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SCIENCE, TECHNOLOGY AND INDUSTRY OUTLOOK

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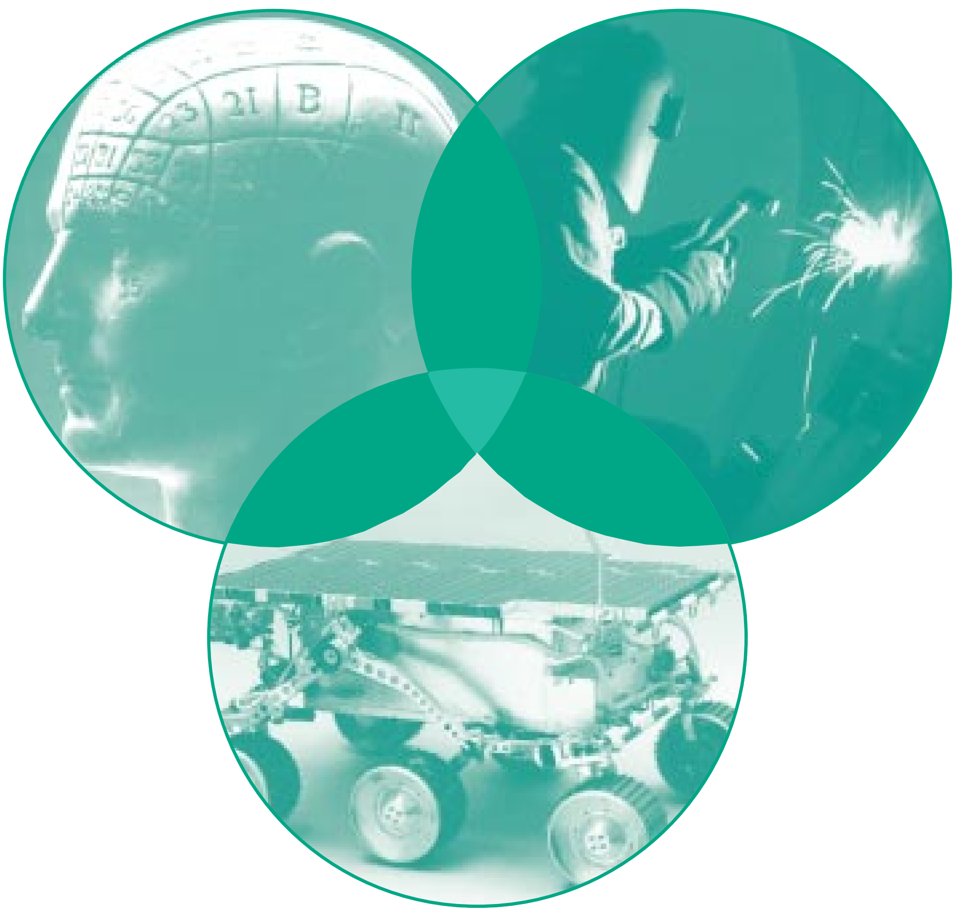

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

– to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
– to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
– to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

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FOREWORD

The *1998 Science, Technology and Industry Outlook* has been prepared by the OECD Secretariat under the guidance of OECD's Committee for Scientific and Technological Policy and the Industry Committee. It is the second in a biennial series designed to provide Member countries with a broad overview of trends, prospects and policy directions in science, technology and industry across the OECD area. It also provides a detailed analysis of key themes in science, technology and industry policy.

Building on the 1996 edition, the 1998 edition further extends the economic and policy analysis. For the first time, it includes an overview of the prospects for science, technology and industry in the OECD area. It provides comparative indicators for many relevant aspects of science, technology and industry performance, discusses recent trends and provides an integrated assessment of recent policy trends in OECD Member countries. The thematic part of the *STI Outlook* is considerably extended from its previous version. It includes four special chapters, covering issues such as productivity; the role of technology in traditional industries; recent changes in expenditure on research and development and its consequences for innovation and growth; and the impact of information and communication technologies on the science system. A statistical annex provides detailed indicators for all OECD countries.

The report is published on the responsibility of the Secretary-General of the OECD.

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EDITORIAL: SCIENCE, TECHNOLOGY AND INDUSTRY IN TRANSITION

The conditions for science, technology and industry have changed owing to the shift towards the knowledge-based economy.

Science, technology and industry (STI) now face substantially different conditions from those of a decade ago. As macroeconomic conditions in the OECD area improve, there is greater dynamism at industry level. The structure of OECD economies continues to shift towards services and knowledge-based industries. Investment in intangible assets, such as research and development, training and information, are enabling this transition, and information and communication technologies continue to diffuse throughout society. Productivity continues to increase, albeit slowly, enabling cost and price reductions in several parts of the economy. Workers must have more skills than ever before, while firms must become more flexible and are forced to adjust their organisational structure. Global patterns increasingly affect OECD economies, which depend more and more on world markets for access to consumers, capital, technology and workers. Technological change is occurring at a rapid pace, owing to the strong performance of the scientific community in OECD countries and the increasing efficiency of enterprises in turning research results into successful products.

The potential for growth is great, but there are also substantial policy challenges.

While these developments hold out the promise of further technological change and economic growth, they also present important challenges. The shifting structure of OECD economies, the rapid pace of technological change, globalisation, and changing skill requirements force continuous adjustment on the part of workers, firms, and governments. Many OECD economies are confronted with high unemployment and low growth, and some are faced with widening income distributions. Some firms and industries face stagnant demand and growing international competition and are forced to restructure and often to reduce employment; others face growing demand and hire additional workers. OECD policy makers face a crucial challenge: they need to support the shift from declining to growing sectors while generating new employment prospects. This is not the only challenge, however. Adapting to a global economy and capitalising on the potential impacts of rapid technological change are also important objectives of government policy.

Fiscal restraint and the declining effectiveness of domestic STI policies point up the need for new approaches.

These policy challenges come at a time when OECD governments are taking a critical look at many policy areas. High public debt burdens, an increasing awareness of the limitations on the government's role in the economy, the reduced effectiveness of domestic policies in a rapidly globalising world, and the end of the cold war are among the reasons for a major reorientation of government policy over the past decade. The importance of direct government intervention has lessened, and policies are increasingly aimed at improving framework conditions for the business sector. These changes in the role of government affect all areas of policy, including science, technology and industrial policies.

Today's industrial policy emphasizes market liberalisation and support for firm competitiveness.

Industrial policy has been particularly affected by these changes. There is less emphasis on direct support to specific sectors, although many OECD countries still use such measures to assist the restructuring process in declining industries or to aid specific regions. The liberalisation of national, and international, product and factor markets has become the core of industrial policy in many OECD countries. In addition, industrial policy seeks to support firms' ability to compete, primarily in areas where market failures can be identified, such as investment in infrastructure, skills, and R&D. Attention is being given to closer co-operation with the private sector, for instance through partnership programmes. There is a broadly shared view that improving the business environment will require greater efficiency in the public sector and a reduction of the administrative burden, for example in terms of regulation and taxation. Greater emphasis is also placed on the need for a horizontal, or systemic, policy approach and on more efficient policy design and delivery. The interest in policy evaluation in many OECD countries is an important sign of this shift.

It is now based on a better understanding of the main determinants of firm performance.

The policy shift reflects a better understanding of the main determinants of industrial performance. Productivity analysis indicates that firm performance depends mainly on private investment in physical and intangible capital and on firms' ability to organise and manage change. However, governments play an important role in supporting investment in infrastructure, education, and research and in pressuring firms to improve their performance by strengthening the degree of competition in the economy. Microeconomic analysis of productivity growth shows that firms perform very differently and that the effects of competition, such as the entry and exit of firms and changes in market shares, are important drivers of productivity growth. The best firms, those that survive, are able to manage change, adapt their organisation and management, improve worker skills, and incorporate advanced technology. Policies to encourage productivity growth thus need to be embedded in a competitive framework, where a process of "creative destruction" enables the exit and entry of firms.

Technological change makes considerable improvements in industrial performance possible, even in mature parts of the economy.

There have been significant changes in industrial performance in mature OECD-area industries, such as textiles, steel, automobiles, and construction. These industries have all, in varying degrees, been confronted with the need to restructure, owing to stagnating demand, intensified international competition, and changing consumer needs. Although this process has sometimes resulted in job losses, technological change has revitalised these industries, permitted productivity gains, boosted product quality and allowed a shift to high-quality goods and services, and more flexible responses to changing needs. Improvements in performance have generally been accompanied by improvements in worker skills, by organisational change, and by closer co-operation with suppliers and consumers. Closer links between producers and their customers and suppliers have been particularly important in guiding technological change. In several industries, but particularly in the automobile industry, the combination of organisational change and information and communication technologies has played a key role in improving performance and enabling greater flexibility. In some industries, notably textiles and steel, smaller firms have taken on greater prominence.

Technological policy has been marked by shifts in the level and nature of government support for R&D...

Technology policy has also changed over the past decade. Government support for research and development has declined, partly because of fiscal constraints and partly because of lower defence expenditure following the end of the cold war. In some countries, the drop in government expenditure has also affected basic research, although government funding of the science system and fundamental research has been relatively sheltered in most OECD countries. However, government support for R&D is changing in other ways. Greater demand for accountability has led to greater emphasis on commercially relevant R&D, and there is more focus on partnerships with the private sector and on indirect policy measures to stimulate innovation. Furthermore, because of the increasing globalisation of the innovation process, greater attention is being given to diffusion and international co-operation in research efforts.

... and the business sector is emphasizing collaborative R&D.

The nature of technological progress has also been affected by increased competitive pressures in the business sector. Firms are integrating their R&D efforts more closely with their business strategies and are doing less basic research. The desire to reduce product development time and costs and to achieve positive results more rapidly is driving this trend. As new technologies and innovative concepts can emerge from a wide variety of sources, many of which are beyond the direct control of firms, firms are also working together more closely. In their innovation efforts, they face the challenge of managing complex relationships, often at international level, with other firms, universities, public laboratories, and governments. There are also indications of shorter time horizons for business sector research, although this may be due in part to more efficient research practices. At the same time, the business sector is increasingly relying on co-operation with universities and public laboratories to keep abreast of fundamental research.

Technological change is also influenced by evolving science systems...

Over the past decade, OECD-area science systems (universities and government research institutes) have faced many new challenges, including stagnating government funding, growing demands for economic relevance, and increasing student enrolments in universities. At the same time, they have taken on importance as a source of innovation and become more closely linked to the business sector. In some areas of science, particularly biotechnology, the distinction between basic and applied research and between the roles of the public and private sector is blurring, posing an additional challenge to science policy. If science is to support future economic growth, governments must maintain support for basic science and for its human resource base, as private funding is likely to remain limited. To support the innovative process, governments will also need to facilitate co-operation between science and industry and protect intellectual property rights in a globalising economy.

... whose continuing excellent performance is attributable in part to greater use of information and communication technologies.

Despite these changes, science remains highly productive. Areas such as biochemistry, genetics, high energy physics, space research, and superconductivity continue to generate a stream of scientific discoveries. In information technology, health and life sciences, manufacturing and material technologies, and environmental and energy technologies, science is making an important contribution to innovative activity. To some extent, this high scientific productivity is due to advances in computational research, which allow scientists to address increasingly complex problems and open up entirely new areas of inquiry. Information and communication technologies also help improve communication among scientists, facilitate data and information sharing, provide access to distant research facilities, revolutionise scientific instruments and enable their use across great distances. They are also changing scientific publishing. All these developments help to improve science productivity and may help to accommodate budgetary pressures on the science system at a time when the costs of scientific research are rising.

If the potential for growth is to be realised, science, technology and industry policies should be more fully integrated with other policies.

In this time of change, risks and challenges abound, and government policies – macroeconomic, structural, industrial, technological, and scientific, among others – will play an important role in shaping OECD economies and societies over the near term. Well-designed and coherent policies that enhance the ability of OECD economies to adjust to rapidly changing conditions can contribute significantly to sustainable economic growth, whereas failure to adapt policy frameworks may jeopardise future growth prospects. Differences in performance across the OECD area, particularly in terms of income and productivity, suggest that there is considerable potential for growth. Further progress needs to be made in identifying and implementing best-practice policies and in developing an integrated approach to fostering growth in knowledge-based economies.

LOOKING AHEAD

INTRODUCTION

Over the past decade, various developments have affected OECD economies. Technological change and the growing importance of information and knowledge have significantly changed society, and the globalisation of the world economy has increasingly transformed national economies. Moreover, demand patterns have shifted, owing to rapidly ageing populations, rising incomes, high unemployment in many OECD economies and widening income distributions in others, changing lifestyles, urbanisation, and growing awareness of environmental constraints. These and other factors will continue to shape OECD economies in the foreseeable future.

Against the background of these long-term trends, this chapter looks at OECD-area prospects for the coming years. Using the OECD's half-yearly projections (OECD, 1998*a*), it first touches on the macroeconomic outlook. It then assesses prospects for industry and services and discusses how the economy is likely to change, as some sectors decline in importance and new growth areas emerge; it also looks briefly at important changes in industrial performance, many of them made possible by rapid technological change. The chapter turns next to technological change. Technology strongly affects how people live and work, and several emerging technologies hold great promise for the near future. Finally, the chapter summarises the outlook for science and discusses how the science system may adapt to changing resources and demands.

THE MACROECONOMIC OUTLOOK

The latest OECD *Economic Outlook* indicates that economic prospects for the OECD area are relatively favourable (OECD, 1998*a*).[1] ***For 1998 and 1999,*** gross domestic product (GDP) is projected to grow about 2.5 per cent in real terms, slightly less than in 1997 (Table 1.1). In the United States, growth is likely to drop from close to 4 per cent in 1997 to almost 3 per cent in 1998 and about 2 per cent in 1999. In Japan, output might decline this year and grow by only slightly more than 1 per cent in 1999. In the European Union, growth should pick up slightly in 1998 and 1999, but remain just below 3 per cent each year.

In the United States, employment growth is expected to slow somewhat over the next few years; in Europe, it is likely to pick up throughout 1998 and 1999. Unemployment is projected to decline in most countries, but is likely to rise slightly in the United States from 1998 onwards, albeit from a very low level. In 1999, it will probably remain at a high level of around 10.5 per cent in the European Union. Unemployment in Japan should remain low, at around 3.5 per cent of the labour force. OECD projections indicate that only a few countries with high unemployment rates – Finland, Ireland and Poland – can expect a significant improvement in labour market performance in the near future.

Inflation should remain low, with prices stable in the OECD area. Excluding the high-inflation countries, GDP inflation should remain at about 1.5 per cent a year.[2] Inflation in the United States and the European Union will continue to hover around 2 per cent a year over 1998 and 1999, but will fall further in Japan, where prices may be stable in 1999. Short-term interest rates in the United States and Japan may remain stable over the next few years, and fall slightly in the main European countries. German short-term interest rates should edge up, however, in the run-up to monetary union.

OECD projections indicate that the fiscal balances of OECD governments will continue to improve, with the average financial balance of OECD countries rising from –1.3 per cent of GDP in 1997 to –0.9 per cent in 1999. A number of OECD governments, including Canada, Denmark, Ireland, Korea, New Zealand

Table 1.1. **OECD macroeconomic projections for 1997-99**

Seasonally adjusted at annual rates

	1997	1998	1999
Real GDP (percentage change)			
United States	3.8	2.7	2.1
Japan	0.9	–0.3	1.3
Germany	2.2	2.7	2.9
European Union	2.6	2.7	2.8
Total OECD	3.1	2.4	2.5
Inflation (GDP deflator – in per cent)			
United States	2.0	1.6	1.8
Japan	0.6	0.5	0.0
Germany	0.6	0.9	1.3
European Union	1.8	1.8	1.9
Total OECD	3.7	3.4	3.1
Total OECD, excl. high inflation countries[1]	1.6	1.6	1.6
Unemployment (per cent of labour force)			
United States	4.9	4.8	5.0
Japan	3.4	3.5	3.6
Germany	11.4	11.5	11.1
European Union	11.2	10.9	10.5
Total OECD	7.2	7.1	7.0
Short-term interest rates (per cent)			
United States	5.1	5.1	5.1
Japan	0.6	0.8	0.6
Germany	3.3	3.7	4.0
Four major European countries[2]	5.1	4.8	4.4
Financial balances (per cent of GDP)[3]			
United States	0.0	0.4	0.0
Japan	–3.1	–3.5	–2.7
Germany	–2.6	–2.3	–2.4
European Union countries	–2.4	–2.0	–1.8
Total OECD	–1.3	–1.0	–0.9
Gross financial liabilities (per cent of GDP)[4]			
United States	61.5	60.6	60.0
Japan	86.7	89.6	92.1
Germany	65.1	64.3	63.8
European Union countries	77.7	76.5	75.4
Total OECD	70.7	70.1	69.7

1. High-inflation countries are defined as those countries that had, on average, 10 per cent or more GDP inflation during the 1990s. They are the Czech Republic, Greece, Hungary, Mexico, Poland and Turkey.
2. Unweighted average of France, Germany, Italy and the United Kingdom.
3. General government fiscal surplus or deficit as a percentage of GDP.
4. General government gross financial liabilities according to SNA (System of National Accounts) definitions, as a percentage of GDP.

Source: OECD, 1998*a*; gross financial liabilities from OECD, 1997*a*.

and Norway, have been able to achieve a substantial fiscal surplus. In several, the surplus is set to increase further over the coming years (OECD, 1998*a*). Public debt levels should remain high, however, at over 70 per cent of GDP for the OECD area as a whole (OECD, 1997*a*).

The OECD's ***medium-term projections*** to the year 2003 indicate a continuation of the short-term growth prospects, with OECD-wide GDP growing by 2.7 per cent between 2000 and 2003 and inflation falling slightly (OECD, 1998*a*). Unemployment should decline further, but remain at a high level in many European countries. The fiscal consolidation of OECD economies should continue, given policy objectives in this area, although public debt levels are likely to remain high in many OECD economies and fall from just under 70 per cent of GDP in 1999 to just over 65 per cent of GDP in 2003 (OECD, 1997*a*).

Over the ***long term,*** recent OECD analysis suggests that OECD countries will continue to have annual economic growth rates of between 2 and 3 per cent to the year 2020. Higher growth will be contingent on the ability of OECD governments to implement a range of growth-enhancing policy measures, such as further trade liberalisation, successful fiscal consolidation, and extensive labour market reform (OECD, 1997*b*). Growth is likely to be much higher in the developing world over the next 20 years, with the result that non-OECD economies will have a greater impact on world economic growth and may further the globalisation process. A small number of developing countries, particularly in Asia, are likely to become industrialised. The Big Five (Brazil, China, India, Indonesia and the Russian Federation) should emerge as major economic powers. Other areas, and Sub-Saharan Africa in particular, may fall further behind the rest of the world.

THE PROSPECTS FOR INDUSTRY

Long-term trends in combination with macroeconomic conditions, fluctuations in both domestic and external demand, and the competitiveness and productivity performance of particular industries all drive ***structural change*** and the growth and decline of specific sectors (Box 1.1). For instance, saturated

Box 1.1. **Key forces driving structural change**

Future-oriented and foresight studies seek to predict broad socio-economic trends on the basis of assumptions about the forces of change affecting the world economy. Apart from economic growth, a number of key developments drive long-term change in OECD economies (OECD, 1997*b*), namely: *i)* technological change; *ii)* globalisation; *iii)* changes in lifestyles and demand patterns; and *iv)* environmental concerns.

Current trends indicate that ***technological change*** will continue to shape the lives of people world-wide. New technologies are being introduced and product life cycles continue to shorten in many industries. New structures and networks are emerging to produce, disseminate and manage knowledge and information. The functioning of such networks, including national innovation systems, will become more important to overall economic growth. Knowledge intensity is likely to increase further in nearly all sectors of society, and information and communication technologies (ICT) will be more broadly integrated. Ongoing technological change will create the need for a highly skilled and flexible workforce and, therefore, lifelong learning and continuous upskilling. It may also require significant organisational changes in firms.

The term "***globalisation***" is used to refer to the growing irrelevance of national boundaries to the flow of capital, skills, technology, ideas, data, products and services around the world (see Chapter 2). Current trends suggest that offshore production and global manufacturing will continue to increase and that further growth in international trade will primarily involve services and high-technology manufacturing goods. Rapid growth in foreign direct investment (FDI) is strengthening competitive pressures in the services sector. Globalisation has been made possible by ICT, by international trade- and investment-enhancing agreements such as the conclusion of the GATT Uruguay Round, by regional integration, and by the internationalisation of financial markets. It is spreading beyond large multinationals to other large and medium-sized companies, and even to some small companies, as they seek to take advantage of global market opportunities.

Changing lifestyles and demand patterns are closely linked to economic growth. Higher incomes lead to more demand for leisure, better health, and improved quality of life. Demographic changes are also likely to affect demand patterns. Declining birth rates and longer life expectancy in industrialised countries are resulting in a rapidly ageing population, so that demand for certain goods and services (*e.g.* primary schooling) will decline and demand for others (*e.g.* health and personal services) will rise. High unemployment in many OECD countries and widening income distributions in some may also affect demand patterns.

Many studies highlight concerns that growing human populations and the pressures of economic development threaten the global ***environment.*** The world's population may double over the next 50 years, and poorer countries may increasingly lack access to adequate water, food or energy supplies. This rapid population growth will exacerbate disparities in wealth and access to food and other resources. High-income economies are, for their part, confronted with problems of growing waste, traffic congestion, and rising greenhouse gas emissions. They remain the major source of global environmental problems, although there is growing environmental awareness in both developing and developed economies. Environmental policies increasingly emphasize sustainability as the key to future economic development.

demand for food products in the OECD area and rapid productivity growth have meant that the share of the agricultural sector in the economy has declined. Some mature manufacturing sectors, such as textiles and steel production, have been affected by international competition (see Chapter 5) and have declined in relative importance.

Because OECD economies have different economic structures and comparative advantages, it is impossible to gauge OECD-wide prospects for specific economic sectors. Nonetheless, it is possible to identify a number of processes that affect sectoral prospects. They include the increasing role of knowledge-intensive industries, the growth of certain service sectors, and the changing competitiveness of OECD economies.

Future ***technological change*** will be an important driver of structural change. Two processes should be distinguished, however. First, emerging demand for new technologies (discussed in more detail below) may increase the role of the sectors that produce these technologies; for instance, growing demand for software and for environmental goods and services has increased their contribution to the economy. Second, technological change may facilitate productivity growth, as labour-intensive production can be automated and processes can be improved by implementing information and other advanced technologies. The share of employment in sectors using and/or producing such technologies may decline; for instance, the share of high-technology manufacturing sectors in OECD employment has declined since 1985, accompanied by strong productivity gains. Furthermore, while the demand for telecommunications goods and services has increased substantially over the past decade, their share of employment has changed little, while the use of advanced technologies has resulted in considerable productivity growth.[3] Productivity growth may also allow for cutting costs and lowering prices, thereby reducing the nominal share of these sectors' output in the economy.[4] The interaction of growing demand and rapid productivity growth indicates that new technologies do not necessarily mean that sectors producing or using these technologies will make a greater contribution to the economy.[5]

Long-term trends indicate that the structure of OECD economies will continue to shift to ***services.*** The most rapidly growing sectors in both output and employment terms are finance, insurance and real estate (FIRE), business services, and community, social and personal services (OECD, 1997*c*; 1998*b*). The output and employment shares for electricity, gas and water, construction, and transport and communication services have generally remained stable or have fallen slightly. This reflects saturated demand for these services, although not for all components; relatively rapid productivity growth in some of these sectors has contributed to changes in relative prices. The share of the distribution sector has remained relatively stable. In some OECD economies, fiscal constraints have limited the government sector's contribution to output and employment over the past decade.

The share of the ***manufacturing sector*** in the economy will continue to decline. High-technology manufacturing (aerospace, computers, electronics, pharmaceuticals) has been able to maintain reasonably well its share in the economy, but medium-technology (*e.g.* chemicals) and low-technology (*e.g.* food products, textiles, paper and wood products) manufacturing have declined rapidly over the past years. The changing composition of the manufacturing sector is also apparent in the trade structure of OECD economies: exports of low-technology industries such as textiles have declined in importance, whereas exports of high-technology industries have grown rapidly (OECD, 1998*b*).

While these broad patterns are apparent throughout the OECD area, future sectoral developments in individual OECD countries will vary significantly. Their patterns of specialisation and comparative advantages are quite stable over time and often reflect well-established patterns. The effects of the move towards a knowledge-based economy will therefore differ, often building on existing comparative advantages, such as those embedded in industrial clusters (see Chapter 3).

Nevertheless, rapid growth is likely to characterise a number of sectors, albeit with differences in individual countries. This is most evidently the case for ***information-related goods and services.*** The world information-technology (IT) market grew twice as fast as GDP between 1987 and 1995 (OECD, 1997*d*); growth was particularly rapid in software and computer services. Rapid growth in this sector in almost every OECD country points to its overwhelming importance. As many new technological advances are projected in this market (see below), the IT sector will remain a very dynamic part of the economy.

The ***health-care*** market is another that will have continuing rapid growth over the coming years. The rapid ageing of OECD populations and greater health awareness is increasing demand, while advances in biotechnology and other health-related technologies (Box 1.2) are opening up a range of new technological options. Health care may also move gradually from hospitals to the home, partly as a result of financial constraints. This may increase demand for simple and user-friendly health products and services, some of which may be provided via the Internet.

Environmental goods and services represent a third market that is widely projected to grow rapidly. Although the market is still relatively small (OECD, 1998*c*), environmental awareness is increasing in many OECD countries, partly owing to demand for better quality of life. Efforts to tackle global environmental problems, such as global warming, may also increase demand for environmental goods and services, including those related to the energy market. Various technologies are emerging in this area (Box 1.2), an indication of a significant potential for change. In terms of growth sectors, the environmental industry links several economic sectors, including parts of agriculture, manufacturing, energy, construction, transport, and certain services.

Specialised business-sector services are a fourth market that is likely to see continuing rapid growth (OECD, 1998*b*). One of the most rapidly growing segments of the US economy, this market covers sectors such as management consulting and auditing. As competition in manufacturing and services continues to increase, firms are looking for ways to reduce costs and improve efficiency. One strategy is the contracting out (outsourcing) of certain services, a development that will exert further downward pressure on the share of manufacturing in the economy. The growth of business services and the outsourcing of services are one sign of a growing interaction between manufacturing and services. The commercial success of manufacturing products increasingly depends on associated services, and services are now among the main users of advanced technologies.

While these broad patterns are likely to affect all OECD economies to some extent, some countries have made more specific sectoral forecasts. The United States has recently published detailed sectoral projections for 1998 (US Department of Commerce, 1997) which indicate that strong growth in the high-technology sectors, including the information industries and aerospace, will continue to feed a dynamic US economy. Real output growth in computer equipment should continue to lead the manufacturing sector, with shipments expected to increase by about 30 per cent in 1997 and in 1998. The high growth of this sector alone will contribute almost two percentage points to projected manufacturing output growth over the 1996-98 period.

Over the same period, aerospace equipment, aircraft and parts, dental equipment, and radio and TV equipment are also expected to grow rapidly. These projections point to a strong turnaround in the high-technology manufacturing sector, which had below-average growth in 1995 and 1996. At the same time, US manufacturing industries that are likely to decline are shipbuilding, printing and publishing, leather footwear, and electric household equipment. The decline in shipbuilding and some related sectors is closely linked to lower spending on defence.

According to these projections, the US services sector will continue to increase in importance. Several information and communication technology services – cable television, computer professional services, data processing, and network services – are projected to have real annual output growth in excess of 10 per cent over the period. Other rapidly growing services are those that support manufacturing and other services sectors, such as management consulting, accounting, auditing, and bookkeeping. To some extent, growth in these services reflects increased outsourcing by manufacturing and service firms.

The European Commission also engages in sectoral projections (European Commission, 1997*a*). It foresees a continuing trend towards specialised high-technology products and services and a decline in standardised goods and services, such as apparel, footwear, standardised machinery and basic metals. In the short term, as the EU economy moves out of recession, most growth is expected in investment goods and construction. Little growth is expected in consumer goods, as high unemployment rates and continued fiscal constraints will limit consumer spending over the near term.

In terms of employment, the European Union, like the United States, should see a continuing move towards services and a knowledge-based economy. Over the 1995-99 period, the European Commission projects a considerable decline in employment in agriculture, energy supply, basic metals, pharmaceuticals, food, textiles and clothing, as well as in commercial services. In some of these industries, demand is relatively saturated; productivity gains and increasing international competition also add to a decline in share. Employment gains are most likely in the services sector, including restaurants and hotels, business services, maritime and air transport, and distribution. Parts of the manufacturing sector, such as the electrical and mechanical engineering industries, should also see some employment growth.

A number of other developments will continue to affect industrial performance in OECD economies. Owing to continuing globalisation and deregulation, competitive pressures are likely to intensify in many parts of the economy and increasingly affect sectors such as energy, transport, communication, and distribution, which have remained sheltered until now. The rapid growth in foreign direct investment, particularly through mergers and acquisitions (see Chapter 2), should increase competitive pressures in many parts of the services sector. This will create further pressures to adjust and could lead to transition problems in economies insufficiently able to change. Coherent and integrated government policies may play a major role in facilitating the transition process as OECD economies become knowledge-based societies (see Chapter 3).

Industry is also likely to change in other ways. Ongoing technological change in many areas (see below) will enable further improvements in product quality, driven by changes in consumer demand. Firms will need to become more flexible but, to do so, will have to undergo considerable organisational change (OECD, 1998*c*). Recent developments also suggest the re-emergence of small firms in many industries, partly because they can be more flexible than large ones and partly because technological change has limited the role of economies of scale in industries such as textiles and steel production. Closer co-operation among firms, in formal joint ventures or in industrial clusters, as well as with universities and public laboratories, will increasingly characterise firms' efforts to adapt to technological change and to innovate. These changes in industrial performance go beyond the high-technology part of the economy and affect most industries, including mature industries, such as food, textiles, steel and automobiles (see Chapter 5).

FUTURE TECHNOLOGICAL CHANGE

Technological change is a main driver of economic development, but one that is difficult to project. Over the past decades, governments and private institutions have undertaken a range of studies, including technology foresight activities, to try to forecast future technological change. Technology foresight attempts to look into the longer-term future of science, technology, the economy, and society, with a view to identifying the emerging technologies that are likely to yield the greatest economic and/or social benefits. OECD countries have increasingly used such studies as a means to guide research and development (R&D) and aid in policy design. They also are valuable as a means of bringing together scientists and representatives from diverse parts of society to speculate about future opportunities and challenges. They encourage knowledge flows in the economy and are seen as a valuable tool for strengthening national innovation systems.

While foresight studies are an imperfect guide to future developments, most suggest that a limited number of technologies will be central to future socio-economic development (Box 1.2).[6] Topping the list are information and communication technologies, particularly high-density components and new types of software; and health and life science technologies, including biotechnology, genomics, and combinatorial chemistry. In manufacturing, robotics and micro-/nano-scale fabrication are considered among the core technologies, while the development of advanced materials – high-temperature, Box 1.2. **Main technological developments projected by foresight studies**

Information technology is identified by most studies as the main driver of technological change and economic growth. Explosive growth is projected for information and communication technologies. These include components, software, communication networks, and multimedia systems. Developments in components are proceeding rapidly, often outpacing the predictions of technology foresight studies. Most exercises identify continuing advances in semiconductor manufacturing, particularly in the areas of high-density data storage and high-definition displays. With regard to software, most foresight exercises emphasize the development of interactive software to facilitate communication on the information highway, such as interface software, virtual reality systems, image analysis and speech recognition. Computer software to facilitate advances in other scientific fields is also considered significant, such as modelling and simulation software, bioinformatics, non-linear dynamics and simulation in manufacturing and product design. With regard to communication networks, the emphasis is on future developments in digitisation and broadband communications technology. Many of the foresight recommendations in the ICT field focus on consumer applications**,** especially those based on multimedia, such as telemedicine, teleshopping, remote learning, environmental monitoring, financial services, and leisure products.

There is also a strong level of international consensus on the importance of technologies related to ***health and life sciences.*** In this area, important advances emerge from genomics, combinatorial chemistry, and biotechnology. Genome research increases the understanding of many diseases; combinatorial chemistry significantly improves the development of new drugs. Most technology foresight lists emphasize understanding, prevention, treatment and/or cure for cancer. The three most promising technical approaches in this area are believed to be gene therapy, recombinant DNA techniques, and monoclonal antibody development. For the treatment of other diseases, cellular biotechnology is particularly emphasized, as it may become the bridge between molecular genetics, biochemistry, and medicine. Among biotechnology applications specifically aimed at the health sciences, biomedicine, recombinant DNA technologies, biocompatible materials and genetically engineered vaccines have a high rating, as does the development of biosensor technology for medicine, but also for manufacturing and the environment. The application of biotechnology to agriculture, *e.g.* biomass and food preservation technologies, and to the environment, *e.g.* bioremediation, are also considered important. Many of the technologies featured in the health and life sciences category are expected to meet the needs of ageing populations. This concern is reflected in recommendations for more research into ageing and disabling diseases and for technologies that will allow older people to maintain their independence and a reasonable quality of life. Technology foresight reports also indicate a need for further understanding of how genetic information can be used to prevent and treat common diseases. In addition, research into key metabolic pathways and metabolic engineering, the development of diagnostic applications of molecular biology, and the establishment of programmes on drug creation and delivery appear important areas for research on ageing.

Automation and robotics – the application of computers to processing technology – head the list of important future ***manufacturing technologies.*** It is predicted that robotics will make major inroads in food processing, materials handling, hazardous waste cleanup, microsurgery and many other applications. Similarly, for most countries, computer-aided design (CAD) and computer-aided manufacturing (CAM) are fields where many promising developments have yet to be implemented. New process technologies emphasize process engineering and control, particularly the further development of continuous process manufacturing. Micro-/nano-scale manufacturing will be very important for the production of semiconductors, microdevices, and computer components. The continuing drive for compactness requires miniaturisation that takes into account the precision, efficiency, reliability and combination of components and allows mass production of very small systems. Sensors are another important technology associated with intelligent manufacturing processes; new chemical, biological, mechanical and electromagnetic sensors and instruments are central to better manufacturing operations and product development.

Materials technologies cover a wide field. Several materials technologies are commonly included in foresight results, including advanced ceramics, polymers, composites and electronic and photonic (*i.e.* involving the combined use of microelectronics, optoelectronics and integrated optics) materials. In general, foresight exercises underline the future significance of high-temperature, lightweight, energy-efficient and biocompatible materials. Advanced ceramics feature on most technology foresight lists because of their high-temperature, heat-resistant features. Development of composite materials, particularly heat-resistant engineering plastics or polymers are also important. With regard to electronic materials, most reports underline the importance of superconducting materials. Photonic materials will increasingly be used in industrial applications. In addition, "smart materials", which possess automatic sensing

(continued on next page)

(continued)

functions for temperature, humidity and light, are considered an emerging technology. The development of advanced materials will also require new fabrication techniques.

Environmental technologies are rated highly in most foresight exercises. Clean processing technologies, which minimise resource inputs and waste outputs, top most critical technology lists. Many countries are concerned about greenhouse gas emissions and are seeking ways to reduce carbon dioxide, methane, and nitrous oxide through biological or chemical conversion, sequestration, storage or other means. Several countries stress technologies for more integrated monitoring and control of pollution from manufacturing processes. There is also agreement that waste disposal and storage are important environmental issues. New technologies for wastewater treatment, including water recycling for individual dwellings, are of interest in urban areas. Technologies to cope with nuclear waste are considered especially in need of study. Remediation and recycling technologies are considered crucial for the future. Biotechnology may also have important environmental applications, *e.g.* in the bioremediation of air, water, and soil and to preserve biodiversity. Better recycling technologies, particularly for plastics, are also needed, as are means for tracking and recycling complicated products such as automobiles. Technologies are required to understand and monitor global ecological trends. Many studies mention counteractive measures to reduce global pollution, replacements for CFCs and other damaging pollutants, and recovery of damaged ecosystems.

Technologies to improve energy efficiency stand out among ***energy-related technologies.*** Particularly important are new fuel-efficient cars based on new materials and greater engine efficiency. New approaches to power generation are also highlighted. Here, the principal technologies relate to the use of superconductors, fast breeder nuclear reactors, and combined cycle generators. Prominently featured on most foresight lists is the use of fuel cells for co-generation of heat and electricity, although the time needed to develop fuel-cell technology remains unclear. Renewable energy, such as solar and wind power, is featured in several foresight studies, with photovoltaics as one of the main technologies.

Technology foresight exercises increasingly identify the value of ***interdisciplinary technologies.*** Examples identified include photonics, nanotechnology, bioelectronics, biocompatible materials and optoelectronics.

lightweight and biocompatible – also appears important. Equally significant are biotechnology applications for clean industrial products and processes and for the bioremediation of air, water and soil. Technologies to improve energy efficiency and power generation and those enabling the use of renewable energy are also important. Most foresight exercises predict that interdisciplinary technologies, including photonics, bionics and bioelectronics, are areas with great potential.

Many of the technologies highlighted above also emerge in other studies. For instance, a special issue of *Scientific American* (1995) mentions information technologies, medicine, material and manufacturing technologies, energy and environmental technologies, and transport technologies as areas with great potential for the 21st century. Transport technologies, which include high-speed rail, cleaner cars and safer air travel, are not always covered in foresight studies. Furthermore, a study by Battelle (1997) projects major market demands for the year 2007, including: affordable home-based health care, personalised consumer products, technology in the home, environmentally friendly products, products related to good nutrition, mobile energy sources, microsecurity, infrastructure, and products and services related to global competition. There therefore seems to be considerable agreement on the main areas for future technological advance, although the emphasis may differ, sometimes owing to national characteristics and comparative advantages.

Nevertheless, technological change remains uncertain, and the developments mentioned above only serve as broad guidelines to coming changes. Several technological breakthroughs projected decades ago have failed to emerge, while others that were not foreseen have had an enormous impact on society. Research may not always lead to success in the short run, and technological change must meet the crucial test of market forces and rapidly changing demand. Successful application of new technologies increasingly depends on non-technological factors, particularly how well they can be commercially applied. Potential commercial applications, such as the rapid diffusion of personal computers in the home, are not always foreseen. Many factors determine success, including an effective interface between science and industry, sufficient feedback from changes in demand to innovative efforts, government regulations, the organisation of the workplace, the availability of appropriate skills, as well as effective factor and product markets. Attention to these factors in government policy is crucial for ensuring the benefits of future technological change (see Chapter 3).

THE OUTLOOK FOR SCIENCE

In terms of the outlook for science, two aspects should be distinguished. First, the science system will continue to be extremely productive and will generate an ongoing stream of ***scientific discoveries*** that may contribute to rapid technological change. This is the case in scientific fields such as biochemistry, genetics, high energy physics, and superconductivity. This positive outlook is partly due to the impact of ICTs on productivity in the science system (see Chapter 7). Advances in computational research have opened up entirely new areas of scientific research and greatly improved computational analysis in all areas of science. ICTs also improve communication among scientists by facilitating data sharing, providing remote access to distant, central research facilities, and revolutionising scientific instruments. In this respect, the outlook for science is excellent.

The second aspect concerns the ***science system,*** which is in a period of transition, owing to changes in the level and character of funding, difficulties in setting priorities for science funding following the end of the cold war, human resource problems, increasing demands for accountability, the internationalisation of the science system, and the effects of ICT. The science system is becoming increasingly important in the transition to a knowledge-based economy, as it provides the foundation for innovation systems and plays a key role in transferring and disseminating knowledge. This is not its only role, however. Science also pursues several non-economic goals, and its role in economy and society cannot be judged solely in terms of its impact on innovation and economic growth.

The funding of science systems, particularly by government, has faced problems over the past decade. Public funding has been constrained, owing to efforts at fiscal consolidation, although science budgets have been somewhat protected as compared to government funding of R&D (see Chapter 6). Moreover, government research funding in many OECD countries is becoming more mission-oriented and contract-based. Funding pressures on the science system are accompanied by demands for accountability in the expenditure of public funds. In many OECD countries, the general public and their representatives are calling for more tangible results and transparency from the science system, and this has led to greater efforts to evaluate policies.

Public funding for science in the OECD area is likely to be relatively stable over the near term (see Chapter 3). Budget projections for the United States, the leading supporter of R&D, indicate a slight rise (in real terms) in government funding of R&D between 1998 and 2003 (see Chapter 3). Japan, another important supporter of public R&D, aims to increase spending on science and technology by 50 per cent between 1996 and 2001, with the proposed R&D budget for 1998 calling for a 4.9 per cent increase in real terms. Prospects for the three major European R&D spenders (France, Germany, and the United Kingdom) indicate a slight decline in government funding for R&D over the near term. The budgets of some other OECD countries with significant R&D spending (Canada and the Netherlands) also indicate a decline in government funding. However, a small number of OECD countries, including Korea and Finland, aim for a significant increase.

The short-term outlook for ***business funding*** of research and development, which is particularly aimed at applied R&D, is more positive, particularly in the United States. A recent study (Schonfeld & Associates, 1997) projects a sharp increase in R&D spending in 1998 in a number of industries. It should increase by almost 10 per cent over 1997 in the automotive industry, by almost 12 per cent in telecommunications equipment, by 13 per cent in semiconductors, by 4.5 per cent in computing and office equipment, by 17.9 per cent in pre-packaged software, and by 11.6 per cent in biotechnology. Spending on pharmaceutical R&D is expected to increase by almost 18 per cent worldwide. Other recent estimates roughly confirm these projections (Battelle, 1998). The Industrial Research

Institute (IRI) also projects an overall increase of just under 5 per cent in US business R&D spending in 1998 (Industrial Research Institute, 1997). Surveys by IRI's counterparts in Australia, Europe, Japan, and Korea indicate a slightly more positive outlook for business R&D in Australia and Japan in 1998, while business spending in Europe and Korea may be somewhat more subdued than in 1997. However, the pick-up in economic activity in European countries could help boost business sector R&D spending in this part of the OECD area (see Chapter 6). Business R&D spending in Japan is likely to remain subdued, owing to slow economic growth and continuing financial turmoil. Overall, this suggests an increase in the share of business sector R&D in total R&D spending, with the possible exception of Japan.

The intensification of competitive pressures in the business sector and more efficiency in research will continue to shorten ***research time horizons.*** On the basis of current trends, firms and governments are expected to maintain their support for basic (or long-term) research but will increasingly demand rapid results from their R&D expenditures. The integration of technology in firms is likely to intensify as global competition increases, while greater efficiency in research, partly owing to closer integration of fundamental and applied research in areas such as biotechnology, will also enable more rapid technological progress (see Chapter 6). Firms will increasingly collaborate with other firms, universities and public laboratories in order to gain access to emerging technologies (Battelle, 1998).

