HIGHLIGHTS

OECD Science, Technology and Industry Outlook

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HIGHLIGHTS

Science, technology and innovation remain central to economic growth

Increasing investments in knowledge remain a key driver of economic performance in the OECD area…

Despite the economic slowdown that spread across the OECD area in 2001, investment in and exploitation of knowledge remain key drivers of innovation, economic performance and social well-being. Over the last decade, investments in knowledge – as measured by expenditures on research and development (R&D), higher education, and information and communication technologies (ICTs) – grew more rapidly than gross fixed capital formation. Admittedly, the pace and depth of this transition has varied considerably, notably in regard to relative investments in R&D, higher education and software. Nevertheless, the general trend continues apace, as is clear from the rising share of technology and knowledge-based industries in total gross value added and employment in the OECD area.

… and are associated with the emergence of a more networked economy.

The movement of OECD countries towards a knowledge-based society is linked to the emergence of a more networked economy, which has helped to improve productivity, chiefly through the generation, diffusion and use of information. ICTs in particular played a key role in the increase in labour productivity in several OECD countries in the 1990s and, although investment in ICTs was severely affected, it is now beginning to recover. The widespread adoption of ICTs has led to new modes of work organisation which enhance the benefits these technologies offer for disseminating and using information. In several OECD countries in the 1990s, ICTs played a key role in boosting labour productivity through additional capital formation and the acceleration of multifactor productivity growth.

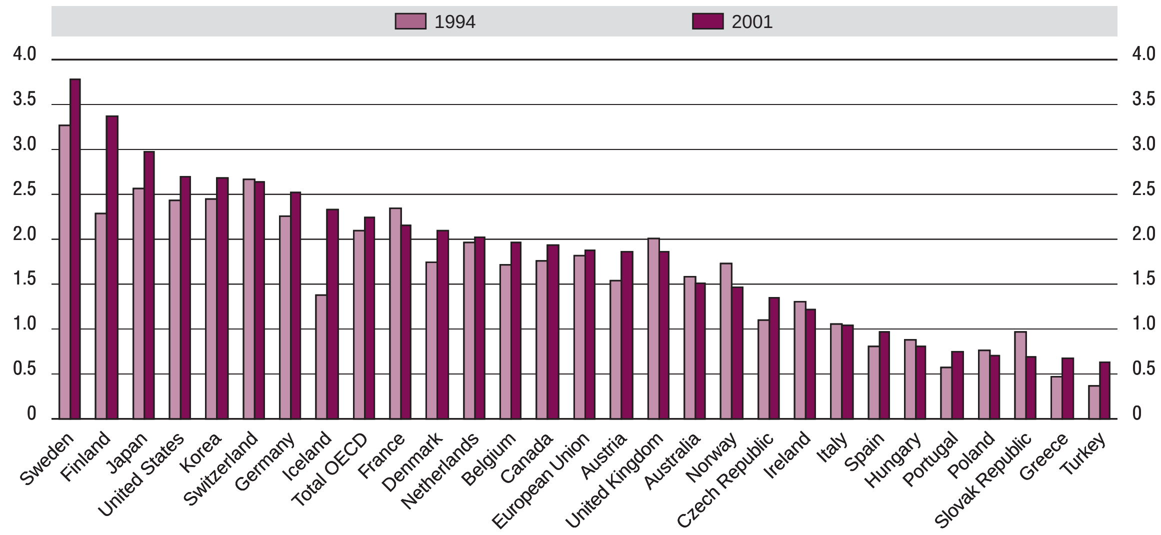
Knowledge creation and application has become more collaborative.

The shift towards a more networked economy has been accompanied by – and facilitated – tighter integration of the knowledge economy and an expansion of market and non-market knowledge transactions. The production and application of scientific and technological knowledge has become a more collective effort, linking the activities of industry, academia, and government. Formal and informal co-operation among institutions has become crucial for reaping the full benefits of knowledge creation and fostering the development of new technological innovations. Virtually all forms of collaboration, including co-operative research, public/private partnerships, international and domestic strategic alliances, and foreign direct investment, show signs of increasing.

R&D spending has increased, but the gap separating Europe from the United States and Japan is widening.

