechnology R&D are not yet available, but inventive output in nanotechnology has grown in recent years. Figure 1.19 shows that the share of nanotechnology in total national

Figure 1.19. **Nanotechnology patents as a percentage of national total (PCT filings), 2002-04**



StatLink http://dx.doi.org/10.1787/450771726830

Note: Patent counts are based on the priority date, the inventor's country of residence and fractional counts. Patent applications filed under the Patent Co-operation Treaty, at international phase, designating the European Patent Office. Only countries with more than 250 PCT filings during 2002-04 are included.

Source: OECD, *Patent Database*, 2008.

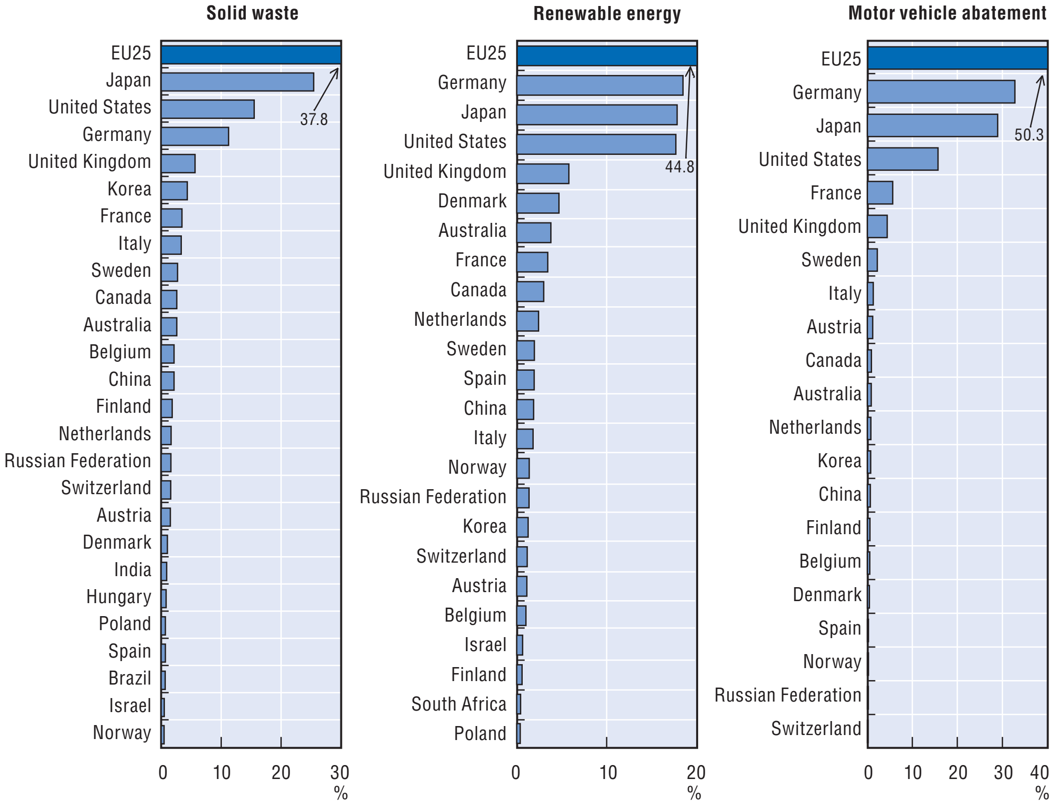
patenting increased markedly between 1996-98 and 2002-04 in the majority of countries, although the total amount of patenting remains low. Apart from Singapore, no country has more than 1.5% of total PCT filings in nanotechnology.

Environmental technologies are attracting considerably more policy attention as a result of growing concerns about climate change and enhanced public awareness of this issue across the globe. Many governments view technological innovation as a means to promote sustainable development, and public policy can play an important role through public R&D expenditures, fiscal reforms, tax-based measures, etc. At present, the emphasis in environmental technology is on applications. Key fields include the treatment and management of solid waste, renewable energies, and reduction of greenhouse gas emissions from motor vehicles. Figure 1.20 shows patenting in these fields for 2000-04. Here, the EU25 is the clear leader, with patent shares of around 40% in waste and renewable energy and 50% in motor vehicle abatement. At the national level, Japan and Germany are particularly prominent, as each is very active in all three aspects of the field.

Regardless of the structure of shares, work from the OECD Environment Directorate shows that patenting in key environmental technologies, such as renewable energy, is growing sharply (Figure 1.21). This is a major dynamic of patenting at the present time.

The ICT sector invests heavily in R&D. In 2004, ICT manufacturing industries accounted for more than a quarter of total manufacturing R&D expenditure in most OECD countries, and over half in Finland and Korea. The share of ICT in total patent applications rose in almost all countries from the mid-1990s to the beginning of the 2000s. In OECD countries, ICT-related patents represented, on average, 35% of total PCT filings in 2005. Over 50% were related to ICT in Finland and Singapore, and in China, the share of ICT in total patent applications more than doubled over 1996-2005 (OECD, 2008d).

Figure 1.20. **Countries' shares in environmental technology patents filed under the PCT, 2000-04**



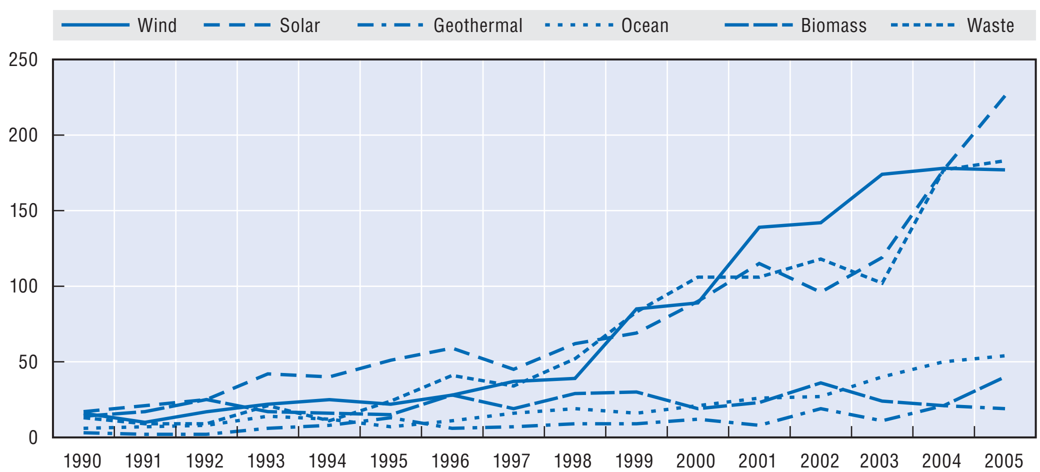
StatLink http://dx.doi.org/10.1787/450806870707

Note: Patent counts are based on the priority date, the inventor's country of residence and fractional counts. Patent applications filed under the Patent Co-operation Treaty, at international phase, designating the European Patent Office.

Source: OECD, *Patent Database*, April 2007.

Figure 1.21. **Renewable energy patenting, by energy source, 1990-2005**

Number of patent applications filed under the PCT, at international phase, designating the EPO, by priority date



StatLink http://dx.doi.org/10.1787/450820142002

Note: Patents relating to renewable energy are identified using a selection of IPC classes (defined by the OECD Environment Directorate).

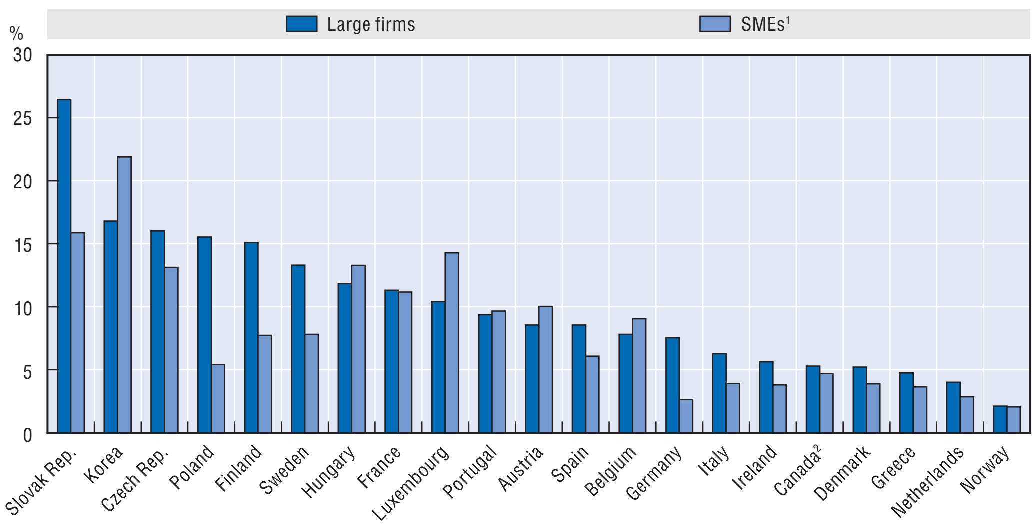
Source: OECD, *Patent Database*, 2008.

Innovation performance varies across countries[6]

Innovation surveys provide data on a range of indicators of innovation performance in the economy. Perhaps the most widely used indicator from these surveys is the proportion of firms reporting innovative activity. In the EU27, for example, 42% of firms reported some form of innovation activity between 2002 and 2004 (*i.e.* the market introduction of a new or significantly improved good, service or process). In the EU as a whole, the manufacturing sector had a higher proportion of innovative firms (37.4%) than services (33.7%), and firms with more than 250 employees had a higher propensity to innovate (49.2%) than small (33.2%) and medium-sized firms (39.6%). Other indicators can be used to measure the degree of novelty of innovations: new to the firm, new to the market and new to the world. The category "new to the firm" captures innovation diffusion whereas "new to the market" and "new to the world" reveal more novel and radical innovations. This makes it possible to distinguish between developers, adapters and adopters of innovations. Moreover, the share of turnover from product innovations (goods and services) that are new to the market can be used to measure innovation performance across firms and industries, since it translates innovation activity into a common monetary indicator. Figure 1.22 shows that there are big differences among countries but less variation between SMEs and large firms. Indeed, in Korea, Hungary, Luxembourg, Portugal, Austria and Belgium, SMEs reported a larger share of their turnover from new to the market product innovations than large firms.