Science-industry partnerships will take on greater importance as a key link in national innovation systems. The private sector in OECD countries increasingly looks to universities for relevant skills and experience. It is also making greater use of research results from universities and public research facilities to develop commercial technologies. Private enterprise is funding a greater share of university research and entering into new types of joint research ventures with both universities and government laboratories. These public/private research partnerships have proven to be an efficient means of combining financial and technical resources and leveraging private funds with smaller public investments. Increasing links between the science system and industry will raise complex questions regarding ownership of research results, sharing of intellectual property rights, and the need for technology brokers and specialised commercialisation units. Governments will need to reduce or eliminate regulatory barriers that might inhibit gr eater commercialisation of publicly funded research.

The short-term ***outlook for universities*** remains uncertain (OECD, 1997*e*). In recent years, significant changes in the university environment have affected research at these institutions. Universities are becoming more diverse in structure and more oriented towards economic and industrial needs, while coping with rising student enrolments. Due to the decline in support for funding to university research, R&Duniversities are seeking leading to the search for new sources, such as the private sector, and a new basis for that supportfunding. In addition, as government funding forto academicuniversity research is increasingly of a mission-oriented, contract-based, nature and linked to performance criteria, universities increasingly engage in short-term and market-oriented researchuniversity R&D. This trend is reinforced by the larger share of private funding – often in the form of joint projects, contracted R&D research, and financing of researchers – which also leads universities to perform to research directed towards potential commercial applications. This development, if taken too far, risks eroding basic research and its long-term contribution to economic growth (see Chapter 6).

The university system will also be challenged in other ways. Mismatches between supply and demand for scientific personnel in some countries, an ageing scientific workforce, and declining interest in some fields of science among the youth of some countries raise concerns about the future availability of sufficient numbers of well-trained researchers. An adequate supply of highly trained scientists and engineers is central to the vitality of OECD knowledge-based economies. Particularly needed are scientists with broad training, able to address multidisciplinary problems. Uncertainties over financial support and sharply increasing undergraduate enrolments are making it difficult for many university systems to provide high-quality, research-oriented training at the most advanced levels. In some newer disciplines, shortages of trained personnel are already serious. Other fields have excess personnel, especially where numbers of public sector research positions are declining. These imbalances in supply and demand may increase during the coming years, although some countries have undertaken reforms to reduce the mismatch (OECD, 1998*c*).

Furthermore, the search for excellence, combined with financial constraints on government support, is leading to greater concentration of research capabilities in centres of excellence. in smaller numbers of institutions,Competition among research universities will increase and will increasingly become international as the quality of research in universities in non-OECD countries becomes internationally competitive. Today, competition mainly concerns obtaining resources, on a world-wide scale in the case of megascience. The increasing complexity and sophistication of research has contributed to a growing need for large- scale facilities or apparatus, which can only be made available at national research centres or, in some cases, internationally funded onescentres. A challenge to governments at both the national and international level is to enassure optimal use of such facilities. While the trend towards concentration and selectivity are one aspect of the continuing search for excellence, there is also a strong trend towards more ***interdisciplinary research.*** Many of the recent breakthroughs in science reflect the joint efforts of previously unrelated scientific disciplines.

Scientists will make greater use of ***information and communication technologies,*** with dramatic consequences for the science system (see Chapter 7), particularly by enabling scientists to engage in new areas of scientific research. ICT should, over the long term, reduce costs and increase science productivity as well as contribute to the realisation of the "global research village". Governments have a role in ensuring that the benefits are widespread by establishing adequate networks and regulatory frameworks for access, protection of intellectual property, and the development of collaborative structures.

Globalisation, stemming partly from advances in ICT, will increasingly affect R&D. The science system has always had an international dimension, but its global character is becoming ever more apparent. The need to pool technical and financial resources has led to a growing number of collaborative research ventures among countries in a variety of disciplines. Owing to the globalisation of industry, multinational corporations are conducting more research abroad. International mobility of research personnel will be important to the growing globalisation of the scientific enterprise, with the transfer of knowledge across borders increasingly embodied in the researchers themselves. However, the mobility of students and scientists, particularly to and from countries outside the OECD area, is often constrained by regulatory, institutional and other barriers.

Government policy will play a crucial role in determining whether the future science system will be able to meet the demands of the 21st century. OECD economies are moving towards knowledge-based societies, yet government spending on science and technology has declined, the science system is in transition, and governments have difficulty setting priorities for science and technology policies. Governments will need to continue their support for basic and fundamental research and for the science system in a broader sense, as the private sector is unlikely to increase its funding significantly. An area that will be crucial in the coming years is the human resource base. Governments will also need to help facilitate knowledge flows among firms and between firms and universities, to adjust legal frameworks to enable such collaborative arrangements, and to look for ways to use public funds to leverage private sector spending. Another area where government policy will play a crucial role in determining the future success of the science system is its response to the globalisation of research. However, in spite of these problems, the outlook for scientific discovery remains excellent, particularly over the longer term.

NOTES

1. Although the current financial turmoil in Asia continues to pose a risk to growth prospects for 1998.
2. High-inflation countries are defined as those which had, on average, 10 per cent or more inflation annually during the 1990s. They are the Czech Republic, Greece, Hungary, Mexico, Poland and Turkey.
3. The impact of sectoral employment gains and losses on economy-wide employment depends on broader macroeconomic interactions and the flexibility of labour and product markets.
4. Differences in productivity growth among sectors may contribute to changing relative prices (Baumol *et al.,* 1989). Goods and services from sectors with low rates of productivity growth, such as social and personal services, are likely to face more rapid price increases than goods and services from sectors with high rates of productivity growth. This process contributes to the changing composition of the economy.
5. The structural transformation of OECD economies goes beyond changes in production and employment shares and also affects R&D and innovation patterns (OECD, 1998*b*). The services sector is increasingly important as a performer of R&D – about 30 per cent of all R&D in Australia and 20 per cent in the United States – and is emerging as a significant user of advanced technologies. By 1993, service firms in the G7 countries accounted for between 30 and 50 per cent of all "embodied" technology acquisition (technology acquired in the form of equipment or intermediate goods).
6. Box 1.2 summarises the results of recent foresight studies for Australia, France, Germany, Japan, the Netherlands, New Zealand, the United Kingdom, and the United States. However, several other OECD countries are also engaged in foresight studies, including Austria, Korea, Spain, and Sweden.

TRENDS IN PERFORMANCE

INTRODUCTION

This chapter discusses recent trends in industrial and technological performance. It first looks at some underlying forces that drive these trends. They include macroeconomic trends, the rapid process of globalisation, technological change, and the behaviour of individual firms. Next, it discusses trends in industrial performance, including movements in output, investment, employment, productivity and international competitiveness. Finally, it provides a brief overview of the main trends in science and technology, including recent developments in support for research and development (R&D), and in innovation and knowledge flows and technological diffusion.

UNDERLYING FORCES

Recent macroeconomic developments

Over 1996 and 1997, ***economic growth*** in the OECD area gathered further pace (OECD, 1997*a*; 1998*a*; Figure 2.1).[1] In North America, growth in the United States picked up considerably, from 2 per cent in 1995 to 2.8 per cent in 1996 and 3.8 per cent in 1997, while growth in Canada was also strong in 1997. In Mexico, growth rates in excess of 5 per cent were recorded over both years, partly as a result of a catch-up process following the 1995 fall in activity.

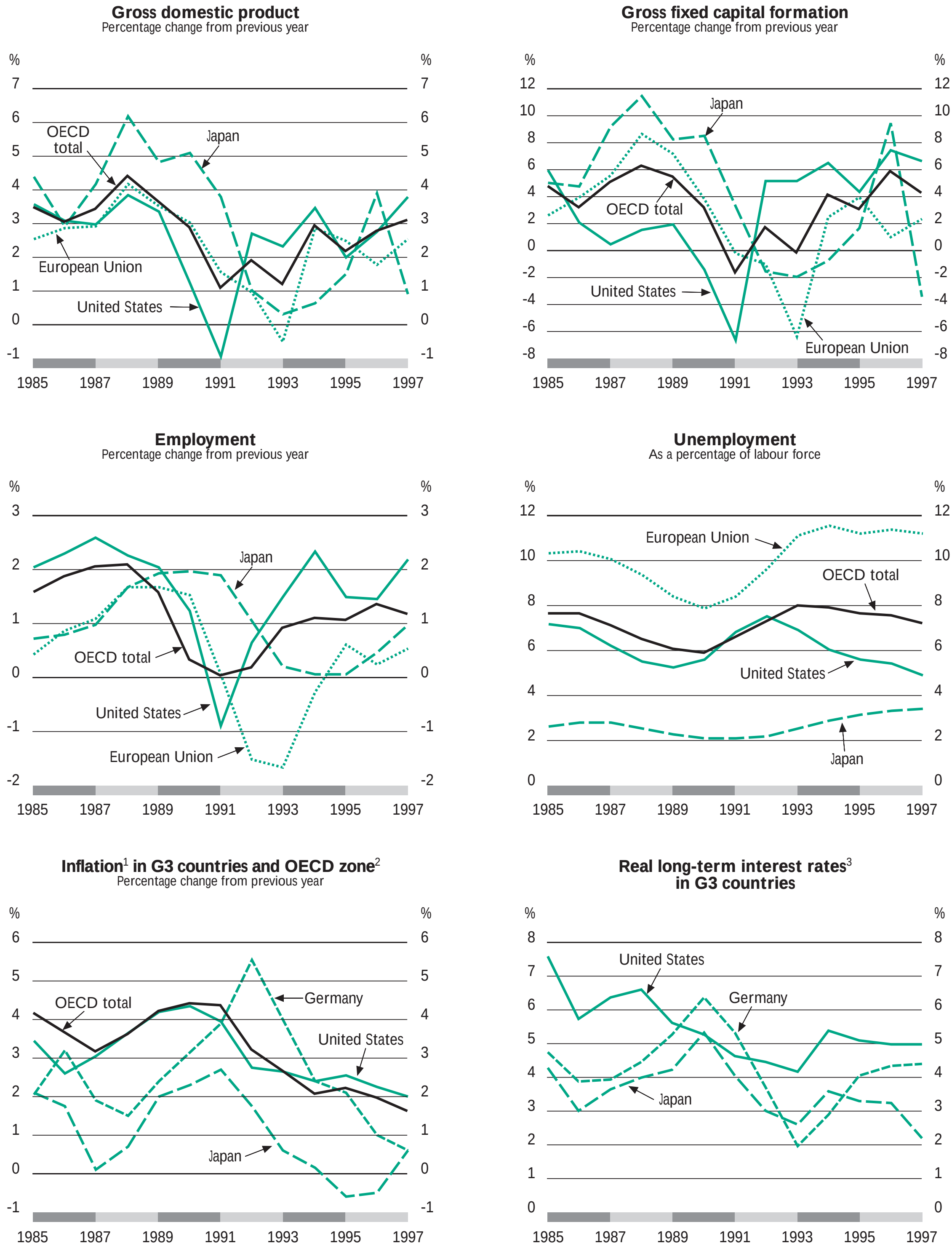
In 1997, growth in the European Union (EU) was much stronger than in 1996, at 2.6 per cent versus 1.7 per cent. Denmark, Finland, Ireland, the Netherlands and the United Kingdom continued their strong non-inflationary performance, while in France, Germany and Italy, growth rates improved considerably following weak performance in 1996. In Iceland, Norway and Poland, the economy continued strong, while in Hungary, growth picked up following the 1995-96 slowdown. However, growth in the Czech Republic slowed sharply. Finally, the Turkish economy continued its strong recovery.

In the Asia-Pacific area, performance was mixed. In Japan, growth slowed sharply, from 3.9 per cent of GDP (gross domestic product) in 1996 to only 0.9 per cent in 1997. In Korea, growth continued to slow in 1997, although it remained at a high level, at 5.5 per cent on an annual basis. In November 1997, the Korean economy was confronted with a major financial crisis and had to request assistance from the International Monetary Fund. Growth rates in Australia and New Zealand remain modest, although there are some signs of a pick-up in activity.

Employment growth in the OECD area improved considerably in 1997, driven mainly by buoyant activity in the United States. Employment growth in Japan and the European Union also improved somewhat over 1996, although insufficiently in the EU area to result in a significant decline in unemployment. Unemployment rates in the United States fell further in 1997, to 4.9 per cent of the labour force, while unemployment in Japan remained stable at 3.4 per cent. The unemployment rate in the European Union fell marginally from 1996 to 1997, from 11.4 per cent to 11.2 per cent.

Inflation remained low throughout most of the OECD area in 1997. Excluding a limited number of countries with high inflation rates, it remained below 2 per cent for the OECD area as a whole. In the United States, inflation fell slightly from its 1996 level of 2.3 per cent, despite a significant increase in economic activity. In Japan, it stood at 0.6 per cent in 1997, but this was mainly the result of a one-off increase in the consumption tax, underlying inflation being almost zero. In the EU area, inflation fell

◆ Figure 2.1. ***Recent macroeconomic trends***



1. Implicit price index of GDP (gross domestic product).
2. OECD total does not include high-inflation countries.
3. Real long-term interest rates, based on lagged GDP deflator.

Source: OECD, 1997*a*; 1998*a*.

from 2.4 per cent in 1996 to 1.8 per cent in 1997, although some inflationary pressures are appearing in European economies with more mature economic expansions.

Long-term ***real interest rates*** have also come down over the past years, particularly in the prospective euro area, where interest rates are converging in the run-up to monetary union. The trend towards lower real interest rates appears driven by success in fiscal consolidation and by low and stable inflation across much of the OECD area. The average general government deficit in the OECD area improved from 4.3 per cent of GDP in 1993 to 1.3 per cent in 1997, and looks set to improve further over 1998 and 1999 (OECD, 1998*a*).

Globalisation

The term globalisation refers to the transborder operations undertaken by firms to organise their development, production, sourcing, marketing and financing activities (OECD, 1996*a*). Globalisation is characterised by profound changes in the world-wide organisation of production: increasing and intensified international competition, greatly increased trade and investment, growing co-operation among firms, and new types of interdependence among economic actors. While these changes offer new opportunities, they also present new challenges to firms and policy makers.

A number of factors are enabling and shaping the process of globalisation. Four broad categories can be distinguished, namely: ***firm behaviour*** (firms' strategic decision making regarding location and the need to exploit technological and organisational advantages); ***technology-related factors*** [lower information and communication technology (ICT) and transport costs which enable globalisation, along with the growing need to shorten technology and product cycles and to increase customisation of intermediate and final goods]; ***macroeconomic factors*** (the availability of key production factors, productivity differentials across countries, the increasing integration of international financial markets, the "catch-up" of some developing economies and the emergence of new growth poles); and ***government policy*** (liberalisation of trade and financial flows, regional integration, differences in R&D support policies, support for venture capital, intellectual property rights regimes).

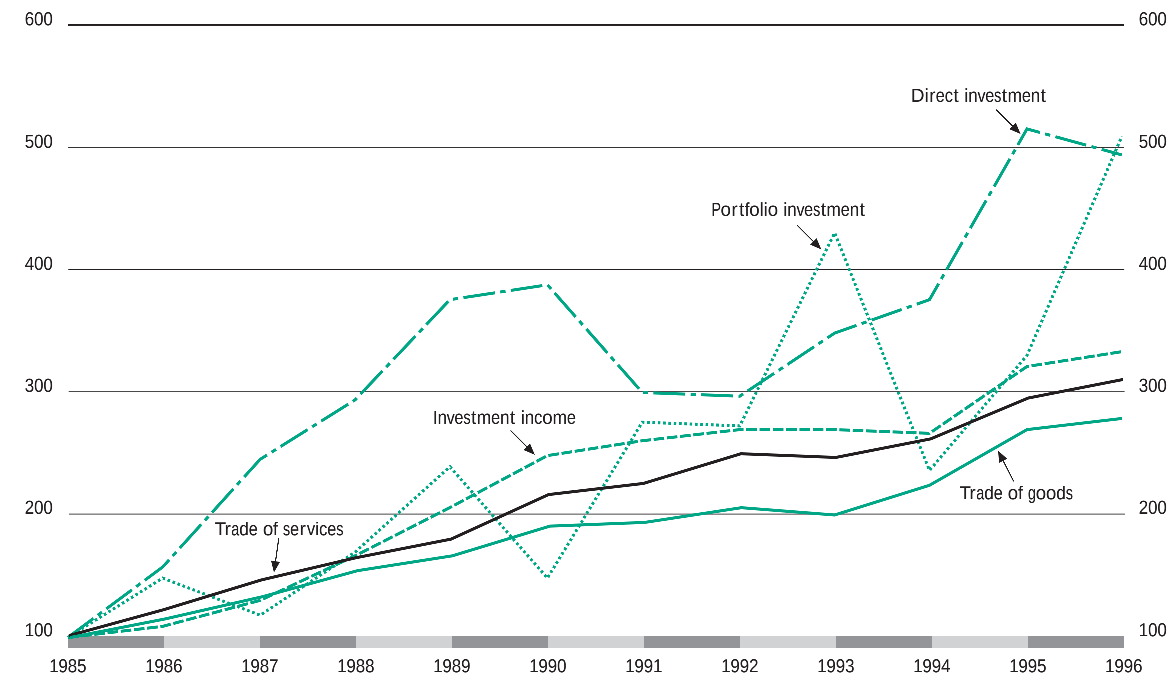
Globalisation is by no means a recent phenomenon. OECD economies are currently experiencing a third wave of internationalisation, following a first period of strong growth of trade, financial and migratory flows before World War I; and a second period of rapid growth after World War II in the 1950s and 1960s, which was characterised by the development of multinational enterprises and foreign direct investment (FDI). The most visible features of the globalisation process are trade, FDI, and strategic international interfirm alliances, although these activities appear to be taking place largely within the OECD area.

World trade has continued to grow at a faster pace than world output since the early 1970s: the growth rate of world merchandise trade was over four times that of world output in 1995. OECD trade still mainly takes place within the OECD area: non-OECD countries accounted for about one-fourth of OECD trade in 1995, versus almost 30 per cent in the late 1970s. Intra-regional trade continues to expand, both within the OECD area and in non-OECD countries: in 1995, it accounted for 46 per cent of exports in North America, 62 per cent in the European Union, and 75 per cent in the OECD area as a whole.

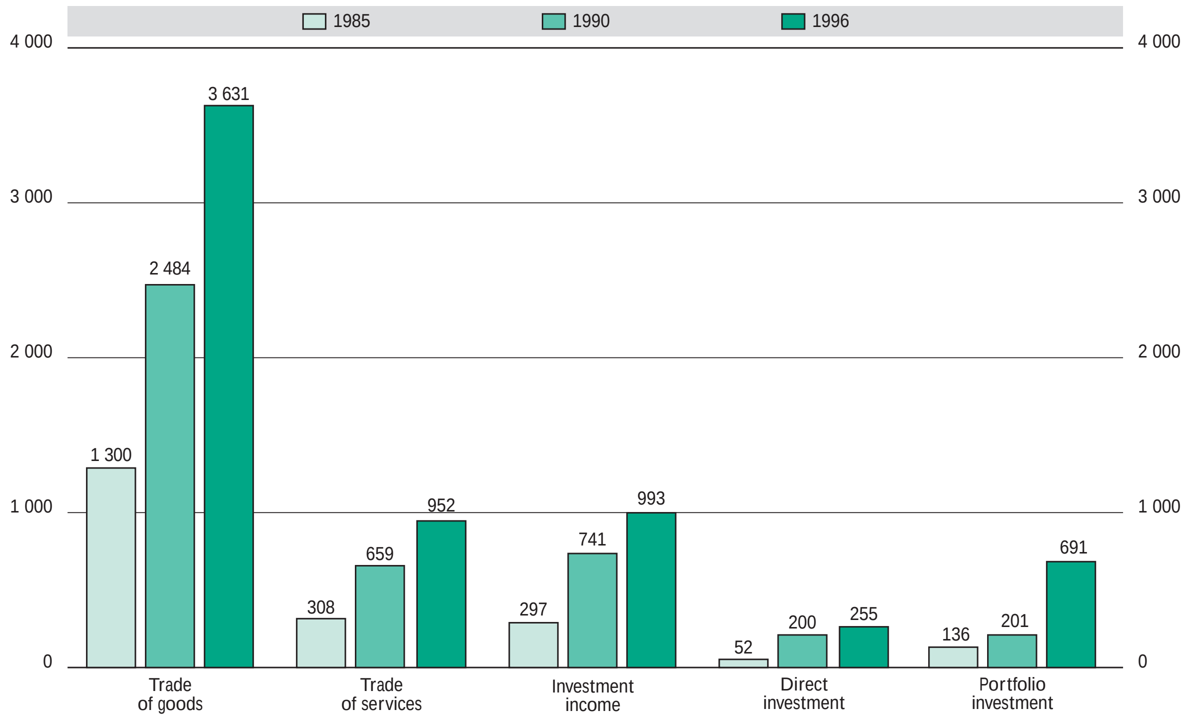
Intra-industry trade has continued to grow strongly. It accounts for more than half of all trade in most OECD countries and for between half and three-quarters of total trade among large European countries. This trade pattern reflects growing product differentiation, the relative similarity of industrial structures in certain OECD countries, and the growing importance of manufactured intermediary inputs (particularly in technology-intensive assembly industries). Although the data are less complete, intra-firm trade also represents an increasing portion of total OECD trade: between 1983 and 1992, it accounted for about 43 per cent of all US-European and 71 per cent of all US-Japanese merchandise trade (OECD, 1996*a*).

Financial transactions (direct investment, investment income, and portfolio investment) are growing faster than trade, however (Figure 2.2). While trade continues to play a dominant role, its structure

◆ Figure 2.2*a*. ***Trends in the main components of international transactions***
Index: 1985 = 100

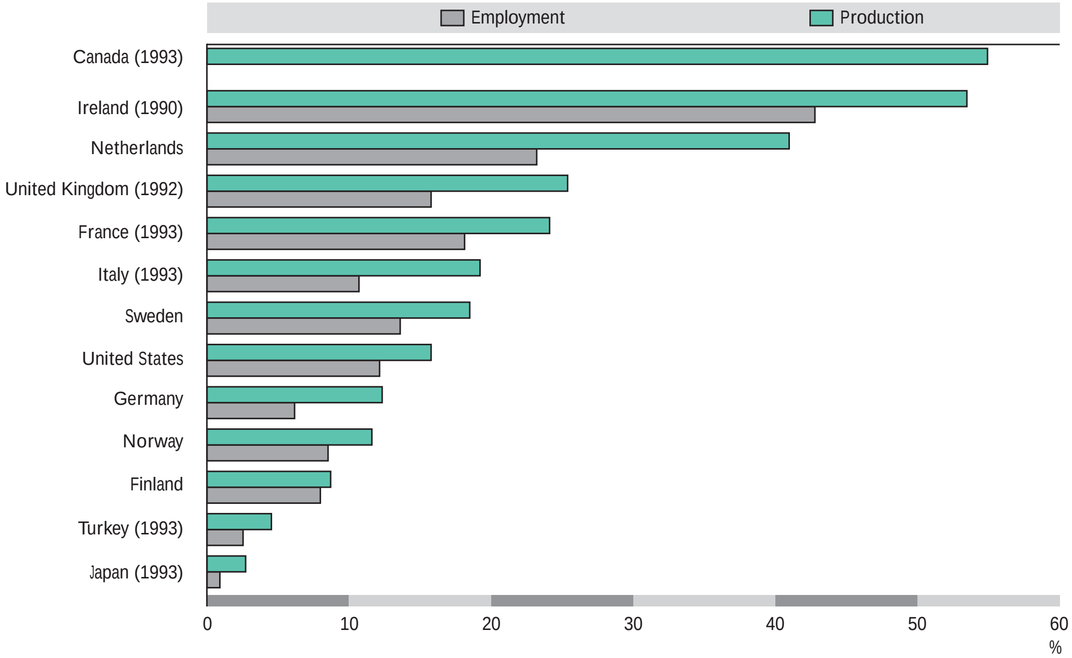


◆ Figure 2.2*b*. ***Value of the main components of international transactions, total OECD***
US$ billions



Source: OECD, Balance of Payments database, December 1997.

◆ Figure 2.3. ***Share of foreign affiliates in manufacturing production and employment, 1994***



Source: OECD, AFA database, December 1997.

has changed. Services account for a rising share of international trade, as do high-technology products in total trade in manufactured goods.

The increasing integration of the international financial system is evident in the rapid expansion of foreign exchange markets: by April 1995, daily average foreign exchange turnover (spot, forward, and swap markets) had reached about US$1.6 trillion (OECD, 1997*f*). Borrowing by OECD countries on international capital markets tripled from around US$20 billion in 1986 (monthly average) to over US$60 billion ten years later. Non-OECD countries continue to be minor recipients of these funds (less than US$10 billion in 1996).

Globalisation and technological change are closely linked: countries that are now exposed to intensified global competition are taking advantage of their increasing technological specialisation. Although a distinction must be made between globalisation of product markets (driven by trade and FDI) and that of factor markets (financial markets, labour markets, technology), it appears that the globalisation process increases the impact of nation-specific factors on competitiveness, while also magnifying the international division of labour. Firms increasingly seek optimal locations for their production activities and for greater efficiency, so as to allow them to build or sustain a competitive position in both domestic and foreign markets. OECD data show that although employment in foreign affiliates remained relatively stable throughout the early 1990s, value added by these firms, and especially their R&D expenditure, have continued to grow. The share of foreign affiliates in manufacturing production and employment is now quite substantial in several OECD economies (Figure 2.3).

Technological change

Technology plays a central role in shaping economic performance and is generally regarded as a main determinant of economic growth (see Chapters 4 and 5). New technologies contribute to productivity change, have led to many new and improved products, allow better and closer links between firms, can help to improve information flows and the organisation of production, and are an important driver of structural change (OECD, 1996*b*; 1997*g*; also see Chapter 1). It is also increasingly recognised that knowledge plays a crucial role in economic processes. As investments in various type of knowledge and technology increase, the OECD area is undergoing a shift to a knowledge-based economy (see below). The increasing use of ICTs is at the heart of this shift, as they greatly facilitate the generation, transmission and exploitation of knowledge.

Several studies have demonstrated the positive effect of technological change on productivity. Aggregate studies generally find that R&D expenditures provide a positive contribution to productivity growth but also that technology diffusion from other industries is a major source of productivity gains. Increasingly, modern technology imported from abroad helps drive productivity growth (OECD, 1996*a*). Recent studies of firm-level and sectoral performance also indicate the key role of technology in enhancing productivity (see Chapters 4 and 5).

Technological change and productivity gains are generally accompanied by changes in skill requirements. During the 1980s, employment of high-skilled workers increased faster than that of low-skilled workers in most OECD countries (see below). White-collar, high-skill jobs grew fastest, followed by white-collar low-skill occupations, while jobs in the blue-collar category declined in most countries. The upskilling trend is closely linked to technological change. Industries that have invested more in research and perform more innovative activity also tend to acquire more human capital. Firm-level studies also provide evidence of technological advance and skill upgrading (see Chapters 4 and 5).

Technological change is not only associated with changes in skill requirements, but also with organisational changes in the innovative firm or industry. The successful introduction of new technologies often depends on new work practices, such as the adoption of work teams, multiskilling and job rotation, quality circles, just-in-time production practices, increased autonomy and responsibility of work groups, and flatter hierarchies. Organisational change is in some cases a prerequisite for adopting advanced technology. New technologies, particularly ICTs, also change the range of goods and services that firms produce, their specialisation pattern, and their links with other firms. Industrial enterprises that reorganise their production process often adopt advanced manufacturing technology, while organisational changes such as the introduction of horizontal management structures, worker autonomy and just-in-time delivery are closely linked to the introduction of advanced technologies (OECD, 1996*b*).

There is also empirical evidence that organisational change contributes to productivity gains. Organisational change is associated not only with the introduction of new technology, but also with higher skills and training. A study of the United States demonstrated strong links between new work practices and the incidence of training, and suggested that investments in human capital had positive effects on productivity (Lynch and Black, 1995). Organisational change was also an important factor in enabling productivity gains and restructuring in several mature industries in the OECD area (see Chapter 5). For example, the "lean system" in the motor vehicle industry involves many new work practices, including multiskilling and increased training.

The use of information technology (IT) is also closely associated with organisational change. A recent study analysing the relationship between organisational practices, IT use and productivity for 273 large firms found that greater IT use is associated with greater use of self-management teams, more investment in human capital, and increased use of worker' incentives. The study found that adoption of new work practices led to improved productivity from investments in information systems (Brynjolfsson and Hitt, 1996). Technological change alone, therefore, cannot bring about productivity gains. However, when it is accompanied by organisational change, training, and upgrading of skills, *i.e.* when the new technologies are thoroughly "learned", it can contribute to significant productivity gains.

The diffusion of technological change is just as important as R&D and innovation to economic growth. A recent OECD study (Sakurai *et al.*, 1996) examined the relationship between R&D, technology diffusion, and productivity growth for ten OECD countries by assuming that industry purchases of intermediate and capital inputs (embodied R&D) acted as carriers of technology. It concluded that technology diffusion contributed substantially to total factor productivity (TFP) growth, that its contribution typically exceeded that of direct R&D efforts, and that technology diffusion had a much greater impact on TFP growth in the 1980s than in the 1970s.

The role of firm behaviour

The behaviour of individual firms is increasingly a key to performance. Traditional analysis of aggregate economic trends is based on the assumption that firms respond in the same way to external forces. Firm-level analysis of firm-level databases indicates that this assumption is false and may obscure important firm-level microeconomic processes. An understanding of these processes is increasingly needed in order to understand aggregate performance trends and to derive policy conclusions that reflect the insights gained at the firm level.

The analysis of longitudinal databases covering individual firms powerfully demonstrates this point. These databases have been used for several types of statistical analysis, but primarily for work on productivity (see Chapter 4). They have also been used for investment analysis (Caballero *et al.*, 1995) and for work on job creation and destruction (OECD, 1994*a*; Davis *et al.*, 1996; Caballero *et al.*, 1997), on technology and wages (Doms *et al.*, 1997), and on the dynamics of internationalisation of firms (Andersson *et al.*, 1996). An important general observation that can be drawn from the work on longitudinal data is the enormous diversity of firms' experience within one industry. Firms appear to react very differently to aggregate shocks, and this suggests that aggregate trends drawn from industry-level data may fail to give a proper understanding of behaviour and that an analysis of microeconomic patterns may be required to understand changes in macroeconomic patterns.

Analysis of these micro-level databases provides a number of important insights (see Chapter 4). First, it shows that competitive effects, such as the exit and entry of firms and changes in market shares, make an important contribution to productivity growth. This effect cannot be demonstrated at the aggregate level, but it has important policy implications. Second, it shows that productivity growth is almost equally due to upsizing (firms adding employment) as to downsizing (firms shedding employment). This insight cannot be derived from aggregate data and goes against the popular view that productivity growth is primarily driven by downsizing. Third, longitudinal analysis indicates that small and medium-sized enterprises (SMEs) are a dynamic component of the economy, because the entry and exit of firms and the process of creative destruction drive changes in performance.

All three processes indicate the importance of turnover for individual firms. They also show that intra-industry dynamics contribute significantly to performance. Technology-driven policies to enhance productivity growth within firms might therefore have to be embedded in a competitive framework in which a process of "creative destruction" enables entry and exit, the growth of successful firms, and the failure of unsuccessful ones. Policies that unduly restrict this process risk lowering productivity growth.

Work with microeconomic data also raises new questions. Principal among them is why firm (or plant) behaviour is so diverse, *i.e.* why some firms do so well and why others fail. Some recent OECD work focuses on the role of individual firms in improving performance, particularly with regard to innovation and technical change (OECD, 1998*c*). It appears that a flexible organisation of the workplace may be an important determinant of a firm's success. Flexible firms appear better able to adapt and to enhance the contribution of intangible assets, such as workers' skills, to firms' performance.

Processes at the firm level are also important to the growing role of national innovation systems and industrial clusters in driving industrial and innovative performance. Analysis in these areas indicates that co-operation and knowledge flows among firms increasingly drive performance. This type of analysis is quite distinct from traditional analysis based on aggregate trends and is contributing to important new policy insights, such as the shift in emphasis from market failures to "systemic failures".[2] In sum, firm-level analysis is becoming an increasingly important complement to traditional analysis of aggregate trends.

INDUSTRIAL PERFORMANCE AND COMPETITIVENESS[3]

Industrial performance in the OECD area exhibits great dynamism: the structure of OECD economies continues to move towards services and knowledge-based industries; investment in physical capital remains important, but the role of intangible investment in R&D, training and information is increasing; the greater role of knowledge has contributed to the upskilling of workers; productivity continues to increase, enabling cost reductions in several sectors; OECD economies are becoming ever more influenced by global patterns; and SMEs continue to play a crucial role in the process of creative destruction.

Output patterns and structural change

The higher pace of growth in the OECD area is reflected in increased growth in ***manufacturing production*** (Figure 2.4). In 1997, manufacturing grew more rapidly than in 1996 in a substantial number of countries, including Canada, the United States, and almost all European countries for which data are available. Manufacturing production increased by over 10 per cent in Ireland, Luxembourg, Mexico, Sweden and Turkey. The only countries that experienced a slowdown in manufacturing production growth over 1997 are Australia and Japan, with production falling in Japan.

Sectoral growth patterns also demonstrate the growing contribution of services to economy-wide growth (Figure 2.5). Between 1985 and 1994, over two-thirds of GDP growth in the OECD business sector – and up to three-quarters in some areas – resulted from growth in the services sector (OECD, 1996*c*; 1998*b*). In the United States and Japan, finance, insurance and business services were the largest contributor to total growth of business sector value added, closely trailed by manufacturing. In Europe, social and personal services provided the largest contribution to growth, closely followed by finance, insurance and business services.

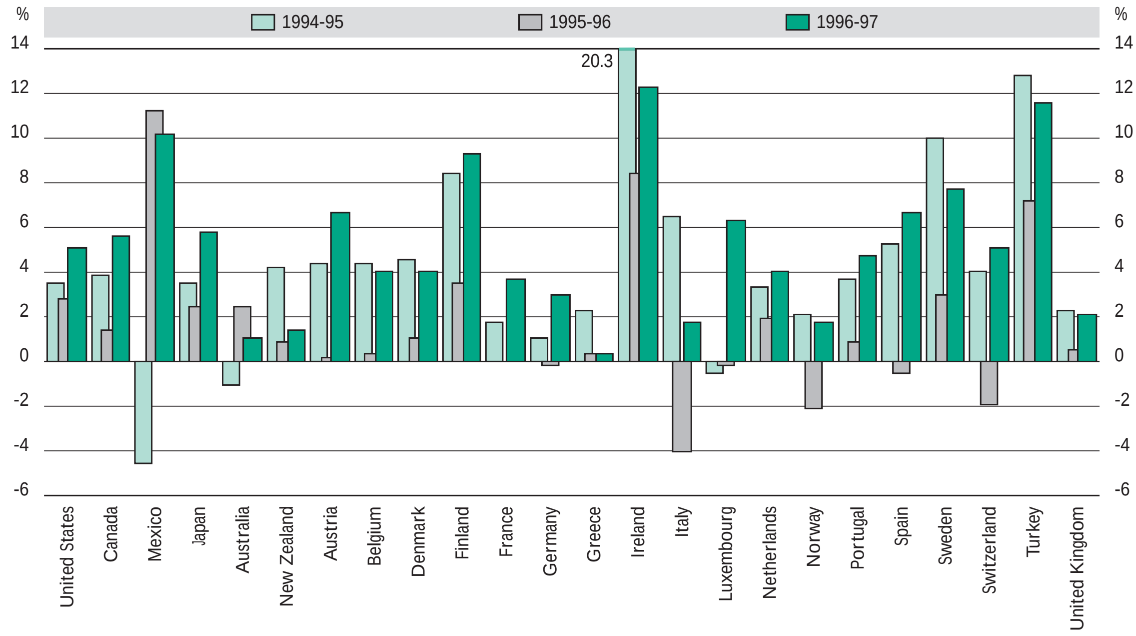
As a consequence of the rapid growth in services, the ***economic structure*** of OECD economies continues to shift towards services.[4] The services sector now accounts for over 60 per cent of GDP in the business sector of the main OECD areas, with the highest share in the United States. The structure of the services sector is changing, too. The shares of finance, insurance, real estate and business services and of community, social and personal services have increased over time, while those of wholesale, retail trade, restaurants and hotels and of transport, storage and communication have declined somewhat.

Within OECD-area manufacturing, structural shifts are also observed. High- and medium-high technology industries are gradually increasing their share in manufacturing at the expense of medium-low and low-technology sectors.[5] The share of the high- and medium-high-technology industries in total manufacturing is particularly large in Germany, Japan, and the United States – at over 45 per cent of total value added – and is also quite high in Canada, France, Sweden and the United Kingdom. The high-technology sectors typically account for only 10-15 per cent of total manufacturing value added.

Although OECD-wide patterns of structural change can be observed, OECD economies differ substantially in their sectoral structure (OECD, 1998*b*). For instance, Greece, Korea and New Zealand have relatively large agricultural sectors; Norway has a large mining sector; Finland, Germany, Korea and Sweden have relatively large manufacturing sectors; and Australia, Greece and Norway have relatively small manufacturing sectors. The share of services also differs substantially across countries: in Korea, services accounted for less than 45 per cent of business sector value added in 1995, while in Australia, Mexico and the United States they accounted for more than 65 per cent.

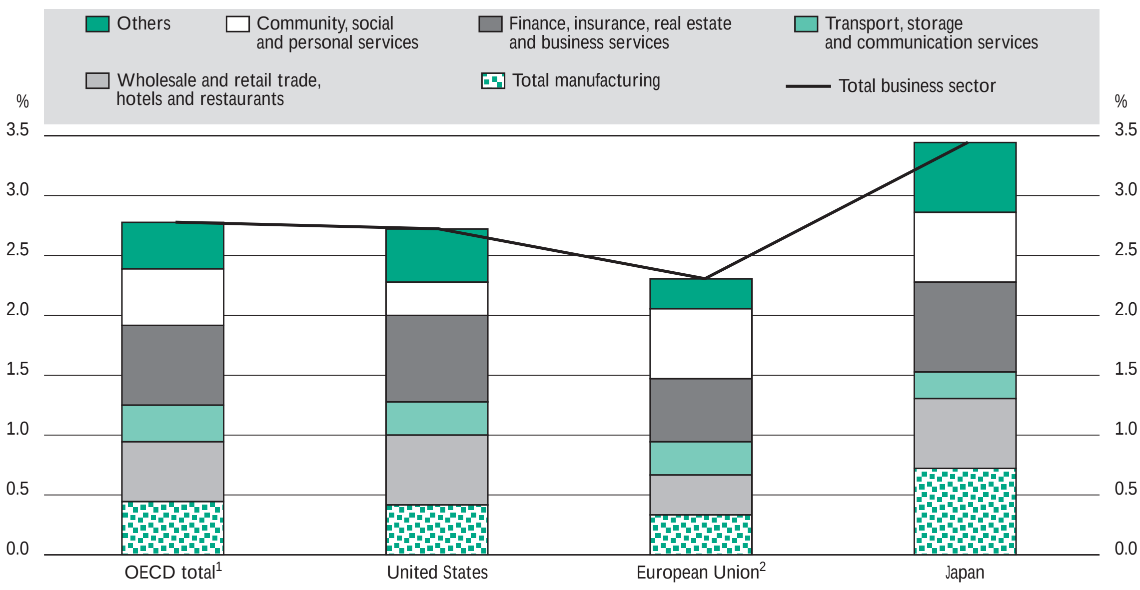
Structural change in the economy also reflects the increasing importance of the production, dissemination and use of technology and information. The pace of change differs from country to country, owing to economic, social or institutional factors, but broadly points to the emergence of a ***knowledge-based economy*** (Figure 2.6). Traditional knowledge-based sectors such as computers, aerospace, pharmaceuticals and communications equipment only account for a few per cent of total GDP. By including ICT-related services, such as communication services, the share of knowledge-based industries in total business sector value added rises somewhat. However, the main contribution to the growth

◆ Figure 2.4. ***Annual growth in manufacturing production by country***
Percentages



Source: OECD, Indicators of Industrial Activity database, February 1998.

◆ Figure 2.5. ***Contributions to GDP growth***
Average annual percentage change and contributions, 1985-94

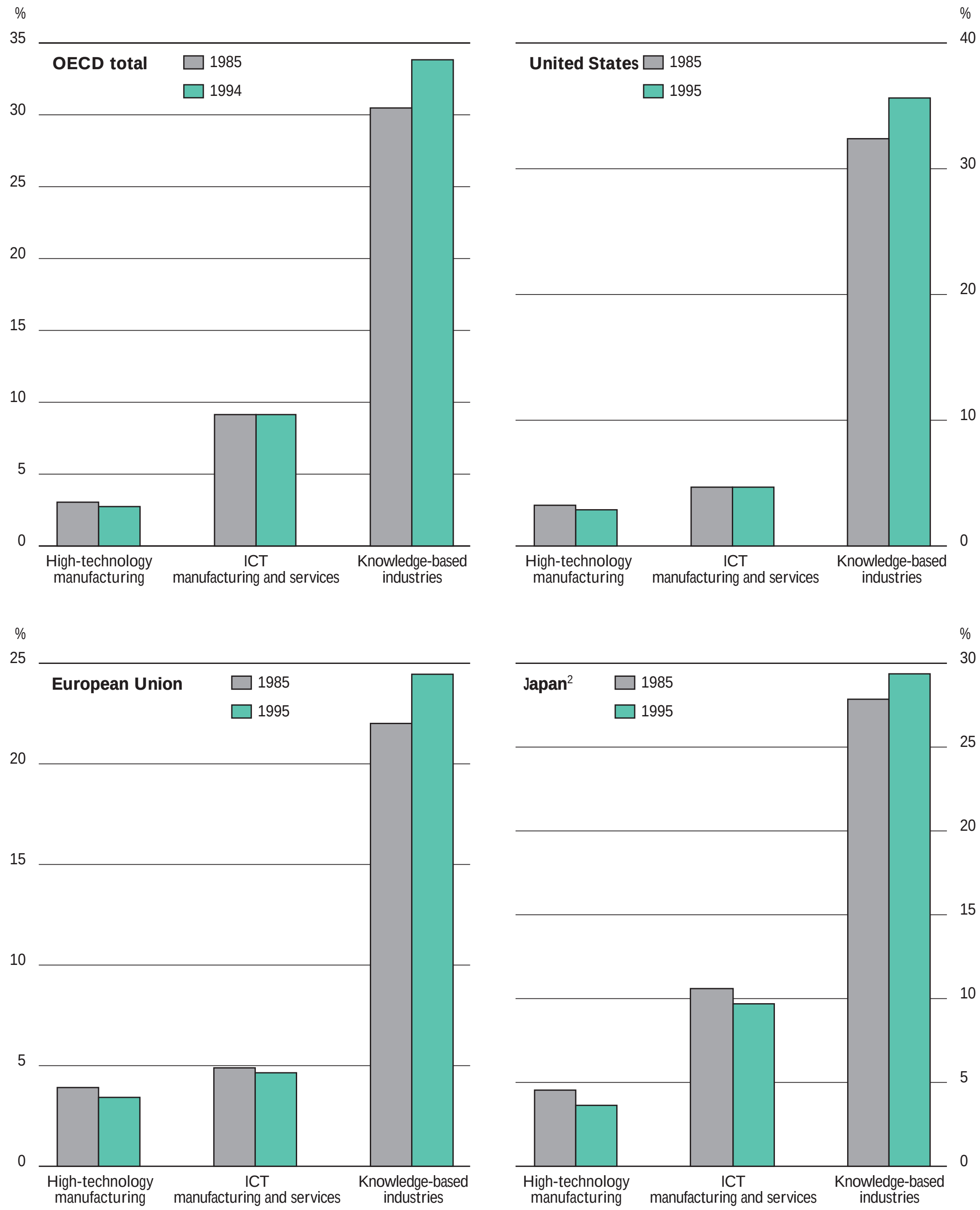


1. OECD excludes Czech Republic, Hungary, Iceland, Ireland, Korea, Luxembourg, Poland, Switzerland.
2. Europan Union excludes Ireland and Luxembourg.