OECD countries as a whole are devoting more resources to R&D. After stagnating in the first part of the 1990s, OECD-wide R&D investments grew in real terms from USD 416 billion to USD 552 billion between 1994 and 2000, and R&D intensity climbed from 2.04% to 2.24% of GDP. Similar patterns were followed in all major OECD regions, although significant differences remain at country and regional levels, and existing gaps have widened. The European Union as a whole lagged behind the United States and Japan, with an R&D intensity of 1.9% in 2000 compared to 2.7% in the United States and almost 3.0% in Japan. Countries that posted the largest percentage point gains in R&D intensity tended to be those with already high levels of R&D, such as Finland and Sweden, further widening the gap between them and less R&D-intensive countries, such as Poland, Hungary and the Slovak Republic.

Figure 1. **GERD as a percentage of GDP, 1994 and 2001**[1]



1. Or nearest available years.
Source: OECD, MSTI database, May 2002.

Industry accounted for nearly all of the growth in R&D during the 1990s…

Growth in R&D expenditures during the 1990s resulted almost exclusively from increases in industry-financed R&D, which grew by more than 50% in real terms between 1990 and 2000. Government-funded R&D grew by only 8.3% during this period. As a result, the share of total R&D financed by industry reached 63.9% in 2000, considerably above its level of 57.5% in 1990, while the government's share declined from 39.6% to 28.9%.

… and is financing more R&D in public research organisations.

Industry is increasingly funding R&D performed by public sector organisations. Industry funding accounted for 6.1% of total R&D funding for universities and 4.4% of total R&D funding for other public research organisations (PROs) in 2000, compared to less than 3%

and 2%, respectively, in 1981. Combined with reduced government funding of business-performed R&D, increased industry funding of public research has meant that the share of R&D performed by the business sector remained stable in the 1990s (69.7% in 2000 against 69.3% in 1990).

Science and technology are becoming more internationalised.

International co-operation in S&T is also increasing: the percentage of scientific publications with a foreign co-author reached 31.3% in the OECD area in 1999 against 14.3% in 1986. Over the same period, the share of US patents with a foreign co-inventor rose from 2.6% to 7%. R&D expenditures by foreign affiliates also increased, both in real terms and as a share of business R&D in many of the OECD countries, including Canada, France, Ireland, Japan, Sweden, the United Kingdom and United States.

The efficiency of R&D investment is predicated upon the availability of highly skilled human resources.

The stock of researchers expanded in almost all OECD countries in the 1990s, with total researchers per thousand in the labour force reaching 6.2 in 2000 compared to 5.6 in 1990. Significant disparities remain, however, among the major OECD regions, with the EU as a whole lagging well behind the United States and Japan. Attempts to boost R&D funding and improve its effectiveness need to be accompanied by commensurate efforts to expand and strengthen the science and technology workforce. Growing emphasis is being placed on the productivity-enhancing role of human capital and higher education systems, which are central to the creation, dissemination and utilisation of S&T knowledge.

Increased mobility of S&T workers raises concerns about a "brain drain".

Closely related to the demand for S&T workers is the increasing international mobility of students, researchers and other highly skilled personnel, both within and to the OECD area. Driven by demand for ICT and other speciality workers, the internationalisation of higher education and research, the migration of scientific talent has renewed concerns about a "brain drain". Ensuring that such mobility results in positive gains for sending and receiving countries – *i.e.* by promoting the circulation of workers – has become an area of growing policy interest.

Governments are adapting policy frameworks to enhance the contribution of science, technology and innovation to economic growth

Science and innovation are receiving greater policy attention.

OECD governments are paying more attention to the contribution of science and innovation to economic growth and have introduced a variety of new initiatives and reforms. Several countries, including Australia, Canada, Hungary, Ireland, Korea and Spain, introduced comprehensive policy frameworks to guide developments in science, technology and innovation. In a number of countries, government institutions and agencies have been restructured in an attempt to improve the governance of innovation systems, and policy evaluation has become more widespread. Public research systems are being reformed to better contribute to economic and social needs.

Industry-science linkages and knowledge diffusion are growing priorities.

Linkages between industry and science and diffusion of knowledge within national innovation systems are emerging as a primary focus for innovation policy. New initiatives target promotion of innovative networks and clusters, creation of centres of excellence, and greater use of public/private partnerships for innovation. Many governments have introduced initiatives to support research in SMEs and facilitate the commercialisation of public research through spin-offs.

Government R&D budgets are poised to grow.