Figure 1.22. **Share of turnover from new-to-market product innovations, by firm size, 2002-04 (or latest available years)**

As a % of turnover



StatLink http://dx.doi.org/10.1787/450834182743

1. SMEs: 10-249 employees.
2. Manufacturing only.

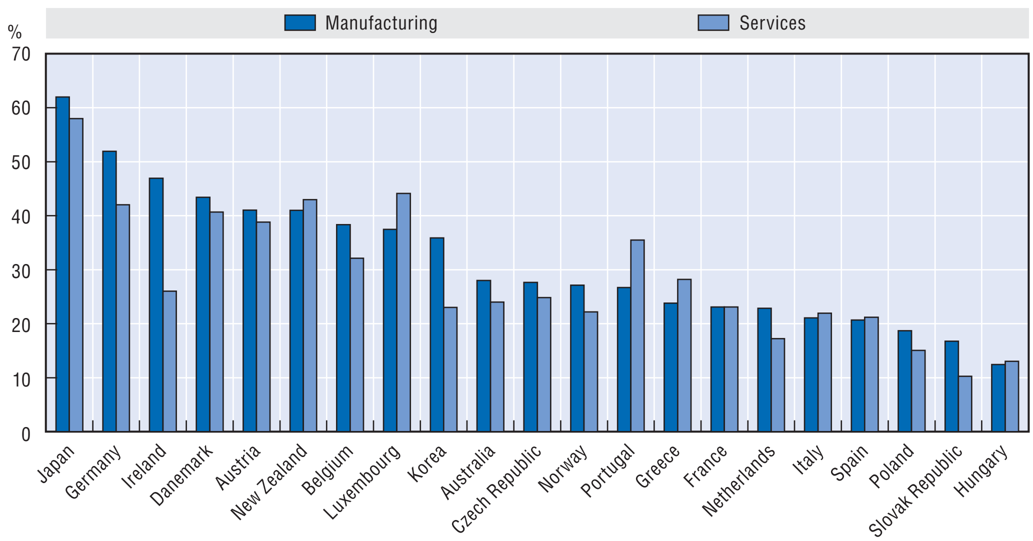
Source: Eurostat, CIS-4 (New Cronos, May 2007) and national data sources.

Non-technological innovation occurs in manufacturing and service firms

In recent years, non-technological innovation has received increasing attention and it is now routinely included in national innovation surveys. Non-technological innovation may include a marketing innovation (the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing) and/or an organisational innovation (the implementation of a new organisational method in the firm's business practices, workplace organisation or external relations) (OECD, 2005). Non-technological innovation is an important part of many firms' innovation activities and a central part of the innovation process. As shown in Figure 1.23, the proportion of firms reporting organisational and marketing innovations (*i.e.* non-technological innovation) varies markedly across countries. In Japan, more than 60% of manufacturing firms reported non-technological innovative activity compared to 10% of service firms in the Slovak Republic. However, the share of non-technological innovators is similar in both the services and manufacturing sectors; That is, non-technological innovation is not stronger in the services sector. Both manufacturing and services engage in product, process and non-technological innovation and differences appear more related to the characteristics of specific industries and firms. Large firms, for example, engage far more in non-technological innovation than SMEs (OECD, 2007a, p. 98).

Figure 1.23. **Non-technological innovators,[1] 2002-04 (or latest available years)**

As a % of all firms



StatLink http://dx.doi.org/10.1787/450852505874

1. Includes firms that introduced an organisational or a marketing innovation (or both).

Source: Eurostat, CIS-4 (New Cronos, May 2007), National data sources.

Foreign innovation linkages fewer than domestic links

Co-operation during the innovation process is essential for knowledge diffusion and innovation. The benefits of collaboration are often mutual and include staff mobility and enhanced learning across firms, institutions and sectors. Innovation surveys reveal the importance of collaboration for firms' innovation processes. Overall in the EU27, around 26% of innovating firms co-operated with other enterprises or institutions during 2002-04. They co-operated with a range of partners, but the most common types in the EU27 were suppliers (17%) and customers (14%). While firms that engaged in innovation reported less co-operation with universities or other higher education institutions (9%) and government or public research institutes (6%), these types of partners are particularly important for developing more novel and radical products and processes.

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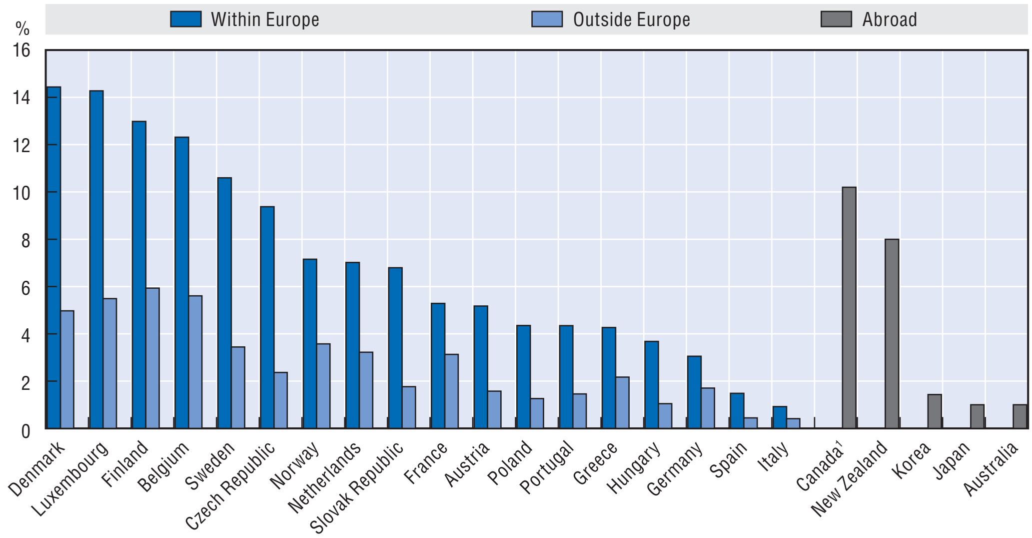
Firms report more co-operation with partners that are geographically close. Among European firms, for example, the share of those collaborating with partners in a different country within Europe ranged from less than 2% (Italy, Romania, Spain and Bulgaria) to more than 12% (Denmark, Luxembourg, Finland and Belgium). Collaboration with partners outside Europe was much less prevalent and concerned only between 2 and 6% of all firms in most European countries (Figure 1.24). The propensity to collaborate on innovation with partners abroad varies widely among countries in other regions, ranging from less than 2% of all firms in Korea, Japan and Australia, to more than 8% in Canada and New Zealand.

Figure 1.24. **Firms with foreign co-operation for innovation, 2002-04 (or latest available years)**

As a % of all firms



StatLink http://dx.doi.org/10.1787/451024017671

Note: Firms may have more than one co-operation partner.

1. Manufacturing sector only.

Source: Eurostat, CIS-4 (New Cronos, May 2007), National data sources.

Financing innovation

Financing innovation remains a challenge for many firms. Traditional bank finance or listing on traditional stock exchanges can be of limited relevance to innovative firms, which often have, at least initially, negative cash flows, untried business models and uncertain prospects of success. Innovative firms often move through several stages of private equity as they progress from "seed" to "early stage" to "expansion" stages of their life cycle, and creative and diverse ways of financing are required to meet the demands of both firms and investors.

In recent years, the challenges for financing have grown, as "intangible" or "intellectual" assets have become increasingly central to value creation by firms. The importance of intellectual assets for value creation is reflected in corporate expenditure, where investment in intangible assets appears to be approaching levels comparable to investment in tangibles. A number of statistical assessments are under way to improve estimates of the scale of investment in intangible assets at the national level for selected OECD countries. Those presented in Table 1.1 consider estimates of total annual

Table 1.1. **Investment in intellectual assets in five OECD countries, by asset category**

Percentage of GDP

	United States 1998-2000	United Kingdom 2004	Japan 2000-02	Netherlands 2004	Finland 2005
Computerised Information	**1.7**	**1.7**	**2.0**	**1.2**	**1.0**
Innovative property	**4.6**	**3.4**	**3.7**	**2.4**	**4.0**
Scientific R&D	2.0	1.1	2.1	1.5	2.7
Mineral exploration	0.2	0.0	0.0	0.0	0.0
Copyright and licence costs	0.8	0.2	0.9	0.1	0.1
Other product development, design and research	1.6	2.0	0.7[1]	0.7	1.1
Economic competencies	**5.4**	**5.0**	**2.5**	**3.6**	**4.1**
Brand equity	1.5	0.9	1.0	1.6	1.7
Firm-specific human capital	1.3	2.5	0.3[2]	0.8	1.2
Organisational structure	2.7	1.6	1.2[3]	1.2	1.1
Total investment in intangible assets	**11.7**	**10.1**	**8.3[4]**	**7.5**	**9.1**

StatLink http://dx.doi.org/10.1787/456178253012

1. Product development in financial services only.
2. Direct firm expenses only.
3. Purchased organisational structure is not included.
4. Not strictly comparable with the figures for the other countries due to incomplete coverage of some asset classes.