Source: OECD, STAN, ANA and ISDB databases, December 1997.

◆ Figure 2.6. ***The emergence of knowledge-based industries***[1]

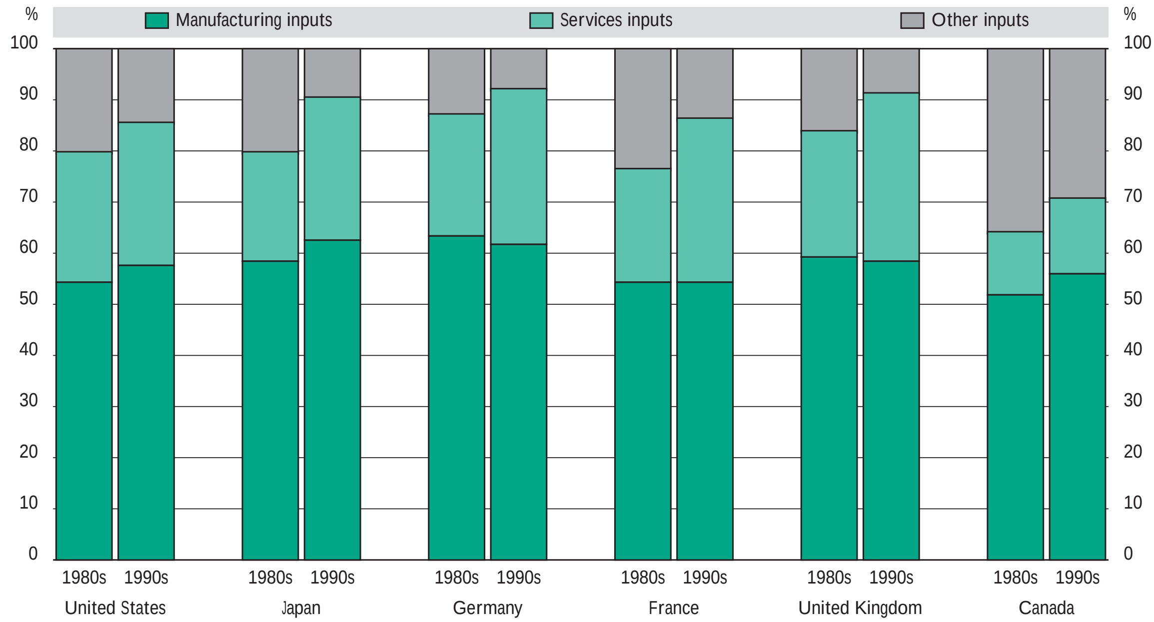
Value added
Share in total business sector



1. Information and communication technology (ICT) manufacturing: office and computing equipment; radio, TV and communication equipment; ICT services: communication services. Knowledge-based industries also incorporate finance, insurance and business services.
2. For Japan, transport and storage activities are included in ICT services.

Source: OECD, STAN and ISDB databases, December 1997.

◆ Figure 2.7. ***Sourcing of inputs in manufacturing in the early 1980s and 1990s***
As a percentage of total intermediate inputs



Source: OECD, STAN and Input-Output databases, December 1997.

of knowledge-based industries is made by finance, insurance and business services. This broad definition accounts for almost 35 per cent of business sector value added, a share that has grown considerably over the past years. A major characteristic of the transition to a knowledge-based economy is that output is growing fastest in the manufacturing and services sectors that develop and use technology most intensively and have the highest skill requirements.

Efficient ***interaction between manufacturing and services*** is becoming a key feature of firm performance. It is evident in the growing importance of business services, but also in the sourcing of inputs (Figure 2.7). In both manufacturing and services, firms have increased their sourcing of service inputs. The role of manufacturing inputs in services has declined over time, but has remained relatively stable in the manufacturing sector itself. The increased role of service inputs may be linked to several processes, including increased outsourcing of activities such as cleaning, catering, computer and business services, and also to the growing role of intangible investment in production and the associated increase in demand for intangibles, such as information, skills and R&D.

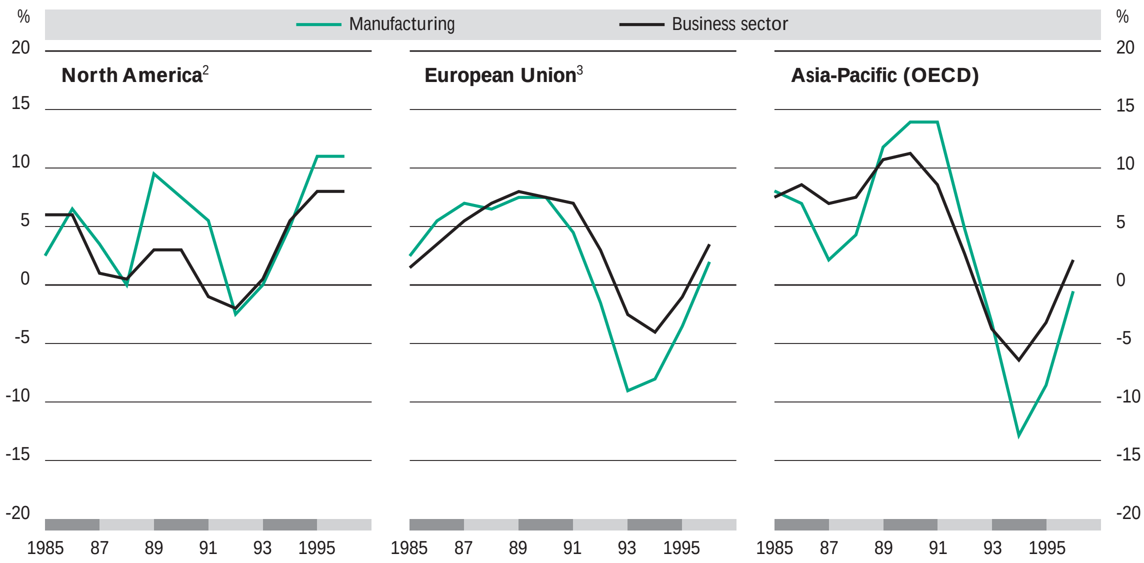
Investment

Investment is the primary way to increase and improve production capacity and is therefore an important determinant of growth and competitiveness. The nature of investment has changed somewhat over time: investment in intangibles has become more important; investment in ICT and innovative firms has increased; and investment patterns increasingly take on a global character.

In many countries, investment declined in the early 1990s after rising rapidly in the late 1980s. However, investment in the OECD area picked up considerably over 1996 and 1997, rising by almost 6 per cent in 1996 and by just over 4 per cent in 1997 (Figure 2.1; Figure 2.8). Investment growth in 1996 and 1997 was especially buoyant in North America, although a number of smaller OECD economies,

◆ Figure 2.8. ***Gross fixed capital formation by zone***

Percentage change from preceding year[1]

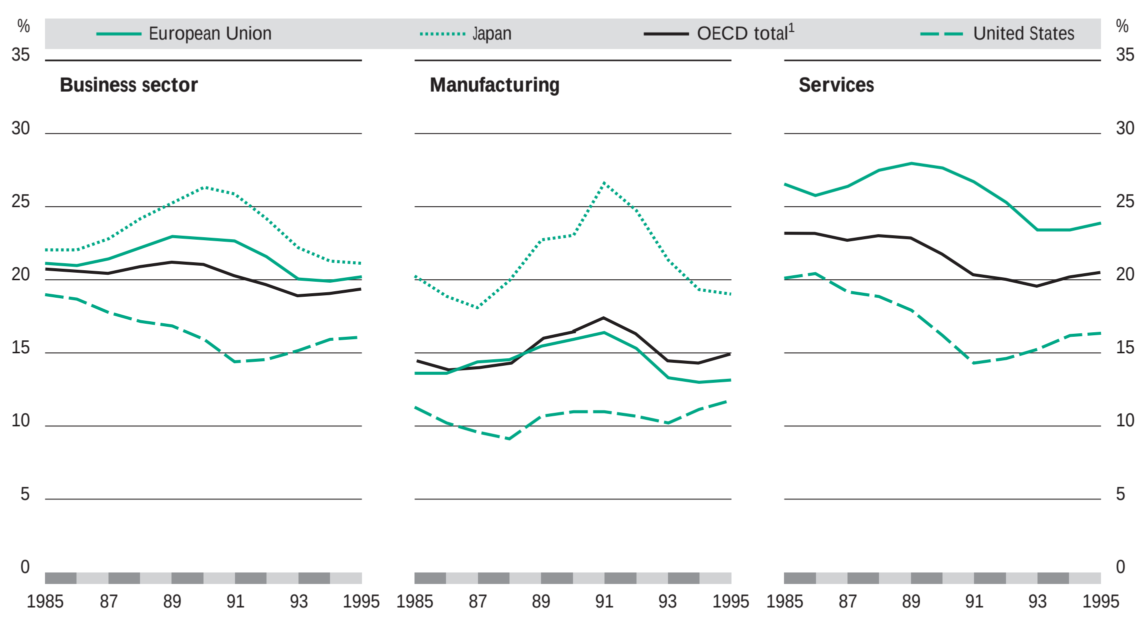


1. Three-year, left-sided moving average.
2. Excludes Mexico.
3. Excludes Ireland, Luxembourg and Portugal.

Source: OECD calculations from STAN and Economic Outlook databases, March 1997.

◆ Figure 2.9. ***Investment intensities in manufacturing and services***

Gross fixed capital formation as a percentage of sectoral value added



1. OECD total excludes Japan.

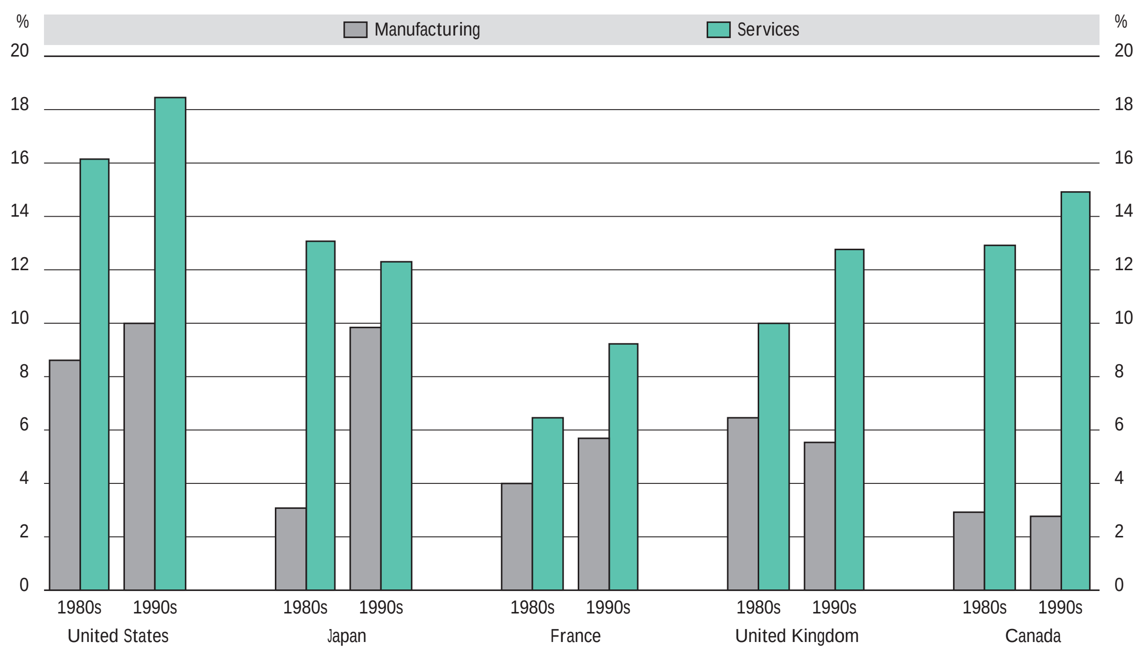
Source: OECD, ISDB database, December 1997.

including Australia, Denmark, Finland, Greece, Hungary, Iceland, Ireland, the Netherlands, Norway, Poland, Portugal and Turkey, also experienced strong investment growth. On the other hand, investment in other parts of the OECD remained subdued or fell over 1996 and 1997. The volume of investment fell in 1997 in Italy, Japan, Korea and Switzerland, and remained stable in France, Germany and Sweden. As a consequence, investment activity in the EU area remained weak over 1996 and 1997, growing by only 1.2 per cent and 2.4 per cent, respectively. Investment cycles in manufacturing closely reflect patterns in total investment, although manufacturing investment tends to be slightly more cyclical than investment in services.

Investment can take many forms, and intangible investment, in research and training especially, plays an increasingly important role in knowledge-based economies.[6] Physical capital investment, in buildings or equipment, continues to account for the bulk of investment. The ***intensity of physical investment*** differs considerably across the OECD area (Figure 2.9).[7] Among the main regions, it is highest in Japan and lowest in the United States. The investment intensity of the OECD business sector has fallen considerably over the past five years, particularly due to a sharp decline in Japanese investment and a more limited decline in the European Union. The investment intensity of the US business sector picked up somewhat over the period 1993-95, although it remains at a low level compared to most other countries in the OECD area. In both Europe and the United States, the services sector has a higher investment intensity than the manufacturing sector.

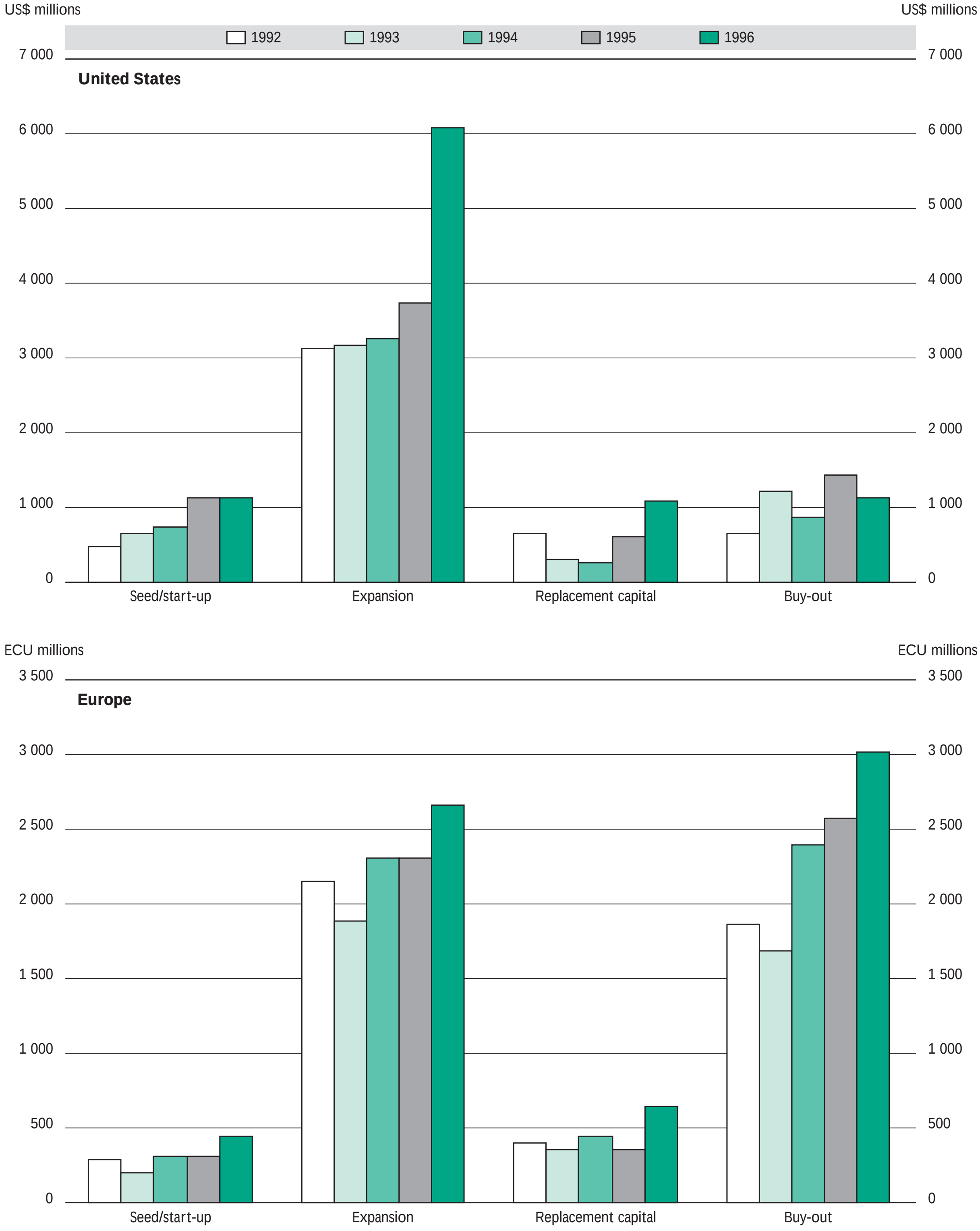
The growing importance of knowledge in the production process and in the structure of OECD economies is reflected in the rapid growth of ***investment in information and communication technologies*** (Figure 2.10). In most OECD economies, the ICT market has grown more rapidly than GDP over the period 1985-95, although growth has levelled off somewhat in parts of the OECD area since 1990. ICT equipment represents a growing share of total OECD business sector investment, although this is

◆ Figure 2.10. ***Investment in information and communication technology***
Percentages of total investment, by sector



Source: OECD, calculations from OECD Input-Output database, March 997.

◆ Figure 2.11. ***Venture capital investment by development stage***[1]



1. Categories of investment are ranked from upstream to downstream stages. Figures in the United States and Europe are not strictly comparable. In particular, the US definition of buy-outs is narrower than the European one.

Source: Venture Economics Investor Services, European Venture Capital Association.

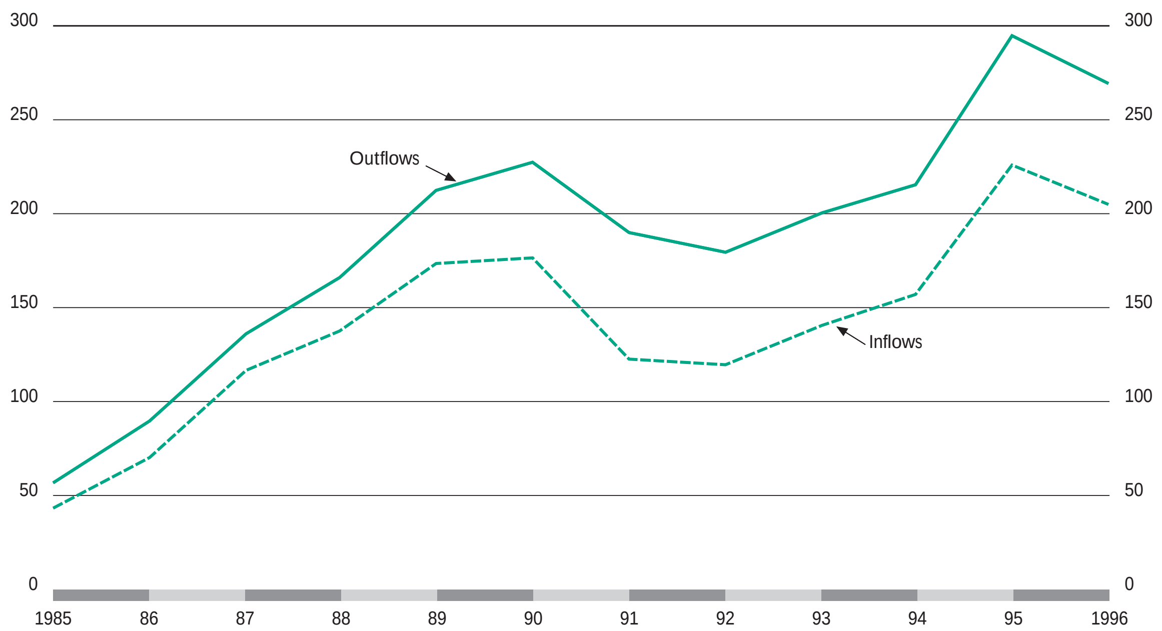
mainly due to rapid growth in the United States. In Europe and Japan, the share of ICT in total investment has remained stable since the early 1990s. ICT investment is more important in services than in manufacturing (OECD, 1998*b*).[8]

Although ***venture capital*** is only a small component of total investment, it plays an important role in stimulating innovation and in the emergence of high-growth firms. Venture capital funding has risen over the past few years (Figure 2.11). In both Europe and the United States, the bulk of investment is directed at the ''expansion'' stage, with only about 10-15 per cent of total funding going to seed and start-up capital. The small share of seed and start-up initiatives in total funding by venture capital partly reflects the low costs of deals at this stage.

There continue to be considerable differences in the maturity of venture capital markets across the OECD area (OECD, 1997*h*). The US market is particularly well developed, with about US$10 billion of venture capital disbursed in 1996. Within Europe, the United Kingdom has the largest market for venture capital, with about US$1 billion raised in 1996, followed by France with almost US$950 million, Germany with just over US$700 million, and the Netherlands with just over US$500 million. There also appear to be considerable differences in the distribution of venture capital across sectors. In Canada and the United States, technology-based firms attract more funding than similar firms in other OECD economies. In 1994, 65 per cent of US venture capital disbursements went to technology-based firms, compared with only 15 per cent in Europe.

Investment is also increasingly taking on a global character. ***Foreign direct investment*** grew rapidly over the period 1992-95, but fell slightly over 1996 from its 1995 peak (Figure 2.12). By 1996, direct inward and outward investment flows in the OECD area amounted to US$198 billion and US$259 billion respectively (OECD, 1997*i*). Although investment in the manufacturing sector has increased more rapidly since 1993-94, most direct inward and outward OECD investment goes to the services sector.

◆ Figure 2.12. ***Total OECD FDI flows, 1985-96***[1]
US$ billions



1. Includes all 29 OECD Member countries for the entire period.
Source: OECD, 1997*i*.

The recent liberalisation of international capital flows has encouraged different kinds of foreign investment, such as greenfield investment, mergers and acquisitions, as well as joint ventures.

The continuing expansion of FDI indicates an intensification of the globalisation process (OECD, 1997*i*). Deregulation, privatisation, and liberalisation of trade and investment barriers have given a strong impetus to FDI growth over the past years. Deregulation has led to a wave of mergers and acquisitions in airlines and telecommunications, while privatisation has often been accompanied by a greater role for foreign shareholders. OECD estimates suggest that the world-wide receipts of privatisation amounted to a record US$88 billion in 1996, of which US$68 billion from OECD countries. A small number of countries account for the bulk of OECD FDI flows (OECD, 1997*i*). In 1996, FDI outflows in excess of US$10 billion occurred in France, Germany, Japan, the Netherlands, the United Kingdom and the United States. The main FDI inflows in 1996 were to Belgium/Luxembourg, France, the United Kingdom and the United States.

Capital flows to developing countries have also increased rapidly during the 1990s, reaching a record high in 1996: annual net private capital flows to these countries averaged almost US$16 billion over the 1983-88 period, US$103 billion over 1989-95, and US$207 billion in 1996 (International Monetary Fund, 1997). Although there has been a recent move towards diversification within the OECD area, the main FDI flows are still between the United States, Japan and the European Union.

Employment and skills

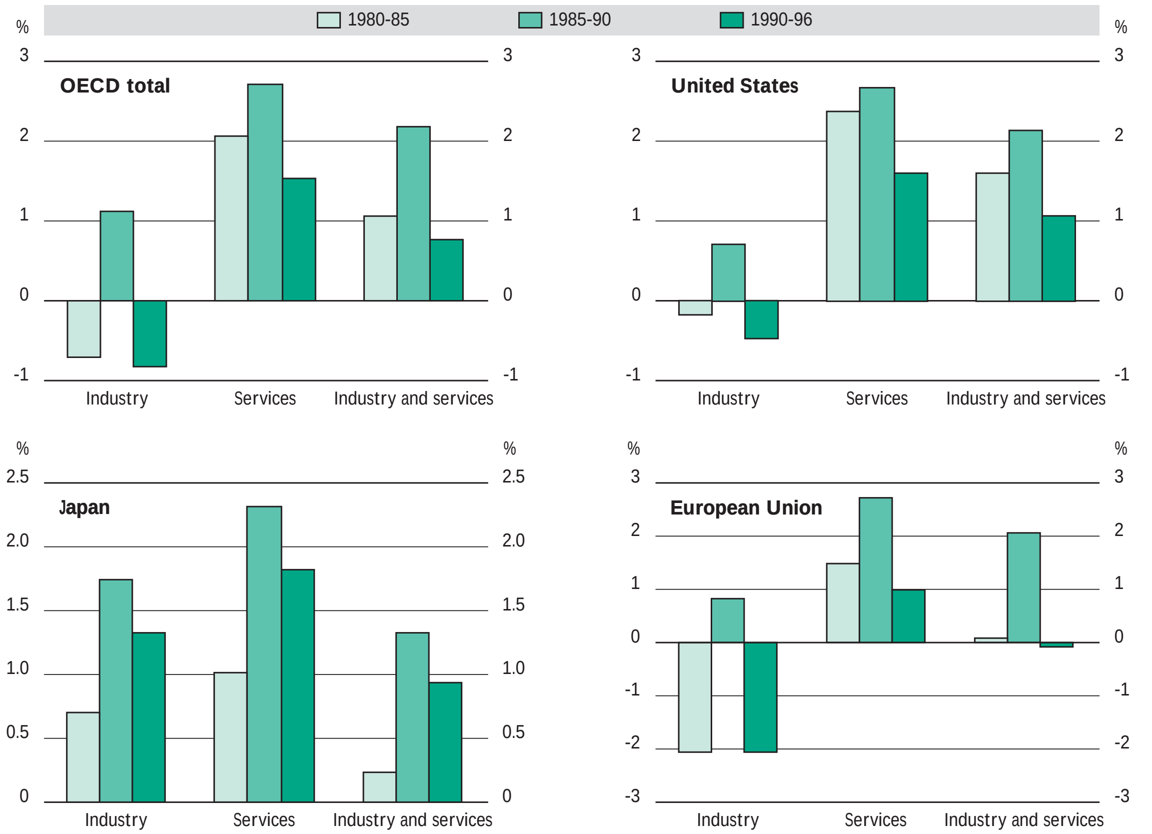
The employment structure of OECD economies is slowly shifting towards the services sector, with an growing emphasis on high-skill work. ***Employment growth*** in the OECD area remains subdued, however. Over the period 1991-97, only six OECD economies – Ireland, Korea, Luxembourg, Mexico, New Zealand and Turkey – registered annual employment growth rates in excess of 2 per cent. In the European Union, employment growth was particularly weak and fell by 0.4 per cent a year over this period. The main contributor to falling employment over this period was the German economy. However, employment also declined over 1991-97 in Belgium, Finland, France, Italy, Portugal, Spain, Sweden and Switzerland, although employment performance has significantly improved in Finland, Portugal and Spain over the past few years. Employment growth tends to be much higher in the non-European than in the European economies. In fact, a large part of the OECD-wide pick-up in employment growth over 1997 can be attributed to improved performance in the United States.

Throughout the OECD area, employment growth is driven by the services sector (Figure 2.13). Over the 1990-96 period, all OECD economies except Norway registered more rapid employment growth in the services sector than in industry.[9] Employment growth in services was particularly buoyant over this period in Mexico, Korea and Ireland, at 7.4 per cent, 5.5 per cent and 4.4 per cent a year, respectively. Growth rates in excess of 3 per cent were also registered in Austria, the Czech Republic, Greece, Iceland and Switzerland. Within services, employment growth has been strongest in community, social and personal services, closely followed by finance, insurance, real estate and business services. OECD-wide employment in wholesale and retail trade and in transport, storage and communication services has been stable since the early 1990s.

Confirming the transition to a services-based economy, employment growth in industry was negative in many OECD economies over the 1990-96 period. Between 1985 and 1995, only Korea and Spain registered significant employment growth in the manufacturing sector. Within manufacturing, the sharpest decline in employment occurred in low-technology industries. High- and medium-high-technology industries have also shed jobs since 1990, but experienced some employment gains over 1995.

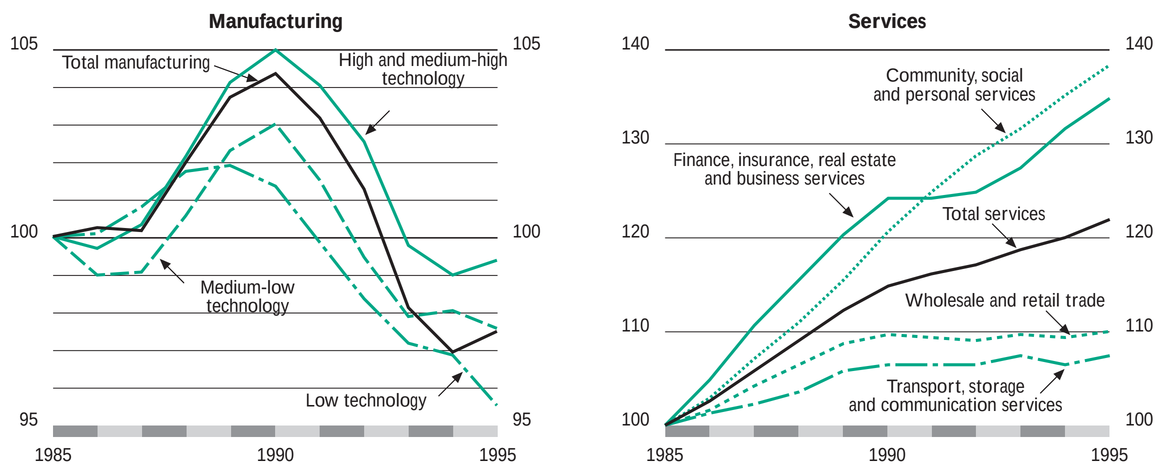
The main ***employment losses*** by industry – in percentage terms – over the 1985-95 period are concentrated in agriculture, mining and manufacturing (Figure 2.14). Within manufacturing, the largest job losses occurred in ferrous metals, shipbuilding, textiles and footwear, and petroleum refining. However, employment also declined considerably in some high-technology manufacturing industries, such as aerospace, computing equipment, and scientific instruments; this may be related to the decline in defence spending in a number of major OECD economies. The greatest job gains – in percentage

◆ Figure 2.13*a*. ***Employment growth in industry and services***[1]
Compound annual growth rates



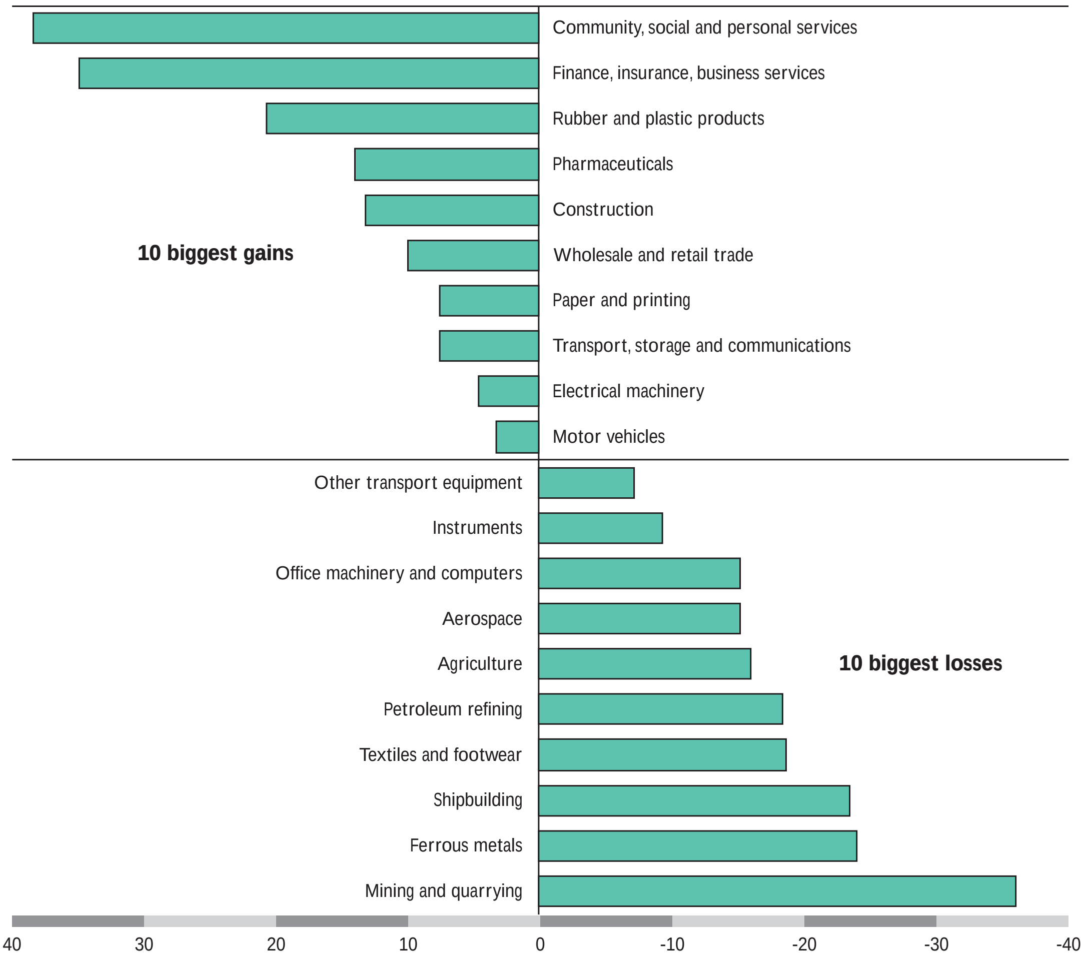
1. Industry covers mining, manufacturing, utilities and construction. Services covers all services, including government.
Source: OECD, *Labour Force Statistics*, December 1997.

◆ Figure 2.13*b*. ***OECD employment trends in manufacturing and services industries***
Index: 1985 = 100



Source: OECD, calculations from STAN and ISDB databases, December 1997.

◆ Figure 2.14. ***Job gains and losses by industry, OECD total***
Percentage change from 1985 to 1995



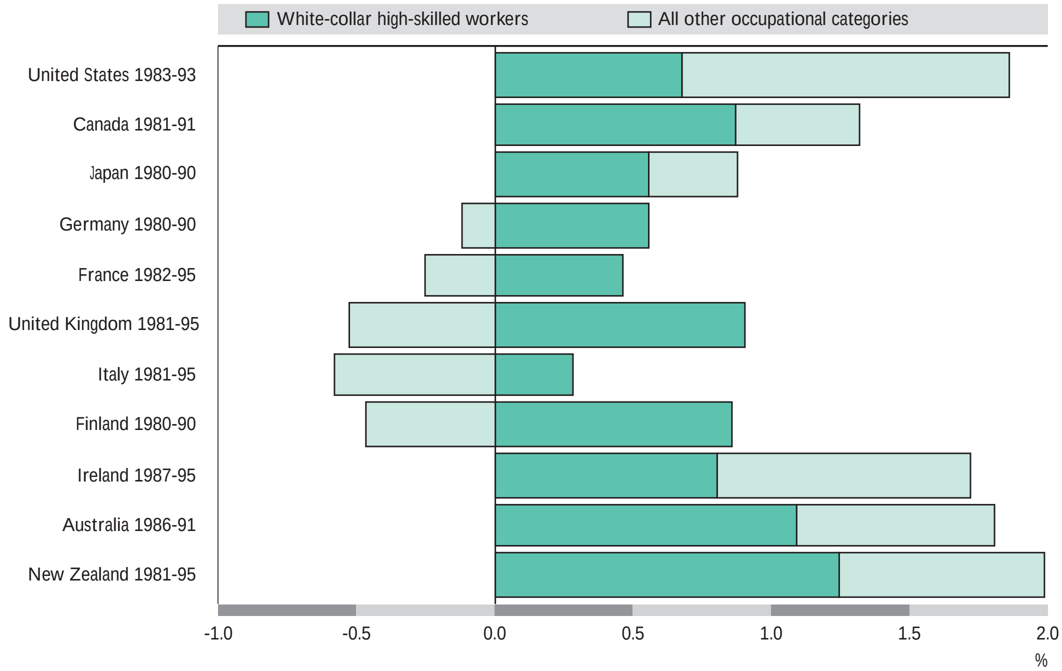
Source: OECD, STAN and ISDB databases, December 1997.

terms – over the same period were made in the two main service sectors mentioned above. However, OECD-wide employment in rubber and plastic products, pharmaceuticals, and construction also rose.

Changing employment patterns are also reflected in the changing ***occupational structure*** of the workforce (Figure 2.15). High-skilled white-collar workers account for an increasing proportion of total employment and made up between 25 per cent and 35 per cent of total employment in the mid-1990s. The bulk of employment growth over the past decade has been in this category. In many European countries, this is the only category that shows an increase in employment. In Australia, Canada, Ireland, Japan, New Zealand and the United States, employment also grew for other occupational categories. In Ireland and the United States, most job gains over the past decade have been in categories other than white-collar high-skill jobs.

The upskilling trend is observed in both manufacturing and services (OECD, 1998*b*). The manufacturing sector typically has a large proportion of blue-collar workers and a relatively small proportion of high-skilled white-collar workers, while the services sector is dominated by white-collar workers and has a large proportion of high-skilled white-collar workers. Current trends indicate a rapid upskilling of the

◆ Figure 2.15. ***Contribution by occupational category to total employment growth***



Source: OECD estimates from national data, International Labour Office and Eurostat.

workforce in both manufacturing and services. Employment for white-collar high-skilled workers is accelerating in finance, insurance and business services, while jobs for white-collar low-skilled workers are expanding rapidly in community, social and personal services.

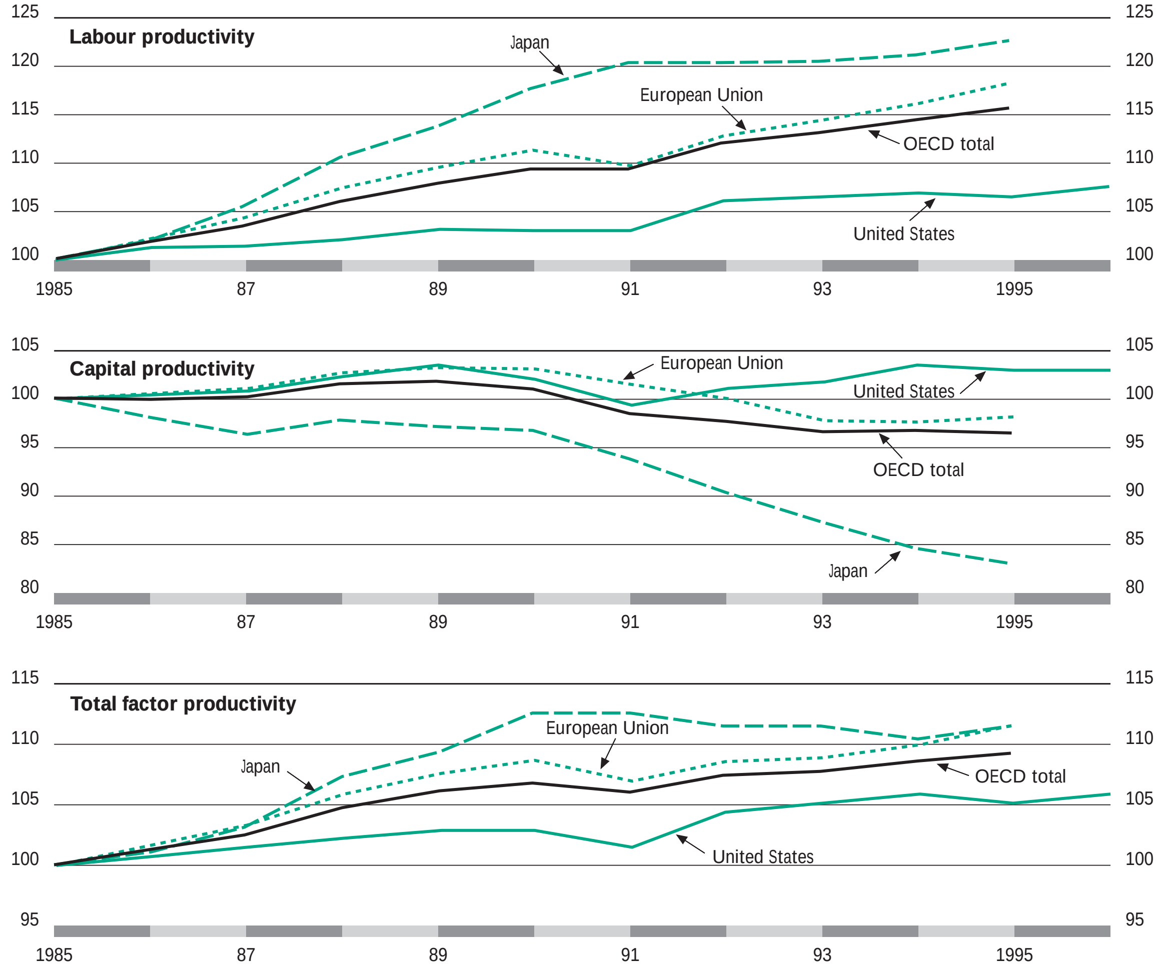
The upskilling of the workforce in OECD economies is reflected in significant ***investment in training*** (OECD, 1998*b*). Spending on training improves workers' skills and therefore their ability to innovate and to use technology-intensive equipment effectively. There is still no satisfactory international measure of spending on training. However, in countries for which figures are available, about half of all skilled workers receive training every year. Furthermore, the share of workers receiving training increases sharply with the level of initial education – workers with a university degree are two or three times more likely to receive training than workers only possessing a lower secondary degree.