After a decade or so of stagnation, many OECD countries are reporting recent or expected increases in their investment in R&D and innovation. EU leaders pledged to increase spending on R&D and innovation to 3% of GDP by 2010. The governments of Austria, Canada, Korea, Norway and Spain have established explicit targets to increase national investment in R&D and innovation. Non-member countries, including China and Russia, also report significant increases in government R&D spending. All such attempts to raise levels of R&D spending will call for complementary efforts to increase the supply of the S&T graduates and research personnel, especially in the business sector.

ICTs and biotechnology continue to receive priority in research funding.

Traditional public missions such as health, defence and environmental protection remain major areas for public funding of R&D, but most OECD governments have also identified priorities in specific fields of science and technology. In general, these involve enabling technologies that address a number of social objectives and are of value to fast-growing industrial sectors. ICTs and biotechnology have received special attention in most OECD countries, with nanotechnology also attracting considerable support. In many countries, there has been a noticeable shift towards basic research and an increase in the role of higher education in performing research.

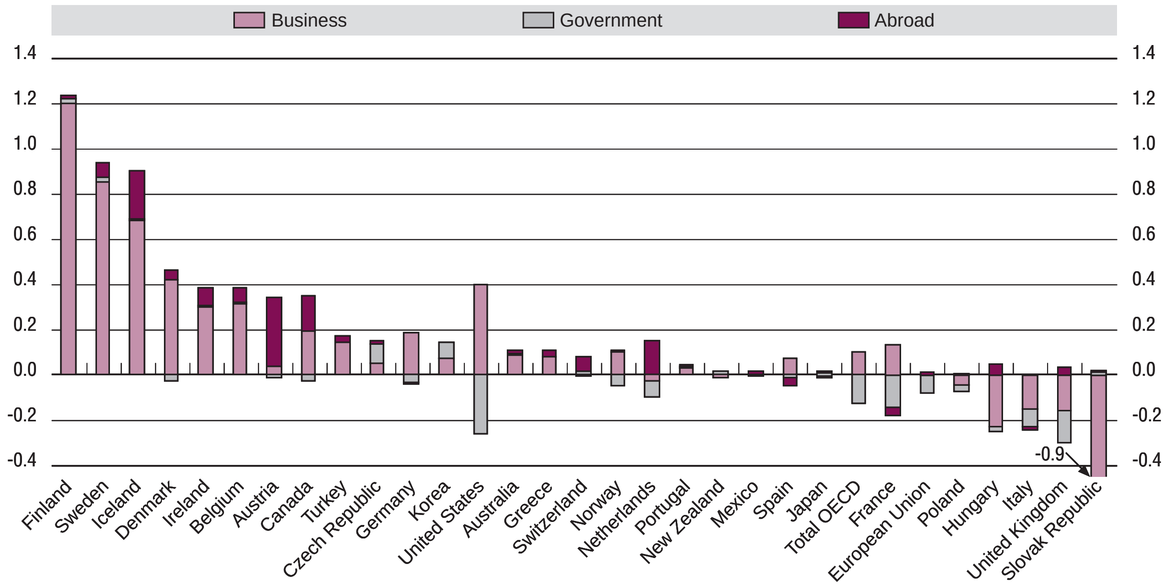
Changing patterns of business R&D imply a broader set of government policies to stimulate innovation

Business R&D expenditures have grown, led by high-technology industries.

Steady growth in industry funding for R&D between 1994 and 2000 reflected expansion of high-technology manufacturing (including ICTs and pharmaceuticals) and service sector industries. Together, these sectors accounted for 70% or more of the growth in business R&D in Finland, the United States and Ireland, three countries where business R&D performance registered among the highest growth rates in the 1990s. Growing venture capital investments further contributed to rising R&D investments in these fields before declining precipitously in 2001. Growth in business R&D was greatest in smaller, northern European economies, including Sweden, Finland, Iceland, Denmark, Ireland and Belgium, each of which saw business R&D intensity grow by at least 0.4% of GDP between 1990 and 2000. It declined in several Eastern European countries (Poland, Hungary, Slovak Republic), as well as in Italy and the United Kingdom.

Figure 2. **Percentage point change in BERD intensity by source of funds, 1990-2000**[1]

As a share of GDP



1. Nearest available years.

Source: OECD, MSTI database, June 2002.