Source: OECD (2008e) based on Corrado *et al.* (2005, 2006) for the United States, Giorgio-Marrano and Haskel (2006) for the United Kingdom, Fukao *et al.* (2007) for Japan, van Rooijen *et al.* (2008) for the Netherlands, and Jalva *et al.* (2007) for Finland.

investment in intellectual assets for Finland, Japan, the Netherlands, the United Kingdom and the United States. The estimates were developed using similar methodological approaches, but they are not strictly comparable in terms of the variables covered. The estimates underscore the large scale of this investment; they range from 7.5 to 11.7% of GDP (OECD, 2008e).

Moreover, several studies suggest that firms now often spend as much on intellectual assets as on tangible assets. For example, total annual investment in intellectual assets by US businesses in the late 1990s was estimated to have amounted to around USD 1.1 trillion, or 12% of GDP, roughly the same as tangible investments (Corrado *et al.* 2005, 2006). The problem is that these assets, which include not just R&D, patents and trademarks, but also human resources and capabilities, organisational competencies (such as databases and routines) and "relational" capital (such as customer and supplier networks), are difficult to measure and most do not appear in firm-level or national accounts. As a result, firms with a significant share of such assets can face particular difficulties for accessing finance and resource misallocation can occur as investors put their money in more certain, but less economically efficient, projects.

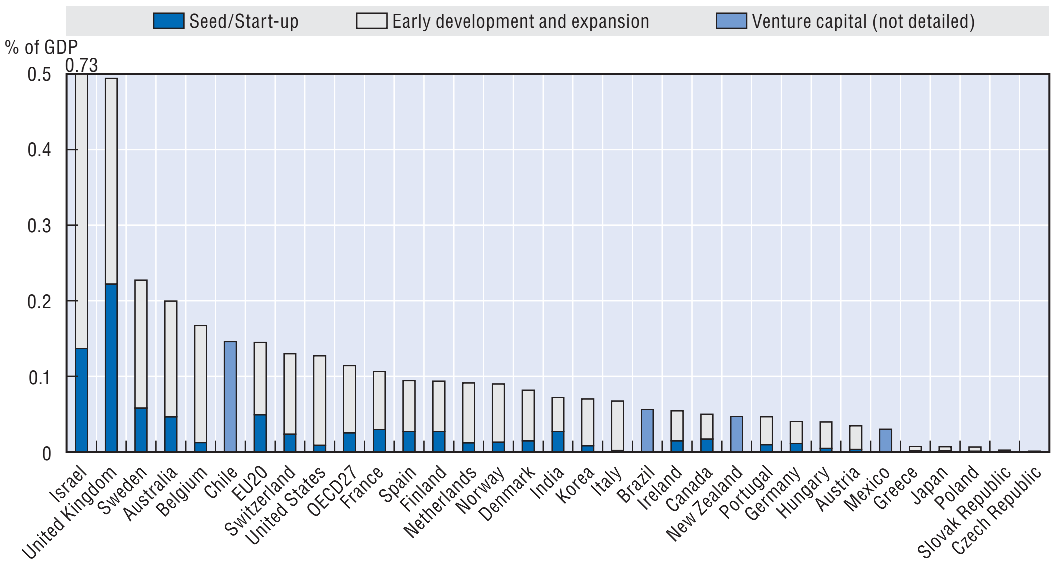
Across the OECD, the market for risk capital varies widely, with a country's overall macroeconomic, legal, regulatory and financial framework shaping willingness to invest in risky and volatile assets. Venture capital remains a key financing arrangement for innovative firms.

Venture capital investment directed towards expansion

Venture capital investment grew substantially in the United Kingdom, Belgium and Sweden from 0.16, 0.04 and 0.14% of GDP, respectively, in 2003 to 0.5, 0.17 and 0.23%, respectively, in 2006. In the OECD area overall, venture capital as a percentage of GDP reached 0.16% in 2006, a modest increase of 0.04 percentage point from 2003. However, in most countries investment was more directed towards the expansion stage rather than the early stages of business formation (Figure 1.25). While various financial sources are generally available to firms, they continue to find it more difficult to finance the seed, start-up and early growth phases through commercial channels; these stages remain primarily self-funded through personal savings and funding from family and friends (Bozkaya and van Pottelsberghe de la Potterie, 2008).

Figure 1.25. **Venture capital investment, 2006**

As a % of GDP



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Notes: Venture capital includes seed, start-up, early development and expansion stages. Later stages and buyouts are excluded except for Chile, Mexico, and Brazil. Total OECD (27) excludes Luxembourg, Turkey and Iceland.

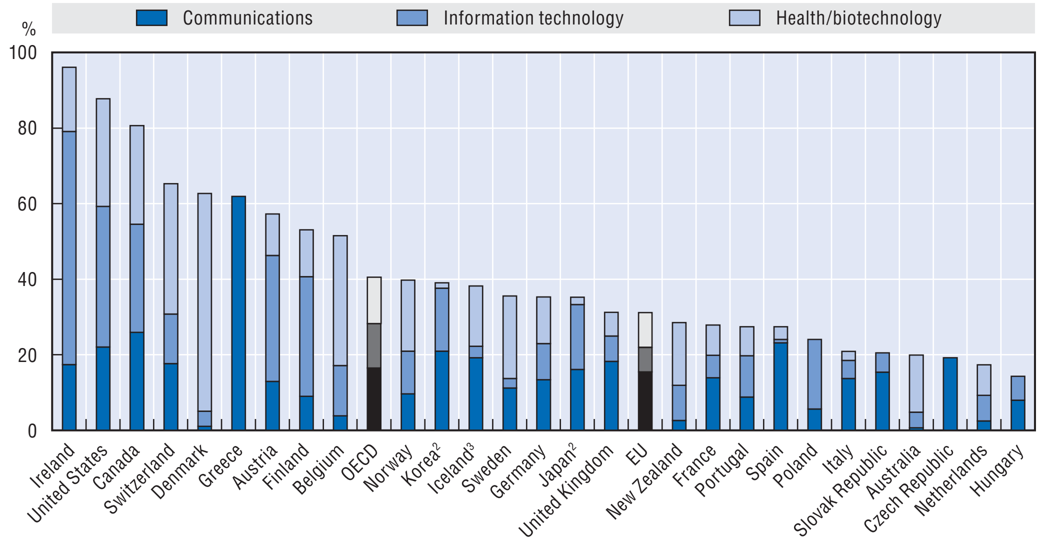
Source: OECD Venture Capital Database. Based on data from Thomson Financial, PwC, EVCA, LVCA, and National Venture Capital Associations.

Figure 1.26 shows that high-technology sectors represented 41% of OECD venture capital investment, but large differences are evident across countries. High-technology sectors accounted for 96% of venture capital investment in Ireland, 88% in the United States and 81% in Canada, but in Australia, the Czech Republic, the Netherlands and Hungary the share was less than 20%. These differences indicate differences in industrial structures. There is also considerable investment diversity in the three main high-technology sectors. Communications attracted 62% of venture capital funds in Greece, information technology accounted for 62% in Ireland, and health/biotechnology dominated in Denmark with 58%.

Other financing tools that help firms to leverage their intellectual assets and finance follow-on innovation are also emerging. For example, licensing of inventions is increasingly popular, particularly among SMEs. The market for technology licensing has grown strongly over the last decade, especially in the United States. There is also growing use of intellectual property rights as collateral to access capital, particularly among new start-ups.

Figure 1.26. **Share of high-technology sectors in total venture capital, 2005 (or latest available year)**

As a % of total venture capital investment[1]



StatLink http://dx.doi.org/10.1787/451076733881

1. For European countries, total venture capital investment broken down by sectors includes investments in early-stage, expansion, buy-out and others.
2. 2001 data.
3. 2002 data.

Source: OECD Venture Capital Database. Based on data from EVCA (Europe); NVCA (United States); CVCA (Canada); AVCAL (Australia), NZVCA (New Zealand), Asian Venture Capital Journal (The 2003 Guide to Venture Capital in Asia) for Japan and Korea.

Patents and scientific publications surge

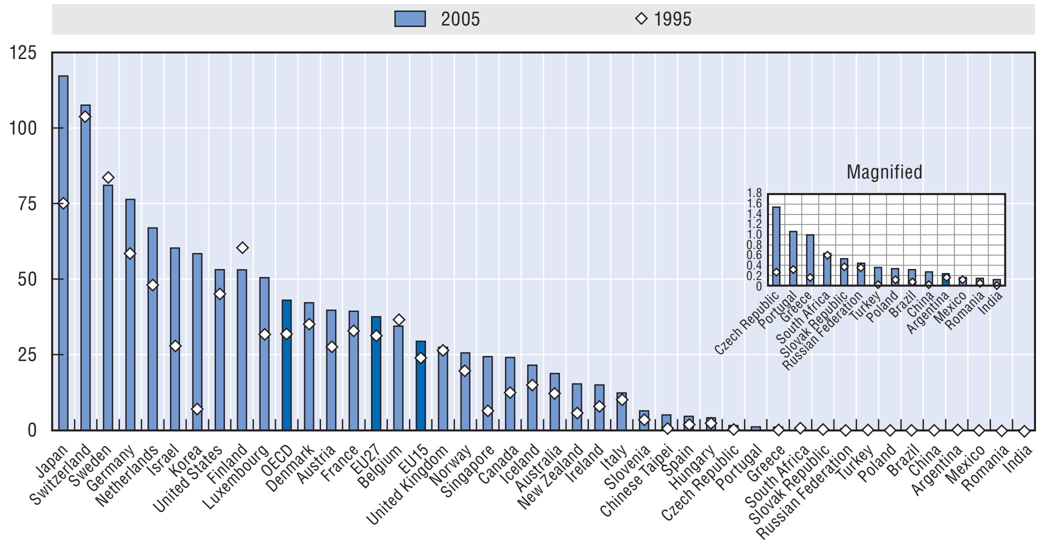
Among the main indicators of R&D output are patents (applied research and experimental development) and published journal articles (basic R&D). With increased R&D funding, most countries have seen an increased propensity to patent and publish in recent years. In fact, changes in R&D expenditure largely mirror changes in patenting and publishing. For example, analysis has shown that there is a strong positive correlation between the number of triadic patent families and industry-financed R&D expenditure ($R^2 = 0.98$). Thus, the more the United States, Japan, Germany and France spend on R&D, the higher their propensity to patent (OECD, 2007a, p. 86). It is important to remember, however, that patent data do not capture all R&D outcomes. Patents are an indicator of invention rather than innovation since not all patents are commercialised, and some types of technology are not patentable.