Productivity, costs and prices

The industrial performance of OECD economies continues to be characterised by slow productivity growth and limited inflationary and cost pressures. Business sector ***productivity growth*** in several OECD countries rebounded somewhat in the 1980s and early 1990s from a low growth rate in the 1970s (Figure 2.16).[10] OECD-wide labour productivity increased by about 15 per cent between 1985 and 1995, most slowly in the United States. Among the main areas, labour productivity grew most rapidly over the 1985-95 period in Japan but slowed considerably after 1991. In the 1990s, labour productivity improved over the 1980s in Australia, Denmark, Italy, Norway, Portugal and Sweden, but deteriorated in most other OECD countries (see Chapter 4). TFP grew somewhat more slowly than labour productivity over the 1985-95 period, due to falling capital productivity in some parts of the OECD, particularly Japan.

Over the 1985-95 period, labour productivity grew fastest in high- and medium-high-technology industries (OECD, 1998*b*). In the major regions, it grew by between 3 per cent and 4 per cent annually in

◆ Figure 2.16. ***Productivity in the business sector***
Index: 1985 = 100



Source: OECD, 1997*a*.

these segments. In the manufacturing sector as a whole, labour productivity grew faster than in services, reflecting slow productivity growth in many parts of the services sector but also substantial measurement problems (see Chapter 4).

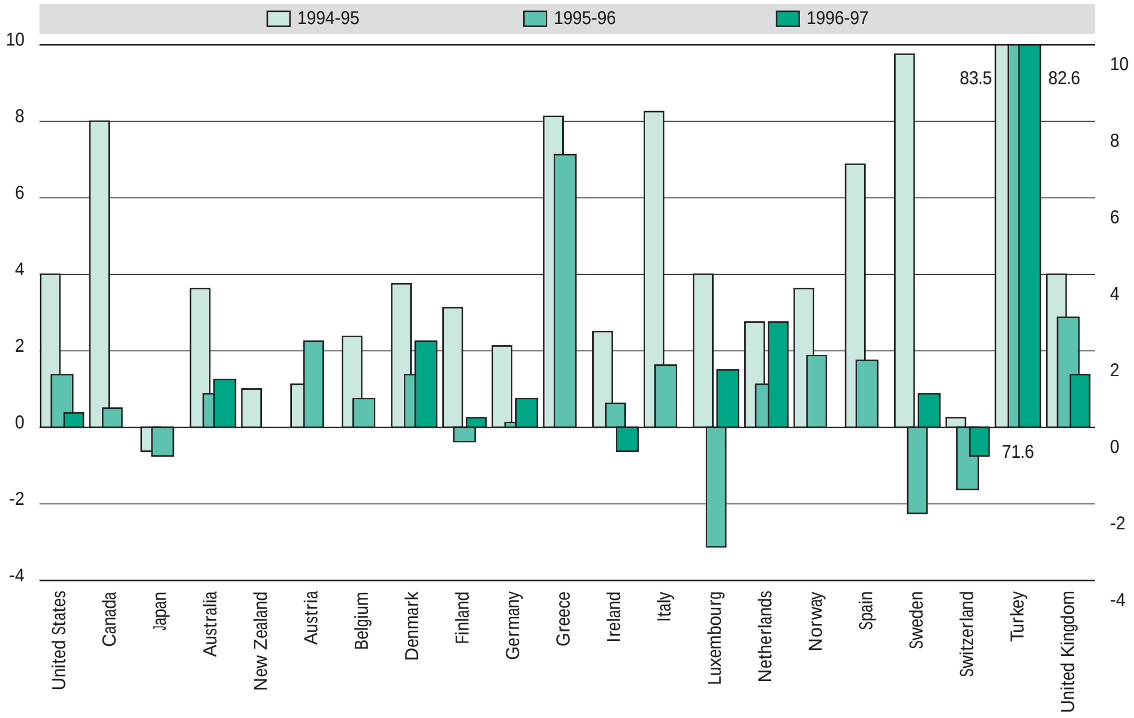
Changes in labour productivity, labour costs and exchange rates determine movements in ***relative unit labour costs*** – the relative cost of labour per unit of output. Changes in relative unit labour costs are a major determinant of countries' competitive position. The past years have seen significant changes in the relative unit labour costs of OECD economies, mainly owing to exchange rate movements. Over the 1993-97 period, relative unit labour costs rose rapidly in Australia, New Zealand and the United Kingdom, and somewhat less in the Scandinavian countries and in Korea, Portugal and Switzerland and the United States (Figure 2.17), while they declined markedly in France, Japan, Mexico, the Netherlands and Spain.

Producer price inflation in the OECD area has become more subdued over the past years (Figure 2.18). The decline in producer price inflation reflects the broader incidence of low inflationary pressures observed in other price indicators. Over 1997, New Zealand and the United States

◆ Figure 2.17. ***Relative unit labour costs in manufacturing, 1990-93 et 1993-97***
Compound annual growth rate in percentages

Source: OECD, 1997*a*.

◆ Figure 2.18. ***Annual growth in manufacturing producer prices by country***
Percentages



Source: OECD, *Indicators of Industrial Activity*, April 1998.

experienced falling producer prices, thereby giving rise to concerns about a possible deflationary environment in some OECD economies, and producer price inflation also fell considerably from 1995 and 1996 levels in a number of other OECD economies, notably Greece, Italy, Norway, Spain and the United Kingdom. Low producer price inflation is partly linked to depressed cyclical conditions in some OECD economies, but it is particularly low in the United Kingdom and the United States, both economies with mature recoveries.

Trade and competitiveness

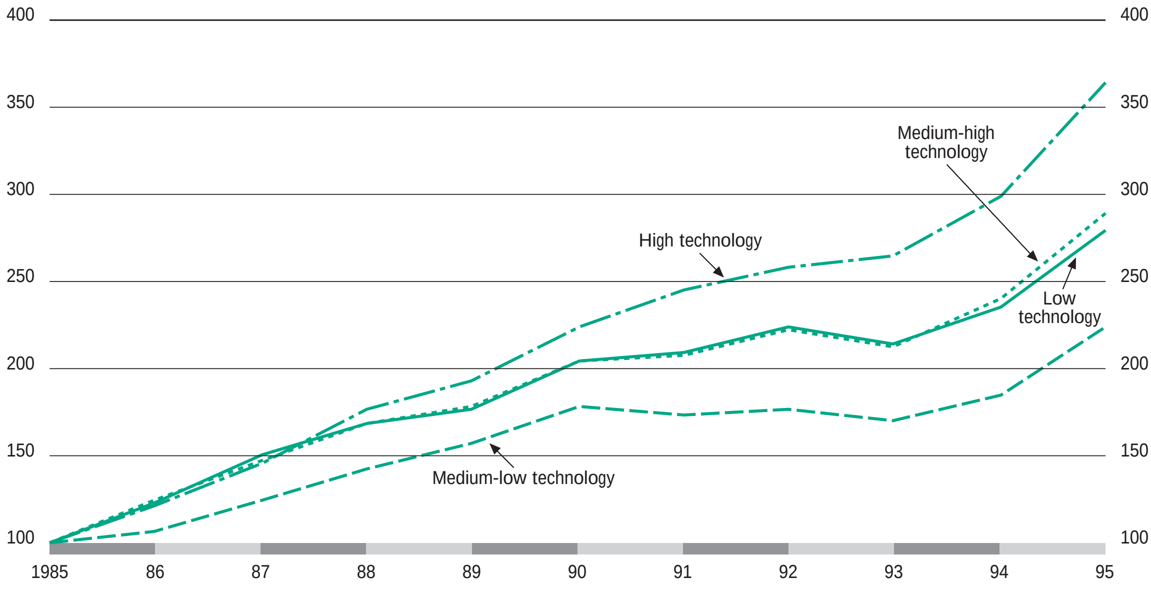
International trade has an increasing impact on developments in OECD economies and is one of the main drivers of the globalisation process (see above). Growth in ***world trade*** picked up significantly from 1996 to 1997, from 6.3 per cent to 9.2 per cent, with manufacturing trade in 1997 rising by over 11 per cent (OECD, 1998*a*). It is mainly driven by intra-OECD trade, which continues to grow faster than trade between the OECD and the non-OECD areas. International trade continues to drive international transactions, although its share is declining relative to that of investment.[11] Trade in goods continues to account for the bulk of international trade (some US$3.6 trillion in 1996); but trade in services is growing faster and accounted for some US$950 billion in 1996 (see above). Within manufacturing trade, high-technology industries registered the fastest growth (exports plus imports) over the past decade, with their share in total manufacturing trade rising to about 18 per cent in 1995 (Figure 2.19). Among the main industry groups, trade grew most slowly in medium-low technology industries.

Over the 1985-95 period, manufacturing export growth was quite similar in the United States, the European Union and Japan. The expansion of high-technology exports was more rapid in the European Union, owing to the rapid expansion of pharmaceutical, aerospace and telecommunications exports (OECD, 1998*b*). Growth in manufacturing imports was more rapid in Japan – though from a low level – than in the United States and the European Union. The growth rate for high-technology imports was generally higher than that of total manufacturing imports.

◆ Figure 2.19. ***Structure of OECD manufacturing trade***

Trends in manufacturing trade[1] by industry groups, OECD total

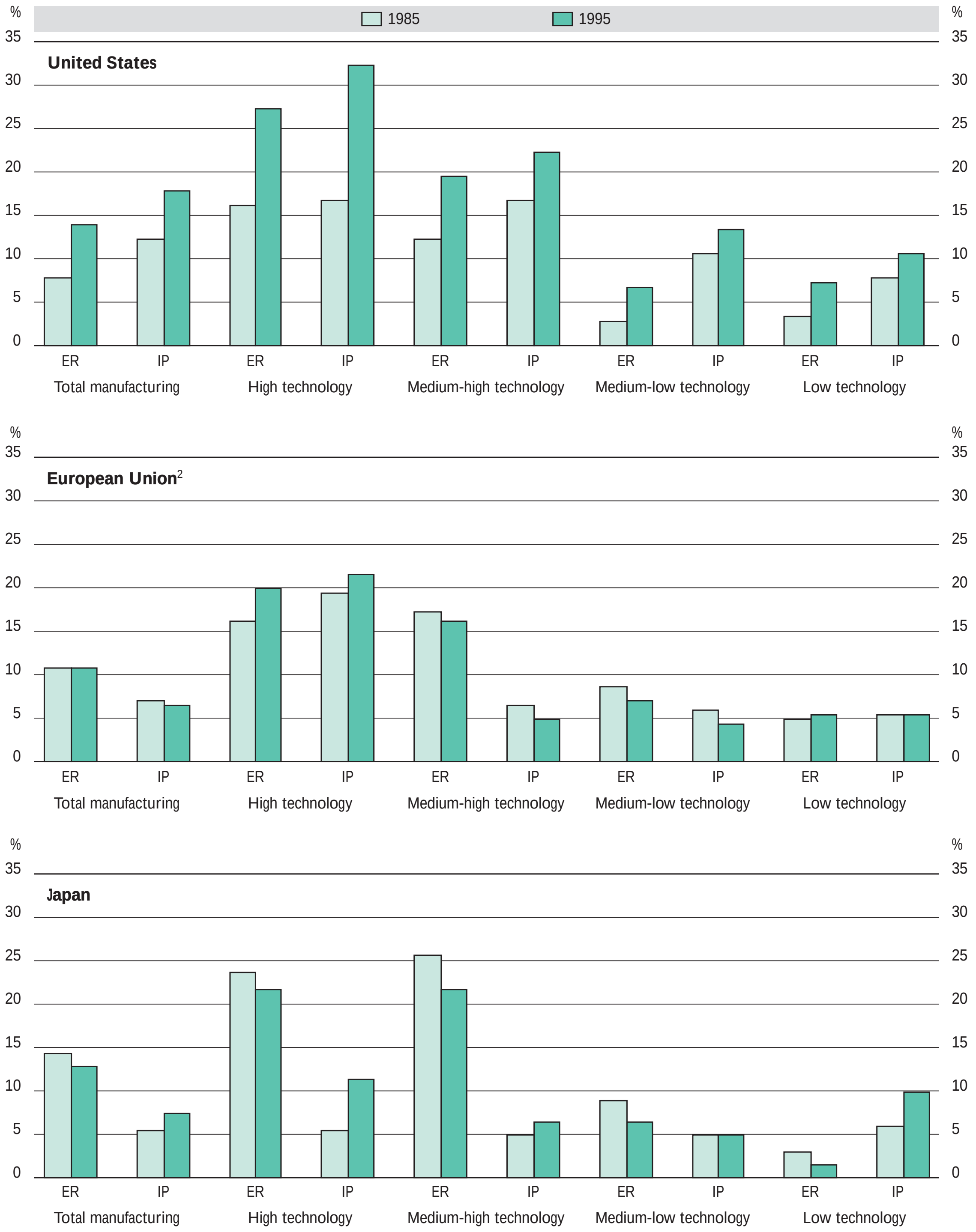
Index: 1985 = 100



1. Sum of exports and imports.

Source: OECD, STAN database, December 1997.

◆ Figure 2.20. ***Export rates and import penetration by type of industry,[1] 1985-95***
Percentages



1. ER: Export rates = exports/production.
   IP: Import penetration = imports/domestic demand.
2. Excluding intra-European Union trade.

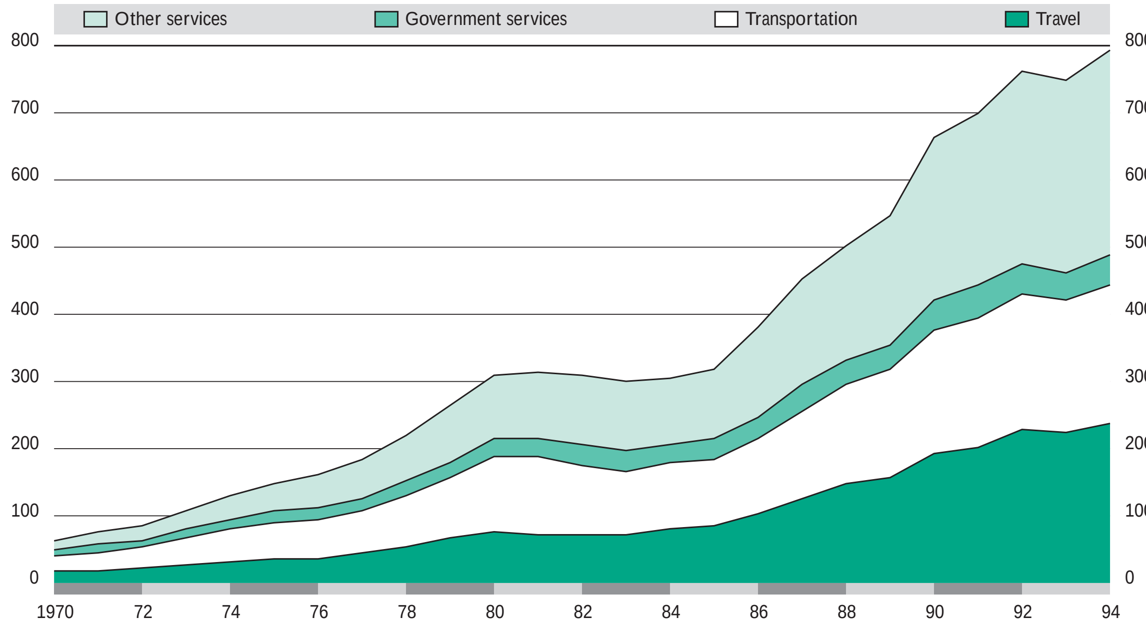
Source: OECD, Main Industrial Indicators database, December 1997.

The ***export market shares*** of the main OECD areas have remained relatively stable over the past decade. In 1995, the European Union accounted for almost 38 per cent of OECD manufacturing exports, the United States almost 26 per cent, and Japan almost 23 per cent.[12] Among the European economies, Belgium/Luxembourg, France, Germany, Italy, the Netherlands and the United Kingdom account for the bulk of manufacturing exports. The EU countries have substantially increased their market share in high-technology industries over the past decade, somewhat at the expense of the United States. The United States particularly gained ground in medium-low and low-technology industries, areas where Japan has lost some ground over the past decade.

Trade liberalisation and the ongoing process of globalisation have significantly increased countries' ***exposure to international competition.*** Between 1985 and 1995, the import penetration and export rate of manufacturing increased significantly in almost all OECD economies (Figure 2.20). Import penetration and export rates increased particularly fast in Canada, Finland, Greece, Portugal and Spain. The exposure to international competition of the European Union as a whole changed little between 1985 and 1995, indicating that increased exposure of individual countries was mainly driven by greater economic integration within Europe and the conclusion of the single market. Japan's export rate has declined over the past decade, while its rate of import penetration has increased.

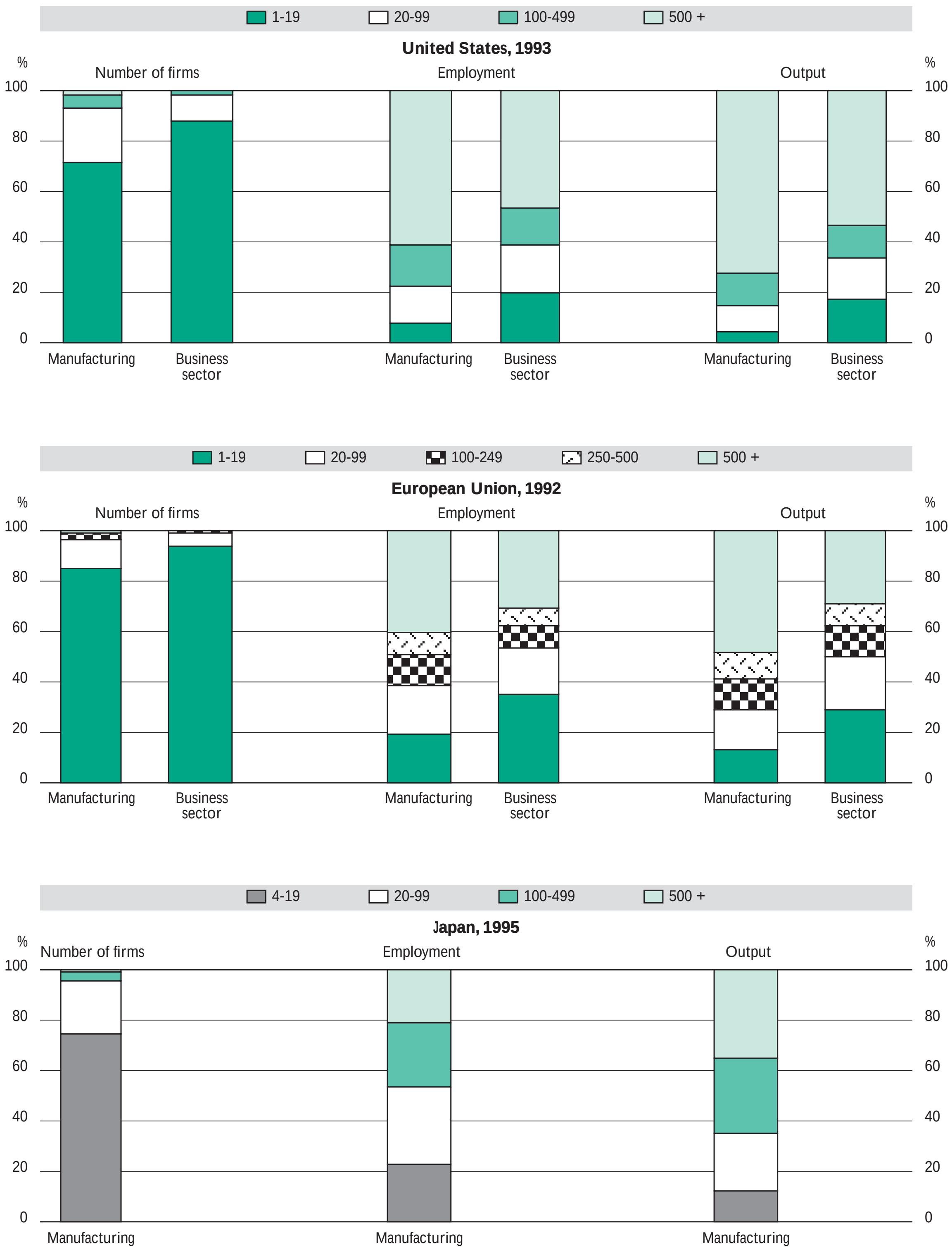
Trade in services is rapidly growing in importance (Figure 2.21). By 1996, trade in services corresponded to about 25 per cent of trade in goods. OECD statistics on trade in services distinguish four categories of services, namely travel, transportation, government services and other services (including financial services) (OECD, 1996*d*). Government services are a relatively minor component of total trade in services and have grown little. Travel and transportation services have grown steadily over the past decade, reflecting the globalisation process and the rapid growth of international tourism. The most rapid growth has been in other services, however, a sign that trade in services is increasingly moving beyond traditional service categories.

◆ Figure 2.21. ***Trade in services, 1970-94***
US$ billions



Source: OECD, 1996*d*.

◆ Figure 2.22. ***Contribution of SMEs to output and employment***[1]



1. Data for the United States and the European Union refer to enterprises only, data for Japan refer to establishments.

Source: OECD, Database on SME statistics; Eurostat, *Enterprises in Europe*, 1996.

The role of SMEs

Small and medium-sized enterprises play an important role in OECD economies. Typically, they account for almost 95 per cent of all enterprises, for between 60 per cent and 70 per cent of employment, and for between 30 per cent and 70 per cent of total output (Figure 2.22).[13] SMEs are particularly important in some areas, such as retail trade and construction, while large firms are more important in manufacturing.

Although the size distribution of firms is relatively stable over time, SMEs are a highly dynamic part of the economy. The entry and exit, expansion and contraction of firms help drive competition in the economy and these processes are particularly characteristic of SMEs' contribution to the economy (see Chapter 4; and OECD, 1998*d*). SMEs account for a large share of job creation, through both start-ups and expansion, but also for a large part of employment losses, through contraction and the exit of firms. There are also marked differences within SME size classes (very small firms often show higher net job creation rates than small or medium-sized ones), and results vary with the business cycle and by industry. Job turnover is quite high in SMEs compared with larger firms, as SMEs' share of gross job gains and losses exceed their share in total employment (OECD, 1998*b*).

SMEs also play an important role in technical change (OECD, 1998*c*). While the evidence shows that relatively more R&D is carried out in large firms than in small ones, it is also recognised that many small firms engage in informal R&D efforts and are innovative without formally undertaking R&D. Further, there are important differences among small firms: for example, some small technology-based enterprises operate at the cutting edge of research and innovation and contribute significantly to the development and diffusion of technology.

SCIENCE, TECHNOLOGY AND INNOVATION

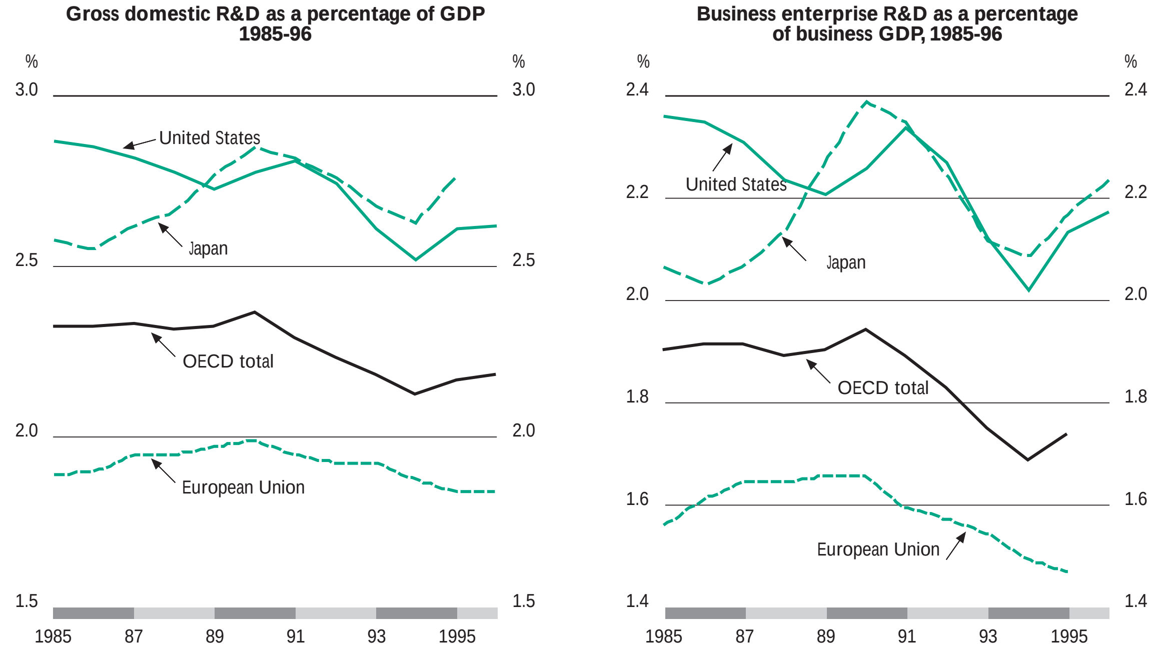
Technological change in OECD economies is occurring at an ever faster pace. While funding for R&D has declined somewhat, the scientific community continues to be highly productive, and is engaging in closer links with the business sector and with scientists throughout the world. Firms have integrated research into their commercial strategy and have improved the ability to turn research into successful products and services. In addition, the process of technological change has become more complex. Innovation is increasingly driven by networks among firms, universities and governments, and R&D expenditure represents only part – and not always the bulk – of firms' expenditure on innovation. Technological diffusion within and across countries has become more important in the management of technological change, and the globalisation process influences all aspects of the research enterprise.

Support for R&D[14]

Expenditures on R&D are an important pillar of knowledge-based economies. In 1995, OECD economies spent about US$400 billion on R&D, equivalent to 2.2 per cent of OECD-wide GDP. The main contributors were the United States (44 per cent), Japan (18 per cent), Germany (9 per cent), France (7 per cent) and the United Kingdom (5 per cent). The R&D intensity of OECD economies declined between 1990 and 1994, but has increased somewhat since (Figure 2.23; see also Chapter 6). The decline in spending was due to lower defence spending in certain countries and to fiscal consolidation and depressed economic conditions in several OECD economies. Spending has picked up somewhat since 1994, although the R&D intensity of the OECD area as a whole remains below 1989 levels. A small number of OECD countries spend more than 2 per cent of their GDP on R&D. Sweden's R&D intensity is the highest in the OECD area, at over 3 per cent of GDP, followed by Japan and Korea, at 2.8 per cent and 2.7 per cent of GDP, respectively.

By 1993, there were almost 2.5 million ***researchers engaged in R&D*** in the OECD area, corresponding to 55 researchers per 10 000 labour force. The number of researchers has grown continuously (Figure 2.24) since the early 1980s, although the growth rate slowed somewhat in the early 1990s, owing to lower expenditures on R&D in the United States. The number of researchers has continued to increase steadily in the EU area and more rapidly in the Asia-Pacific OECD area. The Asia-Pacific zone

◆ Figure 2.23. ***R&D intensities in major OECD areas***



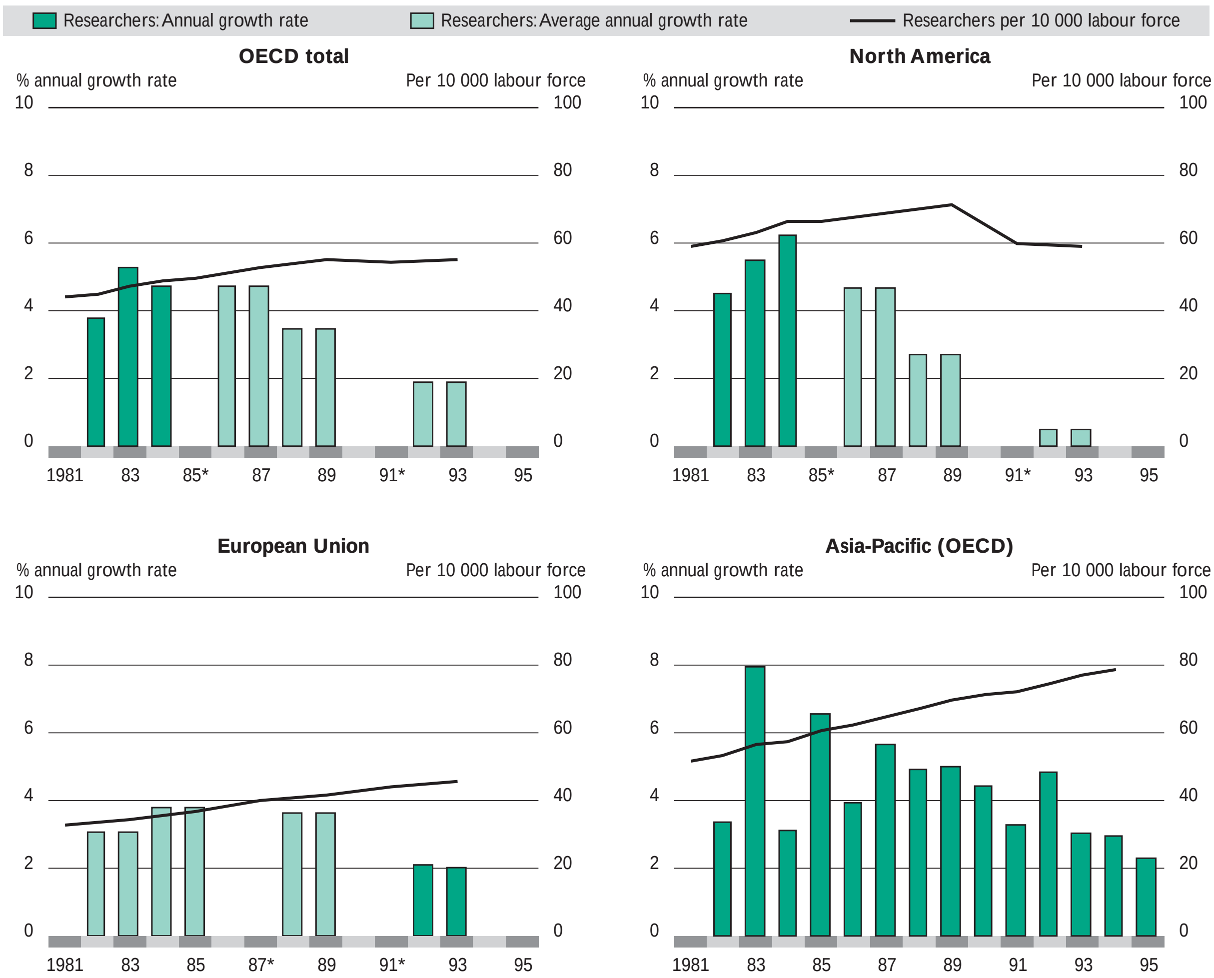
Source: OECD, MSTI database, December 1997.

– primarily Japan – has by far the highest share of researchers per 10 000 labour force, although the share is also quite high in Australia, Finland, Norway and Sweden and the United States. This indicator of an economy's research intensity has declined in a number of countries over the past five years, notably in the Czech Republic and Hungary, but has shown an upward trend in the vast majority of OECD economies.

The drop in R&D expenditure is linked to a decline in government-funded R&D. Although governments remain the largest source of ***R&D funding*** in several OECD Member countries, the business sector has taken on an increased role in almost all. By 1995, business sector finance contributed almost 60 per cent of OECD R&D expenditure, up from just over 50 per cent in the early 1980s (see Chapter 6). However, the business sector's increased role reflects less an increase in private expenditure than a decline in government-funded R&D. However, a small number of countries, including Australia and Finland, have experienced a simultaneous increase in business and government funding of R&D. The volume of funds from abroad has increased in a number of countries over the past decade. In Canada, Greece, Portugal and the United Kingdom funding from abroad accounts for more than 10 per cent of R&D expenditure.

The government's share of R&D funding has declined significantly since the early 1980s, although it still plays an important part in the R&D efforts of OECD countries. In 1995, the share of R&D expenditure financed by government varied between 20 per cent and 65 per cent, with an OECD average of about 35 per cent (see Chapter 6). During the 1990s, government-financed R&D as a percentage of GDP decreased in North America and to a lesser extent in the major European countries. Growth of government-funded R&D has been negative or near zero (in real terms) in North America since the late 1980s and in the European Union since the early 1990s. Japan is one of the few countries – and the only major OECD economy – where growth in government-funded R&D has accelerated since the 1980s. For the OECD area as a whole, there was an upturn in the growth rate of government-funded R&D in 1995, partly

◆ Figure 2.24. ***Researchers by main OECD zone***
Growth in percentages and per 10 000 labour force

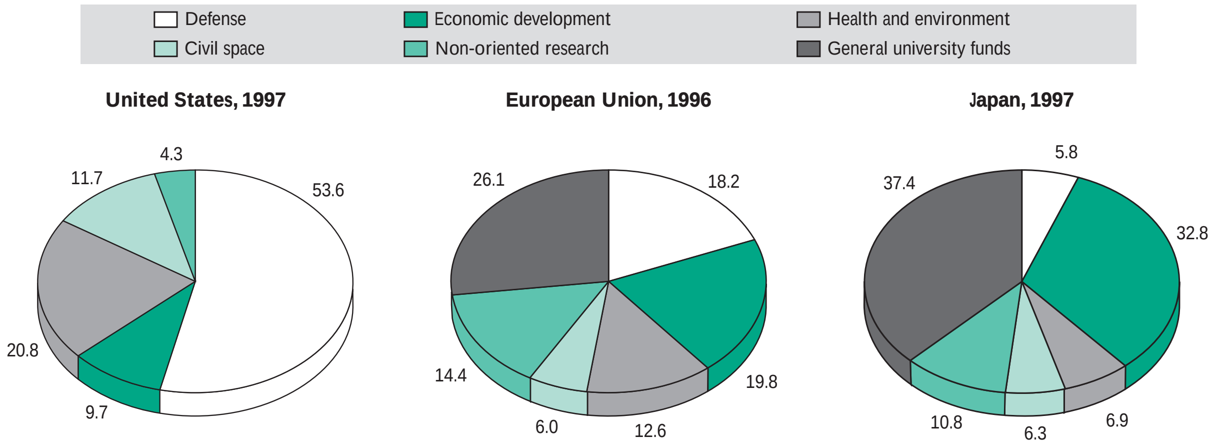


* Year for which the growth rate cannot be calculated due to a break in series.
Source: OECD, MSTI database, March 1997.

due to increased US government funding. For 1996, however, the available data suggest a further decline in OECD-wide government-funded R&D.

Government budget ***appropriations for R&D by socio-economic objective*** show large differences among OECD countries and major OECD zones (Figure 2.25). Although these budget appropriations remain difficult to interpret – and partly reflect methodological differences – it appears that the United States continues to emphasize support for defence R&D, followed by health- and environment-related R&D. The EU countries and Japan both allocate a large part of their budget appropriations to general university funds.[15] In the European Union, defence also remains a considerable priority in R&D spending, although European countries differ significantly on this point. Japan only allocates a small part of its R&D budget to defence. Funding for civil space research is a greater priority in the United States than in the European Union area or Japan. Both the European Union and Japan allocate a large part of their funding to economic development, a category that is only partly separated out in the US budget

◆ Figure 2.25. ***Total government budget appropriations or outlays for R&D by socio-economic objective***
Percentages



Source: OECD, MSTI database, March 1997.

appropriations. These differences in funding also reflect institutional differences, *i.e.* in the ministries that are responsible for allocating R&D across various objectives (see Chapter 3).

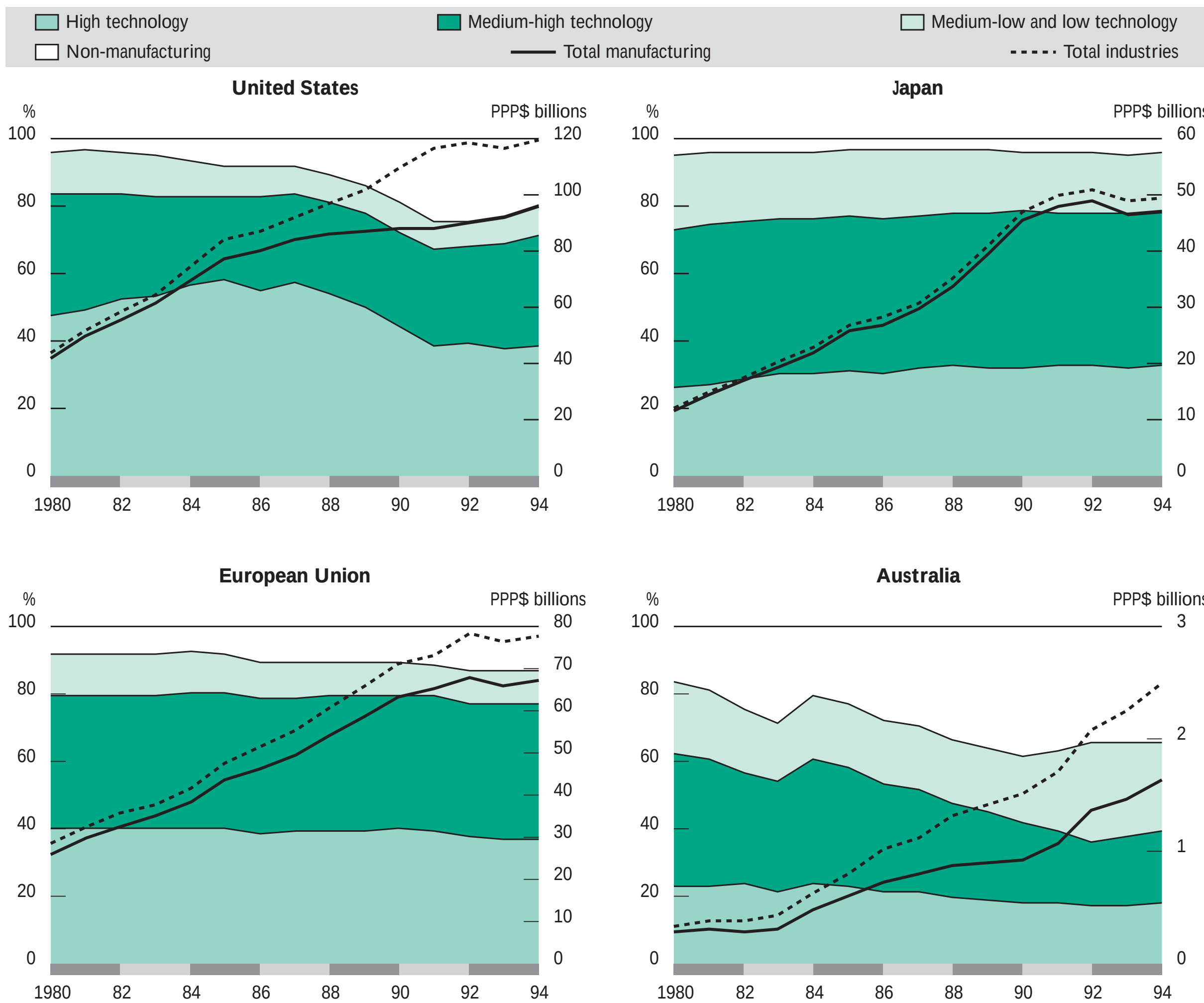
Funding for the science system typically consists of three elements: support for higher education, support for government laboratories, and support for international institutions. In most countries, institutions of higher education (universities) are the mainstay of the national science system. Government funding of university research has declined in some OECD countries over the past few years, but has remained stable as a percentage of GDP in most. In several countries, the business sector has increased its spending on university research over the past decade (see Chapter 6). The share of university research in total R&D expenditure increased slowly in most OECD countries across the second half of the 1980s, but this trend has flattened out – and even reversed in some countries – in the first half of the 1990s. Consequently, the share of higher education R&D (HERD) in GDP declined somewhat over the past few years in Canada, Italy and the United States, after increasing steadily up to the beginning of the 1990s. The level of industry funding of university research remains modest at less than 5 per cent in half of the OECD countries.

By the mid-1990s the business sector accounted for about two-thirds of OECD-wide ***R&D expenditure by sector of performance.*** Its share of researchers is slightly lower, although countries differ considerably in this respect. In the United States, over 70 per cent of all R&D is performed by the business sector, compared to just over 60 per cent in the European Union, where less than 50 per cent of researchers are employed by the business sector. These differences are a reflection of institutional arrangements in OECD Member countries. In North America, about one-third of all government-funded R&D is performed by the business sector, compared with only 15 per cent in the European Union and only 5 per cent in the Asia-Pacific OECD area. The share of government-financed R&D performed by the business sector has fallen over the past decade, however, owing to the decline in defence funding in a number of major OECD economies. Government-funded R&D performed by institutions of higher education has increased over the past decade, while that performed in government laboratories has remained relatively stable.

Total OECD expenditure on business enterprise R&D fell over the period 1992-94. The decline was not universal, however, and particularly affected the larger OECD economies, including France, Germany, Italy, Japan and the United States. Business R&D expenditure rose substantially in some other countries over this period, particularly in Australia, Canada, Finland and Ireland. Available data for 1995-97 suggest a resurgence in business R&D expenditures, mainly due to higher expenditures in the United States and Japan, which together account for about two-thirds of total OECD business R&D. As a consequence of the decline in business R&D spending over the 1992-94 period, the R&D intensity of private industry has fallen across most of the OECD area.

The ***sectoral composition of R&D*** is changing, too. R&D expenditure remains concentrated in the manufacturing sector but is also increasingly being performed in the services sector (Figure 2.26). Although this development partly reflects improved data collection for the services sector, the available data suggest that about 20 per cent of all R&D in the United States and about 30 per cent in Australia are now being performed in the services sector. In Australia, the software industry is an important contributor to R&D in services, whereas in the United States, the communications industry is a major contributor to economy-wide R&D efforts. The shares of R&D in high-, medium- and low-technology sectors have remained fairly stable since the mid-1980s in the European Union and Japan, but the share

◆ Figure 2.26. ***R&D trends in manufacturing and non-manufacturing industries, 1980-94***
Percentages and PPP$ billions



Source: OECD, ANBERD database, January 1998.

of high-technology sectors in the United States has declined sharply, reflecting a slowdown in these sectors that was partly due to lower defence spending.