Changes in the business environment – technological change, competition and globalisation – are motivating a restructuring of business R&D processes and strategies. Increasing competition has shortened product lifecycles in many industries, and scientific and technological advances have opened up new business opportunities. In response, firms are linking their R&D programmes more closely to their business needs and taking greater advantage of technologies developed in other firms and in universities and government research labs.

Firms are opening up their innovation processes to take advantage of external technology…

In line with the trend towards outsourcing R&D, firms increasingly market technologies developed internally but which do not fit their business plans or competencies. By licensing technology to other firms or establishing spin-out firms to bring the technology to market, they are able to generate value – and revenues – from technology that might otherwise remain unexploited. This may encourage firms to invest in more broad-based R&D programmes that need not closely match their internal product and service development capabilities.

… and to externalise technologies developed in house.

Various other forms of inter-firm co-operation – ranging from joint ventures to mergers and acquisitions (M&As) – show signs of increasing. Such co-operation may raise competition policy issues, especially where it concerns M&As in high-technology markets or co-operation agreements to elaborate existing technologies or commercialise inventions, rather than to conduct pre-competitive research.

Inter-firm co-operation is rising, especially in high-technology industries.

Inter-firm co-operation, however, does not necessarily diminish the role of competition in driving innovation: the creation of new markets may be made possible through co-operation in R&D or standards setting, and co-operation through technology licensing may actually increase the number of competitors in a market.

Governments need to employ a mix of direct and indirect R&D financing mechanisms.

As knowledge-intensive sectors continue to expand and competitive pressures grow, government financing of basic research will become a more central element of support to business R&D. The balance of more direct forms of government support for business R&D, such as tax incentives, grants and loans and government financing, will also need to be better tailored to the specific obstacles that firms confront in different countries and industry sectors in financing and performing R&D. Support for R&D in SMEs will remain an important element of the policy mix, but will need to take into account the increased availability of venture capital funds aimed at new technology-based firms.

Policy responses should aim to create an environment that is conducive to business innovation and experimentation.

Nevertheless, successful promotion of business R&D now hinges less on financial support to individual firms and more on the development of a fertile environment for innovation. This entails promoting networking and interaction among firms and between the public and private sectors, ensuring adequate intellectual property regimes (including regulations governing patenting and licensing by public research organisations, and creation of a strong scientific and technical resources. Governments also need to foster entrepreneurship by removing obstacles to new firm entry and exit and by reforming capital markets to ensure availability of risk capital.

Science systems face new pressures to better contribute to social and economic goals

Universities and public research organisations are under increasing pressure to show results.

As the contributions of basic scientific and technological research to innovation, economic growth and other social objectives become clearer and constraints on government budgets for public research grow, governments are seeking greater efficiency and accountability in public R&D spending. Governments in most OECD countries are taking steps to reshape and improve the governance of public research systems (comprised of universities and other public research organisations, or PROs), notably as regards mechanisms to define research priorities and allocate funding to projects and institutions.

Structural reforms have been introduced to enhance governance and accountability.

Numerous reforms have been introduced to increase the social and economic returns from public research without sacrificing their ability to ability to explore fundamental scientific and technical phenomena, disseminate knowledge broadly, and address research problems beyond those of immediate commercial interest. Several countries have established new priority setting mechanisms that include formalised foresight exercises and increased involvement of industry and other stakeholders. Centres of excellence have been established to bring together researchers from different disciplines to tackle problems of common interest. Germany, for example, has restructured portions of its public laboratory systems to increase their efficiency and ensure better links to industry and universities.

Funding mechanisms are becoming more competitive.