Patents

Over the past decade, the number of triadic patents[7] filed and granted has jumped considerably. In 2005, around 52 000 triadic patent families were filed worldwide, around 17 000 more than in 1995. During the second half of the 1990s, triadic family patent growth averaged 6% a year until 2000, before slowing to around 2% a year. While the United States continues to account for the largest share of patent families, with 31% of the total, its share has fallen by around 4 percentage points since 1995. In the EU25 the share of patent

Figure 1.27. **Triadic patents, 2005**

Per million population



StatLink http://dx.doi.org/10.1787/451147414512

Notes: Patent counts are based on the earliest priority date, the inventor's country of residence and fractional counts. The data mainly derive from the EPO Worldwide Statistical Patent Database (April 2007). Patents filed at the European Patent Office (EPO), the US Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO) which protect the same invention. Data from 1998 onwards are OECD estimates. Only countries/economies with more than ten families in 2005 are included.

Source: OECD, *Patent Database*, 2008.

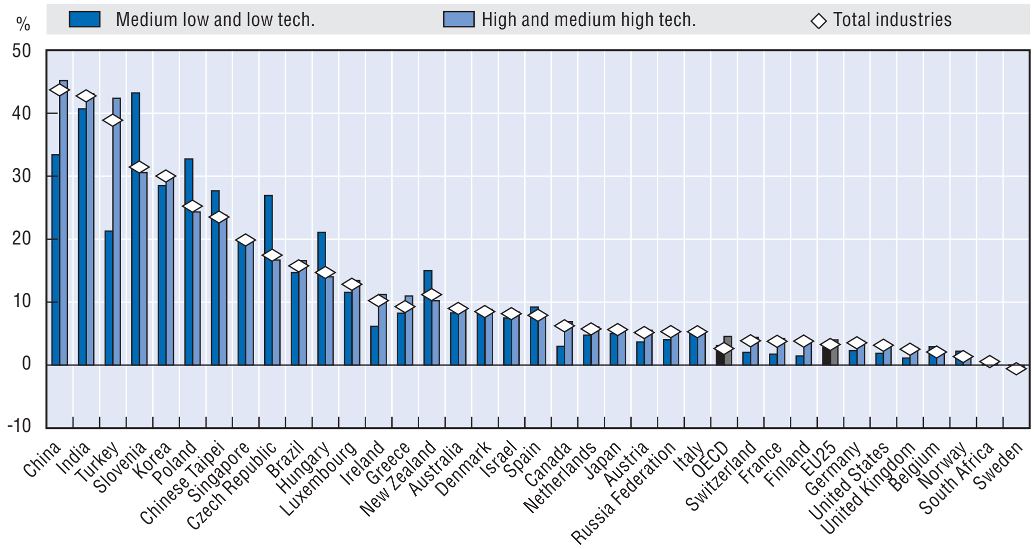
families fell from 33% in 1995 to 28% in 2005, largely as a result of shrinking shares in Germany, the United Kingdom and France. Japan, Switzerland, Sweden, Germany and the Netherlands are the top five inventing countries (Figure 1.27).

The share of patent families from Asian economies increased markedly between 1995 and 2005 with Korea's share increasing 5 percentage points, followed by Japan (2 percentage points) and China (0.7 percentage point). Shares also increased in India, Chinese Taipei and Singapore, and the growth of patent families from China, India, Korea and Chinese Taipei surged from 20% to 42% annually. Despite this impressive growth, the picture changes when triadic patent families are normalised using total population. In China and India, for example, the number of patent families per million population was 0.3 and 0.1, respectively, in 2005. These levels are largely due to these countries' massive populations, but the gap is also due to the fact that their R&D is adaptive and primarily aimed at the domestic market.

While R&D-intensive industries, such as pharmaceuticals and ICT, are among those that patent the most, patents are also important for protecting knowledge in less R&D-intensive industries such as textiles, food, wood and paper industries. Given the strong relationship between R&D investment and patenting, it is not surprising to find that high- and medium-high technology sectors account for the strongest patent growth in the majority of countries (Figure 1.28). However, growth in patenting in medium-low and low-technology industries is strong and differences in the growth rate between the two are small. Figure 1.28 also shows that China and India are emerging as new high-technology players with patent growth in these industries considerably higher than in the United States and Japan. Turkey's patent growth was also high at 39%. This further confirms the changing patterns of research and scientific activity.

Figure 1.28. **Annual growth rates of patenting, 1997-2004**

Growth rate of PCT filings (%)



StatLink http://dx.doi.org/10.1787/451152124658

Note: Patent counts are based on the priority date, the inventor's country of residence and fractional counts. Patent applications filed under the Patent Co-operation Treaty, at international phase, designating the European Patent Office. Only countries with more than 200 PCT filings during 2002-04 are included.

Source: OECD, *Patent Database* and ANBERD.

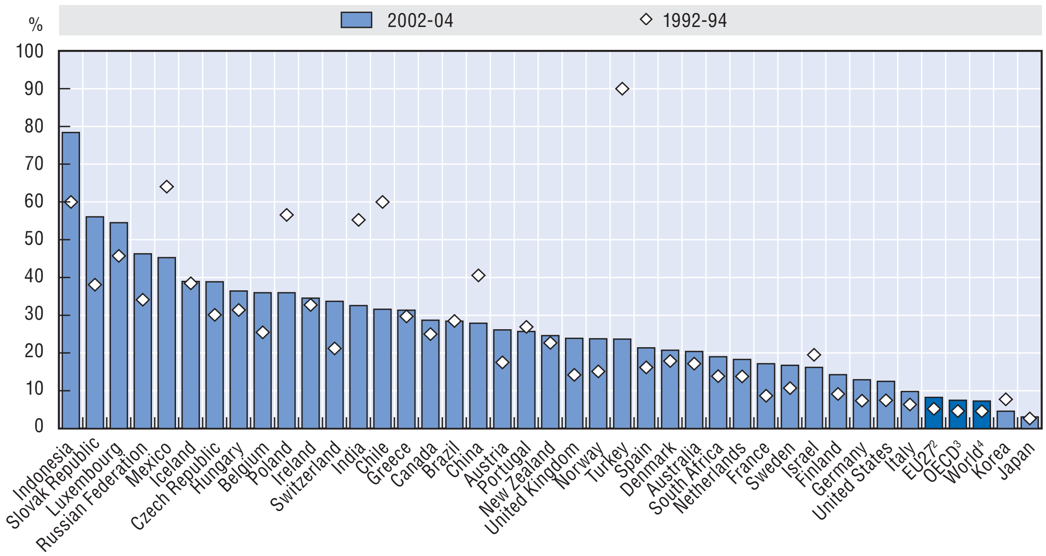
International co-invention

International co-invention of patents provides further evidence of the internationalisation of R&D. A country's degree of international co-invention is seen in the number of patents invented by a country with at least one foreign inventor in the total number of patents invented domestically. As such, it can also be considered a proxy of formal R&D co-operation and knowledge exchange between inventors in different countries. The total world share of patents involving international co-invention increased from 4.6% in 1992-94 to 7.3% in 2002-04 (Figure 1.29). Small and less developed economies typically engage more actively in international collaboration, as they need to overcome limitations associated with the size of their internal markets and the lack of the infrastructure required to develop technology (OECD, 2008b). Larger countries, such as the United States, the United Kingdom, Germany and France, have shares between 13 and 24% (in 2002-04), but their international collaboration has expanded. Japan and Korea have the least international co-invention in the OECD area. Turkey, Chile, India, Poland, Mexico and China have reduced the share of patents involving international co-invention over the past decade; this may indicate that they are strengthening their domestic technological capabilities.

Scientific publications

Rising R&D budgets have resulted in increases in the number of research publications from around 565 000 in 1995 to some 710 000 in 2005. However, scientific publications are highly concentrated in a few countries, dominated by the United States with 29% of total world scientific articles (Figure 1.30). The OECD area accounted for just over 81% of overall production of articles. The intensity of output (measured as scientific articles per million population) has increased in the majority of countries over the past decade. Decreases were reported in only eight countries: Israel had the largest drop (125 articles per million population), followed by the

Figure 1.29. **Patents with foreign co-inventors,[1] 2002-04**



StatLink http://dx.doi.org/10.1787/451223256780

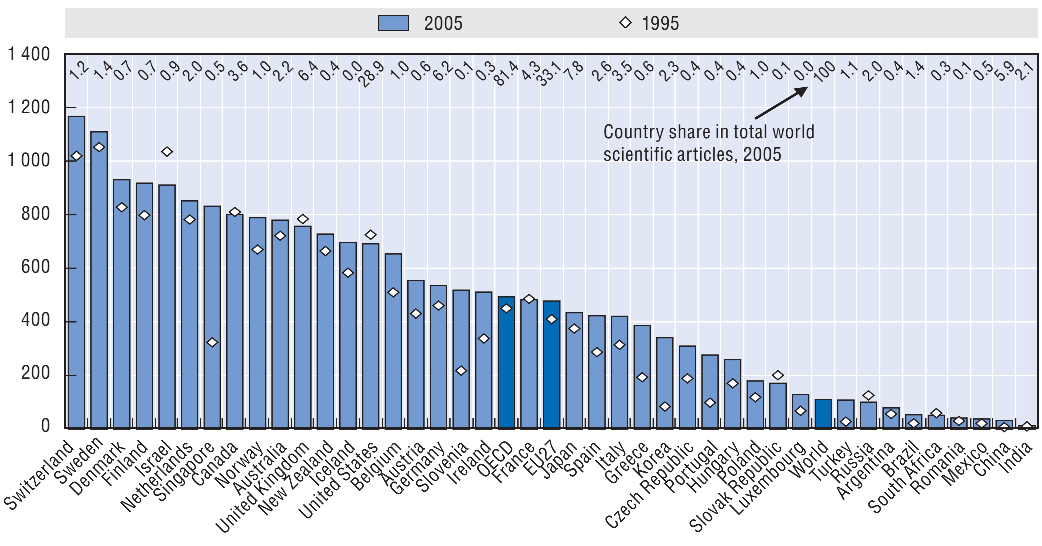
Note: Patent counts are based on the priority date, the inventor's country of residence, using simple counts.