The R&D intensity of manufacturing sectors differs substantially (OECD, 1997*c*). In 1994, in the pharmaceuticals, computers and office machinery, communication equipment, aerospace and scientific instruments industries, the average R&D expenditure was over 15 per cent of value added. In contrast, the textiles and clothing, wood and wood products, and paper and printing sectors spent less than 1 per cent of value added on R&D. Differences in R&D intensity across industries can exert an important influence on the overall level of R&D intensity in various OECD economies. In practice, this is not the case (OECD, 1997*c*). A country's low R&D intensity is generally linked to low R&D intensity in all industries rather than a specialisation in low-technology industries.

Innovation and knowledge flows

It is increasingly recognised that resources spent on R&D are only one indicator of the ***innovative efforts*** of OECD economies. Efforts at the OECD and elsewhere aim to develop complementary indicators of innovation and knowledge flows, which can be used to analyse and illustrate the ongoing transformation of OECD economies into knowledge-based economies.[16]

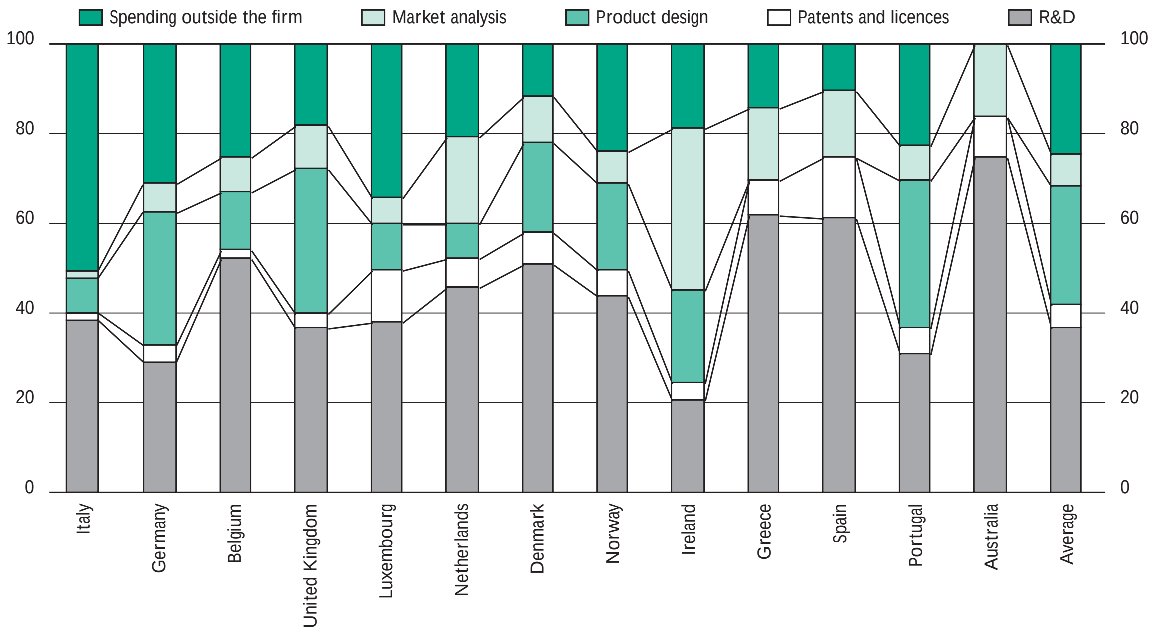
The ***science system*** increasingly exerts a direct influence on the innovation process. A recent study of the United States reveals that patents increasingly rely on basic, publicly supported research (see Chapter 6). Among the papers cited in US patents in 1993-94, over 70 per cent originate in public science. The links between science and industry differ substantially by sector, however. They are very strong in a few areas, notably pharmaceuticals, organic and food chemistry, biotechnology and semiconductors. These are also areas where it is increasingly difficult to distinguish between basic and applied research and where results of fundamental scientific work can feed quickly into commercial applications (OECD, 1998*c*). However, the links between science and industry are relatively weak in other areas, such as civil engineering, machine tools or transport. They also differ across countries; they are particularly strong in Canada, Denmark, the United Kingdom and the United States, while they are relatively weak in Germany, Japan and Korea (OECD, 1997*j*).

In OECD economies, scientific specialisations differ substantially and are quite stable over time (OECD, 1997*j*). To some extent, these differences are attributable to country size (the US science base is much broader than that of most other countries); to standards of living in high-income economies, which contribute to high shares of clinical medicine and biomedical research; and to patterns of industrial specialisation (probably owing to their industrial structure, Germany and Japan, for instance, are heavily represented in engineering and technology, chemistry and physics).

Science is only one actor – albeit an important one – in the innovation process. Traditionally, science was regarded as the basis of the innovative process, and it was thought that an increase in science inputs (R&D expenditure or other resources) would directly increase the rate of innovation. Scientific discoveries were picked up by the private sector and turned into commercial applications. This "linear" model of innovation is increasingly regarded as outdated because it does not properly reflect the complexity of the innovative process. For instance, some countries with weak science links, such as Germany, Japan and Korea, have strong innovative performance, an indication that innovation does not necessarily rely on strong links with the science system. The current view is that innovation can arise from many sources and from any part of the process of research, development, marketing and diffusion. Furthermore, it results from the interaction of all actors in the national system of innovation, including governments, universities, and private enterprises. Bibliometric analysis suggests that knowledge is increasingly developed internationally, in a transdisciplinary way, and by various actors in addition to the academic community.

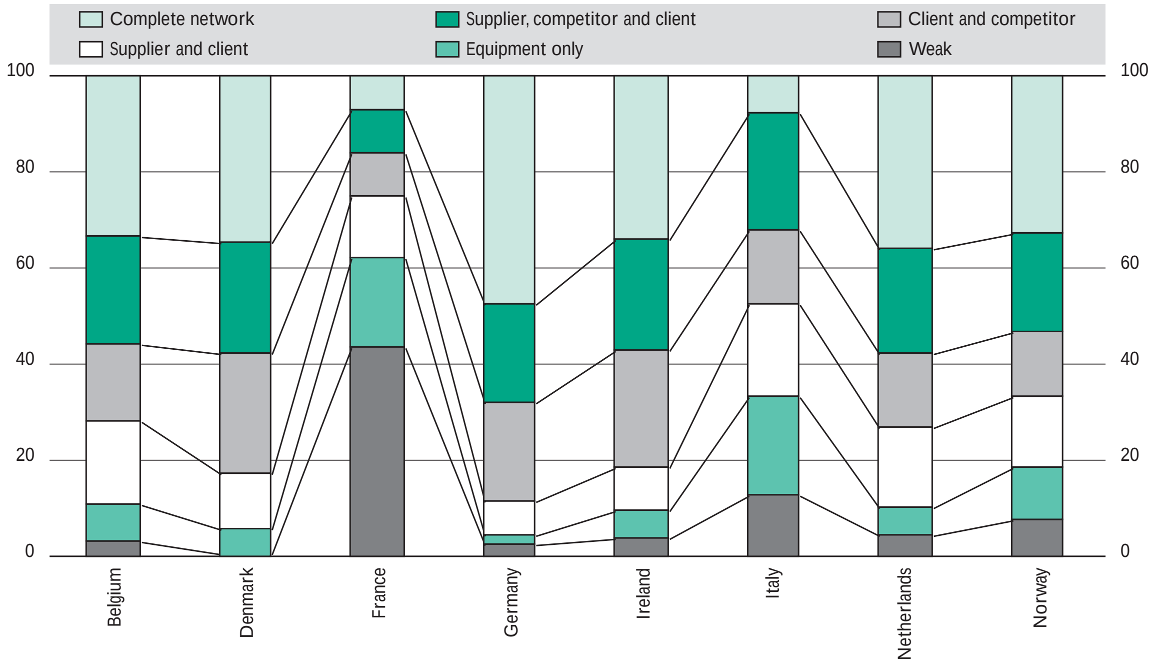
Empirical analysis supports these views. A ***breakdown of firms' innovation expenditures*** indicates that only about 30-50 per cent of all innovation costs relate to R&D expenditures (Figure 2.27). Firms spend large sums on product design, although market analysis is also important in some countries, while in others, firms contract out a significant portion of their innovation efforts. Expenditures on patents and licenses are a small, but important component of the total innovative effort.

◆ Figure 2.27. ***Breakdown of innovation expenditures***
Percentages



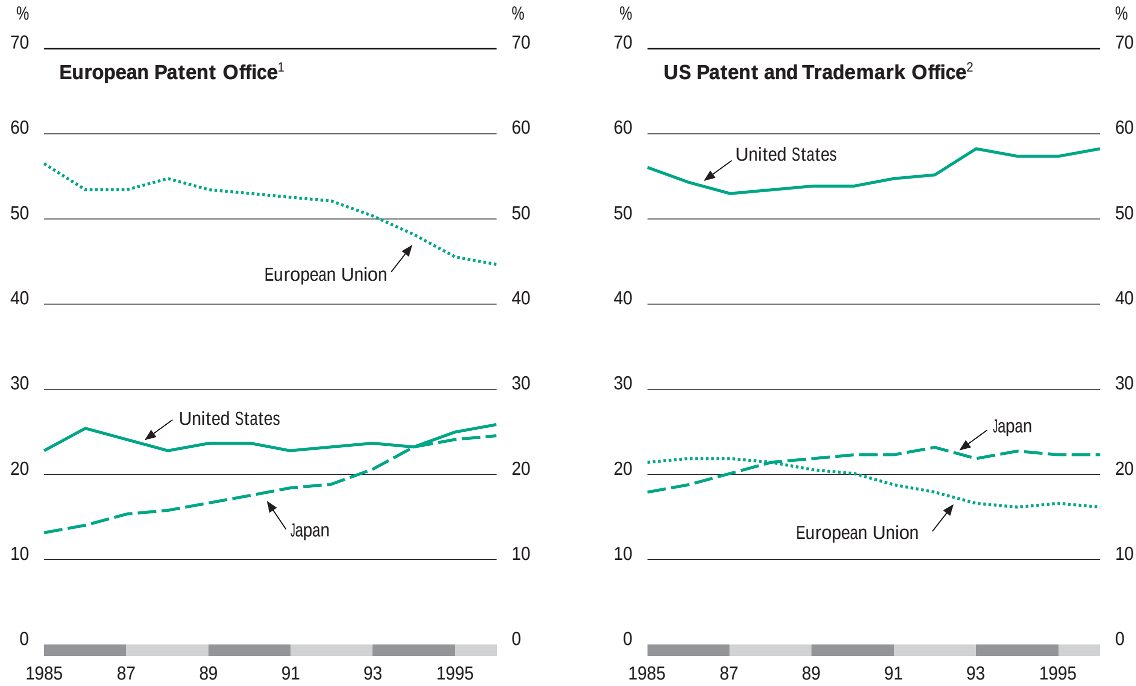
Source: Bosworth and Stoneman, 1996; CIS data; ISTAT, 1995; Australian Bureau of Statistics, 1994.

◆ Figure 2.28. ***Networks of innovation***
Percentages



Source: DeBresson *et al.*, 1997.

◆ Figure 2.29*a*. ***Shares in patents***

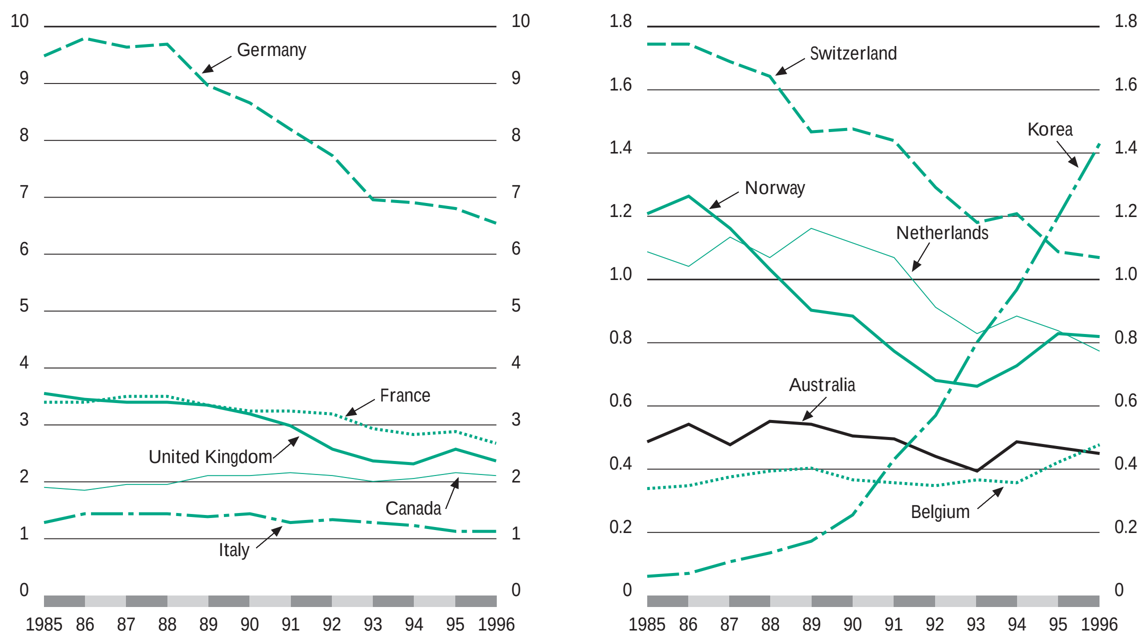


1. EPO. Data cover patent applications.
2. USPTO. Data cover patents granted.

Source: OECD, from CHI Research and EPO data, December 1997.

◆ Figure 2.29*b*. ***Shares in USPTO patents***

Percentages



Source: OECD, from CHI Research data, December 1997.

Innovation thus goes beyond R&D efforts to rely increasingly on networks and knowledge flows among firms. There are several reasons why ***"innovation networks"*** have become more important and why firms might want to engage in – often semi-permanent – relationships with other firms and share resources (see also Chapter 6):

- the range and sources of technologies have expanded rapidly, making it impossible for a company to cover all the main disciplines or sources of technology;
- networking allows firms to share costs, particularly for fundamental innovations;
- highly skilled researchers are scarce in several important areas, and firms may want to share these resources;
- some key technological developments, including biotechnology, cross traditional scientific and firm boundaries, reinforcing the need for co-operation;
- networking may reduce duplication of efforts and thus improve efficiency;
- networking may be needed to gain insights into market demands and requirements.

A recent analysis of European countries suggests that almost all firms engage in some type of network (Figure 2.28). In six out of the eight countries studied, about 30 per cent of all firms are part of a "complete network", which includes supplier firms, competitors and users, as well as public research institutes and universities. Market-oriented networks, involving suppliers, competitors and users are even more common. Networks dominated by equipment suppliers are more limited in scope, but appear relatively important in France and Italy. Innovative networks are thus an important characteristic of innovative activity, although there appear to be some important differences among OECD economies.

Most indicators of innovation are linked to inputs into the innovative process. ***Patent indicators*** are one reflection of the output of the innovative process and thus can be used to measure innovative performance. Patenting activity rose in the United States over the 1985-95 period, in terms of patents applied for at the European Patent Office (EPO) and patents granted at the US Patent and Trademarks Office (USPTO) (Figure 2.29). This increase has occurred despite lower R&D funding. At the same time, the share of the European Union in patents has declined in both patents offices.[17] Japan's share in the total number of patents granted in the European Union has steadily increased over the past decade, but has stabilised in the United States, at about 20 per cent of all patents. Korea's share has increased rapidly over the same period and has now surpassed that of several small OECD economies considered important innovators, such as the Netherlands, Sweden and Switzerland.

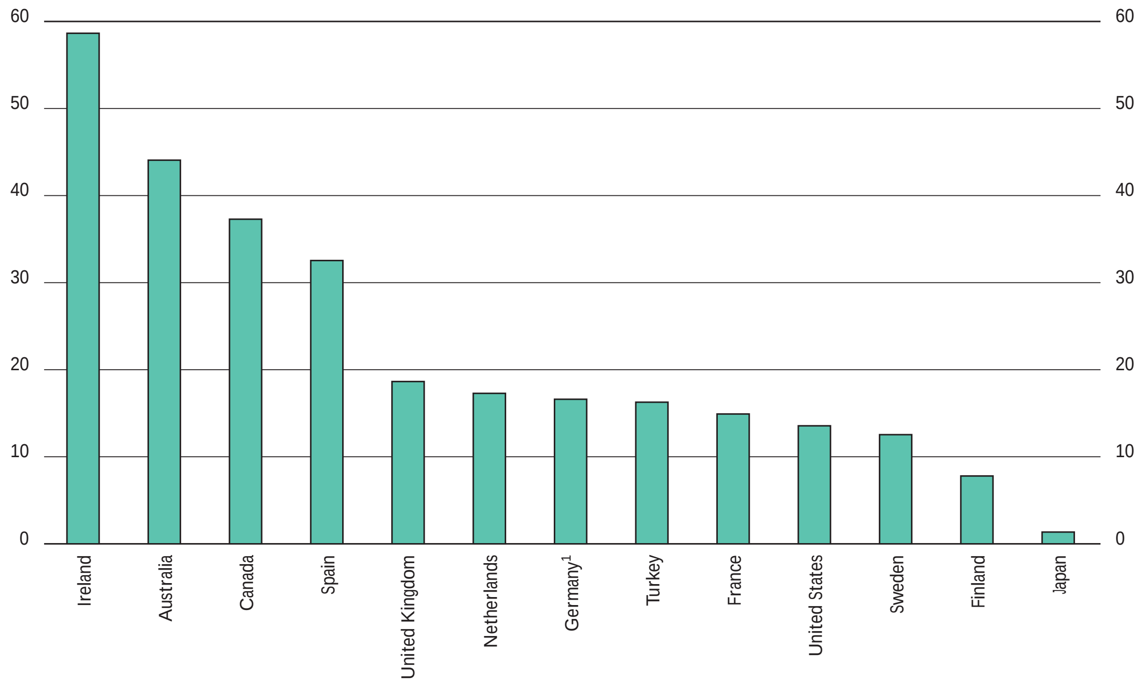
The globalisation of the innovation process

The globalisation of product and factor markets (see above) is accompanied by the globalisation of innovation and scientific research. The production of scientific knowledge increasingly cuts across disciplines, institutions and countries. As a consequence, ***international scientific collaboration*** has risen significantly during the early 1990s: 26 per cent of all scientific articles published between 1988 and 1993 were internationally co-authored, up from 19 per cent over the period 1981-87 (OECD, 1997*j*). Although the United States remains the principal international collaborator, other poles are starting to emerge: Europe, the East Asian new industrial economies, China.[18]

The business sector also contributes to the globalisation of the research effort (OECD, 1998*e*). By 1994, ***R&D performed by foreign subsidiaries*** represented more than 11 per cent of the total industrial R&D spending of the 12 OECD countries that account for 95 per cent of OECD industrial R&D (Figure 2.30). Although the data available do not capture the true level of the internationalisation of R&D, they do confirm its growing importance, particularly in the case of smaller European countries (*e.g.* Belgium, Ireland, the Netherlands, Sweden, Switzerland). Firms are increasingly decentralising their R&D activities, although in most cases this consists mostly of design and development activities in view of adapting products to local markets. Access to knowledge centres or clusters of specific expertise – which allow firms to benefit from extensive local networks – is an increasingly important driver of research globalisation. The pace, extent and nature of R&D globalisation vary widely across industries:

◆ Figure 2.30. ***Share of foreign affiliates in total manufacturing R&D expenditures in 1994 (or nearest available year)***

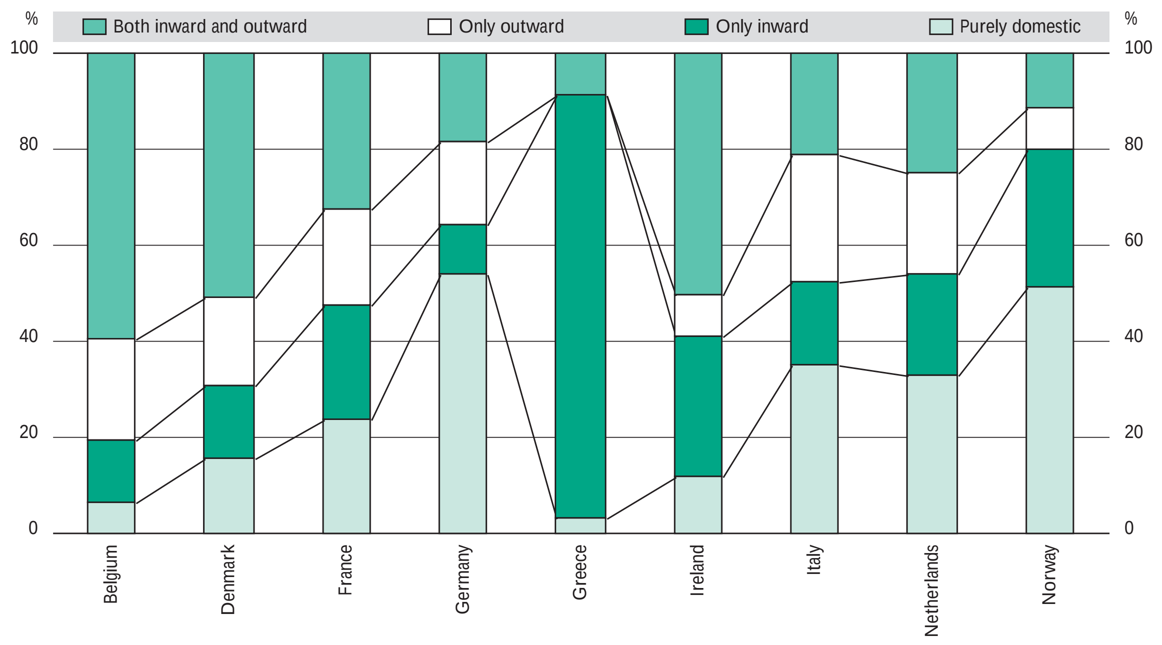
Percentages



1. Sample of the 500 most R&D-intensive firms.

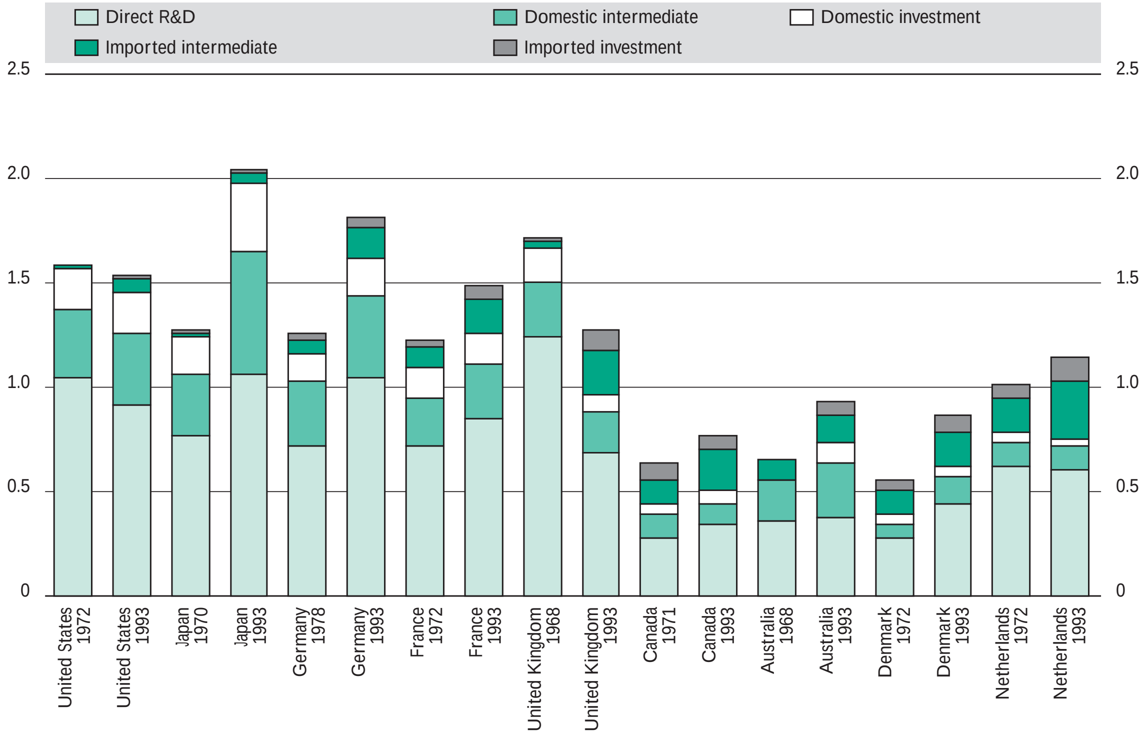
Source: OECD, AFA and ANBERD databases, December1997.

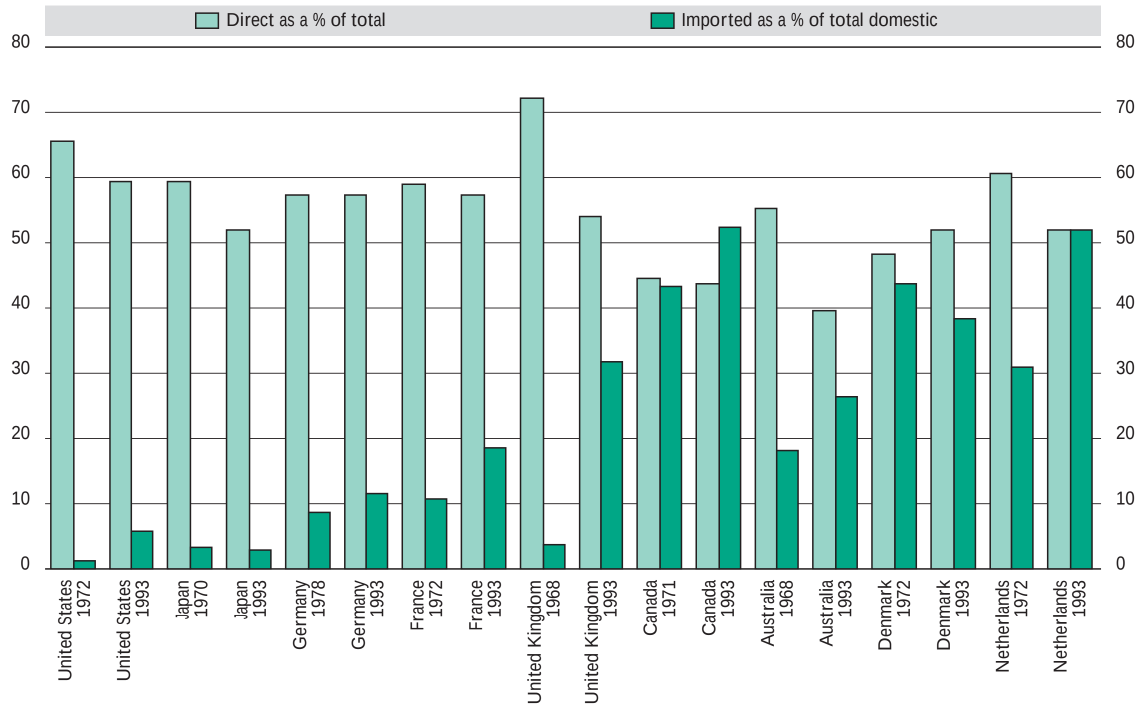
◆ Figure 2.31. ***Distribution of flows of technical information on innovative activity***



Source: DeBresson *et al.*, 1997.

◆ Figure 2.32. ***Direct and indirect R&D intensities***
Percentages





Source: OECD, based on Input-Output and ANBERD databases.

industries requiring specialised skills (*e.g.* the computer, software or semiconductor industries) or those experiencing high regulatory barriers (*e.g.* biomedical devices, pharmaceuticals or biotechnology) are most likely to engage in global R&D activities.

The innovation process is also becoming more globalised in terms of networking. Among European countries, a large majority of firms – especially from small economies – are engaged in some kind of ***international networking*** (Figure 2.31). These international interfirm networks involve different arrangements, such as non-equity contractual agreements for development, production and marketing; minority equity participation; and jointly owned subsidiaries. They mostly involve large multinational enterprises located in knowledge-intensive industries and are often driven by technology-related needs and a desire for access to new markets. Many firms now acquire technology from abroad or export technology, and a majority of firms in Belgium, Denmark and Ireland are involved in both inward and outward innovation flows. Purely domestic knowledge flows are the main source of innovation in Germany and Norway, however, and are also of great importance in Italy and the Netherlands.

The globalisation of science and R&D is accompanied by increasingly ***rapid technological diffusion.*** Analysis of national innovation systems points to the important role of knowledge and technology flows among enterprises, universities and other entities as drivers of technological change. Increasingly, and particularly in smaller economies, such enterprises and universities may be located abroad. Analysis of the technology balance of payments indicates that the United States remains the main exporter of disembodied technology (patents, licenses, know-how, and so on), although Japan has also become a net exporter of technology over the past five years (OECD, 1998*b*). The European Union's overall technology balance of payments shows a slight deficit, reflecting deficits for most countries against surpluses for the Netherlands, Sweden and the United Kingdom. European countries receive most of their technology from other European countries, while Japan imports most of its technology from the United States.

Traditional ***technology flows,*** embodied in equipment or intermediate goods, remain an important component of technology flows. OECD analysis on the basis of input-output tables indicates that in total manufacturing sector R&D intensity (as measured by the sum of direct R&D and all types of indirect flows, *i.e.* intermediary and investment goods from both home and abroad), indirect R&D intensity may account for 30-50 per cent of the total (Figure 2.32). Indirect R&D has become increasingly important over the past decades, but differs substantially among countries. In smaller OECD economies, such as Canada or the Netherlands, technology imports may account for up to 50 per cent of all acquired technology, whereas they account for less than 5 per cent in Japan and the United States.

NOTES

1. OECD's semi-annual *Economic Outlook* (OECD, 1998*a*) provides more detail about recent macroeconomic developments. This section provides a brief summary.
2. Chapter 3 discusses the policy implications of this insight in greater detail. See also OECD (1998*c*).
3. Further details about recent industry trends are also available in OECD's *Science, Technology and Industry – Scoreboard of Indicators 1997* (OECD, 1997*c*) and in *Meeting of the Industry Committee at Ministerial Level – Scoreboard of Indicators* (OECD, 1998*b*). These publications also provide further methodological detail. The Statistical Annex provides country-specific details on trends in performance and also describes some of the main OECD databases underlying the chapter.
4. The services sector includes transport, storage and communication services; wholesale and retail trade, restaurants and hotels; finance, insurance, real estate and business services; and community, social and personal services.
5. High-technology industries include aircraft, office and computing equipment, drugs and medicines, and radio, TV and communication equipment. Medium-high technology industries include professional goods, chemicals excluding drugs, and most manufacturing industries producing machinery and equipment. The Statistical Annex provides further details on this classification.
6. Investment in R&D and training is discussed below.
7. Investment intensity is measured as gross fixed capital formation as a percentage of sectoral value added.
8. ICT investment, particularly investment in computers, is sometimes attributed greater importance than non-ICT investment, since ICT may enable rapid productivity growth. The role of computers in productivity is discussed further in Chapter 4.
9. Where industry covers mining, manufacturing, utilities and construction, and where services includes the government sector (OECD, 1998*b*).
10. A more extensive discussion of productivity growth and its determinants is available in Chapter 4.
11. A further look at the globalisation process is provided elsewhere in this chapter.
12. The European Union's share excludes intra-European trade.
13. Depending on the country, SMEs are defined as firms with either less than 500 employees or less than 250 employees (OECD, 1998*b*).
14. This section only gives a brief summary of trends in R&D support. A more detailed discussion of trends in R&D spending and the factors influencing R&D expenditure can be found in Chapter 6.
15. This type of funding is not included in the US budget appropriations, as the responsibility for such funding rests with individual states.
16. Several indicators on "national innovation systems" are only available for recent years. This implies that it remains difficult to discuss performance trends in national innovation systems (see OECD, 1997*j*).
17. The USPTO data cover patents granted. Patents are generally granted from two to five years after being applied for. For most non-US patentees, there is an additional delay of one year (OECD, 1997*c*). The EPO data cover patent applications. While the time lag is shorter than for patents granted, the data include many applications that may later be rejected.
18. The rapid growth in international collaboration is facilitated by the use of information and communications technologies. Chapter 7 discusses this issue in more detail.

STRENGTHENING THE ROLE OF POLICY

INTRODUCTION

Rapid technological change, globalisation and the integration of international markets, tighter government budgets, and the increasing complexity of economies have forced OECD governments to reconsider their policies for science, technology and industry. This chapter discusses how such policies have changed in OECD Member countries. It first looks at industrial policies, including structural reform. It then examines policies to encourage technological change and to expand the knowledge base. While it does not provide exhaustive coverage of policy developments, some policy initiatives in OECD Member countries are highlighted in boxes. Further details on specific measures can be found on Internet Web sites of ministries in charge of science, technology and industry policies (Box 3.1).

It should be noted that the definition of science, technology and industrial policies is far from uniform and depends in part on the responsibilities of the relevant ministry. In some countries, industrial policy is closely integrated with science and technology (S&T) policies, in others with broader economic policies, and in yet others with trade policies. Current policy developments include greater efforts to integrate policies for the different areas.

IMPROVING INDUSTRIAL PERFORMANCE AND COMPETITIVENESS[1]

The changing character of industrial policy

Industrial policy in OECD countries covers a wide range. In many countries, measures to liberalise national and international product and factor markets lie at the core of industrial policy. In addition, countries use more targeted policies to improve the business environment and stimulate growth or structural change. Measures in this category include investment promotion and export financing programmes, support for small and medium-sized enterprises (SMEs), and direct support to industry.[2]

While some of these measures appear to be traditional instruments of industrial policy, the character of industrial policy in the OECD area has in fact changed considerably over the past decade. There is far less emphasis on direct support to specific sectors, as fiscal restraints have curbed government spending, the effectiveness of public support to industry appears limited and it is increasingly regarded as distorting international trade and investment. However, many OECD countries still use such measures to assist the restructuring process in declining industries or to aid specific regions. Instead, policies have shifted towards improving framework conditions for industry, primarily in areas where market failures can be identified, such as investment in infrastructure, skills, and research and development (R&D). In addition, many governments emphasize closer co-operation with the private sector, for instance through partnership programmes. There is also a broadly shared view that improving the business environment will require greater emphasis on efficiency in the public sector and on reducing the burden of government in terms of regulation and taxation, for example.

Greater emphasis is also being placed on the need for a horizontal, or systemic, policy approach. To some extent, this reflects the view that globalisation and rapid technological change will require continuous structural adjustment. To this end, governments will need to apply, in a coherent and co-ordinated manner, all the policies, including macroeconomic policies, that affect the functioning of the economy in the global competitive environment. Recent macroeconomic policy developments in the OECD area therefore have an important bearing on the evolution of industrial policy (Box 3.2). The orientation of industrial policy has changed too. It is no longer aimed solely at the manufacturing sector, Box 3.1. **Internet sites of main government offices for science, technology and industry**

Australia:	http://www.dist.gov.au/ (Department of Industry, Science and Tourism)
Austria:	http://www.bmwa.gv.at/bmwa/ (Federal Ministry of Economic Affairs)
	http://www.bmwf.gv.at/ (Federal Ministry for Science and Transport)
Belgium:	http://belgium.fgov.be/ (Belgian Federal Government)
	http://www.belspo/be/ (Federal Office for Scientific, Technical and Cultural Affairs)
Canada:	http://www.ic.gc.ca/ (Industry Canada)
	http://www.nrc.ca (National Research Council)
Czech Republic:	http://www.mpo.cz/ (Ministry of Industry and Trade)
	http://www.msmt.cz/ (Ministry of Education, Youth and Sports)
Denmark:	http://www.em.dk/ (Ministry of Business and Industry)
	http://www.fsk.dk/ (Ministry of Research and Information Technology)
Finland:	http://www.vn.fi/ktm/ (Ministry of Trade and Industry)
	http://www.minedu.fi/ (Ministry of Education, Science and Culture)
France:	http://www.industrie.gouv.fr/ (Ministry of Industry)
	http://www.mesr.fr/ (Ministry of Education, Research and Technology)
Germany:	http://www.bmwi.de/ (Federal Ministry of Economics)
	http://www.bmbf.de/ (Federal Ministry of Education, Science, Research and Technology)
Greece:	http://www.gsrt.gr/ (General Secretariat for Research and Technology)
Hungary:	http://www.ikm.iif.hu/ (Ministry of Industry, Trade and Tourism)
Iceland:	http://www.iceland.org/polisubgn.htm (The Government of Iceland)
Ireland:	http://www.irlgov.ie/ (Irish government)
	http://193.1.228.3:80/entemp/ (Department of Enterprise and Employment)
Italy:	http://www.murst.it/ (Ministry of the Universities, Research and Science)
Japan:	http://www.miti.go.jp/ (Ministry of Trade and Industry)
	http://www.monbu.go.jp/ (Ministry of Education, Science, Sports and Culture)
	http://www.sta.go.jp/ (Science and Technology Agency)
Korea:	http://www.motie.go.kr/ (Ministry of Trade, Industry and Energy)
	http://www.most.go.kr/ (Ministry of Science and Technology)
Luxembourg:	http://www.etat.lu/EC/ (Ministry of Economics)
	http://www.men.lu/ (Ministry of Education and Professional Training)
Mexico:	http://www.secofi.gob.mx/ (Ministry of Trade and Industrial Development)
	http://info.main.conacyt.mx/ (National Council for Science and Technology)
Netherlands:	http://info.minez.nl/ (Ministry of Economic Affairs)
	http://www.minocw.nl/ (Ministry of Education, Culture and Science)
New Zealand:	http://www.moc.govt.nz/ (Ministry of Commerce)
	http://www.morst.govt.nz/ (Ministry of Research, Science and Technology)
Norway:	http://odin.dep.no/nhd/ (Ministry of Trade and Industry)
	http://odin.dep.no/kuf/ (Ministry of Education, Research and Church Affairs)
Poland:	http://www.mit.gov.pl/ (Ministry of the Treasury)
	http://eris.kbn.gov.pl/ (State Committee for Scientific Research)
Portugal:	http://www.mct.pt/ (Ministry of Science and Technology)
Spain:	http://www.la-moncloa.es/ (Spanish Government)
Sweden:	http://www.sb.gov.se/ (Swedish government)
	http://www.nutek.se/ (National Board for Industrial and Technical Development)
Switzerland:	http://www.biga.ch/ (Federal Office for Industry, Enterprises and Labour)
	http://www.admin.ch/bfk/ (Federal Office for Economic Policy)
	http://www.admin.ch/bbw/ (Federal Office for Education and Sciences)
Turkey:	http://www.kosgeb.gov.tr/ (Ministry of Industry and Trade)
United Kingdom:	http://www.dti.gov.uk/ (Department of Trade and Industry)
United States:	http://www.doc.gov/ (Department of Commerce)
	http://www.nsf.gov/ (National Science Foundation)
European Commission:	http://europa.eu.int

Box 3.2. **The macroeconomic policy framework in the OECD area**[1]

In the OECD area, macroeconomic policies have pursued two main goals over the past decade: achieving price stability and restoring the health of public finances. ***Monetary policy*** has sought to contain inflation and has been quite successful in the vast majority of OECD economies, with 21 countries having consumer price inflation below 3 per cent in 1997. A number of other countries are also edging closer to this goal. As a result of the cautious stance of monetary policy, OECD-wide[2] consumer price inflation has fallen from 12.3 per cent in 1980 to 2.3 per cent in 1996 (OECD, 1997*a*).

This low level of inflation has helped to ensure a more stable economic climate and therefore perhaps a better environment for private investment. In the past, there have been some concerns that monetary policies may have been too tight, resulting in high real interest rates, an undesirable situation in a period of low growth and increasing unemployment. Real interest rates have come down somewhat in recent years, however, and this may stimulate investment and help to improve economic growth in the OECD area.

Fiscal consolidation continues to be the other main feature of OECD-area macroeconomic policy. It appeared as a response to rising levels of public debt and concerns about long-term spending pressures owing to ageing populations. In the European Union, the convergence criteria for monetary union have also forced fiscal consolidation. OECD-area experience suggests that consolidation is often a response to deteriorating economic conditions, such as rising inflation or widening current account balances (OECD, 1996*e*). Throughout the OECD area, significant progress in fiscal consolidation has been made both through increases in revenues, often by increases in direct rather than indirect taxes, and through cuts in expenditure, mainly in government investment and consumption, but only to a limited degree in transfer spending.

While fiscal policy has helped to come closer to balancing government budgets – average general government structural balances improved from a deficit of 3.8 per cent in 1992 to an estimated deficit of 1.1 per cent in 1997 – public debt has continued to rise. In the OECD area, the average level of gross government debt increased from just over 40 per cent of gross domestic product (GDP) in 1980 to 56.8 per cent in 1990 and to 70.7 per cent in 1997 (OECD, 1997*a*). The average level of public debt has fallen somewhat in the United States and has stabilised in the European Union area – at around 78 per cent of GDP – but continues to increase sharply in Japan. Public debt levels have fallen sharply, however, in most other OECD economies.

Fiscal reform can improve macroeconomic performance directly (OECD, 1996*f*). Reductions in public deficits and the public debt ratio can help lower real interest rates and increase investment. Fiscal reforms, if they are properly designed and implemented, also permit governments to reduce the distorting effects of taxation on resource allocation and thus potentially increase economic growth. However, if fiscal consolidation results in excessive cuts in public investment in human and physical capital or in R&D, the long-term potential for growth may be reduced.

In Europe, the move towards ***European Monetary Union*** (EMU) will have a substantial impact on the scope for macroeconomic policy. A unified monetary policy will continue to be effective in the event of symmetric shocks – *i.e.* shocks that affect all EMU countries – but will be much less effective for dealing with asymmetric ones. The scope for individual EMU member countries to pursue their own fiscal policy is also likely to diminish, although the recently concluded Stability and Growth Pact will provide some leeway, once countries have achieved a balanced budget. More broadly, the reduced scope for macroeconomic policy to respond to asymmetric shocks is likely to mean that greater use will have to be made of structural policy to respond to such shocks and improve the flexibility of EMU economies.

1. Details of macroeconomic policies of OECD Member countries are available in OECD (1998*a*).
2. Excluding OECD high-inflation countries (Czech Republic, Greece, Hungary, Mexico, Poland and Turkey); see OECD, 1998*a*.

but increasingly also at the services sector as countries recognise its importance and its growth potential.