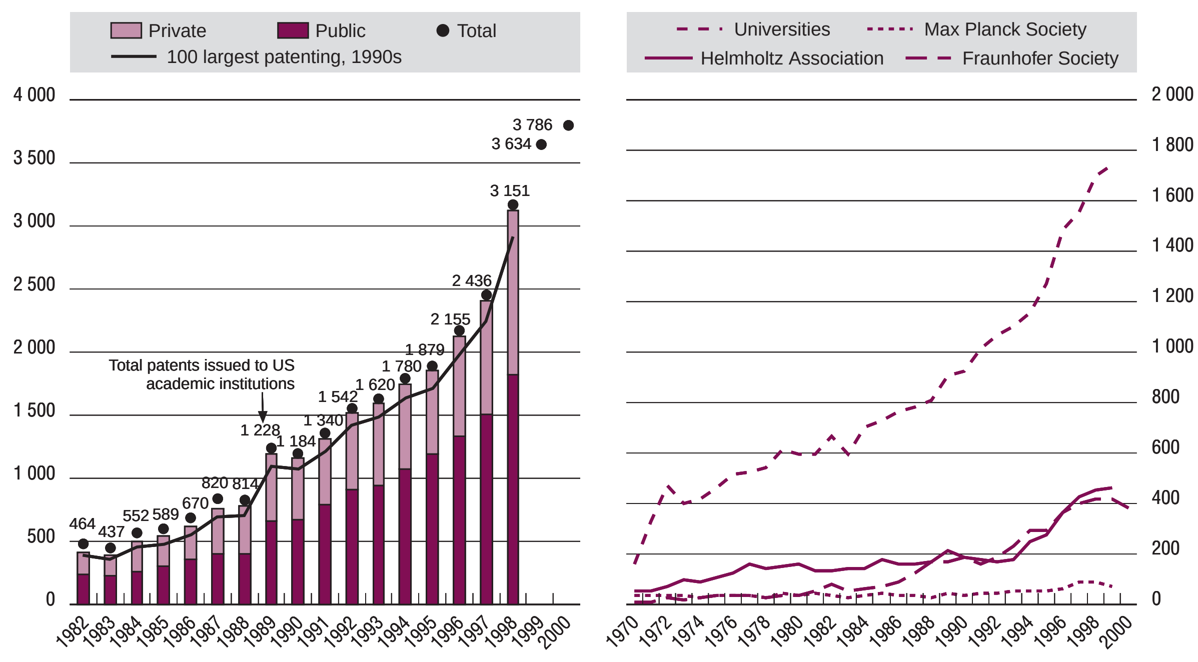
While governments in most European and Asian countries continue to provide institutional funding for universities and PROs, many are increasing their emphasis on project funding linked to specific deliverables and time schedules. Much of this funding is tied to specific government priority areas. This trend causes some concern regarding the ability of researchers to pursue basic, long-term research, but experience in the United States and the United Kingdom suggests that project funding does not impede the ability of researchers to pursue fundamental studies of scientific and technological phenomena. Nevertheless, continued monitoring and evaluation will remain important for improving the efficiency and governance of the public research system.

Universities and PROs are more actively managing their intellectual property.

With encouragement from governments and appropriate regulatory reforms, universities and other PROs across the OECD are increasingly patenting and licensing their research results. While these activities are often viewed as a source of additional revenue, preliminary evidence indicates that few technology transfer

Figure 3. **Trends in patenting in public research organisations**

a. Patents awarded to US universities *b. Patent applications in German PROs*



Note: Data for 1999 and 2000 are OECD estimates based on total recurrent respondents to the AUTM Licensing Survey in fiscal year 2000.
Source: NSF (2002); AUTM (2002).

Source: Ulrich Schmoch, Fraunhofer ISI, Max-Planck-Gesellschaft: Jahrbuch, different years; BMBF; Fraunhofer Patentstelle: Jahresbericht 2000/2001.

offices generate a profit. Their more important role may be in facilitating technology transfer between the public and private sectors, and thereby contributing to economic growth. Universities and other PROs are generally aware of concerns that greater licensing activity may alter research agendas, delay publication of results and restrict knowledge flows, but such concerns appear premature given current levels of licensing, and the fact that many universities and other PROs craft licences that protect the interests of the scientific community.

Growing competition for skilled science and technology workers is boosting international migration

Patterns of international migration of skilled S&T workers are changing as OECD countries become more knowledge-intensive.

Uneven demand for S&T workers, combined with differences in the opportunities available to such workers in various OECD and non-OECD economies, has boosted both temporary and permanent migration of workers. Not only does international migration help fill gaps, but skilled foreign workers also make significant contributions to innovation and economic growth. International mobility within the OECD area consists primarily of the circulation of skilled workers among countries, and tends to aid knowledge transfer rather than act as a brain drain. However, migration from Asia to the United States, Australia, Canada and the United Kingdom has grown significantly, particularly among students and skilled professionals with sought-after skills in areas such as ICT.

Efforts to attract foreign students and scholars are intensifying.

Many countries are actively recruiting foreign students because a significant percentage of graduates remain, at least temporarily, in the host country. PhD and master's students are of particular interest because many move into research positions in the public or private sector. Several North American universities have expanded their overseas recruitment of students, in some cases establishing campuses in foreign countries to expand the pool of candidates for graduate students. European universities have also increased their efforts to attract students from abroad. Several countries have expedited procedures for switching from student to work visas.