1. Share of patent applications to the European Patent Office (EPO) with at least one foreign co-inventors in total patents invented domestically. This graph only covers countries/economies with more than 200 EPO applications over 2002-04.
2. The EU is treated as one country; intra-EU co-operation is excluded.
3. Patents of OECD residents that involve international co-operation.
4. All EPO patents that involve international co-operation.

Source: OECD, *Patent Database*, 2008.

Figure 1.30. **Scientific articles, 2005**

Per million population



StatLink http://dx.doi.org/10.1787/451253513718

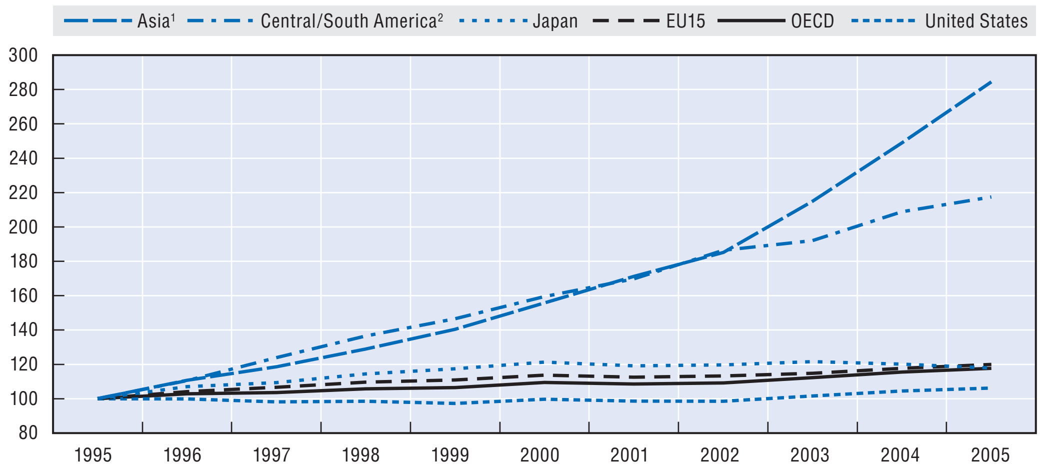
Source: National Science Foundation, *Science and Engineering Indicators 2008.*

United States (33.8), the Slovak Republic (30.6), the United Kingdom (27.3), Russia (25.4), Canada (9.6) South Africa (8.5) and France (3). Output growth was highest in Singapore (507.5 articles per million population), Slovenia (300) and Korea (256.3).

Scientific capabilities are growing strongly in some emerging economies. Over the past years, scientific articles from Latin America have more than doubled, with some South-East Asian economies (Indonesia, Malaysia and Vietnam) following closely behind. Singapore and Thailand have more than tripled their output (Figure 1.31). In China the average annual change in output was 16.5% from 1995 to 2005, while in India it was a more modest 4.7%. Among OECD countries, the average annual change in scientific output was less than 1% in Canada (0.8%), France (0.5%), Sweden (0.8%), and the United States (0.6%), and flat in the United Kingdom (0.0%). This provides another indication of the dramatic change in world scientific activity in recent years.

Figure 1.31. **Growth of scientific articles by area, 1995-2005**

Index 1995 = 100



StatLink http://dx.doi.org/10.1787/451261523635

1. Excluding Japan and Korea.
2. Excluding Mexico.

Source: National Science Foundation, *Science and Engineering Indicators 2008*.

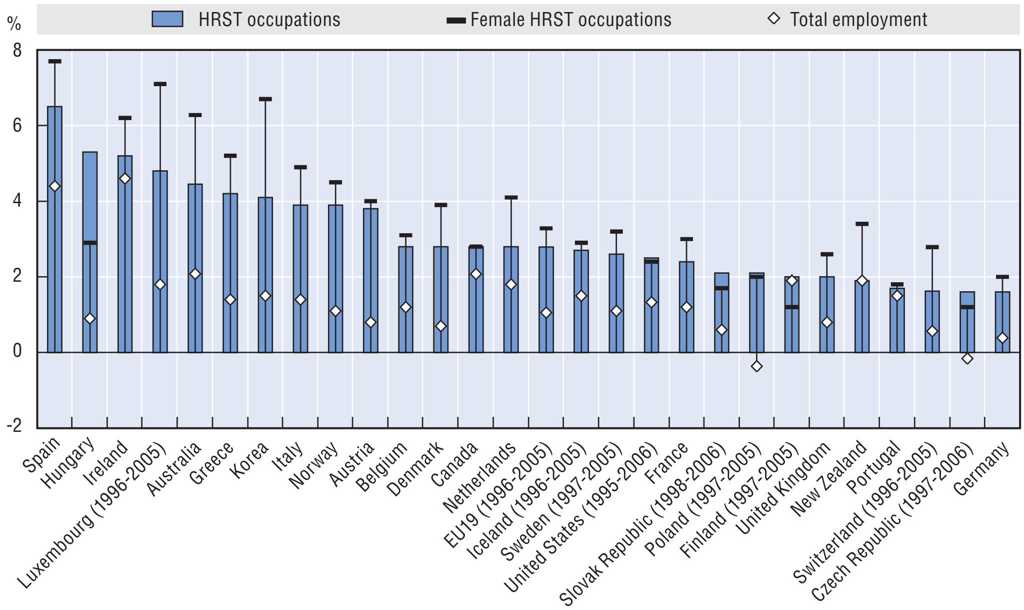
Demand for human resources accelerates

Human resources for science and technology are vital to innovation and economic growth because highly skilled people create and diffuse innovations. They are therefore essential for maintaining and expanding science and innovation systems. In most countries, the demand for skilled workers is expected to increase owing to real growth in R&D and the growing application of advanced technologies in many industries. This is not purely a matter of human resources for R&D because it reflects an increasing need for highly skilled workers across the economy as a whole. In the OECD area, employment in HRST occupations has outpaced employment growth overall, often by a wide margin. In Spain, Hungary and Ireland, with relatively low shares of HRST in total employment (between 23 and 27%), growth of HRST has been strongest. In Sweden, Luxembourg, Switzerland and Australia, HRST represents between 38 and 39% of total employment. Apart from Hungary, Poland, the Slovak Republic and the Czech Republic, growth in HRST can largely be attributed to increases in female employment (Figure 1.32).

The expansion of R&D in the services sector and with it, the increase in knowledge-intensive services (*e.g.* banking, financial and business services, health and education) has also changed the composition of demand for HRST. Analysing the growth of HRST by

Figure 1.32. **Growth rate of HRST occupations and total employment, 2000-06**

Average annual growth (%)



StatLink http://dx.doi.org/10.1787/451340223141

Source: OECD (2007a). OECD calculations, based on data from the EU Labour Force Survey, from the US Current Population Survey, from the Canadian and Japanese labour force surveys the Korean Economically Active Population survey, and the Australian and New Zealand censuses.

industry reveals that it increased more rapidly than total employment in both the manufacturing and services sector in most countries. In manufacturing, total employment fell in 14 out of 19 countries (*i.e.* in nearly 75%), but HRST employment grew to a similar extent. Manufacturing HRST in fact outpaced growth in services HRST in Spain, Ireland, Greece, Italy, Austria, Finland and Portugal (Figure 1.33). Canada was the only country in which the growth of total employment outpaced growth of HRST in manufacturing. In services, all countries reported growth in HRST and total employment, and, except in Finland and Portugal, HRST employment grew at a faster pace than total employment.