While the industrial policy efforts of OECD Member countries have common elements, many differences remain. For instance, the Czech Republic, Hungary and Poland are still engaged in a process of economic transformation, although many fundamental steps have now been taken. In these countries, policy currently emphasizes the further liberalisation of markets and price formation, the restructuring of (former) state-owned enterprises, and the development of a supportive legal and institutional framework. In Mexico and New Zealand, industrial policy in the traditional sense has all but disappeared, and policies are primarily oriented at improving the business environment through measures involving regulatory frameworks, the opening of markets, and the protection of intellectual property rights (IPR).

This chapter broadly distinguishes four elements of industrial policy. One is structural policy, *i.e.* efforts to improve the functioning of product and factor markets. The second involves measures to improve the quality and quantity of, or access to, specific factors of production through, for example, support for tangible investment such as improved access to financial resources; policies to enrich human capital and improve skills and competencies; and support for R&D and technology. The third type targets specific economic segments, for instance by providing support to SMEs or to specific sectors or regions. The fourth pertains to the analytical tools and the policy framework. For instance, several countries use cluster analysis and benchmarking studies to assess their economies' comparative advantage, and many evaluate the impact of their policies so as to improve policy action. The following sections discusses these aspects of industrial policy in greater detail.

Structural reform

Structural policy, in particular the liberalisation of national and international product and capital markets, is a crucial component of policies to strengthen the business environment and framework conditions for industry. In fact, many OECD countries list measures in this area, such as lower trade barriers, liberalised foreign direct investment (FDI), and regulatory reform, as the core of their industrial development policies (OECD, 1998*f*). Although they differ in their comprehensiveness, regulatory reform is under way in almost every OECD economy, and many countries, including Iceland, Ireland, Italy, the Netherlands, Sweden, Switzerland and Turkey, have recently strengthened their competition policy framework as a way to reduce anti-competitive conduct and increase competition in the economy. Countries continue to differ substantially, however, in terms of the degree of liberalisation of product and factor markets and their appreciation of the respective roles of governments and the private sector.

Structural policies seek to ensure the better functioning of product and factor markets, greater flexibility, and improved capacity to adjust to economic shocks and to structural change in general. By improving the functioning of markets, such policies can support economic growth. The past decade has seen the following main reforms:

- ***Financial markets*** have been liberalised to a considerable extent (OECD, 1996*f*). Domestic financial markets have been deregulated in most countries, and controls on international capital movements have been eliminated. Recent financial tensions in East Asia, including in Japan and Korea, suggest the need for further adjustments to regulatory frameworks (OECD, 1997*a*; 1998*a*). The recently concluded international agreement on trade in financial services also marks a significant step in the further deregulation of financial markets.
- ***Trade and investment*** have also undergone significant liberalisation. Considerable progress has been made in reducing tariff barriers to trade, and average tariff rates for most-favoured nations (MFN) will fall to very low levels following the implementation of the Uruguay Round. The proportion of goods subject to non-tariff barriers has also fallen in recent years, although the share of imports subject to such restrictions has risen in a few countries and remained constant in most others, except Australia and New Zealand (OECD, 1996*f*). The number of outstanding dumping actions has risen sharply over the past years, however, and government support to the agricultural sector continues to rely heavily on border measures. The successful conclusion of the Uruguay Round has been accompanied by several regional initiatives to liberalise trade and investment, including further progress in European unification, the emergence of the North American Free Trade Agreement (NAFTA), and initiatives in the Asia-Pacific Economic Cooperation (APEC) area. Progress on liberalising international trade has also been made at the sectoral level, for instance in telecommunications. The World Trade Organization (WTO) agreement on

this sector took effect in January 1998, with new multilateral rules for trade and investment in basic telecommunications services.

- Reforms in ***domestic product markets*** have been slower, but have gained some momentum. Previously, many sectors of OECD economies were seen either as natural monopolies or as of vital social or strategic interest, or both, and therefore requiring at a minimum heavy regulation, if not direct public ownership. In many cases, these views are no longer considered valid; changes in technology and experience have cast doubt on the pervasiveness of natural monopolies, or narrowed their existence to certain network facilities. The growing complexity of OECD economies and increasing globalisation have also resulted in greater scope for actual or potential competition. Starting with comprehensive regulatory reform efforts in the United Kingdom and the United States, regulatory reform has gained ground in Australia, Japan, and New Zealand. In Europe, the process of European integration has created momentum for regulatory reform, and many countries are now opening up markets that were, until recently, reserved for public monopolies. The increased international integration and globalisation of economic activity are also likely to spur product market reform in many sectors of the economy, in part because domestic regulations have gained in importance as a barrier to international trade and investment since the conclusion of the Uruguay Round.[3]
- Poor ***labour market*** performance has been a growing source of concern in OECD countries, particularly in Europe. The *OECD Jobs Study* (OECD, 1994*b*) set out a broad programme of action designed to improve labour-market performance in Member countries. Implementation of its recommendations in specific structural policy areas differs considerably from country to country, however, in part because of widely different starting positions.
- ***Tax reforms*** have also been implemented in many OECD Member countries. Most have sought simplification of the tax system and a reduction of the tax burden. Several OECD countries, including Germany and the Netherlands, are currently implementing further comprehensive tax reforms.

Structural reform can help improve economic performance in several ways. The liberalisation of financial markets over the past decade, in combination with the rapid introduction of information technology (IT), has contributed to innovation in financial products, reduced costs of financial intermediation, improved allocation of funds, and deepened financial markets (OECD, 1996*f*).

The increasing integration of world markets enabled by the liberalisation of trade and investment allows for fuller use of economies of scale and more rapid technology diffusion. For instance, the harmonisation of standards in the European Union (EU), while still incomplete, means that producers no longer have to make smaller production lots for individual countries. This may reduce prices and increase international competition. More generally, the free flows of goods and services allows better resource allocation, can bring firms up to international standards of performance, and may ultimately boost economic growth. OECD Member country policies generally support the process of internationalisation (see below).

The liberalisation of domestic product markets can also contribute to better economic performance by reducing costs and increasing productivity, by strengthening firms' incentives to economise on resources, by reducing excessive rents accruing to producers and workers in the form of excessive profits or high wage premiums, and by enabling firms to take advantage of economies of scale and scope (OECD, 1997*k*). In addition, the liberalisation of product markets and increased competition may also provide greater incentives for firms to pursue product and process innovations and adapt goods and services to changing consumer needs. The experience of some countries and sectors suggests that such policies can spur growth (OECD, 1997*k*).

While labour market reforms are mainly aimed at improving labour market performance and reducing unemployment, they also support the economy's growth potential. Labour market reforms can reduce structural unemployment, thereby enabling a shift in the level of structural unemployment at which inflation is likely to emerge (the NAIRU – non-accelerating inflation rate of unemployment). A shift in the NAIRU allows monetary authorities to accommodate expansion for a longer period and can improve the economy's growth potential. More generally, labour market reforms can improve resource allocation and the capacity to adjust to shocks. Although many OECD countries have not yet been able to implement significant labour and product market reforms, a few have made substantial progress. The evaluation of OECD Member countries' experience with the *OECD Jobs Study* singled out four countries that had been able to significantly improve labour market performance, namely Ireland, the Netherlands, New Zealand, and the United Kingdom (OECD, 1997*l*). Several of these were also among the first to implement product market reforms.

The positive effects of structural reform often take time to emerge, however. The liberalisation of product and labour markets may initially result in substantial transition costs, such as losses in sectoral employment and bankruptcies. By increasing the economy's capacity to adapt and adjust, and by ensuring a stable macroeconomic framework geared towards growth, government policies can help to avoid or minimise such adverse consequences.

Supporting tangible and intangible investment

The emphasis in industrial policy is shifting from direct to indirect measures, such as the improvement of framework conditions, and from support for physical investment to support for intangible investment. To some extent, this reflects a view that the private sector is likely to invest sufficiently in physical assets (infrastructure being a possible exception), but that market failures may lead to insufficient private support for intangible assets, such as human capital and innovation. In addition, intangible investment is a growing share of total investment. By 1994, investment in intangibles (R&D, training, marketing and software) accounted for 35 per cent of total investment in France (OECD, 1998*f*). Across the OECD area, a range of measures support investment.[4]

Improving access to financial resources

Financial market reform is a first important measure that has helped improve access to financial resources, notably for private firms. Nevertheless, governments may sometimes wish to use further measures to increase firms' access to financial resources. In particular, SMEs may have difficulty in finding funding at reasonable terms, while capital markets for high-risk and innovative projects are as yet insufficiently developed in many OECD economies. Many governments are therefore implementing policies to improve access to venture capital (see below). Other measures applied in many OECD countries to stimulate investment include tax breaks and favourable amortisation rules.[5]

Governments also use direct measures, such as ***grants and subsidies,*** to stimulate investment. Such measures continue to diminish in importance in most OECD Member economies. For instance, recent policy efforts in Portugal, under the PEDIP II programme, involve giving a smaller share of grants to support investment and placing greater emphasis on interest-free loans. A similar reorientation of policies can be observed in Canada, Denmark, Finland, and Italy.

Nonetheless, OECD Member countries continue to use direct grants, generally in a more selective way. Greece provides direct grants for certain modernisation and restructuring efforts. Spain provides public support for structural adjustment in certain sensitive sectors, including textiles, steel, and shipbuilding. However, support is linked to special EU provisions and is meant to be temporary, targeted at feasible projects and linked to competitive goals.[6]

OECD data on public support to industry (OECD, 1997*c*) confirm some of these developments. They indicate that the level of public support increased substantially from 1989 to 1991, but has declined since. The composition of public support has changed as well. Support to SMEs, specific sectors, and investment has fallen, but support for regional policies, R&D and technology, crisis aid, and energy increased over the 1989-93 period. Some of these measures, particularly those relating to SMEs, regional policies and technology, are discussed in more detail below.

Improving the physical infrastructure

A well-developed and modern physical infrastructure, including transport and telecommunication networks, is essential for economic development. Some studies have pointed to investment in infrastructure as an important prerequisite for productivity growth and have argued that there are high payoffs to such investment. However, a recent review of the literature (Sturm *et al.*, 1996) finds little hard evidence to confirm that (public) investment in infrastructure has above-normal payoffs. However, although there may be little agreement about the size of its contribution, infrastructure investment is an important condition of growth in modern OECD economies.

Governments continue to finance most investment in physical infrastructure, although private firms have demonstrated that they can take on responsibilities in certain areas, *e.g.* telecommunications or toll tunnels, and there is a growing emphasis on public/private partnerships (P/PPs) in this area. Nevertheless, owing to the difficulties encountered by private firms in appropriating benefits from investments in infrastructure, as well as the high costs involved, governments are likely to continue to play a key role in this area. Many countries emphasize support for infrastructure as a core element of their economic growth policy. In the Netherlands, for instance, such support is considered essential, given the country's central position in many European distribution networks. Germany plans to spend about DM 20 billion annually up to the year 2000 in improving the transport infrastructure and enhancing the environment.

Countries such as Canada, Ireland and the Netherlands view regulatory reform in the utility and telecommunications markets as essential for guaranteeing investment and innovative behaviour in the delivery of these services. Canada, Japan, Korea and Turkey give special emphasis to support for information and communication technology (ICT)-related infrastructure, which is seen as essential for the move towards a knowledge-based society. In France, considerable emphasis is placed on improving small firms' access to communication networks, including the Internet.

Promoting skills development

The ongoing move towards a knowledge-based economy and the increased use of advanced technologies will require substantial and continuous upskilling of the labour force.[7] This is recognised

Box 3.3. **Promoting skills development**

Programmes to stimulate skills development are an important element of industrial policy efforts in almost every OECD Member country. Various means are used, including greater co-operation between SMEs and training providers (***Denmark***); low-interest and long-term loans to SMEs in order to strengthen their willingness to take on apprentices (***Germany***); development of a quality assurance system for human resource development (***Ireland***); establishment of industry training organisations to promote training by industry for industry (***New Zealand***); measures to strengthen adult and higher education (***Sweden***); establishment of a University of Industry to provide affordable training in IT and management skills (***United Kingdom***); promotion of social partnerships between employers and employees (***United Kingdom***); introduction of tax credits to reduce the costs of higher education (***United States***); and a push for higher standards by nation-wide testing, which would allow parents and local authorities to judge the quality of local education (***United States***).

Other measures have been applied in recent years (OECD, 1997*a;* 1997*m*). A number of countries have recently extended the length of compulsory education, while national testing at key stages was introduced in ***England, France, New Zealand, Spain*** and ***Sweden.*** Several countries have also reformed curricula and school governance, and many emphasize strengthening vocational education. ***Denmark, Spain*** and ***Sweden*** have strengthened adult education; like other OECD countries, they recognise that rapid changes in consumption patterns and technologies will require lifelong learning and thus changes in education and training systems.

Initiatives in some countries also involve foresight activities, *i.e.* identifying future skills needs. The ***Irish*** government established a Future Skills Identification Group in 1996 to assess existing and emerging skills and identify plans to develop those that will be needed.

throughout the OECD area not only as a requirement for sustained economic growth, but also as a means for helping workers to adapt more easily to rapidly changing circumstances and for improving labour market performance (OECD, 1997*l;* 1997*m*). While governments continue to be the main providers of education, policies increasingly emphasize stimulating skills development in close co-operation with the private sector (Box 3.3).

Specific support measures

Policies for SMEs

SMEs are a focal point of the industrial policies of almost every OECD Member country. They are important in terms of economic growth, job creation, and innovation. Policies in this area therefore emphasize the need to meet the particular requirements of SMEs and to provide the means to encourage the establishment and growth of small businesses (Box 3.4).

Box 3.4. **Support for SMEs: some examples from the OECD area**

Austria has recently implemented a number of initiatives to aid SMEs: a soft aid programme for SMEs as of 1 January 1996; the establishment of a new stock market segment for SMEs, which is designed to improve their access to equity capital; the development of a comprehensive management consultancy service aimed particularly at SMEs; and the passing of a law to promote SMEs, which provides a uniform legal basis for all SME-related support activities.

Policies in ***Canada*** acknowledge the importance of small businesses for job creation. Assistance to SMEs is being refocused from a subsidy-based to a commercial and loan-based approach. The 1997 budget increased the ceiling under the Small Business Loans Act from C$ 12 billion to C$ 14 billion, as this programme fills an important need.

In ***Denmark,*** a task force has been established to develop proposals that reduce SMEs' administrative burdens. The initiatives include deregulation, improved co-ordination of public authorities, reporting via Internet or other ICT-based means, and the development of new services for outsourcing administrative burdens. The government has also introduced a guarantee scheme to promote the provision of venture capital to SMEs, and has reformed stock markets in order to open access to them.

In ***France,*** several initiatives aim to support SMEs. Since 1990, the *Commission de Simplification des Formalités* has taken several initiatives to reduce administrative formalities. Furthermore, several measures are in place to stimulate R&D by SMEs or to promote technology diffusion. Measures have also been taken to enhance SMEs' access to information and specialist advice, including audits. Some support is also provided to enable SMEs to attract more qualified personnel.

Germany's policy of "Innovation Assistance to Small and Midsize Enterprises" seeks to create favourable framework conditions for SMEs in business, research and education as they are considered crucial links in innovation networks. The federal government also assists where market failures limit innovation, where there are shortcomings in infrastructure, or where the risk involved is too high for private industry.

Greece feels that SMEs constitute the backbone of its economy. A range of policy measures has been implemented over the past years, many in collaboration with the European Union, to improve the competitive position, flexibility, and adaptability of SMEs. The measures aim to strengthen the internal workings of SMEs by improving organisation, management, and the application of modern technologies; to help provide greater access to markets and technologies and stimulate collaboration; and to stimulate upskilling of the workforce.

In ***Ireland,*** specific initiatives for SMEs include a local partnership initiative to provide advice, mentoring, and seed capital; subsidised and low-interest loan schemes; a programme of administrative simplification; legislation for prompt payments to SMEs applying to government agencies; and an information programme to help small businesses gain access to public procurement programmes.

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Korea has placed substantial emphasis on SMEs over the past decade. Recent policies emphasize measures that support SMEs by eliminating red tape, simplifying procedures, and strengthening links between large and small firms. In 1997, the government also established the Venture Business Promotion Act to accelerate the start-up of technology- and knowledge-based SMEs.

Luxembourg has recently established an action plan for SMEs that aims to promote start-ups and to strengthen existing firms. The plan includes measures to reduce regulatory burdens, enhance SMEs' access to private capital, promote co-operation among enterprises, and strengthen the relevant skills among SMEs' entrepreneurs.

New Zealand has recently refocused its Business Development Programme, which aims to assist SMEs in three ways, namely: providing economic and regulatory information; improving business capabilities; and enhancing co-operation among SMEs and between SMEs and other relevant parties. Policies to improve business capabilities include a – partly subsidised – capability assessment by the Business Development Board; measures to improve practical business skills; a grant scheme to provide assistance regarding business strategy, innovation and R&D, and implementation (*e.g.* market research and advertising); and initiatives to promote business best practices.

Industrial policy in ***Sweden*** includes a wide range of initiatives to support SMEs, many at the regional level. In recent years, several initiatives to improve the access of SMEs to risk capital have been introduced, as the Swedish economy still lacks a properly functioning venture capital market. Several tax breaks have been introduced to promote SMEs, and employers' fees have been reduced in a way that is favourable to SMEs. Support to SMEs also includes assistance with marketing and information. Finally, a Small Business Delegation has been recently appointed to propose concrete ways to cut red tape.

In ***Turkey,*** a programme of the Small and Medium Industry Development Organisation aims to train new entrepreneurs and provide financial, technical and management consultancy services to projects started by them. Policies are also aimed at improving access to financial resources, including risk capital.

Some countries have set up institutions whose explicit purpose is to help SMEs to become established and grow. Several have specific support measures for marketing or financial assistance. SMEs, particularly high-growth firms, also frequently receive assistance to facilitate their access to venture capital and alternative equity markets. Other areas of support include better loan procedures, provision of credit guarantees, promotion of business angels, and tax relief. Considerable emphasis is also placed on improving access to technology and information so as to foster innovation.[8]

OECD governments also increasingly recognise that small companies may have difficulty with the regulatory system, as they tend to lack the necessary financial and administrative resources. Countries address this issue via a range of policies, such as cutting compliance costs, decreasing the paperwork and simplifying regulations and administrative procedures. Such policies do not necessarily focus on SMEs. For instance, New Zealand has implemented a range of measures to minimise red tape, including the introduction of a Regulatory Responsibility Act which aims to impose discipline on the regulatory process by establishing a set of principles to guide regulatory decision making (OECD, 1998*f*).

Promoting internationalisation and export performance

In a substantial number of OECD countries, attention is given in industrial policy frameworks to internationalisation, the promotion of export performance, and an increase in national market shares (Box 3.5). Several measures are used, including financial assistance in the form of export credits and guarantees, as well as information and export assistance services provided by public authorities, and promotional activities (OECD, 1998*f*). Several countries, as diverse as Iceland, Ireland, Switzerland and Turkey, see the promotion of FDI in their domestic economies as an integral part of the internationalisation of their economies. Some countries explicitly aim at making their country a very attractive investment site for foreign companies.

Box 3.5. **Promoting exports: selected policy initiatives**

Austria has taken several initiatives over the past years to improve its system of export financing and guarantees. It currently aims for an "export offensive", on the basis of a broader range of financial instruments, new services for enterprises, and improved institutional procedures.

The ***Czech Republic*** has a range of measures to improve export performance, including export credits, export guarantees and insurance; a stronger role for Czech embassies and centres abroad; trade agencies and promotion of Czech firms' participation in trade fairs and exhibitions.

In ***Denmark,*** various initiatives promote exports, including practical training of students in marketing and export skills, improved use of information and export assistance services and introduction of user fees, help for Danish companies entering selected new markets, assistance to long-term export campaigns, privatisation of marketable export risks and streamlining of state export credit insurance, and exporting finance assistance to ensure internationally competitive terms.

Policies in ***Germany*** include initiatives to expand information and consultancy services to the private sector, harmonisation of export credit insurance in EU member states and in the OECD, the extension of bilateral investment promotion treaties with developing and transition economies, and continued support to trade fairs abroad.

Policies in ***Hungary*** aim at improving financial conditions for exports, for instance through pre-financing and buyer credit arrangements, an export-stimulating exchange rate policy, and better market access conditions for enterprises through economic diplomacy and trade promotion activities.

Norway seeks to promote internationalisation and exports through a range of initiatives, including schemes for credit insurance and export guarantees, regional plans to promote exports to distant markets partly in close co-operation with the business sector, information supply and exchange, and the development of networks.

Export-oriented policies in ***Poland*** aim at a sustainable rise in exports to help increase growth. Among them are financial measures, such as investment relief for exporters and the establishment of an export credit insurance scheme; informative and organisational measures, such as assistance to exporting SMEs and the provision of training services to exporting firms; and specific trade measures, such as the elaboration of a new customs code and a customs duty exemption for indispensable equipment and materials.

While the internationalisation of markets mainly proceeds through multilateral measures and agreements – WTO agreements, European unification, NAFTA and APEC – some governments have also taken unilateral policy actions to reduce border measures. Australia has unilaterally reduced tariffs over the past years, while New Zealand prepared the 1996 APEC Unilateral Action Plan, which aims at unilateral liberalisation in a range of border and domestic policy areas. Several countries, including Austria and Germany, have concluded bilateral agreements with developing or transition countries to promote mutual market access.

Regional policies

Regional industrial policy continues to be an important aspect of the policy framework of several OECD Member countries, including Iceland, Italy, Japan, Korea, Poland, Spain, Sweden, and the United Kingdom. These efforts often aim at improving the economic performance of less developed regions and may have a strong sectoral component if a specific region is geared towards certain economic sectors. Many regional policies explicitly seek to spread the benefits of economic growth to lagging areas in the economy (Box 3.6).

Providing information

Firms both large and small may have difficulty accessing new markets or dealing with the public sector because of lack of information ("information failure"). Several OECD governments are taking

Box 3.6. **Examples of regional policy in the OECD area**

Policies in ***Iceland*** aim at reducing the costs of telecommunications and heating for remote areas or areas where these costs are considered excessive. In addition, explicit efforts are being made to transfer tasks from central to local governments.

In 1992, ***Italy*** introduced Act 488/1992, which aims to provide assistance to all depressed regions of the country in accordance with EU criteria and objectives. The Act replaced a 1986 Act that specifically targeted the *Mezzogiorno* regions. Policies also aim at transferring responsibilities from central to local and regional governments within a federal perspective.

Japan formerly emphasized the dispersion of industries from large city areas to local regions, as well as the adjustment of industrial structures in depressed or disadvantaged regions. Recently, the emphasis has shifted towards a revitalisation of the industrial potential in regions and encouraging the agglomeration of industries in specific regions.

Korea also explicitly seeks to develop regional industries. It aims to establish credit unions in all regions, to be supported by local governments and industrial sectors. It also plans to devise a basic plan for the regional distribution of industries, based on each region's characteristics.

Spain wishes to establish a geographical balance by providing national aid at regional level, in co-ordination with EU support frameworks. The support programmes aim to promote investment in less developed regions and those in industrial decline.

In ***Sweden,*** the focus has shifted from providing public aid to regions with ailing industries or lacking infrastructure to promoting long-term growth by improving infrastructure and the business climate. Recent policies also emphasize the clustering of economic activities and the need to improve the quality of regional networks. To this end, the government has decentralised some responsibilities to regional authorities, which may be in a better position to judge the needs of local business.

Recent policy efforts in the ***United Kingdom*** aim to promote local economic growth by establishing new regional development agencies in England and strengthening those in Scotland and Wales, and by working with the local partners to produce improved regional competitiveness strategies.

initiatives to improve firms' access to information. For instance, Industry Canada recently launched its Strategis Web site, the largest business Internet site in Canada, which provides comprehensive information targeted to meet the needs of Canadian firms. In the United Kingdom, measures are also being implemented to develop an ''Enterprise Zone'' on the Internet. Similar initiatives are under way in many OECD countries, and many relevant ministries now maintain a comprehensive Web site (Box 3.1). Most OECD countries also supply information to firms in other countries, as a means to attract FDI or promote exports.

The role of public procurement

OECD governments continue to use public procurement as an industrial policy tool, although often in a more competitive framework than in the past. For instance, Australia considers initiatives in this area a way to promote industrial development in the areas of telecommunications and pharmaceuticals, for example, without compromising quality or price. In 1994, Sweden passed legislation making public production and purchases above a certain level subject to tender. Turkey aims to rearrange procurement policies in a way that stimulates national R&D efforts and the supply of products and services at world standards and prices.

Improving industrial policy

Policy evaluation

Industrial policy continues to change, partly owing to increasing efforts at policy evaluation. Policy evaluation has contributed to a better understanding of what works and what does not and to a major reorientation of the role of government in modern industrialised economies. Pressures to improve the effectiveness of policy programmes increased in the early 1990s as a consequence of globalisation, the deterioration of public finances in almost all OECD Member countries, and an increasing demand for public sector accountability and better "governance". Improving the efficiency and effectiveness of national support programmes, which annually transfer more than US$50 billion from public budgets to the enterprise sector in the OECD area alone, constitutes a huge task and challenge for governments. Governments need to know whether their policies make a difference and deliver value for money: whether their support programmes are implemented with the right tools, whether they are appropriately administered, whether they achieve the desired results, and at what cost. Policy evaluation is a key tool in this process.

Nearly every OECD country now evaluates at least some of its programmes of industrial and technical support. Some countries are relatively advanced in this area, while others are just starting to set up the administrative environment that will help them evaluate policies. The use of evaluations has increased remarkably in recent years, particularly in the area of innovation and technology policies. Evaluation practices differ widely and often do not achieve the desired results, however. The main problem is generally the feedback of evaluation results into policy design.

Canada's experience over the past years offers a good example of policy evaluation. A government-wide exercise, known as Program Review and initiated in 1994, re-examined and evaluated all government programmes on the basis of six basic questions. Does the activity continue to serve the public interest? Is there a legitimate and necessary role for government? Is the current federal role appropriate or should the activity be realigned with the provinces? Which activities should and could be transferred in whole or part to the private sector? Can the efficiency of the programme be improved, if it is to continue? Is the activity affordable within existing fiscal restraints? Program Review led to considerable realignment of policies and priorities, notably greater emphasis on private/public initiatives in high-growth sectors, framework policies, and provision of strategic information and advice. Support was shifted from subsidies to loans, and assistance was reoriented towards areas recognised as engines of growth, including trade, innovation and SMEs (OECD, 1998*f*).

Benchmarking industrial performance

Benchmarking is emerging as an important tool for improving performance and industrial policy design through exchange of experience, awareness of weaknesses, and diffusion of best practices (Box 3.7). The globalisation of industry and the ensuing heightened competitive pressures have led firms to apply benchmarking methods. In Australia and the United Kingdom, government has also used benchmarking to improve government services, in order to ensure better delivery to customers or clients.

The role of industrial clusters

The analysis of industrial clusters is also leading to changes in industrial policy design. A substantial number of small OECD countries, including Austria, Belgium, Denmark, Finland, Greece, the Netherlands and Sweden, make certain industrial clusters the focus of industrial and technology policy.[9] For instance, Denmark's industrial policy focuses on certain "resource areas" in which Danish enterprises are specialised, thus reflecting the comparative advantage of the Danish economy. These areas are broadly defined and include several industrial and service sectors that are mutually interdependent and linked through their "knowledge base". Industrial policy needs to take account of these interdependencies and the complex interactions between the various parts of the cluster, including public institutions.[10] More specifically, industrial policies may need to differentiate among the resource areas.

Finland's *1996 White Paper* also emphasized the need for a cluster-based approach to practical industrial policy measures. Such an approach was considered consistent with the specialised needs of firms responding to specific market failures. A cluster analysis for Finland (OECD, 1997*n*) covers ten clusters, based on an analysis of export performance and expert opinions. The strongest cluster was

Box 3.7. **Benchmarking for international competitiveness**

Several types of benchmarking can be distinguished. Benchmarking of ***framework conditions*** compares certain sets of conditions, parameters or structural characteristics in different countries. The purpose is to evaluate a particular country's level of industrial competitiveness in a certain area compared to that of other countries. Benchmarking of ***policies*** looks for those that have best promoted industrial or economic performance and therefore can be defined as best practice. An important problem here is the fact that while a particular policy may be effective in one country, there is no guarantee that it will work well in another, as the socio-economic and cultural environment may be quite different and interaction or conflict with other policies or institutional conditions may adversely affect the efficacy of the policy in question.

An example of policy benchmarking is the follow-up work to the report, *Benchmarking the Netherlands – Test of Dutch Competitiveness,* which compared the following parameters for the ***Netherlands*** with those for Belgium, Denmark, Germany, Japan and the United States: monetary and fiscal stability, technological and scientific infrastructure, education, physical infrastructure (transport, telecommunications, energy supply, the environment), capital markets, labour market, product markets, and fiscal infrastructure. The report reached certain conclusions about the Netherlands' position as compared to that of the other countries studied, but did not aim to make policy recommendations. The follow-up study consists of comparative policy studies in specific fields that will lead to policy recommendations for improving the Netherlands' performance.

In ***Belgium,*** the 1996 Act on Competitiveness requires a comparison with Belgium's main trading partners (France, Germany and the Netherlands) to be submitted twice a year to the Central Economic Council and the National Labour Council. An initial version of this report draws attention to the comparability of systems to promote job creation in the four countries and to the lack of coherence and continuity in the policy framework. It recommends improving Belgium's industrial specialisation and a more systematic use of domestic clusters of economic activity.

The ***European Commission*** is involved in several benchmarking projects. Two concern the benchmarking of enterprises, including a project to develop a framework for benchmarking European companies and a project by *Eurochambres* to promote quality awareness programmes for SMEs. Several sectors have also been proposed for benchmarking, including consumer electronics, chemicals, biotechnology, mechanical engineering, construction and automobiles. Finally, the benchmarking of framework conditions currently covers four pilot studies in the following areas: financing of innovation, skills, the new technological and organisational paradigm, and logistics and transport.

The ***United Kingdom*** has recently published its study, *Competitiveness UK,* which involves a broad benchmarking study of UK performance relative to its main competitors. The study first looks at certain measures of competitiveness at the macroeconomic level. It finds that UK income levels are still below those of its major competitors and attributes this to relatively weak investment, including in training and in R&D, and to a low skills level. It then shows how performance varies across the economy. It finds that the United Kingdom has some star performers, but that it trails other developed economies in most sectors. Finally, it looks more closely at seven sectors and draws some important conclusions. It finds that some UK firms match the world's best performance, even in sectors whose overall performance in relatively poor. The study also concludes that competition policy, inward investment, and trade are important ways to improve domestic productivity performance.

The government of ***Australia*** has engaged in many benchmarking activities over the past years. One of the most recent is a study by the Industry Commission, entitled *Assessing Australia's Productivity Performance.* The study finds that Australian productivity growth has not kept up with global trends in the second half of this century, but that it has improved markedly in the 1990s. It notes room for further improvement, as productivity gaps with comparable countries could be narrowed in several sectors, including manufacturing, transport and communication, and electricity, gas and water. The study notes that productivity growth should continue to be a policy priority, while emphasis should be placed on elements that encourage the advance of new knowledge and technology and on better organisation of production among firms and industries.

considered to be the forestry cluster, which includes wood, pulp, and paper products. Other strong clusters or those with great potential are basic metals, energy, and telecommunications.

Economic policy in the Netherlands also emphasizes clusters (Wijers *et al.*, 1997). A recent letter from the Minister of Economic Affairs to parliament notes that market failure may lead to insufficient growth of clusters, and thus a role for government. One policy instrument is the BTS scheme, which emphasizes business-oriented technological co-operation. It provides limited public support for co-operative arrangements; these are selected on the basis of three criteria: degree of technological co-operation, economic potential, and degree of innovation. Cluster-oriented policies in the Netherlands also include a facilitating role for government, for instance through foresight activities and innovative procurement policies.

Policy integration

Because of the increasing complexity of industrialised economies and the need for coherence and complementarity in policy design, industrial policy is becoming more closely integrated with other policy areas in several countries. For instance, as a result of organisational changes in Canada over the past decade, a single ministry is in charge of science, technology and industry policy, an indication of a belief that these policies are complementary and need to be integrated. More recently, in recognition of the importance of human capital in the move towards a knowledge-based economy and of the need for upskilling to improve labour market outcomes, human resource policies have been incorporated as well. Several other countries, including Finland, Ireland and Italy, also emphasize a horizontal policy view.

Many OECD governments also see closer consultation with the private sector as an important way to improve their industrial policy. Germany, for example, is involved in a range of talks with individual industries to help identify specific steps to improve framework conditions for industry, and the United Kingdom has recently established an advisory group of business representatives to contribute to its competitiveness agenda and identify priorities for action.

STRENGTHENING SCIENCE AND PROMOTING INNOVATION[11]

The changing focus of science, technology and innovation policy

The transition to a knowledge-based economy is highlighting the importance of science, technology and innovation and raising new challenges for policy in OECD economies, including the appropriate level of public investment in technology and innovation and the respective roles of government and the private sector. Governments seek to strengthen the role of the science system in innovation by improving the interaction between science and the private sector and to promote technological change and innovation more broadly.

This section discusses recent policy developments in these areas. After a brief discussion of the changing character of government policies, four areas of science, technology and innovation policy are distinguished. The first is direct support for R&D and technical change; it covers direct government funding of the science system and R&D in general, as well the changing orientation of government funding. Direct support for R&D is only one element of science and technology policy, however, and governments increasingly emphasize the broader policy framework that is needed to stimulate innovation. The second area involves policies to improve the interaction between science and industry, and the third is concerned with measures to enhance technological change and to strengthen national innovation systems (NIS). The fourth and final area covers policies that address the globalisation of R&D and innovation, including the protection of property rights.

Governments have two basic roles in developing the science base: providing financial support to scientific research and improving the interaction between science and industry (OECD, 1998*c*). The first has several aspects, namely: the provision of a sufficient volume of funding for long-term research and related training in areas that cannot be financed by the private sector; finding the correct balance between assured and precarious funding so as to stimulate interaction between the scientific community and the surrounding environment; and finding the right balance between mission -oriented support and non-oriented support for curiosity-driven research. The second role involves adequate financial support; measures to stimulate co-operation (*e.g.* collaborative centres and programmes); the removal of barriers to co-operation, such as those due to inadequate patent regulations; and facilitating the mobility of scientists and engineers, *e.g.* by helping scientists to create technology-based enterprises. Governments also have complementary tasks:

- To steer the orientation of research efforts towards future needs, a task complicated by evolving priorities (defence cutbacks, the increasing importance of competition, growing social and environmental concerns), the multiplicity of technological challenges and opportunities, the increasing cost of research, and the emergence of ethical and legal issues related to major technological developments (such as cloning).
- To improve the framework for international scientific and technological co-operation, an area facing new challenges with the acceleration of the globalisation process. An emerging problem is "free riding" in the world S&T community (as firms and countries benefit freely from R&D and innovation efforts carried out and funded by other countries). International co-operation may also be required to face major global challenges, such as climate change.
- To facilitate the adjustment of S&T training and education to deal with upcoming shortages related to the rapid ageing of the scientific workforce and a certain disinterest in science studies and careers among the young in a number of OECD countries.

This science policy framework is currently changing and forcing governments to reconsider their science policies, although approaches differ. Various factors have caused these changes. First, the funding environment for science is changing. While government support to the science base has been relatively protected until recently, this situation is becoming ever more difficult to maintain. Prospects for government support to R&D, in particular to university and public research, point towards further budget cuts in a number of countries and notably in the large scientific powers (see below). However, countries such as Finland, Japan and Korea have recently increased their support for R&D and the science base.

A related development is the relative decline in core funding for university research as compared to contract-based resources (OECD, 1998*c*). A number of factors contribute to this trend. First, core resources usually come from general allocations to universities for both research and education. The overall amount of such funding has often remained stable, despite a significant increase in student enrolments. Second, contract-based funding for specific goals or time periods has risen sharply. Government laboratories have generally been more affected than universities by the reduction in government support, and this has sometimes resulted in a trend towards privatisation and a strong push to make laboratories self-financing by acting as service providers for industry, government agencies, and local communities. While this trend has probably stimulated innovative behaviour by government laboratories, it has substantially reduced the volume of publicly provided research and services provided by these laboratories.

Second, the innovation process is drawing more and more on advances in knowledge by the science base, although there is no linear relationship between the two. Analysis in the United States shows a threefold increase in publication citations in patents delivered over the period 1987-94 (Narin *et al.*, 1997), an indication of stronger links between science and innovation. Furthermore, it has become increasingly clear that the relation between science and innovation is far more complex than a simple progression from basic to applied research and then to technical development and commercialisation. Instead, the innovation process is increasingly seen as an interactive relationship between science and the market, with feedback loops among the different aspects. Ideas that start and stimulate the innovation process in enterprises tend to come from contacts with clients, suppliers or competitors, rather than from discoveries or advances made by the scientific community (OECD, 1998*c*).

Third, science is becoming more and more international. Bibliometric data show a strong rise in the number of joint publications by scientists from two or more countries, a sign that international collaboration has accelerated over the past ten years. Bibliometrics also point to rapidly growing collaboration within regions (Asia, Europe, North America). This results in part from government initiatives but also from trends towards economic and political integration in these regions. The expansion of information technology is likely to stimulate further the globalisation of science, although in ways that are not yet fully clear and will differ across disciplines (see Chapter 7).

The rationale for technology and innovation policies is also changing. It is evolving from correction of market failures towards addressing systemic failures stemming from institutional rigidities and insufficient interaction within the innovation system. Setting overall priorities for technology and innovation policies and establishing the appropriate modes of government intervention continue to be a challenge in most OECD economies.

The increasing importance of technology as a determining force in economic performance (see Chapter 2) points to the need for coherent policies to promote innovation. Government policy in OECD countries increasingly focuses on establishing appropriate conditions for technological change, partly because the policy stance is shifting from direct support to attention to framework conditions. Technology and innovation policies have tended to evolve from direct support to innovative efforts to policies that enhance technology diffusion. Furthermore, strengthening the links in NIS, building innovative capacity, enhancing organisational innovation and training, strengthening support for SMEs, and promoting innovation in and diffusion of environmental technology are core policy areas. The interdependence of technology and innovation policies with industrial, science, and education policies, and the need to adopt a horizontal approach both within and across these policy areas, are also an underlying concern.

Technology policy is also shifting from promoting innovation in ''hard'' to ''soft'' technology. Most OECD technology policies now recognise the need to invest not only in R&D, but also in ''intangibles'' such as upgrading skills through training and education and adopting new work practices and organisational change. To adopt technologies acquired elsewhere successfully, new skills and knowledge are necessary, and organisational change and new work practices are required to realise the productivity gains enabled by new technologies, such as ICT.

Governments do not deal with these questions at national level alone. They are also trying to reap the benefits of the globalisation of industrial research and to facilitate growth through collaborative international technology efforts. Multinational firms tend to optimise the location of their laboratories, and this may significantly affect how national research efforts evolve. Traditionally, countries' innovative and technological developments drew extensively on national research; while this is still the case, the globalisation of industrial R&D will gradually modify this pattern.

Direct support for R&D and technical change

Direct government support for R&D

Governments can support technological change in various ways. The principal method is direct government funding of R&D, with the R&D performed by the government itself, often in government laboratories, or by the higher education or business sectors. This type of funding has dropped in relative terms over the past decade, and is likely to continue to do so in the near future. The decline is mainly due to falling defence expenditures in a number of major OECD economies and increased fiscal constraints (see Chapter 6). In some countries, establishing new priorities for science and technology following the end of the cold war may also affect funding.

In adjusting to more stringent budgets, countries have adopted different approaches. A first pattern, characteristic of several English-speaking countries, has been to subject the resource allocation process to closer scrutiny by reinforcing selectivity, drastically reducing support to areas no longer considered a priority (such as defence), making government support conditional on matching business funding, and increasing *ex post* evaluation efforts to ensure that governments get the best value for money. This process has stimulated research. On the whole, bibliometric indicators show that the science base in such cases continues to be very productive. Interaction between science and industry has also intensified, with patents and innovative activity increasingly drawing on publicly supported science.

In the United States, the changes are primarily due to the sharp reduction in large-scale defence, space, and energy programmes that began in the late 1980s. The decline in large government contracts appears to have affected basic research in universities and the creation of high-technology firms by university staff, which in the past played an important role in the country's innovative dynamism (Mowery, 1992). In view of the importance of US science and innovation to the global community, these trends may be worrying. However, the US academic community appears to have adopted a more positive attitude towards collaboration with industry, government agencies and others, and research continues to flourish.

Until recently, long-term US budget projections suggested a continued decline in government expenditures over the period to 2002 (American Association for the Advancement of Science, 1997; 1998). However, recent improvements in the US government budget situation suggest a more positive outlook. The budget for 1998 indicates a rise in government support as compared to 1997, with higher funding for the National Science Foundation (NSF), the National Institute of Standards (NIST), and applied research at the Department of Defense (DOD). Funding for the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), and basic research by the Department of Defense looks set to decline substantially from 1997 levels. The proposed budget for 1999 provides an even more positive outlook. Overall funding for 1999 is up by 3 per cent from 1998, with basic research increasing by 8 per cent, applied research by 5 per cent and development falling by 1 per cent. The increase would be entirely in civilian research, defence funding remaining stable. The budget proposes considerable increases for Health and Human Services (up by 9 per cent), NSF and DOE (up by 11 per cent) and a 1 per cent cut for DOD and a 3 per cent cut for NASA. Over the long term, the budget proposes a Research Fund for America, comprising most civilian research in the budget. This Fund would increase by 8 per cent from 1998 to 1999 and by 32 per cent over the 1998-2003 period. The most recent analysis by AAAS (American Association for the Advancement of Science, 1998) is less optimistic and suggests that the overall R&D budget over the 1998-2003 period will fall by 3.3 per cent. Non-defence R&D would increase by almost 9 per cent in real terms, however.

In the United Kingdom, the resource allocation process has been considerably tightened, with increased peer review and greater use of quantitative evaluation criteria, such as publication rates. While greater efficiency may indeed be called for, these measures carry the risk of excessively concentrating research in a limited number of establishments. Spending up to 1999 is expected to remain relatively stable in nominal terms (Office of Science and Technology, 1997), *i.e.* slightly lower in real terms, although the science budget appears likely to receive a slightly higher share of total expenditure at the expense of higher education and civil departments. The UK budget continues to emphasize three main areas for support: improving interaction between science and industry, increasing basic and strategic science, and enhancing people-related programmes. Some 70 per cent of all funding by the Research Councils is in areas that were given priority in UK foresight studies.