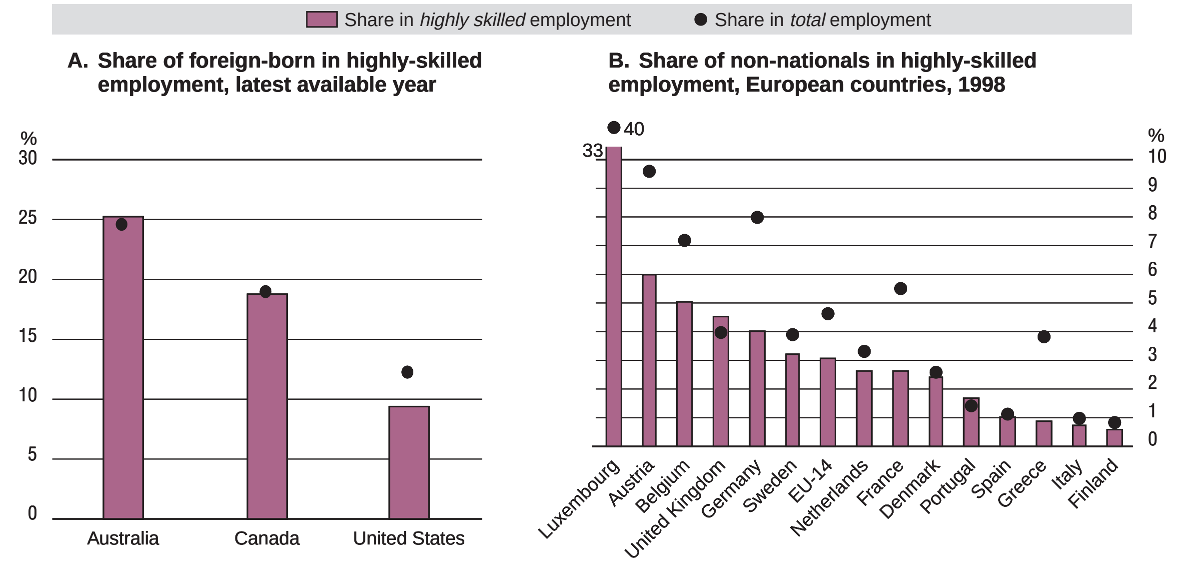
Immigration policies are being revised to address shortages of skilled workers, especially in the ICT sector.

Traditional immigration countries are revising immigration policies to attract both permanent and temporary workers with high skill levels, while European countries focus on temporary residence. In 2001, the United States raised the annual ceiling on temporary immigration visas to allow 195 000 professional and skilled workers to enter the country for temporary work. Germany instituted a programme to allow computer and technology specialists to enter the country and work for up to five years. France and the United Kingdom have simplified procedures for admitting computer specialists and skilled workers in designated shortage occupations, respectively.

Support to S&T helps attract and retain S&T personnel.

OECD countries are also strengthening support to S&T in order to retain talent and attract foreign workers. Initiatives such as increasing researcher salaries, providing new research funding or

Figure 4. **Foreign and foreign-born workers in the highly skilled workforce**



Source: *Trends in International Migration, OECD 2002*.

Source: *Science, Technology and Industry Scoreboard. OECD 2001.* Based on data from the Eurostat Labour Force Survey.

creating new posts have been pursued in Germany, Iceland, Ireland and the United Kingdom. Some sending economies, notably Chinese Taipei, Ireland and Korea, have been successful in luring back graduates and expatriate researchers to work in local universities, technology parks and public research.

Globalisation is driving industrial restructuring and changing the way research and innovation takes place

Globalisation and industrial restructuring have been driven by waves of M&As and strategic alliances.

Market liberalisation, regulatory reform, technological changes and the specialisation of firms spurred a wave of industrial globalisation and restructuring in the 1990s. By some estimates, the number of international M&As grew from 2 600 to 8 300 a year between 1990 and 2000, before retreating to approximately 6 000 during the economic slowdown of 2001. The value of these M&As grew rapidly over the period, from USD 153 billion to USD 1.2 trillion. In the last decade, they represented the majority of global inflows of foreign direct investment. The number of domestic and international strategic alliances also grew during the 1990s. Growth occurred in two waves: one in the first half of the decade that took place mainly between manufacturing firms, and another in the second half that included a greater number of firms in the service sector.