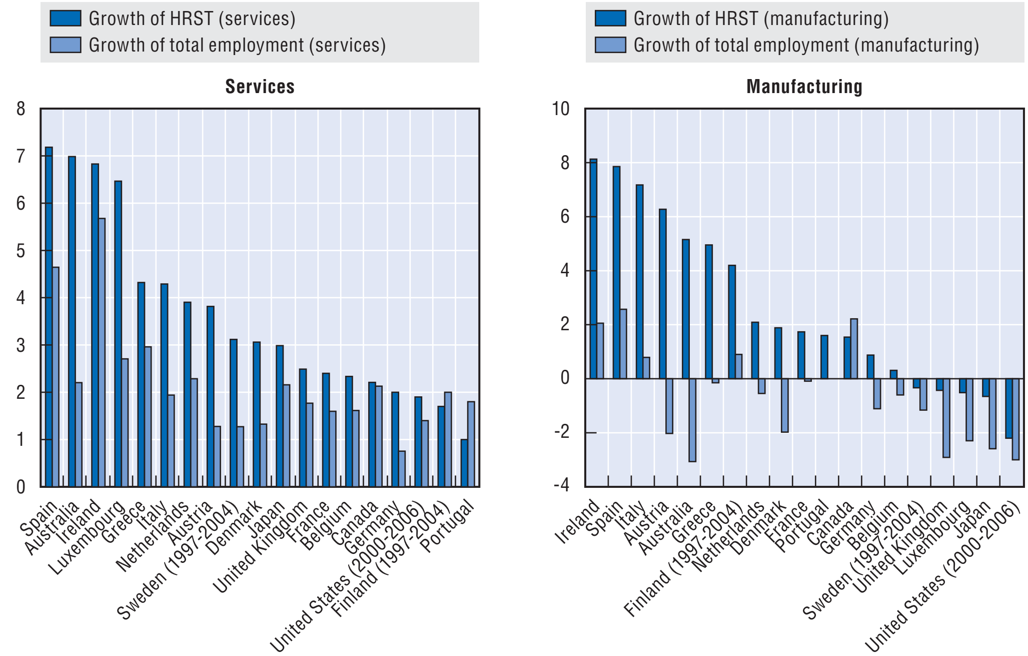
Numbers of researchers growing

As countries differ considerably in terms of the size of their population and labour force, normalising the share of researchers in total employment provides an indicator of the relative size of this group. Finland has the highest intensity with around 24 R&D personnel per 1 000 total employment, followed by Sweden (18), Denmark (16) and Japan (15) (Figure 1.34). In some countries, the balance between researchers and other R&D personnel (*e.g.* technicians and support staff) is highly skewed towards researchers. This may lead to inefficiencies and underutilisation of researchers' skills.

Business enterprise researchers account for the bulk of the researcher population. In 2005, 64% of all researchers in OECD countries (or around 2.5 million of a total of 3.9 million) worked in the business sector, a figure that has remained fairly constant. Nevertheless, there are clear national differences. Business researchers represented 79% of researchers in the United States (2005), 68% in Japan, 78% in Korea and 64% in China (all in 2006). In comparison, business researchers were only 49% of the research population in the EU27 (2006).

Figure 1.33. **Growth of HRST employees by industry 1995-2004 (or latest available years)**

Average annual growth (%)

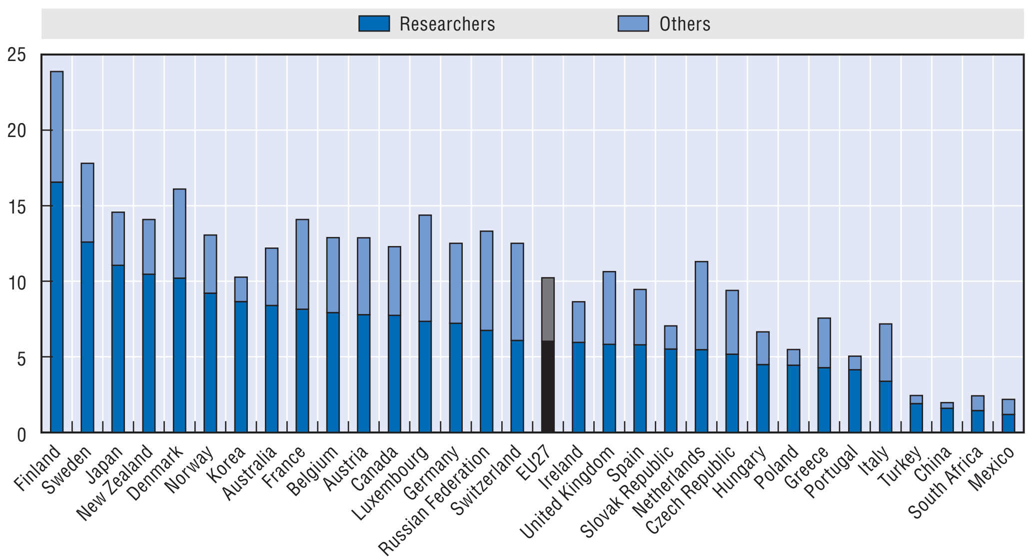


StatLink http://dx.doi.org/10.1787/451348826856

Source: OECD, *ANSKILL Database* (forthcoming).

Figure 1.34. **R&D personnel, 2006**

Per thousand total employment



StatLink http://dx.doi.org/10.1787/451407621458

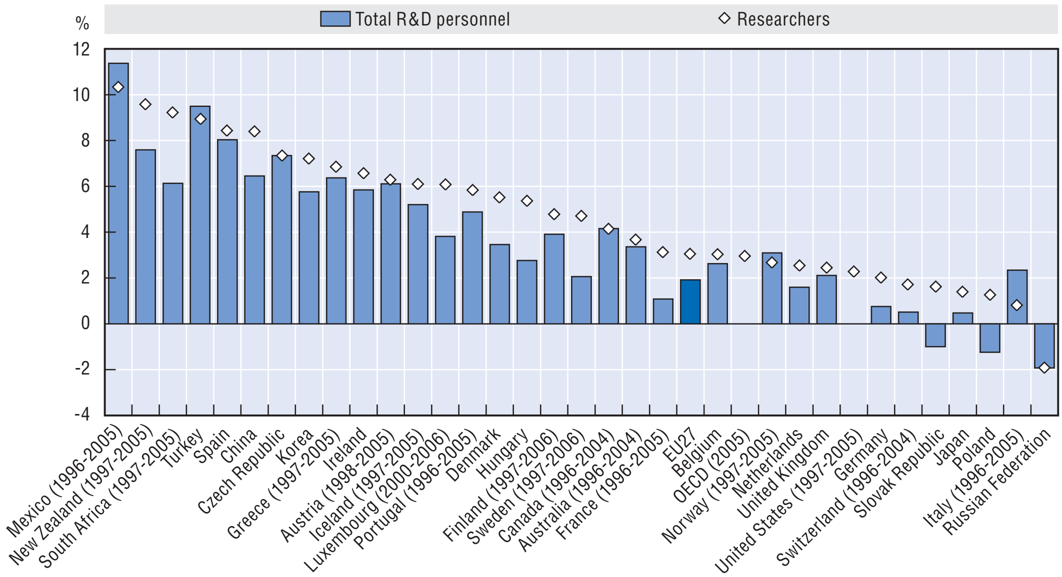
Notes: 2005 instead of 2006 for France, Italy, Mexico, New Zealand, Norway, Portugal, and South Africa. 2004 for Australia, Canada, and Switzerland.

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

Trends in the growth of R&D personnel typically follow patterns of R&D spending because salaries represent a large share of R&D expenditure. Between 1996 and 2006, total R&D personnel increased in most countries, with researchers accounting for most of the growth (Figure 1.35). The largest gains in researchers were in Mexico, which saw an annual increase of 10.4% between 1996 and 2005 from a very small base. New Zealand, South Africa and Turkey also reported strong increases in numbers of researchers, with annual growth rates reaching 9% or more, three times the OECD average of 3%. In South Africa and Turkey, growth was again from a small base.

Figure 1.35. **Growth of R&D personnel, 1996-2006**

Average annual growth rate (%)



StatLink http://dx.doi.org/10.1787/451415834142

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

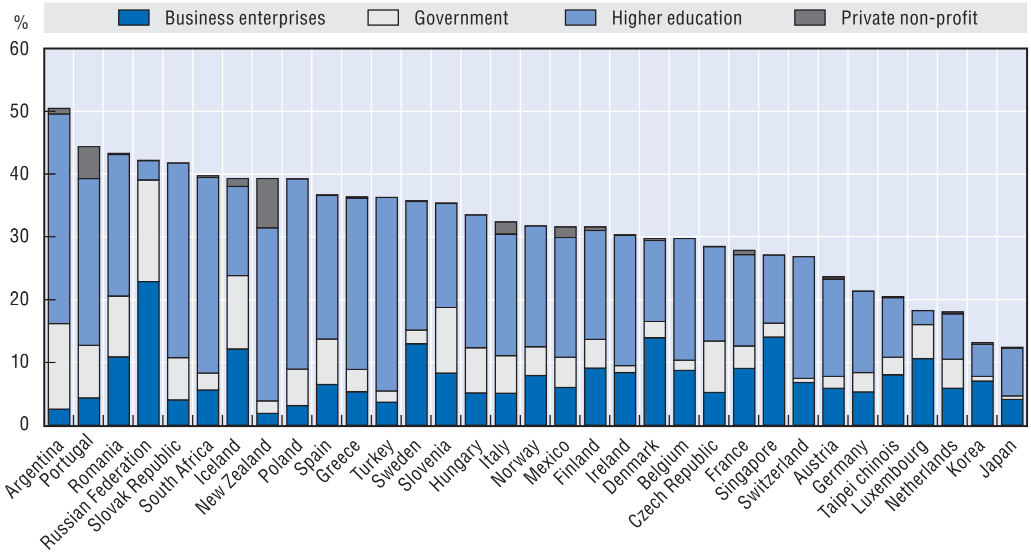
Although women's participation in the HRST labour force has grown, their under-representation in R&D activities is increasingly attracting the attention of policy makers (OECD, 2006b). In most countries for which data are available, women represent from 25 to 35% of total researchers (Figure 1.36). They represent over 40% of researchers in Argentina, Portugal, Romania, Russia and the Slovak Republic but only 13% in Korea and 12% in Japan. Women researchers are principally found in the higher education sector. Their participation is particularly low in the business sector, which employs the largest number of researchers in most countries. This is partly due to the uneven distribution of women science and technology graduates across fields of study: few women are in engineering; they are more numerous in the life sciences and social sciences.