In Canada, budget cuts have been much more drastic and have resulted in a very difficult situation for the universities. Federal support by the Canadian government for R&D is projected to decline further, from C$ 3.4 billion in 1996-97 to less than C$ 3.1 billion in 1997-98, a decline of 10 per cent in nominal terms (Statistics Canada, 1997). Projected annual inflation of around 1 per cent suggests a somewhat larger decline in real terms (OECD, 1998*a*). From 1996-97 to 1997-98, Australia's support for R&D is expected to increase in nominal terms, from A$ 3.5 billion in 1996-97 to A$ 3.6 billion in 1997-98. In real terms, this represents a decrease of 1.3 per cent, most of it due to changes in the rate and application of the industrial R&D tax incentive (Australian Government Publishing Service, 1997). New Zealand has moved towards contract-based science funding as part of its overall policy to push market-based principles. Science policy has been significantly restructured since the early 1980s, and the orientation of support has been completely separated from funding. While the results have been positive on the whole, this policy has induced a certain "short-termism" in research projects (*Nature*, 11 January 1996).

A second pattern characterises the countries of continental Europe. These have maintained, until recently, their overall support for science. However, persistent rigidities prevent significant reallocations among departments, disciplines and institutions and risk causing the sclerosis of research teams and the relative impoverishment of researchers, and may render scientists insufficiently responsive to industry needs. Over the long term, this could lead to the deterioration of both the science base and the innovative potential.

Some governments have reacted against these tendencies. Germany has recently decided to introduce more competition and selectivity for resource allocations to public laboratories, for both basic and applied or technical research. Science funding in Germany, after a decline in 1997, has now stabilised. The 1998 budget for the Federal Ministry of Education, Science and Research (BMBF) increased by 0.9 per cent from 1997. Multimedia, environmental technologies and innovation-enhancing measures are among the areas receiving additional funding. Government funding in France was reduced somewhat for 1997 and 1998, and public research institutes were ordered to reallocate some of their expenditures to the areas considered to have the greatest economic and job creation potential. Policies in France also stress measures to strengthen NIS, for instance by encouraging personnel mobility and greater co-operation between the science system and the private sector (État de la recherche et du développement technologique, 1997). The Netherlands has increased the relative importance of contract-based finance in the university system, while the government laboratory network, notably the TNO (Netherlands Organization for Applied Scientific Research) laboratory, has been obliged to increase its self-financing. The Netherlands' science budget (Ministry of Education, Culture and Science, 1998) indicates a stabilisation of nominal expenditure at around Gld 5.3 billion, a slight decrease in real terms.

Several Scandinavian countries have engaged in reform of their funding agencies, although resource allocation processes and research structures continue to suffer from fragmentation in some. The most significant initiative is in Finland, where despite tight public finances, the government plans to increase its R&D effort by 25 per cent over the period 1997-99. A large part of these funds will be earmarked for technology programmes and basic research in universities on a competitive basis. Furthermore, some reallocation of resources among sectors is also taking place through an incentive mechanism that stimulates the different departments to fund R&D by matching funds from a central R&D budget.

The European Commission has recently proposed its 5th Framework Programme for the period 1998-2002 (European Commission, 1997*b*). Thus far, EU research ministers have reached agreement on an overall budget of ECU 14 billion, which is substantially below the ECU 13.2 billion approved for the 4th Framework Programme over the period 1994-98 (European Commission, 1998). The bulk of the funding would support three thematic programmes on unlocking the resources of the living world and the ecosystem, creating a user-friendly information society, and promoting competitive and sustainable growth.

The Asian OECD economies can be considered to represent a third pattern. In these countries, there is a strong commitment to strengthening public spending on R&D. In Japan, despite the slowdown in economic growth and severe budget problems, support to R&D, and particularly to basic research programmes and structures, remains a clear priority. The government's five-year plan for science and technology aims to increase spending by 50 per cent between 1996 and 2001. The science budget for 1998 is set to increase by 4.9 per cent over 1997, with particularly increased support for basic science (*Nature*, 1998*a*). Substantial funding increases for 1998 were given to the life sciences, particularly brain- and genome-related research; to science-related grants and post-doctoral fellowships supported by the Science and Technology Agency and the Ministry of Education, Science, Sports and Culture (Monbusho); to collaborative research between industry and science supported by both the Ministry of Trade and Industry (MITI) and Monbusho; and to science related to global warming. Support for space programmes, nuclear power and national universities has fallen, however. In Korea, the government also continues to emphasize public R&D spending, despite serious financial and industrial problems (*Nature*, 1998*b*). The government's five-year science and technology plan seeks to increase government expenditure on S&T from about 3 per cent now to 5 per cent by the year 2002. The plan is designed to modernise Korea's science system and enhance the economy's innovation potential.

Important changes in research policy have also taken place in the less developed OECD countries and regions, partly owing to international support. The countries of southern Europe and Ireland have benefited from support by the European Commission, notably the structural funds. These have financed about 50 per cent of infrastructure costs and facilitated the integration of these countries into the European research community. Mexico's science effort has benefited from World Bank support. It should be emphasized, however, that linkages with local industrial needs are far from being ensured in several of these countries.

In the former planned economies, science was part of a hierarchical and compartmentalised innovation system. Institutions for higher education were permitted to pursue research activities only on a limited basis (with some exceptions, as in Poland), and basic and applied research was largely the responsibility of the science academies and related institutes. Branch institutes were in charge of industrial and technical research. Following the collapse of the communist regimes and major economic recessions in these countries, resources for research have been considerably reduced and this has led to a significant brain drain. Reforms to develop university research have been implemented. However, in more than one country, these have met with resistance from the established institutions (for example, several academies have refused to relinquish their monopoly on research). Moreover, the substantial reduction in the S&T capabilities of branch institutes has not been yet compensated by the development of private sector research.

Given these projections, overall public funding of R&D appears likely to remain relatively stable over the coming years. The US prospects remain somewhat uncertain. Furthermore, although Japan and some smaller OECD economies aim to increase government funding of R&D, other major OECD economies may further reduce funding. The impact of further cuts remains unclear, however, and much depends on how and where they are made.

The tax treatment of industrial R&D

Governments can also support technological change by providing tax incentives for industrial R&D. While these remain relatively limited compared with direct support for R&D, they have increased in importance over the past decade and are likely to continue to do so (OECD, 1998*c*). By the end of the 1980s, fiscal R&D incentives corresponded to only 1 per cent of government-financed R&D in Japan, about 3 per cent in France, Germany and the United States, and 10 per cent in Australia and Canada.

Governments can use a number of instruments to reduce the after-tax cost of business R&D, namely: accelerated depreciation of investment in capital stock used for R&D activities, full deductibility of current R&D expenditures from taxable income, additional tax allowances enabling firms to deduct more than 100 per cent of their R&D expenditures from taxable income, and tax credits allowing firms to deduct a percentage of their R&D expenditures from their tax liabilities (OECD, 1996*g;* 1998*c*).[12]

All OECD countries for which information is available (*i.e.* except the Czech Republic, Hungary, Luxembourg, and Poland) allow accelerated depreciation of equipment used for R&D, often at a preferential rate compared to other types of equipment. Almost all OECD countries, with the exception of New Zealand, allow current business expenditures on R&D to be fully deducted for the year in which they are incurred, and several extend this favourable tax treatment to earlier R&D expenditures. Ten OECD Member countries provide additional tax incentives for R&D: Australia and Austria allow extra R&D depreciation allowances amounting to 125 per cent (150 per cent until 1996) and 118 per cent, respectively, of current R&D outlays; and Canada, France, Italy (for SMEs), Japan, Korea, the Netherlands, Spain, and the United States offer R&D tax credits.

The tax treatment of R&D differs in other ways as well, such as the impact of tax treatment by central and regional governments (Belgium, Canada, Switzerland, and the United States); the definition of eligible R&D expenditures; the fiscal status of tax benefits; the existence and nature of a ceiling on tax benefits; the treatment of loss-making firms; and differences in the definition of the reference amount of R&D on which eligible incremental R&D is calculated. Equally important are differences in the degree of selectivity of tax incentives, *i.e.* whether they are more favourable to or exclusively for certain types of firms, technologies, or innovation expenditures.

Important changes in the tax treatment of R&D have taken place in some countries over the past 15 years (OECD, 1998*c*). Australia, Denmark, France, Korea, the Netherlands, and Spain substantially increased fiscal support to R&D, while the tax treatment of R&D activities for firms in Sweden and the United States, and, to a lesser extent, in Italy (mainly large firms) became less favourable. Between 1981 and 1996, the tax treatment of R&D in most OECD countries became more generous, but direct financial support to R&D was reduced; in a sense, tax allowances replaced subsidies. Only Italy and Switzerland have done the reverse, although to a limited extent.

The orientation of government-supported R&D

Given the need to cope with budget reductions, governments face serious problems in identifying where to centre their research efforts. In France, the United Kingdom and the United States, the "downgrading" of defence has helped governments to cope with immediate budget problems, but S&T policy has yet to identify new targets for support. Like many other countries, these countries often use policy as a means to boost competitiveness. This goal is not easily achieved, however, as it requires close interaction with the business sector in selecting R&D projects and areas. In addition, governments are generally prevented from directly subsidising R&D projects, an anti-competitive practice that has proven ineffective in any event. Therefore, governments are often led to support basic research for generic technology developments and to limit their support to pre-competitive R&D.

Support for technical change has been significantly affected by the massive reduction in large-scale defence programmes, by cuts in space and energy funding, and by the reluctance of governments to embark on large programmes for transport or telecommunications infrastructure. Support for R&D for "industrial development" has also declined in most OECD economies. The only major exceptions are support for "information highways", often linked to substantial private financing, and health, the environment, and knowledge in general, areas which have gained in importance over the past decades.[13]

Several OECD economies continue to make support for health and medicine a priority of their science budgets. This reflects strong pressures for technological change in this area (see Chapter 1) as well as the great potential of new technologies, such as genome research and biotechnology. Support for R&D has played an important role in accelerating innovation in this area. Many countries continue to give substantial support to the development and use of information and communication technologies, often in order to facilitate the move to the "information society" or the "knowledge-based economy". Several countries also emphasize efforts to develop and diffuse environment and energy technologies. This is a particular concern for new OECD members in central and eastern Europe faced with the task of restructuring the energy- and pollution-intensive industrial heritage of the planned economy era. Public intervention is necessary, as market mechanisms are insufficient to ensure adequate efforts to develop and diffuse technologies for sustainable development.

Political and institutional frameworks can constitute an important constraint on priority setting and budget allocation. In many countries, the government budget for R&D is the shared responsibility of several ministries (OECD, 1998*c*). In France, Germany, and the Netherlands, the ministry in charge of education and science is responsible for more than half of all R&D funding, while in Australia, Denmark, and Japan, most R&D spending is the shared responsibility of the ministry of education and a science and technology agency. In the United States, the Department of Defense accounts for almost half of all funding. In Canada, R&D funding is spread over many entities. The pluralistic US political system, for instance, allows for a relatively good reflection of national priorities in the R&D budget, but has more difficulty in ensuring continuity of scientific research.

The choice of scientific priorities is further complicated by a tendency towards saturation in some disciplines. Returns to investment appear to be declining in areas such as particle physics, and this has led some observers to point to the "end of science" (Horgan, 1996). On the other hand, major technological breakthroughs, as in genome research, as well as the increasing importance of interdisciplinary work, suggest that the potential of science is far from exhausted.

Improving the interaction between science and industry

The science system continues to be a main source of expansion of an economy's knowledge base. Science only becomes "useful", however, when it is embodied in goods or services and/or reaches a broader public. A major challenge to governments is therefore better interaction between industry and university. Relevant initiatives in the OECD area include the establishment of centres of excellence, co-operative R&D centres, and science parks (Box 3.8).

Other programmes may also strengthen science-industry links.[14] Some countries subsidise in part the costs of research contracts with universities or government laboratories or the costs of employing university researchers on a fixed-term basis. Evaluations in France, Germany, and the Netherlands have generally been positive; however, these incentives are generally meant to increase SMEs' capacity to integrate research rather than to boost their capacity to innovate in the area of advanced technologies.

Other relatively efficient schemes are those facilitating the placement of young academics in firms, where they undertake a specific project under the close supervision of university professors. The Teaching Company Scheme (TCS) in the United Kingdom has been particularly successful and has served as model for a number of other countries (*e.g.* Canada's industrial research fellowships). Similarly, Denmark has developed industrial PhDs, in which graduates are placed in industry to do their research; this has been quite successful. New Zealand has recently established the Graduates in Industry Fellowship programme, which intends to support S&T-based projects in industry by improving university-industry linkages and by increasing the number of science postgraduates in industry.

Box 3.8. **Policies to improve the interaction between science and industry**

Centres of excellence are appearing in a number of countries and receive significant government funding. Each centre often receives around US$500 000, generally for a period of three to five years, with some matching funds required from industry. They are generally located in academic settings and draw on university staff. They are increasingly "virtual"; often, several teams located in various places collaborate in these "research units without walls". The centres are generally interdisciplinary, concerned with generic technology, and serve as sites for training doctoral and "post-doc" researchers. In most countries, they seem to be considered effective and receive renewed funding following the initial period. This suggests that they are good candidates for strong, selective support.

Co-operative R&D centres are generally set up for research of a more applied or technical nature. Industry is required to match funding on an equal basis. While countries such as Germany have a long tradition of such co-operation (the *Fraunhofer* system), others have used these centres to bring industry and university closer together. Evaluations of these centres are generally quite positive (extensive evaluations have been conducted in Australia and the United States), provided that funding is adequate, industrial involvement serious, and the topic well-defined. Joint industrial and academic work at these centres seems to change significantly the "culture" of both parties and to contribute to the establishment of fruitful and durable exchanges of ideas and personnel. However, evaluations report few significant innovations resulting from these collaborations.

Inspired by some famous US examples, some countries have found the concept of ***science parks*** very attractive. These initiatives are also known as technology parks or, when their scope is larger, "science cities". Unfortunately, on the basis of available evaluations and an already sufficient duration, successes appear relatively infrequent, as measured in terms of creation of enterprises, jobs, etc. Success depends on various factors, including an appropriate infrastructure, such as business incubators and services (consulting, venture finance), proximity to a research university, a dynamic industrial base, and possibly even access to an international airport (although telecommunications may make this less important). In addition, interaction among all the actors must be effective, as it has proved to be, in particular, in Finland.

Increasing technical change and innovation

In addition to efforts to support the science system and improve links between science and industry, governments use an increasingly wide range of policy instruments to encourage technological change and innovation. Some of these policies are closely linked to efforts to strengthen the framework conditions for industrial performance (discussed above). For instance, measures that encourage tangible and intangible investment, skills development, or a coherent industrial policy, are closely linked to technology and innovation policy. In addition, policies that seek more specifically to encourage technological change and innovation include initiatives that promote venture capital, technology-based firms and technology incubators, technological diffusion, and public/private partnerships.

Governments increasingly stimulate the supply of ***venture capital*** by modifying fiscal and regulatory frameworks and by establishing programmes to mobilise venture capital in support of small, innovative firms (OECD, 1997*o*). These programmes aim to fill the "funding gaps" that prevent small businesses, particularly technology-based firms, from obtaining sufficient capital and thus from generating public benefits in terms of innovation and job creation. Government venture capital schemes aim to remedy deficiencies in private capital markets, to leverage private sector financing, and to nurture technology-based firms over the longer term (Box 3.9).

Governments should use caution in supplying venture capital directly, since this may create distortions if investment decisions are based on non-economic criteria or if there are overlaps with regional/local programmes. Poorly designed direct government schemes can lead to poor returns at high public cost. Good practice in designing government venture capital programmes includes the following elements: *i)* government venture capital programmes should address market failures and funding gaps arising from inadequacies in the country's financial system; *ii)* they should be designed to exclude inappropriate investments; *iii)* they should stimulate and strengthen private venture capital and be phased out as private capital markets mature; *iv)* the private sector should participate in the design and management of government programmes; *v)* attention should be paid to simplicity of application procedures and dissemination of information about government programmes; and *vi)* government programmes should be evaluated and assessed on a regular basis (OECD 1997*o*).

Technology policy in the OECD area is also giving greater emphasis to ***new technology-based firms*** (NTBFs). For instance, in France, financial support and fiscally attractive ways to use "stock options" aim to encourage the start-up of innovative firms. While technology and innovation policies in general – including R&D tax incentives, funding of basic research, closer links between science and industry, and promotion of technology diffusion – may affect the emergence and survival of such firms, specific policies also help them emerge (OECD, 1998*c*). Technology incubators, for example, have been used since the 1980s to nurture NTBFs (OECD, 1997*p*). They combine the usual functions of business incubators, providing ready access to a package of services that help nurture new firms, with that of organising close links to providers of resources of special importance to NTBFs (scientific and technical expertise or venture capital). Less specifically designed for NTBFs, but of great importance to them, are policies to improve the access of SMEs to information, high-skilled labour, and large-scale public S&T programmes (see above). Measures to assist small firms to hire qualified individuals are widespread, especially in Europe. In general, they do not target NTBFs but aim at increasing the technical and managerial capabilities of existing SMEs.

Technology policies also increasingly involve co-operation with the private sector. ***Public/private partnership programmes*** are designed to address market failures and under-investment in R&D. Many government technology diffusion programmes as well as those directed at building the innovative capacity of SMEs are based on P/PPs. These programmes may involve direct or indirect public funding of private R&D or direct provision of public R&D resources to infrastructure investments. In the United States, the government uses P/PP programmes for both frontier technologies and the diffusion of technology to SMEs. For instance, the Advanced Technology Program (ATP) awards matching funds to industry on a competitive basis to conduct research on cutting-edge technologies with economic potential that would not be undertaken if left to the market. Created in 1988 to strengthen the international competitiveness of smaller US-based manufacturing firms, the Manufacturing Extension

Box 3.9. **Stimulating the provision of venture capital**

To finance the innovation process, venture capital is essential. Venture capitalists are needed to support high-risk investments in small firms, particularly technology-based firms, which are passed over by traditional financial institutions. Governments can support venture capital for SMEs by creating proper economic, institutional and regulatory frameworks within which markets can channel resources effectively to new and innovative enterprises. For example, governments can encourage the development of secondary stock markets, encourage financial institutions to offer a wider range of products, stimulate networking among large and small firms, and facilitate entrepreneurship. Such indirect measures are closely related to direct measures taken by governments to increase the supply of venture capital.

There are broadly three types of direct government measures: *i)* direct supply of capital to venture capital firms or small firms; *ii)* financial incentives for investing in venture capital funds or small firms; and *iii)* regulations controlling types of venture capital investors. The first of these is the most high-profile and high-risk way of providing financial resources to venture capital funds or small firms; in this case, capital is generally provided as equity or low-interest loans. The number of such programmes is limited but increasing in the OECD area. Financial incentives are more widely used and are intended to stimulate private sector investment; they most often take the form of tax credits or deductions, guarantees of loans taken out by venture capital firms or by small start-ups, or guarantees of equity investments made by venture capital firms. Investor regulations, for their part, are now being reviewed and revised in many OECD countries in order to broaden the types of institutions, such as pension funds, permitted or encouraged to make venture capital investments.

Many OECD countries have government programmes to stimulate venture capital markets (OECD, 1998*f;* 1997*o*). Some are general, and others are specifically aimed at SMEs (see above). In most countries, the policies include a mix of direct and indirect measures. ***Austria,*** for instance, aims to promote a network of ''business angels'' by stimulating co-operation with banks, financial institutions, and industry organisations. In ***France,*** a new stock market for innovative firms was created in 1996, while fiscal support is offered to persons participating in innovative firms. ***Germany*** has several initiatives to improve the rules governing the use of private sector venture capital by new firms and SMEs, as well as specific support instruments, such as the Equity Capital Assistance Programme to promote independent companies. In ***Iceland,*** several initiatives have been taken over the past few years to improve access to venture capital, including tax incentives and the establishment of a special innovation fund, which will start operations in January 1998. ***Norway*** has several public financing schemes which aim to ease access to risk or seed capital; in a new scheme, the government will provide a contribution, providing its share is at least matched by contributions from the private sector. ***Portugal'****s* PEDIP II programme also aims to improve firms' access to venture capital, by creating venture capital funds and promoting SMEs' access to capital markets.

Apart from national programmes, many countries also have local or regional initiatives. For example, in the ***United States,*** most of the 50 states have some type of venture capital programme. ***Ireland, Italy, Spain,*** and the ***European Commission*** all have regional venture capital schemes targeted towards economically disadvantaged regions. It is important for venture capital programmes at different levels or for different purposes to be part of a coherent system; overlaps and inconsistencies in publicly supported programmes could introduce distortions and inefficiencies into capital markets and venture capital supply.

Partnership provides information, decision support, and implementation assistance to smaller manufacturing firms, enabling them to adopt more advanced techniques and business best practices. Improving competitiveness is also the aim of a new P/PP initiative in the United Kingdom, Competitiveness UK (OECD, 1998*f*).

Although promotion of R&D constitutes the basis of technology and innovation policy, the policy emphasis continues to shift towards ***diffusion of technology*** rather than direct support of R&D. Technology diffusion often plays a more important role in determining firms' productivity than innovations generated within firms. Public policy on technology diffusion has shifted from transferring public research results to the private sector to improving the capacity of firms to absorb technology. This shift stems from the realisation that successful adoption of technology depends on the management, organisation, and skills of firms and that simply promoting specific technologies does not suffice. However, it is also recognised that the processes of technology creation and diffusion are interdependent, and that firms' capacities for creating or adopting new technologies are essentially similar. Government policies for technology diffusion attempt to address both market and systemic failures and to maximise returns from public investment in R&D (Box 3.10).

Experience in implementing a wide range of policy instruments for technology diffusion suggests some best practice principles (OECD, 1997*q;* 1998*c*). At a general level, technology diffusion should be integrated with other policy areas and coherent with other policies. In designing diffusion programmes, governments need to pay attention to: ensuring quality control in technology diffusion services, building on existing resources, promoting organisational change, and maintaining close links with industry groups and associations. Also, such programmes should be responsive to societal concerns about the environment, health, and education, and should ideally be linked to foresight programmes.

The concept of the ***national innovation system*** is becoming important in technology and innovation policy. It concerns flows of technology and information among firms, individuals, and institutions as the key to the innovation process (OECD, 1997*r*). NIS analysis aims to improve our understanding of the often complex relationships among the actors in the system. Better understanding of knowledge flows can help pinpoint problem areas – the so-called systemic failures – and aid policy makers in their efforts to improve networking and enhance knowledge flows.

In terms of the NIS concept, the main analytical focus is on knowledge flows, which can be subdivided according to: *i)* knowledge flows among industrial firms; *ii)* knowledge flows among firms,

Box 3.10. **Selected technology diffusion initiatives in the OECD area**

Initiatives directed at promoting technology diffusion are of four types: supply-driven, demand-driven, network-based and infrastructure-building (OECD, 1997*q*). ***Supply-side programmes*** basically seek to transfer and commercialise publicly developed advanced technologies to the private sector. An example is the ***Canadian*** Space Agency's Space Station Programme which supports the transfer of dual-use technology (*e.g.* robotics) to firms for use in areas as diverse as agriculture, automation, and toxic waste management.

Demand-driven programmes aim to identify and assess the technological needs and opportunities in enterprises, especially SMEs, and complement existing private sector mechanisms for technology diffusion. They often help SMEs solve managerial, training, or financial problems so that they can develop. An example is the ***United States'*** Manufacturing Extension Partnership (MEP) programme which helps smaller American manufacturing firms to adopt needed technologies and to improve their business practices by providing appropriate information. Similar programmes are ***Austria's*** MINT (Managing the Integration of New Technologies), ***Norway's*** BUNT (Business Development Using New Technologies), and the ***United Kingdom's*** Business Links network programmes.

Network-based initiatives attempt to link institutions in partnerships to promote information flows and technology diffusion and commercialisation, often within a specific region. In ***Germany,*** the government has found that research does not sufficiently result in successful products or services. In order to build interdisciplinary networks, it currently promotes "flagship projects", chosen on a competitive basis, in areas of action regarded as important by business, science and government. In ***France*** and the ***Netherlands,*** innovation centres act as regional intermediaries to strengthen links and technology diffusion between firms and private and public sources of knowledge.

The ***infrastructure-building approach*** aims to increase the diffusion capacity of the entire national technology infrastructure by combining supply, demand, and networking approaches. The technology diffusion programmes of a catch-up economy like ***Korea*** can be characterised as infrastructure-building, and are aimed to increase the absorptive capacity of the economy by augmenting the endogenous capacity of the economy. However, most countries have developed mixes of technology diffusion initiatives that reflect their particular national innovation system and the situation of their industries. In order to develop effective policies for technology diffusion, the technological capacities of firms need to be accurately assessed. Some OECD countries are developing various diagnostic and benchmarking tools for this purpose.

universities and public research institutes; *iii)* diffusion of technology; and *iv)* mobility of personnel (OECD, 1997*r*). Recent trends suggest increasing emphasis on some of these channels. For instance, inter-firm R&D collaboration and technological alliances are increasing, particularly in high-technology industries where development costs are high (see Chapter 6). Technology diffusion studies have also shown the importance of the mobility of personnel, whose skills and networking capabilities are central to the implementation and adoption of new technology.

New analytical tools are being introduced to study information flows in national systems of innovation. These include innovation surveys, cluster analysis (see above), and tools to measure international technology flows, such as patents and capital goods. These tools can be used to measure knowledge flows and to map institutional linkages, human resource flows, industrial clusters, and innovative firms.

Several OECD countries are adopting policy measures to increase the networking of various actors in the NIS. For instance, Denmark is introducing a range of new institutional arrangements to improve co-operation and networking among universities, public research institutions and private enterprises to facilitate the diffusion of knowledge to SMEs. New initiatives include the establishment of research centres to promote co-operative research between private enterprises, universities and specialised research institutes, and innovation centres established in connection with universities and institutions that can provide financial and advisory services to entrepreneurs, new businesses, and potential entrepreneurs among academics and students (OECD, 1998*f*). Several of the policy initiatives discussed above – P/PPs, technology diffusion programmes, technology incubator programmes, as well as programmes aimed at improving the interaction between science and industry – can strengthen knowledge flows in the NIS.

Addressing the impacts of globalisation

The challenge of globalisation

Government technology and innovation policies will have to adjust to the increasing globalisation of industrial research, as more multinational enterprises invest in research facilities abroad.[15] The largest OECD firms now conduct nearly 20 per cent of their research abroad and, for some OECD Member countries, more than 50 per cent of their national firms' R&D is being performed outside the country (see Chapter 2). While market access remains important in the globalisation of research, it is increasingly driven by the desire to tap into foreign sources of skilled personnel and technology.

Many home governments of firms investing abroad are worried about the "hollowing out" of their research capabilities and the effects on long-term innovative capacity. Conversely, governments that host foreign research are concerned about a possible outflow of knowledge and technology and greater competition in local markets. Policies to capture the benefits from both inward and outward R&D investment are still in a state of flux. Adapting to globalisation requires a more flexible society and economy, with a greater ability to gather, assess, and apply globally available knowledge and technology. Policies to address globalisation thus involve upgrading the indigenous technology base and strengthening the NIS linkages to obtain spillovers from research, wherever it is conducted. National innovation policy must also address the quality of universities and research institutes, the skills and flexibility of the labour pool, the degree of access to venture capital, and a range of other enabling conditions sought by multinational enterprises.

Improving competitiveness in a framework of industrial globalisation requires greater openness and international collaboration in R&D. Today, it is difficult to develop excellent technology without global co-operation among enterprises and without involving governments. The trend towards a global innovation system is intensifying pressure for harmonisation of government approaches towards intellectual property protection, competition policy, taxation, regulation, and other framework conditions. Policies are particularly important in two areas, international collaborative R&D and the protection of property rights in a globalising world.

Strengthening international collaborative R&D

International collaborative R&D has grown rapidly over the past years. It brings together complementary inputs, enhances the effectiveness of research, and increases the breadth and speed of diffusion of new technologies. Encouraging such endeavours has therefore become a priority for national S&T policies.

The globalisation of R&D calls for increased attention to the ***international dimension of intellectual property regimes.*** There are increasing demands for countries to set high and effective standards for intellectual property protection and its enforcement. They are called on to recognise the special intellectual property needs of industrial sectors whose inventions, because of regulatory requirements, reach the market with considerable lags well after the patent has been granted and to ensure that intellectual property protection is maintained in a context of rapid technological change.

Despite the considerable harmonisation achieved through the WTO Trade-Related Intellectual Property Rights (TRIPS) Agreement, differences in intellectual property regimes continue to impede research investments in other countries and international collaborative R&D. There are basic differences in filing rules, assignment of rights, criteria for patentability, and disclosure of information. The lack of predictability in intellectual property standards, enforcement, and litigation hampers firms' global operations, particularly in new technology fields. The need for detailed intellectual property agreements for international projects increases the costs and complexity of collaborative research. Despite progress in harmonisation, more needs to be done to increase the compatibility of IPR regimes and to develop frameworks to facilitate the R&D co-operation that is fundamental to a globalised knowledge-based economy.

Other legal and regulatory differences also affect ***international joint ventures in R&D.*** Specific constraints (*e.g.* taxation) may go unrecognised and legislation (*e.g.* competition law) may differ. Problems arising from differences in national approaches may affect the willingness of firms to engage in collaborative international research, the design and effectiveness of the joint ventures, the likelihood that the results will be effectively and rapidly exploited to benefit users and consumers world-wide, and the extent to which the results will serve as stepping stones for further technological advances. A combination of factors stemming from differences in national IPR regimes may work against their main goal, which is to foster innovation, encourage its commercial exploitation, stimulate further technological progress, and, ultimately, promote economic and social development.

The search for solutions to problems currently encountered by international collaborative research projects should go hand in hand with broader attempts to harmonise national IPR regimes, particularly patent systems. Such attempts are being made in the context of the World Intellectual Property Organisation (WIPO) and the WTO TRIPS Agreement. However, new internationally recognised norms may be needed to reflect the increasing trend towards globalisation and the particular circumstances of industries in rapidly evolving or new technological areas. Efforts are needed to develop procedures that balance the interests of intellectual property owners and users as well as the needs of national and international actors.

In the past, a number of governments have taken restrictive measures regarding the involvement of foreign firms in advanced technology centres or programmes or have, when authorising the participation of foreign enterprises, established discriminatory rules for the exploitation of patents and the commercialisation of research results (OECD, 1997*s*). Ongoing discussions on appropriate frameworks for international technology co-operation may help to avoid such conduct in the future. Good management of internationalisation is particularly important for small economies.

International co-operation in megascience projects and programmes continues to be an important policy area. There is a broadly recognised need for such collaboration, either to prevent the duplication of costly facilities and save resources or to engage in joint work on global issues, such as climate change. The OECD's Megascience Forum addresses issues affecting specific scientific disciplines or cross-cutting policy issues. The Forum and its working groups (on neutron sources, bioinformatics, nuclear physics, radio astronomy, and removing obstacles to megascience co-operation) can make policy recommendations to facilitate international collaboration, although the Forum is not responsible for setting up or managing collaborations. Policies in this area continue to evolve and are likely to gain increased importance as the globalisation of S&T proceeds.

Another important issue is related to the ***opening of the non-OECD world,*** notably the former socialist countries, since the late 1980s. This has already had a considerable impact on the science communities of the OECD countries, in various ways. Opportunities have arisen for collaboration and for access to world-class scientific competencies or structures (notably in the Russian Federation), and thousands of world-class scientists have moved to western laboratories and universities, where they have sometimes received posts normally reserved for nationals. The development of science systems in Asia (notably in China) raises another type of challenge, as it reduces the migration of scientists (particularly towards the United States), while creating new opportunities for international collaboration. Possibilities for co-operation with China have so far mainly been exploited by Japan and the United States.

NOTES

1. A more detailed description of industrial policy measures is available in OECD (1998*f*).
2. Other measures, such as technology promotion programmes and the development of venture capital markets, are discussed in the section on S&T policies.
3. The OECD has recently proposed an integrated package of policy recommendations to stimulate further regulatory reform in OECD economies (OECD, 1997*k*).
4. Public support for R&D and technology and access to venture capital are discussed in the section on technology.
5. The fiscal treatment of private investment in R&D is discussed below. See also OECD (1996*g*) and OECD (1998*c*).
6. There are some indications, however, that the level of public support has increased again since 1993, particularly in EU economies such as France and Germany. Over the 1992-94 period, public support to industry as a percentage of total government spending was over 4 per cent in Germany and Italy and over 3 per cent in Belgium, Greece and Ireland.
7. Apart from measures to increase skills development, several countries view measures to make labour markets more flexible and to reduce labour costs as part of their policies to enhance growth and industrial competitiveness. Measures in this area are not explicitly discussed here but are covered in great detail in OECD (1997*m*).
8. Policies to nurture technology-based firms are discussed below.
9. A more extensive discussion of cluster analysis and cluster-based policies is available in OECD (1997*n*).
10. Policies for industrial clusters are closely linked to initiatives aimed at strengthening national innovation systems. Such measures are discussed below.
11. Recent developments in selected areas of S&T policy are discussed in more detail in a range of OECD publications (see Bibliography).
12. A more detailed discussion of the current tax treatment of industrial R&D across OECD countries is available in OECD (1998*c*).
13. Many of these areas hold considerable potential for future technological development, as suggested by several technology foresight studies (see Chapter 1).
14. Chapter 6 discusses recent trends in the role of industry in universities.
15. International flows of government funds are also important, particularly in certain areas of research. They involve payments to international organisations such as CERN (European Organization for Nuclear Research, now fully devoted to particle physics), to foreign institutions that carry out R&D abroad, or to international agencies such as the European Space Agency (ESA), which return most of the funds to the country. The European Commission is an increasingly important source of international funding and accounted for almost 7.5 per cent of all civil R&D in the European Union in 1995 (OECD, 1998*c*).

THE DYNAMICS OF INDUSTRIAL PERFORMANCE: WHAT DRIVES PRODUCTIVITY GROWTH?

INTRODUCTION

Productivity is the key to improving real income and competitiveness and is one of the most important yardsticks of industrial performance. The slowdown of productivity growth in the OECD area over the past decade therefore has important implications. However, productivity levels still differ substantially, possibly indicating under-utilised potential for growth.

Productivity growth is influenced by a range of factors, and there is no simple way to boost it (Englander and Gurney, 1994; OECD, 1996*b*). Two types of policy measures can be envisaged. The first focuses on ensuring a stable macroeconomic framework and efficient and competitive factor and product markets. The second type involves more specific policies, such as investment in education and infrastructure, or the establishment of a proper framework for technological change and innovation. Underlying these policy options is an implicit view of the main drivers of productivity growth. A wide range of economic studies have established that productivity growth is due to firms' investments in physical capital, training and technology, and may also be aided by public investment in education, research and infrastructure. Moreover, a more recent strand of microeconomic work suggests that the process of creative destruction and the exit and entry of firms may also provide an important contribution to productivity growth. Finally, firm-specific factors, including management and workplace arrangements, may also affect productivity growth in important ways.

Even though our understanding of the drivers of productivity is increasing, much remains unclear, and the precise contribution of each factor to productivity growth remains unknown. In addition, productivity growth continues to differ widely across the OECD area, and estimates of productivity levels suggest substantial scope for improvement in many countries. Although there appears to be some convergence at the economy-wide level, large differences in productivity persist at the sectoral level, in both industry and services.

Better understanding of productivity growth is therefore needed. This chapter builds on some recent work on productivity, including that related to the analysis of productivity levels and of productivity growth at the microeconomic level. It also briefly touches on some problems in measuring productivity, particularly in parts of the services sector. The next two sections discuss the diversity in productivity levels across the OECD area as regards growth rates and productivity levels. This is followed by a brief summary of the main factors that drive productivity growth. The subsequent section analyses productivity growth from a microeconomic perspective and considers whether such a perspective adds to our understanding of productivity growth. The final section draws some conclusions and discusses some implications for policy.

TRENDS IN PRODUCTIVITY GROWTH

Business sector productivity growth in several OECD countries rebounded somewhat in the 1980s and early 1990s, from its low level of the 1970s (Table 4.1). This was true for both labour and total factor productivity (TFP). Although productivity growth in the 1980s was below growth rates in the 1960s, performance in several countries improved significantly. Productivity growth during the 1980s picked up in Japan, the United Kingdom and the United States, among the G7 countries, but also in Finland, New Zealand, Portugal, Spain and Sweden. Productivity growth in the business sector deteriorated further in the 1980s and early 1990s in Canada, Germany, Greece, Italy and the Netherlands. In the

Table 4.1. **Productivity in the business sector**

Compound annual growth rates, in per cent

	Total factor productivity[1]				Labour productivity[2]			
	1960[3]-73	1973-79	1979-89	1989-96[4]	1960[3]-73	1973-79	1979-89	1989-96[4]
United States	2.0	0.0	0.7	0.4	2.7	0.3	1.0	0.6
Canada	2.1	0.6	0.2	–0.4	2.9	1.5	1.2	0.7
Japan	5.6	1.1	1.6	0.3	8.4	2.8	2.7	1.3
Korea	..	3.0	2.9	2.4	..	6.6	5.6	5.5
Australia	2.1	1.1	0.5	1.2	3.2	2.5	1.0	1.7
New Zealand	1.6	–1.4	1.3	0.8	2.1	–1.1	1.8	0.4
Austria	3.2	1.1	1.2	0.7	5.7	3.0	2.5	1.9
Belgium	3.6	1.4	1.2	0.8	5.3	2.7	2.3	1.6
Denmark	2.0	0.7	0.6	2.0	3.9	2.3	1.5	2.9
Finland	4.0	1.9	2.8	2.2	4.9	3.3	3.6	3.6
France	3.7	1.6	1.6	0.9	5.2	3.0	2.5	1.8
Germany[5]	2.6	1.7	0.8	0.1	4.5	3.1	1.6	0.1
Greece	2.7	0.8	–0.2	–0.2	9.0	3.4	0.8	0.5
Ireland	4.3	3.7	3.4	3.4	4.8	4.4	4.3	3.5
Italy	4.4	1.9	1.3	1.2	6.4	2.8	2.0	2.2
Netherlands	3.6	1.6	1.2	1.1	4.9	2.6	1.7	1.5
Norway[6]	2.1	1.3	–0.3	2.4	3.7	2.7	1.0	3.5
Portugal	4.2	–0.7	0.8	1.6	7.5	0.4	1.8	3.9
Spain	3.3	0.6	2.0	1.2	6.0	2.8	3.0	2.5
Sweden	1.9	0.0	0.9	1.6	3.6	1.4	1.6	2.7
Switzerland	1.3	–0.9	0.2	–0.7	3.3	0.8	0.6	0.2
United Kingdom	2.7	0.7	1.7	1.0	4.1	1.6	2.2	1.2

1. TFP growth is equal to a weighted average of the growth in labour and capital productivity. The sample period averages for capital and labour shares are used as weights.
2. Output per employed person.
3. Or earliest year available: 1961 for Australia, Greece, and Ireland; 1962 for Japan and the United Kingdom; 1964 for Spain; 1965 for France and Sweden; 1966 for Canada and Norway; 1967 for New Zealand; 1969 for the Netherlands; 1970 for Belgium; and 1975 for Korea.
4. Or latest year available: 1993 for Portugal; 1994 for Austria, Germany and Norway; 1995 for Australia, Finland, Ireland, Italy, Japan, Korea, New Zealand, Spain, Sweden, Switzerland and the United Kingdom.
5. The first three averages concern West Germany. The percentage changes for the period 1989-96 are calculated as the weighted average of West German productivity growth between 1989 and 1991 and unified Germany productivity growth between 1991 and the latest year available.
6. Mainland business sector (excluding shipping as well as crude petroleum and gas extraction).

Source: OECD.

1990s, productivity growth improved over the 1980s in Australia, Denmark, Ireland, Norway, Portugal and Sweden, but deteriorated in most other OECD countries. The slowdown in productivity growth from the 1960s occurred despite heavy investment in computing equipment, the so-called productivity paradox (Box 4.1).

Variations in productivity at the economy-wide level are also reflected in sectoral measures. Rises in labour productivity tend to be higher in manufacturing than in the economy as a whole. This reflects more sluggish productivity growth in services and the growing contribution of services to the economy.[1] Improved productivity over the 1980s and early 1990s in a number of OECD countries is also reflected in higher productivity growth in manufacturing (Table 4.2). The pick-up in performance was substantial in the United States, but was particularly large in Finland, Norway, Portugal, Spain, Sweden and the United Kingdom. Most of these countries also showed improved business sector productivity over the past decade, suggesting that manufacturing productivity continues to exert a strong influence on economy-wide performance, in spite of its declining share in total output. The Australian Industry Commission recently found that almost half of the economy-wide productivity growth over the period 1974/75 to 1994/95 could be attributed to the manufacturing sector (Industry Commission, 1997).

The reason for the continued importance of manufacturing for economy-wide productivity growth is the relative poor productivity of the services sector (Table 4.3). However, slow productivity growth in services masks a wide variety of experience at the sectoral level and is also influenced by measurement

Box 4.1. **Further evidence on the productivity paradox: the role of measurement issues**

Mismeasurement has been one the explanations put forward to resolve the productivity paradox. However, a measurement explanation of the productivity paradox requires that mismeasurement *increases* over time. At the level of the aggregate economy, at least one of two conditions must hold to make a case for the measurement explanation: *i)* a rising measurement bias for individual sectors or products; and/or *ii)* a rising share of these sectors or products in aggregate output or productivity.

First, measurement of real output in ***industries producing information and communication technologies*** (ICT) remains problematic. Where quality-adjusted output measures have been introduced, there has been an acceleration of measured productivity growth which has also affected sectoral aggregates such as total manufacturing. In addition, the share of ICT-producing industries in the economy has generally increased. Thus, if the output of ICT-producing industries is not quality-adjusted, their rising share may contribute to a possible measurement bias at the aggregate level. Despite such measurement problems, the Conference Board (1997*a*) recently found that the computer-producing sector in the United States was responsible for almost one-third of all TFP growth in the 1980s.

Second, there are reasons to believe that some gross output growth in ***ICT-using industries,*** mainly in the services sector, may have gone unnoticed: customer orientation, 24-hour service in banking, retail convenience, improved quality of medical treatment, the increased choice of products and their greater quality are all dependent on the intensive use of ICT but hard to capture in traditional output statistics. If the share of unmeasured output has increased, which is possible given the rising share of ICT in these industries' total investment, this would also contribute to the case for a measurement explanation of the productivity paradox. Unfortunately, there is little empirical evidence on this point. Recent work by the Conference Board (1997*a*) indicates that the productivity slowdown in the United States is over for manufacturing industries that use computers intensively. These sectors experienced more than double the productivity growth rate of other manufacturing sectors during the 1990s, 5.7 versus 2.6 per cent.