Research and innovation have become more internationalised…

The expansion of multinational corporations and the growing number of alliances are changing the way science and technology activities are undertaken. Mounting evidence shows that technological innovations are increasingly developed outside a firm's country of origin. Data indicate that foreign ownership of domestic inventions and domestic ownership of inventions made abroad are growing in nearly all OECD countries. The share of R&D performed by foreign affiliates also rose in many OECD countries, as did funding from abroad. In Ireland and Hungary, foreign affiliates accounted for more than two-thirds of business R&D in 2000.

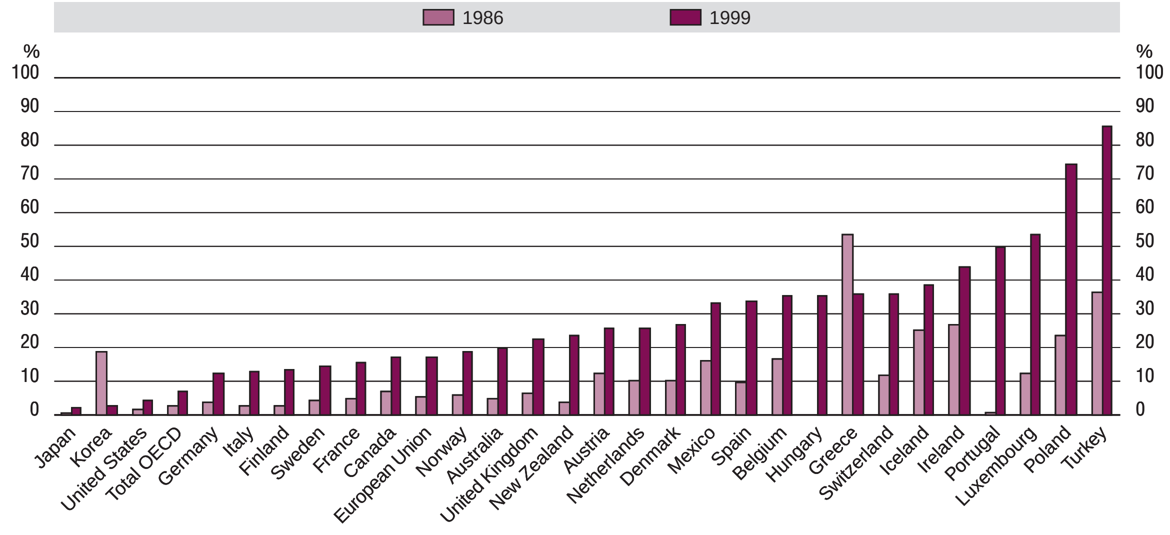
... and OECD trade in high technology industries continues to expand.

International trade in highly R&D-intensive industries also increased rapidly in the OECD area throughout the 1990s, and its share in OECD-wide GDP rose from 3.5% in 1990 to 6.5% in 2000. Most imports and exports associated with highly R&D-intensive industries involve exchanges of high-technology products – a major channel for the diffusion of incorporated technology, notably to the manufacturing sector.

Government policies can influence the internationalisation of innovation.

Government policies can influence firms' ability to restructure via international M&As and strategic alliances (*e.g.* through market deregulation and liberalisation), as well as the distribution of the costs and benefits of such activities. Most directly, countries can relax restrictions of foreign investment in domestic firms, as occurred in Korea in the late 1990s. Reductions in corporate and capital gains taxes can also be used to attract foreign investment, by lowering the cost of entering into M&As and alliances. Greater international co-operation regarding take-over rules and anti-trust reviews would further simplify the process of restructuring for firms. Efforts to develop local science and technology capabilities have also proven effective in attracting R&D investments.

Figure 5. **Percentage of US patents with foreign co-inventors,[1, 2, 3] 1986 and 1999**



1. Owing to the very low share of US patents (as a percentage of total OECD) registered by a large majority of OECD countries, results are mainly significant at the level of G-7 countries.
2. US patents by year of grant.
3. The EU ratio includes intra-EU co-patents.

Source: OECD, Patent database, May 2002.

China's science and technology system is undergoing significant change*

China has made good progress in reforming its S&T system.