The share of science and engineering graduates continues to fall

Graduates in science and engineering (S&E) are an essential component of HRST and are particularly important for science-based industries. Policy makers therefore seek to ensure that the supply continues to grow. On average, 25% of the degrees awarded at universities in the OECD area in 2005 were in science-related fields (engineering, manufacturing and construction, life sciences, physical sciences and agriculture,

Figure 1.36. **Women researchers by sector of employment, 2006**

As a % of total researchers



StatLink http://dx.doi.org/10.1787/451463482377

Notes: 2005 instead of 2006 for Belgium, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, and South Africa; 2004 for Austria, and Switzerland; 2003 for Mexico; 2001 for New Zealand.

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

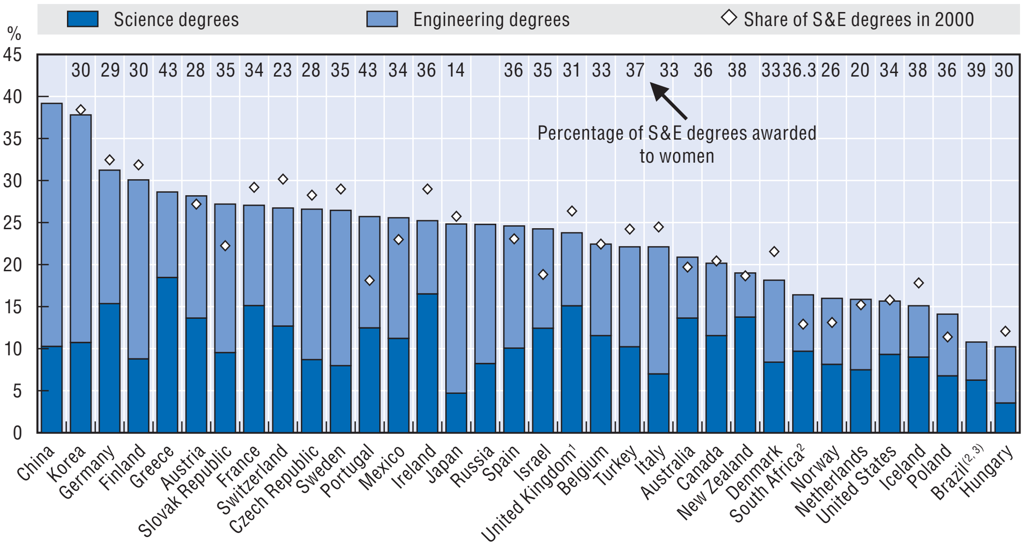
mathematics and computing). However, the number and proportion of S&E graduates has changed markedly in recent years. In absolute terms, the number of students graduating in S&E increased, except in Germany (where engineering graduates fell from 38 761 in 2000 to 38 135 in 2005), in Hungary (where engineering graduates fell from 5 792 in 2000 to 4 582 in 2005) and in Spain (where science graduates declined from 21 679 in 2000 to 20 400 in 2005). However, in relative terms, the share of S&E graduates decreased in 17 of the countries shown in Figure 1.37. The largest drop in the share of S&E graduates (around 3 percentage points or more) occurred in Ireland, Switzerland, Denmark, Iceland, the United Kingdom and Sweden. The share of S&E graduates in Portugal rose from 18% in 2000 to 26% in 2005, whereas growth in the Slovak Republic, Norway, Poland, Mexico and Spain was between 1.5 and 5 percentage points in 2005.

There are however important differences among countries in terms of the mix of S&E graduates. Some countries have more engineering graduates and others have more science graduates. This generally reflects the country's industrial structure and academic tradition, but also higher education and research funding policies. In 2005, more than half of the countries shown in Figure 1.37 had a larger share of engineering graduates than science graduates. In some countries, notably Belgium, Israel, Norway, Germany Poland, Portugal, the Netherlands and Austria, the picture is more balanced, with graduates about evenly divided between the two fields.

The most recent OECD Programme for International Student Assessment (PISA) focuses on science performance and students' attitudes towards science. The results show that the majority of students participating in the study reported valuing science in general, and overall, at the age of 15, the results were similar for males and females. On average, 37% of OECD-area students reported that they would like to work in a career involving

Figure 1.37. **Science and engineering degrees, 2005**

As a % of total new degrees



StatLink http://dx.doi.org/10.1787/451473368317

1. 2003 data.
2. ISCED 5B programmes are included with ISCED 5A/6.
3. Share of S&E degrees awarded to women is for 2003.

Source: OECD, *Education Database 2007*.

science, 31% would like to continue to study science after secondary school and 21% reported that they would aspire to a career in advanced science (OECD, 2007c). While these results are based on students' attitudes, an early interest in science is a strong factor in their pursuit of a scientific career. Moreover, the PISA study found that the motivation to pursue science in the future is positively associated with performance in all OECD countries except Mexico (OECD, 2007c, p. 150). In view of the declining share of S&E graduates in many OECD countries, these results suggest a role for government in terms of improving students' interest in science. Results from PISA show the close relationship between science performance at age 15 and countries' research intensity (Box 1.1).

The supply of doctorates has increased in most OECD countries. Between 2000 and 2005, doctoral degrees grew fastest in Portugal (21%), followed by Italy (18.9%) and Mexico (18.6%). Only Sweden and France experienced an annual decline over the period. Switzerland had the highest number of S&E doctoral degrees per million population (177), followed by Portugal (164), Finland (152), Sweden (134) and the United Kingdom (120). Ireland, Greece, France, the Czech Republic and Chile had a higher ratio of S&E doctorates (per million population) than of doctorates in other fields (Figure 1.38).

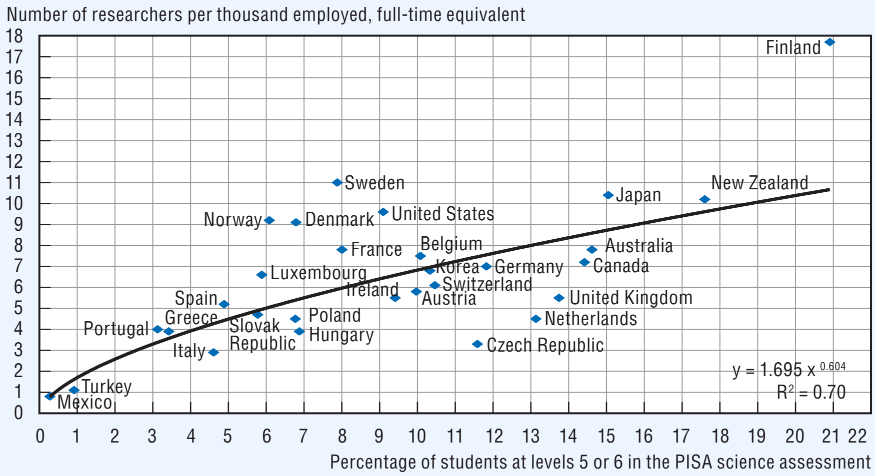
Internationalisation of HRST is expanding

Foreign talent contributes significantly to the supply of S&T personnel in many OECD countries. In the United States in 2003, for example, 26% of college-educated workers in S&E occupations were foreign-born as were 40% of S&E doctorate holders. While immigrant S&E workers in the United States come from a range of countries, 22% of the foreign-born S&E doctorate holders were from China and 14% were from India (NSF, 2008). Countries increasingly seek to attract foreign and expatriate HRST. However, the global

Box 1.1. **Science performance and research intensity: PISA results**

It is not possible to predict to what extent the performance in science of today's 15-year-olds will influence a country's future performance in research and innovation. However, the figure below portrays the close relationship between a country's proportion of 15-year-olds who scored at levels 5 and 6 on the PISA science scale and the current number of full-time equivalent researchers per thousand employed. The existence of such correlations does not, of course, imply a causal relationship, but it does suggest links between educational attainment in science and S&T capabilities.

Top performers in the PISA science assessment and countries' research intensity



StatLink http://dx.doi.org/10.1787/451544011256

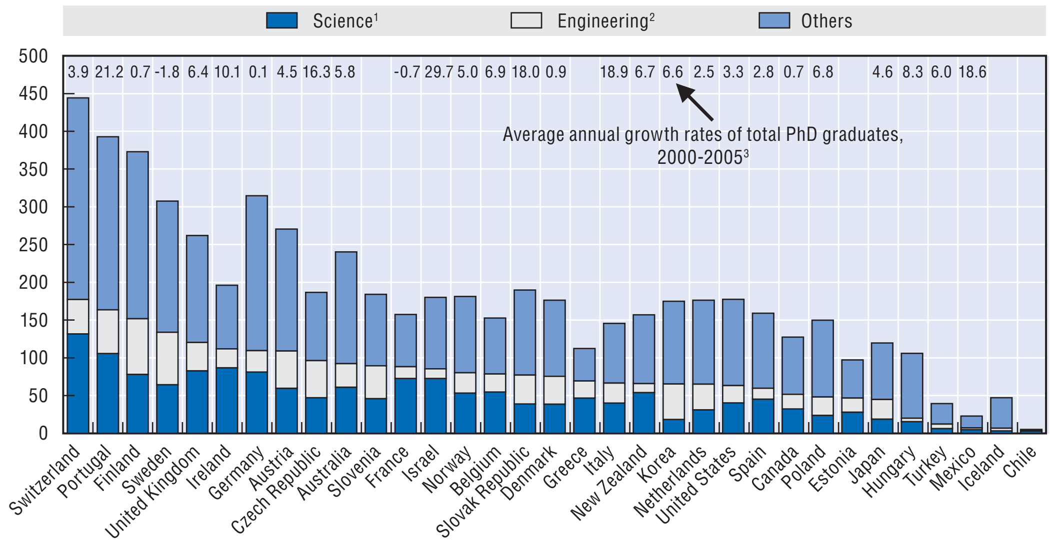
Source: OECD (2007c), p. 51.

market for the highly skilled is becoming more competitive and opportunities in the main supply countries are improving. Countries are therefore competing to attract staff from abroad and to retain their best researchers, scientific talent and foreign graduates. Nevertheless, the labour market for highly skilled researchers and scientists has become more internationalised, a phenomenon that is likely to continue as countries develop a range of initiatives to facilitate mobility (OECD, 2008c, forthcoming).

The internationalisation of HRST can also be seen in the international mobility of students. OECD countries benefit from the inflow of talented students and scholars, and foreign students, especially from developing countries, often remain in OECD countries for further research or employment and thus contribute to innovation. Foreign students can provide a highly qualified reserve of labour that is familiar with prevailing rules and conditions in the host country. The number of tertiary students enrolled outside their country of citizenship grew dramatically from 0.6 million in 1975 to 2.7 million in 2005 (OECD, 2007b) owing to the rapid expansion of tertiary education, policies of expanded access as well as governance changes in universities that place a premium – in some countries – on income from foreign students (OECD, 2007b). In addition, in some countries, recruitment of foreign students is part of a wider strategy of recruiting highly skilled immigrants.

Figure 1.38. **PhD graduates in science, engineering and other fields, 2005**

Per million population



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1. Sciences include life sciences, physical sciences, mathematics and statistics and computing.
2. Engineering includes engineering and engineering trades, manufacturing and processing and architecture and building.
3. 2001 instead of 2000 for Poland and 1999 for the Netherlands.

Source: OECD, *Education Database 2007*.

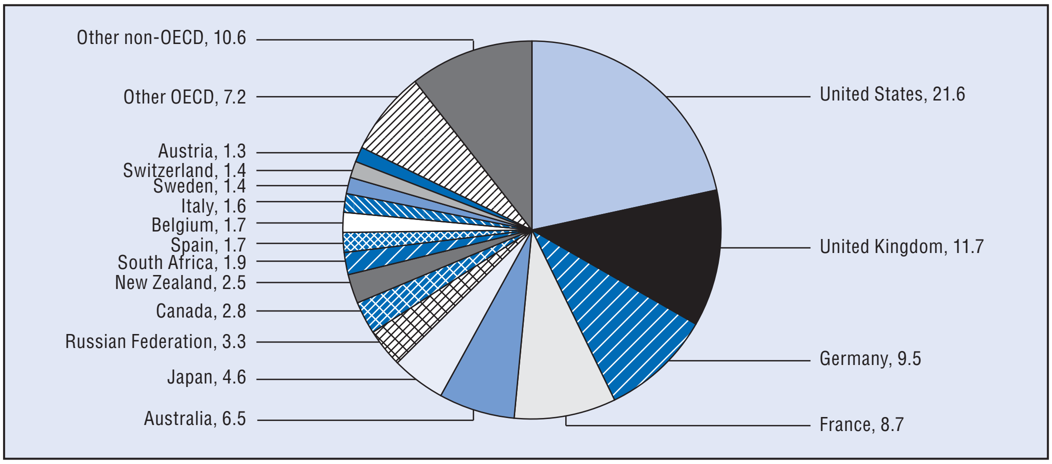
In 2005, four countries hosted the majority of foreign students enrolled outside their country of citizenship. The United States was the main destination of foreign students, with 22% of the world total, followed by the United Kingdom (12%), Germany (10%) and France (9%). These four destinations account for more than half of all tertiary students pursuing their studies abroad (Figure 1.39). Non-OECD economies represented around 16% of the total (OECD, 2007b). Language of tuition is a critical factor in terms of foreign students' choice of country. Languages that are widely spoken and read (English, French, German and Russian) play an important role, and an increasing number of institutions in non-English-speaking countries now offer courses in English. Other factors that also affect foreign student destinations include tuition fees, the cost of living, educational quality and the academic reputation of the institution (OECD, 2007b). Historical and cultural links, geographical proximity, exchange programmes or scholarships as well as immigration policies are also important.

Market shares of foreign students are changing. Between 2000 and 2005, the United States lost 5 percentage points as the preferred destination of foreign students to 21.6% of the global intake. The share of foreign students in Austria, Belgium, Germany, Spain, Switzerland and the United Kingdom also fell, but it expanded by 1 percentage point or more in France, New Zealand, South Africa and Russia (OECD, 2007b). Once again, these results point to geographical shifts in global S&T activity.

There is a wide variation in the distribution of international students by discipline in different countries. As shown in Figure 1.40, Finland has a high proportion of international students in sciences (42%), as do Germany (38%), Sweden (37%), Switzerland and the United States (around 35% each). In contrast, the proportion of international students enrolled in social sciences, business and law exceeded 50% in Australia and New Zealand.

Figure 1.39. **Distribution of foreign students by country of destination, 2005**

% share

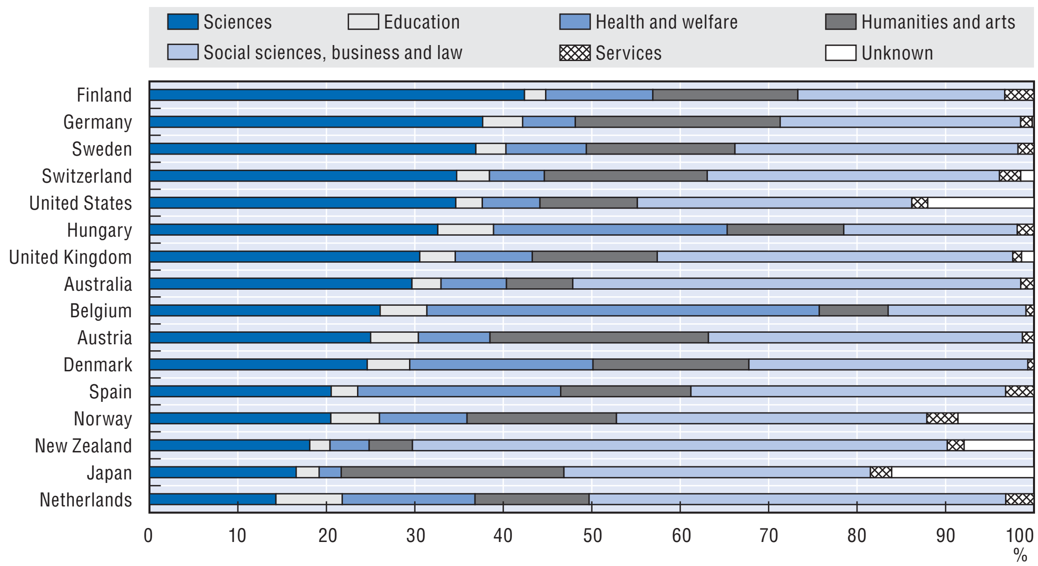


StatLink http://dx.doi.org/10.1787/451518507786

Source: OECD, *Education Database 2007*.

Figure 1.40. **Distribution of international and foreign students by field of education, 2005**

% share



StatLink http://dx.doi.org/10.1787/451542585601

Note: Sciences also includes agriculture, engineering, manufacturing and construction.

Source: OECD, *Education Database 2007*.

The Netherlands and the United Kingdom also had high proportions of international students in the social sciences, business and law disciplines (47% and 40%, respectively). Shares of health and welfare educational programmes are linked to national policies on recognition of medical degrees.

An important message is that the global competition for talent is growing (OECD, 2008c). Many OECD countries and a growing range of non-member economies aim to attract the same pool of highly skilled researchers and scientists. Relying extensively on international flows and mobility policies to fill existing or future gaps in the supply of HRST may therefore entail risks. Policy will also need to focus on addressing shortcomings in national policies that may limit the supply of HRST.

Summary

The evidence presented in this chapter suggests that performance in science, technology and innovation has continued to strengthen in recent years, in OECD and related economies. Against the background of continued diversity within the OECD area, a number of major trends emerge. The absolute growth of R&D and innovation-related activities is leading to continuing growth of the HRST labour force, an increasing need for highly skilled workers across the economy as a whole, and to greater international mobility of researchers and highly skilled people. Continued rapid growth in China has been accompanied by a dramatic increase in R&D and R&D employment, while future targets for Chinese R&D intensity imply that growth will continue. However, China is only part of the story of changes in the developing world. The rise of the BRICS economies and some less developed OECD countries in S&T suggests shifts in the geographical composition of world science and technology activity. Alongside this trend is the continued globalisation of R&D, which also appears to be moving towards worldwide sourcing of technological capabilities. Taken together, the evidence suggests major shifts in the world economy in the years ahead.

Notes

1. Brazil, the Russian Federation, India, China and South Africa.
2. Some OECD countries do not appear in all figures in this chapter because the data are not available.
3. For China, the rates used to convert R&D expenditure from national currency to USD PPP are based on the recently released World Bank estimates of purchasing power parity (PPP) exchange rates. The PPP exchange rate for China (not including Hong Kong, Macau or Chinese Taipei) was CNY 3.45 = USD 1. The exchange rate for China (not including Hong Kong, Macau or Chinese Taipei) was CNY 8.19 = USD 1. See World Bank (2008), p. 11.
4. These data are for 79 non-OECD countries and territories (source UNESCO Institute for Statistics).
5. In biotechnology a distinction is made between "dedicated biotechnology firms", which predominately produce or apply biotechnology to products and services and "biotechnology-active" firms, which apply or develop at least one biotechnology technique while also engaged in other production or R&D activities (OECD, 2007a). The discussion here refers mainly to biotechnology-active firms.
6. Chapter 5 of this volume covers innovation survey data in considerable detail.
7. The OECD defines triadic patent families as a set of patents taken at the European Patent Office (EPO), the Japan Patent Office (JPO) and the United States Patent and Trademark Office (USPTO) that protect the same invention.

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