Since 1985 China has introduced policy reforms in its S&T system with the aim of boosting modernisation and economic growth and becoming better integrated into the global economy. Government research institutions have been restructured to encourage their links with industry, and the share of R&D performed by the enterprise sector has increased. Future S&T priorities are to promote technology updating of industry, and increase scientific and technological innovation capability. To this end, the Chinese government will implement policies to improve enterprise-sector R&D and develop high-technology industries, to further reform the S&T system and to optimise resource allocation for R&D and strengthen R&D financing.

Nevertheless, major structural problems persist, as R&D spending remains low and inefficiently utilised.

Despite notable advances in specific regions, China's overall R&D capabilities remain underdeveloped and insufficiently exploited. China's level of R&D funding, at 1% of GDP in 1999, is below that of most OECD countries. Moreover, the share of R&D performed by government R&D institutions is well above OECD average, while that of the enterprise sector remains low. Chinese enterprises are not yet accustomed to competing on the basis of innovation, although a shift of the focus of competition from quantity to quality and innovation does seem to have started. The higher education sector continues to account for less than 10% of total R&D expenditure and allocates a relatively small percentage of its efforts to basic research, due in part to a high share of industry funding.

Industrial innovation continues to lag, despite growing foreign direct investment.

While China's scientific and technological output has increased, as measured by publications and patents, the share of patents awarded to Chinese enterprises remains well below their relative share of R&D performance, and only a small share of patents awarded to Chinese applicants are for inventions, as opposed to functional designs or appearances. Foreign applicants account for the overwhelming share of patented inventions, especially in high-technology industries. Foreign direct investment has had only a limited effect on the innovation capacity of Chinese firms, as only a small share of foreign-invested firms have R&D departments and little attention has been paid to technology diffusion.

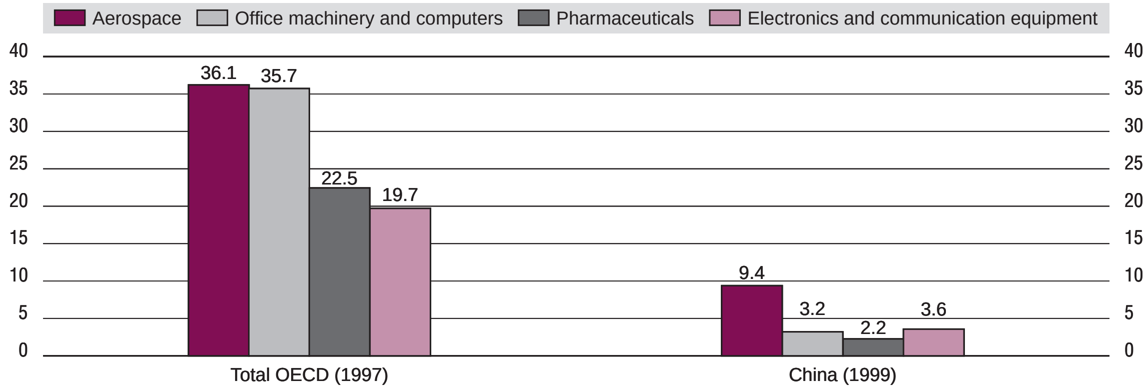
Further policy challenges need to be addressed.

Further progress will require that the role of government be redefined as China shifts from a government-dominated science and innovation system to a more market-oriented one. Efforts will also be needed to enhance the innovation capability of Chinese enterprises, commercialisation of R&D, and technology diffusion among firms. A better balance will need to be struck between improving the market orientation of government research institutions and preserving or boosting long-term S&T capabilities. China will also need to tap into global knowledge networks in order to

* Following the granting of Observer status to China in the OECD Committee for Scientific and Technological Policy in January 2002, it was decided to devote a specific chapter of this volume of the *Outlook* to that country's S&T policy.

benefit from developments in science and technology that will be key to domestic innovation efforts. Additional reforms will be necessary to secure framework conditions that are conducive to innovation. In all these areas, China can benefit from the experiences of the OECD countries.

Figure 6. **R&D intensity in high-technology sectors, late 1990s**
As a percentage of sectoral value added



Note: Total OECD is an estimate from data for 15 countries (Canada, Denmark, Finland, France, Germany, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Spain, Sweden, the United Kingdom and the United States).
Source: OECD, STAN and MSTI databases, April 2002; MOST, 2001a.

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