There is also an ***input-related*** measurement effect in ICT-using industries: the rate and intensity at which these industries have invested in ICTs has risen over the past decade. If ICT capital goods are undermeasured (because improved quality is insufficiently reflected), the contribution of ICT capital goods to output growth is understated and there is a bias in the interpretation of technical change in ICT-using sectors: insufficient weight is given to technical improvements embodied in capital goods and too much to disembodied technical change. This sheds light on the productivity paradox by showing that ICT capital goods have increased their contribution to output and labour productivity growth (Stiroh, 1998), but it does not explain the slowing of productivity growth.

Third, in ***other industries*** that are neither ICT producers nor intensive ICT users, the share of ICT capital goods in overall productive capital may simply be too small to expect sizeable effects on output growth. A productivity paradox is only present in these industries to the extent that an above-normal return to ICT on productivity is expected.

In sum, the measurement issue does shed some light on the productivity paradox, although ICT-producing industries have to be distinguished from ICT-using ones and the industry level from the aggregate economy. Mismeasurement remains a valid explanation for unmeasured productivity growth in ICT-producing industries. Also, in some ICT-using industries, new goods and services and consumer benefits enabled by ICT may have gone unnoticed. In addition, because ICT capital goods have replaced other factors of production, measurement errors in ICT prices would affect the interpretation of technical change. At the aggregate level, measurement effects at the industry level partly cancel out and ICT goods and services remain a comparatively stable part of total final demand. Thus, at the level of economy-wide gross domestic product (GDP), it is more difficult to make a case for mismeasurement as an explanation behind sluggish productivity growth than it is at the level of specific industries.

problems in many services sectors (Box 4.2). At the sectoral level, the different components show substantial differences in productivity growth (Annex I). In some services, such as distribution, telecommunications, and parts of the financial services industry, technological change has strongly affected the production process and the organisation of production and has contributed to significant improvements in productivity, although this may not always be easy to measure.

Productivity growth in some other services – notably community, social and personal services – has been more sluggish. Although this may partly reflect measurement problems, these services are also

Table 4.2. **Manufacturing labour productivity growth**

Compound annual growth rates, in per cent

	Value added[1]			Employment			Labour productivity		
	1973-79	1979-85	1985-95	1973-79	1979-85	1985-95	1973-79	1979-85	1985-95
United States	2.4	2.0	2.2	0.9	–1.5	–0.2	1.5	3.5	2.4
Canada	2.5	1.5	1.7	0.8	–0.8	–0.2	1.7	2.3	1.9
Mexico	5.5	2.0	2.1	2.9	1.1	0.1	2.6	0.8	2.0
Japan	2.5	4.5	2.5	–1.6	1.2	0.2	4.1	3.4	2.3
Australia	1.2	1.1	2.7	–1.6	–0.9	–0.2	2.9	2.0	2.9
Austria	2.6	1.6	2.4	–0.6	–1.5	–1.4	3.3	3.1	3.8
Belgium	1.4	2.8	1.6	–3.4	–2.8	–1.5	4.7	5.6	3.1
Denmark	1.6	2.8	0.5	–2.1	0.8	–1.3	3.7	2.0	1.8
Finland	2.0	3.9	3.0	–0.4	–0.3	–2.8	2.4	4.1	5.7
France	2.7	–0.4	1.2	–0.9	–2.3	–1.6	3.6	1.9	2.8
Germany	1.7	0.2	0.7	–1.6	–1.1	–1.1	3.3	1.3	1.8
Greece	4.2	0.1	–0.3	3.4	–1.0	–1.3	0.8	1.1	1.0
Italy	5.3	1.7	2.5	1.1	–2.5	–1.1	4.2	4.2	3.7
Netherlands	1.4	1.6	2.0	–2.3	–2.2	–0.4	3.8	3.8	2.3
Norway	0.2	0.9	0.5	–0.7	–1.8	–2.2	1.0	2.7	2.7
Portugal	3.4	2.2	2.7	2.1	–0.7	–1.5	1.3	3.0	4.2
Spain	2.0	0.1	2.8	2.8	–4.7	1.0	–0.8	4.8	1.8
Sweden	0.5	2.1	2.2	–0.6	–1.0	–1.8	1.1	3.1	4.0
United Kingdom	–0.7	–1.0	1.8	–1.3	–4.8	–0.6	0.6	3.8	2.4

1. In 1990 constant prices.

Source: OECD, calculations from STAN database, May 1997.

Table 4.3. **Labour productivity growth in services**[1]

Compound annual growth rates, in per cent

	Value added			Employment			Labour productivity		
	1973-79	1979-85	1985-93[2]	1973-79	1979-85	1985-93[2]	1973-79	1979-85	1985-93[2]
United States	3.3	2.9	2.5	3.0	2.4	2.1	0.3	0.5	0.4
Canada	4.2	2.9	2.6	3.6	2.3	1.9	0.6	0.6	0.6
Mexico	..	..	1.8	..	..	..	..	..	..
Japan	4.4	4.3	3.1	2.2	1.8	2.1	2.2	2.4	1.0
Australia	3.1	4.0	3.1	2.6	2.8	2.4	0.5	1.1	0.7
Austria	..	4.0	3.0	..	..	2.0	..	..	1.0
Belgium	2.9	1.5	3.1	2.0	0.6	1.4	0.8	0.9	1.7
Denmark	2.9	1.8	1.8	2.3	1.2	0.5	0.5	0.6	1.3
Finland	3.3	3.7	1.1	1.8	2.2	–0.7	1.5	1.5	1.9
France	3.5	2.5	2.8	2.1	1.4	1.6	1.4	1.1	1.2
Germany	3.6	2.3	4.4	1.6	1.0	2.4	2.0	1.3	2.0
Greece	4.6	2.2	2.1	..	..	..	..	..	..
Italy	3.9	2.3	2.2	2.8	3.1	0.7	1.0	–0.8	1.5
Netherlands	..	..	2.7	1.6	0.4	2.0	..	..	0.7
Norway	4.7	3.0	1.8	3.5	2.2	1.1	1.1	0.8	0.7
Portugal		2.1	5.4	..	1.5	2.7		0.6	2.7
Sweden	2.9	2.0	1.4	2.7	1.4	–0.2	0.2	0.6	1.6
United Kingdom	2.1	1.8	3.4	1.4	1.1	2.9	0.7	0.6	0.5

1. Labour productivity is calculated as value added (in 1990 constant prices) divided by the number of employees.
2. Or latest available year, *i.e.* 1990 for Portugal and the United Kingdom; 1991 for Norway; 1992 for Belgium, France and Germany; 1994 for Italy.

Source: OECD, calculations from ISDB database, October 1997.

Box 4.2. **Measuring real output at the sectoral level**

While most economy-wide productivity measures tend to be based on value added, productivity measurement at the sectoral level should preferably be based on gross output and the full range of inputs (Van Ark, 1996). Measures of total (or multi-) factor productivity can be derived by accounting for the contribution of intermediate inputs, labour and capital. Due to data constraints for many sectors, few countries provide such measures, and no internationally comparable data are available that allow the international comparison of TFP growth on the basis of gross output and the full range of inputs. The OECD has published some TFP measures on the basis of input-output tables, generally with considerable time lags (OECD, 1996*h*).

Internationally comparable sectoral data are available on value added, employment and capital stocks, however. The OECD national accounts and the ISDB database provide considerable detail, which can be used for productivity measurement. However, OECD countries apply quite different procedures in measuring real output in services (OECD, 1996*i*). They also provide varying amounts of detail in their national accounts. While some countries, including Canada, France, the United States, and the Nordic countries, provide details for several service industries, only a rough breakdown is available for others.

In principle, two methods for measuring real value added in services can be distinguished. Countries apply either double or single indicator methods. Double indicator methods take account of changes in both outputs and inputs of goods and services, and value added is derived as a residual by subtracting constant price estimates of intermediate consumption from constant price estimates of gross output. Countries that apply this method often use input-output tables as the framework for deflation. Intermediate inputs are deflated at a relatively detailed level, applying a mix of producer, consumer and import prices. Double indicator methods are theoretically preferable over single indicator methods, since they take account of changes in both output and intermediate input and derive value added as a residual.

Single indicator methods are based on the direct deflation of nominal value added or on the extrapolation of base year value added with a volume index. A wide range of alternatives is available (OECD, 1996*i*), depending on whether the indicator is output- or input-related, whether deflation or extrapolation is used, and also on the variable used to proxy volume changes in value added. Several countries adjust volume indices in some sectors for labour productivity changes. This may be done, for instance, if value added is extrapolated on the basis of employment changes, and if there is strong evidence that the sector has substantial productivity growth.

For many parts of the services sector, output measures are of dubious quality, partly due to the lack of basic data. However, measurement problems also arise because services differ in nature from goods (Hill, 1997). A service can not be stocked as a separate entity and cannot be produced independently of the client to which it is provided. Furthermore, services lead to a transformation or improvement in the consuming unit. These characteristics indicate that the volume and price of services – and changes in their quality – are harder to measure than those of goods. In addition, some services are not sold in the market, so that a price cannot be easily established. In practice, these constraints mean that several output series in the services sector are measured by crude indicators. Several series are deflated by wages or consumer prices, or extrapolated on the basis of employment changes, sometimes with explicit adjustment for labour productivity changes. Given these constraints, adjusting for quality is even more difficult.

less easily automated or affected by technological improvements. Some services probably have little scope for productivity growth, as it is difficult to reduce labour input (for example, the live performance of a piece of classical music) or because the service does not lend itself to standardisation (such as specialised legal advice) (Baumol *et al.*, 1989). The following provides some information about productivity in specific services sectors.

In the distribution sector, labour productivity growth over the period 1979-94 was more rapid than in the economy as a whole in several countries (Table 4.4). In Denmark, Finland, Japan, Korea, Sweden, and the United States, it was close to or over 2 per cent a year. In Japan, it was more than 4 per cent a year, almost double the rate in the economy as a whole; this may partly reflect scale enlargement in the wake of the liberalisation of the Large-scale Retail Store Law. Productivity growth in the distribution sector has benefited from greater use of advanced technologies, such as scanning and inventory management systems, greater use of self-service systems, increases in scale, and closer integration of

Table 4.4. **Output, employment and productivity growth in the distribution sector, 1979-94**

Compound annual growth rates, in per cent

	Growth of value added			Employment growth			Labour productivity growth		
	Total distribution sector	Wholesale trade	Retail trade	Total distribution sector	Wholesale trade	Retail trade	Total distribution sector	Wholesale trade	Retail trade
United States[1]	3.8	4.7	3.3	1.8	1.1	2.0	2.0	3.6	1.3
Canada	2.9	4.6	1.6	1.5	2.3	1.2	1.3	2.2	0.4
Mexico[2]	1.1	..	..	1.3	..	..	–0.2	..	..
Japan	4.7	..	..	0.6	..	..	4.1	..	..
Korea[2]	7.4	..	..	4.5	..	..	2.8	..	..
Australia[3]	1.9	..	..	2.0	..	..	0.0	..	..
Austria[4]	3.1	..	..	1.3	..	..	1.8	..	..
Belgium[3]	0.8	..	..	–0.1	..	..	0.9	..	..
Czech Republic	..	..	..	3.1	..	..	..	..	..
Denmark	2.2	2.4	1.4	–1.0	0.1	–1.7	3.2	2.3	3.1
Finland[3]	0.9	0.8	0.9	–1.1	–0.9	–1.2	2.0	1.7	2.2
France	1.8	..	..	0.2	0.0	0.3	1.7	..	..
Germany	2.2	2.0	2.6	1.0	0.8	1.2	1.2	1.2	1.3
Greece[2]	1.6	..	..	3.2	..	..	–1.5	..	..
Iceland	..	..	..	1.5	2.5	0.9	..	..	..
Ireland	..	..	..	1.7	..	..	..	..	..
Italy[3]	2.5	..	..	1.5	..	..	1.0	..	..
Luxembourg[3]	3.5	..	..	1.4	..	..	2.0	..	..
Netherlands	3.4	..	..	1.6	..	..	1.8	..	..
Norway	..	..	..	0.4	..	..	..	..	..
Portugal	1.6	..	..	0.4	..	..	1.1	..	..
Spain[1]	1.9	..	..	1.4	..	..	0.6	..	..
Sweden	2.8	..	..	–0.6	..	..	3.4	..	..
United Kingdom[3]	2.5	..	..	0.7	..	..	1.8	..	..

1. Distribution and retail trade include restaurants.
2. Distribution value added includes restaurants and hotels.
3. Distribution value added includes repair services.
4. Includes machinery and equipment rental and leasing.

Source: Pilat, 1997*a*.

manufacturers and retailers (Pilat, 1997*a*). Not all OECD countries were able to improve productivity in distribution, however. It was negative in Australia, Greece and Mexico over the 1979-94 period, although this may also reflect measurement difficulties in these countries.

Productivity growth in transport and communication has also been rapid over the past two decades (Annex I), mainly as a result of rapid productivity changes in the communications sector. Several countries (Australia, France, Iceland, Sweden) have sustained annual productivity growth rates of over 8 per cent. A certain number of countries also performed well in the transport sector, with annual productivity growth of around 3 per cent.

More detailed productivity estimates for the United States, based on national accounts data, confirm that several parts of the services sector are characterised by high productivity growth rates (OECD, 1996*j*). For example, over the period 1979-93, labour productivity grew at 3.3 per cent in wholesale trade; 9.1 per cent in railroad transportation; 2.2 per cent in air transport; 5.9 per cent in telephone and telegraph services; 4.2 per cent in security and commodity brokers; and 2.1 per cent in amusement and recreation services. However, other parts of the services sector, such as trucking and warehousing and legal services, had stagnant or negative productivity growth.

For several sectors, measurement problems may obscure a substantial part of the actual productivity gains. A recent study by Fixler and Zieschang (1997), for example, derives new output measures for the US financial services industry. It introduces quality adjustments to capture the effects of improved service characteristics, such as the volume of transactions per account, automatic teller machines, and number of branches. The output index calculated in this study grows by 4.7 per cent a year between 1985 and 1994, well above the standard output measure. Similar measurement problems exist for the insurance industry (Bernstein, 1997; Harchaoui, 1997).

Measurement problems are particularly large in non-market services and the public sector, and measured productivity growth in these sectors tends to be very low. However, productivity gains can even be made in this part of the economy, as a Bureau of Labor Statistics (BLS) study for the US federal government suggests (Fisk and Forte, 1997). This study is based on a wide range of indicators of physical counts or quantities of services provided by different parts of the federal government. For this "measured part", the BLS study found a small but steady increase in labour productivity, with a slowdown in productivity from the mid-1980s. The highest rates of productivity growth were observed in finance and accounting, library services, and regulatory functions, while no or negative productivity growth was measured for legal and judicial activities, personnel management, medical services, and electric power and production.

Multi-factor productivity (MFP) estimates on the basis of gross output for some OECD countries also confirm that parts of the services sector are very dynamic and characterised by high rates of productivity growth. For the United States, MFP in railroad transportation rose by almost 4 per cent on an annual basis from 1973 to 1993, with labour productivity growing by over 6 per cent a year (Kronemer, 1996). This rate of growth is higher than the MFP growth rate for any of the nine manufacturing industries for which the BLS provides data. Annual MFP growth in Australia over the period 1974/75-1994/95 was highest in transport, storage and communication at 3.3 per cent, followed by electricity, gas and water at 2.9 per cent, and the manufacturing sector at 2 per cent (Industry Commission, 1997).

DIVERSITY IN PRODUCTIVITY LEVELS

Productivity, real income and industrial performance

To increase income and economic welfare, productivity improvements are essential. The combination of labour productivity and the amount of labour used in an economy determines the level of real income achieved (Conference Board, 1997*a;* 1997*b*). Economies can increase their level of real income by increasing labour utilisation, for instance by enhancing labour participation or reducing unemployment or by improving labour productivity. These are also areas for government policies.

Table 4.5. **Breakdown of GDP per capita into contributions of labour productivity and labour force participation, 1996**

	GDP per hour worked as % of OECD average[1]	Effect of working hours	GDP per person employed as % of OECD average	Effect of unemployment[2]	Effect of % labour force to active population[3] (15-64 years)	Effect of % active population (15-64 years) to total population[4]	Total effect of labour force participation	GDP per head of population as % of OECD average
	(1)	(2)	(3) [(1) + (2)]	(4)	(5)	(6)	(7) [(4) + (5) + (6)]	(8) [(3) + (7)]
United States	131	–6	125	2	12	–1	13	138
Canada	107	–4	104	–3	5	3	5	109
Mexico	43	8	51	0	–5	–7	–12	39
Japan	94	5	98	4	8	6	18	116
Korea	41	25	66	3	–5	5	3	69
Australia	105	–5	100	–2	6	1	5	105
New Zealand	77	5	81	1	5	0	6	87
Austria	112	–10	102	3	1	2	6	109
Belgium	143	–13	131	–7	–14	1	–20	110
Czech Republic	35	7	42	1	1	2	4	46
Denmark	104	–6	98	0	12	2	14	112
Finland	103	–5	99	–10	4	1	–5	94
France	136	–16	120	–7	–6	–1	–14	106
Germany	121	–16	105	–2	–1	4	0	105
Greece	75	–1	74	–4	–9	2	–11	63
Hungary	. .	. .	42	–1	–7	1	–7	34
Iceland	. .	. .	97	3	20	–3	20	117
Ireland	118	–2	116	–6	–11	–2	–19	96
Italy	132	–19	113	2	–18	3	–13	100
Luxembourg	. .	. .	136	10	14	3	27	163
Netherlands	132	–33	99	0	0	4	4	103
Norway	139	–24	115	3	14	–3	14	129
Poland	. .	. .	38	–2	–2	0	–4	34
Portugal	63	–1	62	0	1	2	3	65
Spain	95	9	104	–17	–13	3	–27	77
Sweden	103	–9	94	–1	6	–3	2	97
Switzerland	105	–5	100	3	17	3	23	123
Turkey	40	0	40	0	–8	–1	–9	31
United Kingdom	111	–15	96	–1	5	–1	2	98
Averages:[1]								
OECD	100	0	100	0	0	0	0	100
North America	110	0	110	1	6	–4	2	112
European Union	117	–12	105	–3	–5	2	–7	98

1. Averages are weighted averages based on 1996 purchasing power parities. Averages exclude Hungary, Iceland, Luxembourg and Poland since no hours worked estimates were available for these countries.
2. The effect of unemployment is calculated by comparing GDP per person employed and GDP per member of the labour force.
3. This effect is calculated by comparing GDP per member of the labour force and GDP per working-age person.
4. This is the difference between GDP per working-age person and GDP per capita.

Sources: OECD National Accounts; *Economic Outlook, Employment Outlook* and *Labour Force Statistics*; GDP converted to US$ with 1993 EKS Purchasing Power Parities from OECD PPP database; PPPs for new Member countries from OECD Analytical Databank. Hours worked based on Maddison, 1995, updated to 1996. See also Conference Board, 1997*a*; 1997*b*.

The OECD area is characterised by a considerable diversity in real income levels, which reflect substantial differences in labour productivity and in the amount of labour used (Table 4.5). The difference between labour productivity – as measured by GDP (gross domestic product) per hour worked – and GDP per capita can be broken down into a number of factors.[2] First, working hours per person employed differ substantially across the OECD area. Recent estimates (Conference Board, 1997*a*, 1997*b;* OECD, 1997*t*) for a wide range of OECD countries indicate very high levels of annual hours worked in the Czech Republic, Korea and Mexico and very low levels in the Netherlands and Norway, partly owing to high levels of part-time employment in these two countries. This variation explains the difference between labour productivity in terms of GDP per hour worked and GDP per person employed. Productivity levels as measured as GDP per hour worked in the Netherlands and Norway are more than 30 per cent above the OECD average, whereas GDP per person employed in the Netherlands is at the OECD average and is only 15 per cent above the OECD average in Norway. For Korea, the level of GDP per person employed stands at two-thirds the OECD average, much higher than its level in terms of GDP per hour worked.

The difference between GDP per person employed and GDP per capita is explained by the amount of labour used in the economy. Three factors can be distinguished, namely the ratio of the working-age population (15-64 years) to the total population, the ratio of the labour force to the working age population (the employment rate) and, finally, the ratio of those employed to the labour force. The first ratio is closely linked to the age structure of the population. The other two are more important in an economic sense, since they largely reflect how well an economy is able to use its workforce. Low employment rates and high unemployment may indicate serious labour market problems.

The gap between labour productivity – measured as GDP per person employed – and GDP per capita can be substantial. Income levels in Belgium, France, Greece, Ireland, Italy, Mexico and Spain are all substantially below corresponding productivity levels. The gap is largest for Belgium, Ireland, Italy and Spain, and is mainly a reflection of low employment rates in these countries, although Spain's high unemployment rate also adds to the difference. A few OECD countries, notably Denmark, Iceland, Japan, Luxembourg, Norway, Switzerland and the United States, have higher relative income levels than relative productivity levels, thereby indicating greater labour utilisation than the OECD average.

Differences in income levels and productivity in the OECD area have narrowed considerably over the post-war period. The catch-up in income levels in Europe, Japan, and other parts of the OECD area with US levels is due less to increasing use of labour, however, than to more rapid rises in labour productivity. This is particularly the case for many European countries, where employment rates have deteriorated over the past two decades and where unemployment rates have increased substantially. Consequently, productivity levels in these countries have caught up more rapidly with the United States than income levels.

Apart from its role in determining income levels, productivity is also an important yardstick of industrial performance. It indicates how well firms are able to combine production factors to produce output and is a major determinant of production costs and thus of competitiveness. The link between productivity and industrial performance should preferably be made at the sectoral level. However, while some of the processes that drive productivity and industrial performance can be identified at the macroeconomic or sectoral level, other important determinants of productivity can best be studied at the firm level. The following analysis begins with the sectoral level and then turns to productivity analysis at the firm level, based on longitudinal databases.

Productivity differences in manufacturing

Cross-country productivity gaps at the economy-wide level, highlighted above, are reflected in differences at the sectoral level. The main problem for international productivity comparisons at the sectoral level is the lack of appropriate conversion factors for real output. Exchange rates are not suitable, since they are strongly influenced by monetary phenomena, and in general do not reflect real price differences between countries. Nor are economy-wide purchasing power parities (PPPs) suitable, since they do not reflect price differences at the sectoral level. In principle, sector-specific PPPs which reflect these differentials across countries are needed (OECD, 1996*k*). For the manufacturing sector, recent studies have made such conversion factors available for a large number of OECD countries (Wagner and Van Ark, 1996; Van Ark, 1996).

Some evidence based on these studies is presented in Table 4.6, which reports estimates of absolute levels of labour productivity (value added per person engaged and per hour worked) in the manufacturing sector over the period 1960-96. Average productivity in the United States continues to outrank that of the other major economies (France, Germany and Japan), although Japan in particular has made considerable gains over the past decades. Labour productivity levels, particularly in terms of hours worked, are also estimated to be high for Belgium, Finland, the Netherlands and Sweden. The manufacturing sectors in these small OECD economies tend to be more specialised than those of the large countries and are, apart from Sweden, relatively capital-intensive (Pilat, 1996). This contributes to a high level of labour productivity.

In the middle of the OECD productivity range are a number of follower countries (Australia, Canada, Korea, Spain, and the United Kingdom) with somewhat lower productivity levels, although Korea, Spain, and the United Kingdom have made substantial progress over the past decades. Canada's manufacturing productivity level was relatively high during the 1970s and 1980s but has fallen substantially over the past decade. At the bottom of the range in Table 4.6 are the Czech Republic, Hungary, Mexico, Poland and Portugal, whose productivity levels still lag well behind. Evidence presented in the table also suggests that US productivity improved relative to that of many countries in the 1980s.

More detailed estimates of labour productivity levels for individual manufacturing industries suggest even more variation (Pilat, 1996; 1997*b*). These data suggest that the United States remains the productivity leader for total manufacturing, but that the leadership in particular manufacturing

Table 4.6. **Relative labour productivity levels in manufacturing, 1960-96**

United States = 100

	1960		1973		1985		1996[1]	
	Value added per person engaged	Value added per hour worked	Value added per person engaged	Value added per hour worked	Value added per person engaged	Value added per hour worked	Value added per person engaged	Value added per hour worked
United States	100	100	100	100	100	100	100	100
Canada	69	68	81	82	82	84	67	68
Mexico	27	25	34	32	34	31	33	..
Japan	25	19	55	48	78	69	76	74
Korea	7	..	14	..	24	..	49	..
Australia	53	50	50	50	54	56	50	51
Belgium	45	46	61	71	83	106	78	101
Czech Republic[2]	28	..	25	..	26	20	16	14
Finland	49	46	54	58	64	72	83	101
France	47	46	66	70	72	86	69	84
Germany	61	56	73	76	76	86	63	82
Hungary	18	..	17	..	21	..	20	..
Netherlands	53	51	77	88	86	107	75	97
Poland	25	..	25	..	22	..	17	..
Portugal[3]	16	..	25	..	24	..	27	..
Spain[3]	15	20	29	38	49	80	40	68
Sweden	48	50	66	80	68	87	74	90
United Kingdom	49	45	52	54	55	60	58	67

1. Or latest available year, *i.e.* 1990 for Mexico and Portugal; 1992 for Spain; 1994 for Australia, Finland and Korea; 1995 for Belgium, the Czech Republic, Hungary, the Netherlands and Poland.
2. Czechoslovakia for 1960, 1973 and 1985.
3. Portugal/United States and Spain/United States are inferential estimates, based on benchmark studies for Portugal/United Kingdom and Spain/United Kingdom. They are therefore not entirely comparable with the other estimates, but are reported here for completeness.

Sources: Pilat, 1997*b*; Czech Republic, Hungary and Poland based on estimates provided by Van Ark, University of Groningen, the Netherlands; Korea based on Timmer and Szirmai, 1997.

industries has become more diversified. For instance, in 1987, the United States was the productivity leader in food products and electrical machinery, the Netherlands in textiles and chemical products, Japan in basic metal products, and Sweden in metal products. By 1993, some of these relative positions had changed, with Swedish productivity in particular improving substantially. The great diversity at industry level partly reflects differences in specialisation and comparative advantage, but it may also indicate that productivity in some countries is far removed from best practice, thus indicating a potential for catch-up.

Country-specific case studies offer more evidence on productivity differences (McKinsey, 1993; 1994; 1995). One advantage of case studies is that products and firms can be carefully matched and several sources of aggregate-level bias can be avoided. However, it is not always easy to generalise the results of case studies to a more aggregate level. In general, these studies found large differences in performance across the OECD area. For instance, in food products, the United States is the undisputed productivity leader, with Japan in particular trailing far behind. In motor vehicles, Japan and the United States are the world productivity leaders, clearly outperforming European countries. In computer equipment, there appear to be only small differences between the three major OECD countries for which data are available.

Some insights into productivity differences can also be obtained via another approach (Caves *et al.*, 1992; Mayes *et al.*, 1994). This method uses estimates of production frontiers and measures inefficiency as the gap between observed efficiency in a particular firm and the estimated efficiency frontier of the industry to which the firm belongs. This approach also provides useful evidence, although it is mainly valuable for analysing inefficiency within a country. Studies of domestic efficiency frontiers have been carried out for five countries (Australia, Canada, Japan, the United Kingdom and the United States), and in each, significant levels of inefficiency were found in many industries. In general, this is interpreted as a long ''tail'' of inefficient firms in each industry, or firms that could produce substantially more output with existing inputs. Measures of efficiency frontiers provide a static view of productivity, however, and do not show how firms' performance changes over time, moving them closer or further away from the efficiency frontier. Analysis using longitudinal databases, discussed below, provides more insight into the dynamic behaviour of firms.

Productivity gaps in other sectors

There thus appears to be substantial evidence of large productivity differences in the manufacturing sector, both within and across countries. Given the low level of international and domestic competition in other parts of the economy, particularly services, productivity might be expected to vary even more there. Data constraints limit the scope of productivity analysis for such sectors, however, so that most of the available work on international productivity comparisons concerns the manufacturing sector. However, for some sectors, crude comparisons of productivity across countries can be made (Pilat, 1996; Vass, 1996; O'Mahony *et al.*, 1997). In those sectors where comparisons are possible, the available evidence points to a large variation in productivity across the OECD area (Table 4.7).

- Output in ***electricity*** can be measured in a relatively straightforward way. Output per person, measured in gigawatthours, differs widely, with Canada, Japan, Norway and the United States having the highest productivity levels. Favourable resource endowments, which allow for a high share of hydropower in countries such as Canada and Norway, may explain part of the reason for high productivity levels. However, labour productivity provides only a partial yardstick of performance in electricity production, since labour costs are only a small proportion of total costs.
- There are also substantial differences in productivity in the ***distribution sector.*** It is estimated that the highest productivity levels are in Belgium, France, Germany, Luxembourg, and the United States, whereas they are low in Japan, the United Kingdom, and some of the smaller OECD economies. A substantial part of these differences appears related to structural characteristics, such as population density, degree of urbanisation, land prices, and car use (Pilat, 1997*a*). These structural characteristics are important determinants of the average size of shops and thus

Table 4.7. **Productivity and efficiency in selected service industries**

	Electricity	Distribution		Airlines			Telecommunications		
	Gigawatt-hour per person engaged, 1993	Distribution GDP per person engaged, 1990 (United States = 100)	Retail sales per employee, 1990 (United States = 100)	Operating expense per available tonne kilometre, 1993 (US$)	Average cost per available seat kilometre, 1993 (US$)	Passenger kilometre per employee, standardised, 1992[1] (United States = 100)	Revenue per employee, 1995 (OECD avg. = 100)[2]	Mainlines per 100 inhabitants, 1995	Revenue per mainline, 1995 (OECD avg. = 100)
United States	8.2	100	100	0.45	0.06	100	114	63	120
Canada	5.5	58	75	0.54	0.07	104	59	58	93
Mexico	..	..	..	..	..	..	184	10	199
Japan	6.3	60	71	0.84	0.12	111	143	48	98
Australia	2.9	59	60	0.35	..	140	83	51	130
New Zealand	3.4	78	86	0.44	0.07	114	112	47	133
Austria	1.8	87	73	1.08	0.14	..	99	47	86
Belgium	3.2	105	94	1.04	0.14	40	75	46	77
Czech Republic	..	..	..	..	..	..	59	23	94
Denmark	3.3	87	69	..	..	..	80	61	78
Finland	3.1	56	86	0.44	0.06	66	64	55	65
France	3.8	97	95	0.88	0.16	59	74	56	64
Germany	2.2	79	101	0.71	0.13	82	81	49	86
Greece	2.5	37	62	0.47	0.07	41	69	49	62
Hungary	..	..	..	..	..	..	59	21	106
Iceland	..	38	75	..	..	..	55	56	71
Ireland	..	69	60	1.46	0.17	40	77	37	136
Italy	1.6	95	72	0.72	0.10	45	110	44	86
Luxembourg	..	101	130	..	..	..	150	57	99
Netherlands	3.1	95	55	0.48	0.08	125	109	52	83
Norway	8.0	42	93	1.10	0.12	..	63	56	92
Portugal	1.2	45	53	0.83	0.11	55	94	36	102
Spain	3.3	78	46	0.66	0.09	50	87	39	76
Sweden	5.6	66	87	1.01	0.13	65	68	68	73
Switzerland	..	116	79	0.75	0.12	79	131	63	110
Turkey	..	..	..	..	..	..	28	23	28
United Kingdom	2.5	60	78	0.43	0.06	109	99	50	98
OECD average							100	47	100

1. Standardised for differences in stage length, load factor and the share of international passengers in total transport. Data cover major airlines as follows: United States: American, United, Delta, Continental, Northwest, TWA; Japan: Japan Airlines; Germany: Lufthansa; France: Air France; Italy: Alitalia; United Kingdom: British Airways, British Midland; Canada: Air Canada, Canadian Airlines; Australia: Qantas; Belgium: Sabena; Finland: Finnair; Greece: Olympic Airlines; Ireland: Aer Lingus; Netherlands: KLM; New Zealand: Air New Zealand; Portugal: TAP; Spain: Iberia; Sweden: SAS; Switzerland: Swissair. National averages are employment-weighted averages of individual airlines. See Vass, 1996, for details.
2. Converted at PPPs for total GDP.

Sources: Pilat, 1997*b*; Vass, 1996, for estimates of passenger kilometre per employee in airlines; telecommunications from OECD, 1997*v*.

of the extent to which economies of scale can be achieved. However, the regulatory framework may also play an important role in determining whether large firms are allowed to establish.

- In ***airlines,*** countries show considerable differences in cost efficiency. In this sector, the highest cost levels tend to be found in continental Europe (and in Ireland), and the lowest in Australia, Finland, New Zealand, the United Kingdom, and the United States. Among the larger countries, the high costs levels of France and Japan stand out. The large variation in performance is confirmed by several recent studies, the latest of which is Vass (1996), which focuses on productivity in the airline industries of France, Germany, the United Kingdom, and the United States, but also presents results for others. It found that in 1992 UK and US airlines were significantly more productive than French and German ones. Although both French and German airlines have since made substantial productivity gains, some of these differences persist (OECD, 1997*u*). Vass found that differences in stage length (the average distance flown) and load factors (a measure of capacity utilisation) explain a substantial part of the productivity difference. She also found that privately owned airlines tend to be more productive than publicly owned airlines. Standardising for some of these factors gives an interesting perspective on cross-country productivity levels in airlines (Table 4.7). The most productive airline industries in the OECD area – in terms of standardised passenger kilometres per employee – are in Australia, Canada, Japan, the Netherlands, New Zealand, the United Kingdom, and the United States. With the exception of Japan, these are all countries where the airline industry has been under strong competitive pressure for some time.
- In ***telecommunications,*** productivity differences are also substantial. Productivity measurement in telecommunications is not straightforward, however (OECD, 1997*v*). Three different measures are shown in Table 4.7. The first shows revenue per employee for public telecommunications operators (PTOs). On this standard, Japan, Luxembourg and Switzerland have the most productive PTOs.[3] The second yardstick, mainlines per employee, is a traditional measure of productivity in telecommunications. However, owing to new practices, such as outsourcing and the diversification of PTOs beyond their core business, this measure is less indicative of efficiency than in the past (OECD, 1997*v*). The third indicator, revenues per mainline, indicates the degree to which PTOs are able to derive revenue from their network and is thus closely linked to measures of capital productivity.

Table 4.7 compares sectors for which relatively comparable international data are available. Moreover, for several sectors, particularly transport and communication, international comparisons of productivity are available. A recent study (O'Mahony *et al.*, 1997) compared German and US productivity in transport with UK levels and found that the United States was much more productive than both other countries in railway transport, even after adjustments for differences in stage length. However, in air transport, the UK airline industry was somewhat more productive than that of the United States and substantially more than that of Germany. In local and bus transport and also in road haulage – after adjustment for differences in stage length – there were only small productivity differences among the three countries.

Some evidence on productivity gaps in services can also be elicited from detailed industry-specific comparisons across countries (Baily, 1993; McKinsey, 1992; 1994; 1995). These studies cover banking, retailing, and construction in France, Germany, Italy, Japan, Spain, Sweden, the United Kingdom, and the United States. In banking, labour productivity in the United States in 1992 was substantially higher than in the other countries (France, Germany, Italy, and Sweden). In general merchandise retailing, 1990 US labour productivity was almost double that of Japan, and was some 10 to 15 per cent higher than of the European countries covered (France, Germany, Spain and Sweden). In construction, the differences were smaller and may be partly the result of cyclical phenomena.

THE DETERMINANTS OF PRODUCTIVITY

The central role of productivity in determining income levels and economic performance has led to an extensive literature on factors influencing its growth. While it is difficult to find empirical support for some factors, the literature appears in broad agreement about many. To some extent, a distinction can be made between ultimate causes of (productivity) growth, such as framework conditions, and proximate causes, such as investment in physical and human capital and technology.

Increases in physical ***capital intensity,*** in particular machinery and equipment, are generally regarded as the major driver of increased labour productivity. It is the standard factor in both neo-classical and ''new growth'' theories, and generally ''explains'' around one-third of labour productivity growth (Englander and Gurney, 1994). There is little hard evidence, however, that increased capital intensity has contributed to TFP growth over the past two decades. Greater capital intensity may contribute to TFP growth if technological change is embodied in capital goods, or if there are spillovers from capital investment to TFP growth. Such a relationship appears to have existed, up to a point, prior to 1973 but is not evident in recent data (Englander and Gurney, 1994). To some extent, this may be related to the decline in capital productivity growth, and would mean that greater attention should be paid to the efficiency of capital use.

Some other factors may affect the modest role of investment in physical capital in explaining TFP growth. First, it is not the stock of capital that matters, but the capital flows stemming from it. This again points to the efficiency of capital use. Secondly, some ***types of capital*** may matter more than others. Some studies have suggested that, for productivity growth, investment in machinery and equipment may be more important than investment in buildings and structures (De Long and Summers, 1991). Other studies have pointed to investment in infrastructure as an important prerequisite of productivity growth and have attributed high payoffs to investment in such capital stock (Aschauer, 1989; Munnell, 1993). However, a recent review of the literature (Sturm *et al.*, 1996) finds little hard evidence that (public) investment in infrastructure has above-normal payoffs. Although such investment may indeed support growth, there is little agreement about the size of its contribution. Furthermore, some types of public investment in infrastructure may matter more than others.

Empirical studies also point to ***human capital*** as an important source of increased labour productivity and TFP growth (Barro and Lee, 1994). Cross-country studies for developed and developing countries often point to general education as an important factor for increases in output and productivity. The evidence is less strong for OECD countries, as they already have relatively high levels of general education and the marginal productivity of an additional year of schooling is quite low (Englander and Gurney, 1994). Human capital is more than general education, however, and many industry-specific studies attest to the importance of skills and in-company training for productivity growth (Wagner and Van Ark, 1996).

Technological change is a major determinant of labour productivity growth. New technologies allow the automation of production processes, have led to many new and improved products, allow for better and closer links among firms, and can help to improve information flows and improve the organisation of production (see Chapter 5). Aggregate studies often find that research and development (R&D) expenditures provide a positive contribution to productivity growth, but also that technology diffusion from other industries is a major source of productivity gains. Increasingly, importing modern technology from abroad is also driving productivity growth (OECD, 1996*h*).

To some extent, it is not appropriate to consider physical capital, human capital and technology as separate factors, as their contributions are closely linked. Advanced technologies are generally incorporated in the production process by investment in physical capital, and appropriate skills are required to use this capital and these advanced technologies in an efficient manner. It is the combination of these three factors, and the way in which they are organised and managed within the firm, that ensures high productivity growth (see Chapter 5).

Framework conditions matter as well. The ***degree of competition*** in a particular country or sector may be among the most important of such factors, since lack of competition reduces the pressure on firms to incorporate better technology, tighten their organisation, and to improve productivity. Many studies find strong links between openness of trade, growth of exports, and productivity, and the diffusion of technology may also be promoted by openness to international competition. However, competition does not affect productivity in a direct and easily measurable way. Rather, it helps determine the conditions under which productivity growth occurs and high productivity levels may emerge.

The impact of competition on productivity is confirmed by recent studies, many of them based on industry- or firm-level panel data for individual countries (*e.g.* Haskel, 1991). Such studies found that strong market concentration and high market share have an adverse effect on the level of TFP. A recent study for the United Kingdom (Nickell, 1996) confirmed this result, but also found that competition, measured by an increase in the number of competitors or lower levels of rents, is associated with higher TFP growth. The link between competition and productivity growth is perhaps most clearly demonstrated by the experience with services sector deregulation in many OECD countries (Winston, 1993; Høj *et al.*, 1996). For instance, the deregulation of the US airline market since 1978 and that of the United Kingdom over the 1980s led to in-depth restructuring and a large increase in productivity. The deregulation of road freight transport in many OECD countries and of the telecommunications industry in Japan, the United Kingdom and the United States had similar results (OECD, 1997*u*).

Insight into determinants of productivity can also be derived from an analysis of productivity levels. Part of the difference in productivity levels between countries can be explained by differences in factor use, reflecting differences in ***factor endowments*** and relative factor prices (Salter, 1966). For instance, firms in countries such as Mexico and Portugal are faced with relatively low labour costs and consequently choose relatively labour-intensive production techniques, thus resulting in low levels of labour productivity (Table 4.6). Best practice technologies from more advanced countries may be of little relevance to these firms, as such technologies are often based on a different set of factor prices.

To some extent, differences in factor prices also affect productivity differentials between countries with similar factor endowments. Thus, part of the difference in labour productivity across countries can be explained by differences in capital intensity. For instance, Japan and the United Kingdom have relatively low levels of capital intensity in their manufacturing sector and relatively high levels of capital productivity (Table 4.8). For these countries, capital intensity explains a substantial part of the labour productivity gap with the United States, more than 25 per cent of the gap between Japan and the United States, and almost 13 per cent of the gap between the United Kingdom and the United States.[4] However, for Canada, France, and the Netherlands, which have more capital-intensive manufacturing industries than the United States (Pilat, 1996), adjustment for capital intensity does not help to explain the labour productivity gap with the United States. In general, this suggests that capital productivity in the manufacturing sector of these countries is relatively low. However, the comparison of real capital stocks and capital productivity across countries is more difficult than the comparison of real output, so that these numbers should be evaluated with care.

Adjusting for the ***average educational level*** of the manufacturing workforce explains little of the labour productivity gap. Although the average level of schooling in the United States is among the

Table 4.8. **Explanations of productivity gaps in manufacturing, 1989**

All levels relative to the United States

	Japan	Germany	France	United Kingdom	United States
Value added per hour worked	74	84	91	62	100
Relative capital intensity	77	102	132	76	100
Value added per unit of fixed capital	97	82	69	82	100
Total factor productivity (TFP)[1]	81	84	84	67	100
Relative level of workforce qualifications	98	99	96	95	100
TFP adjusted for labour force skills[2]	83	85	87	69	100
TFP adjusted for skills and industrial structure[3]	86	79	85	69	100

1. Value added per hour worked adjusted for capital per worker.
2. TFP adjusted for educational levels of the manufacturing workforce. For Japan, the adjustment only takes account of general educational levels; for the other countries, the adjustment is based on the level of vocational education. Educational levels are for 1987.
3. TFP adjusted for the composition of manufacturing. Industrial composition based on 1987 data.

Sources: Labour productivity levels are from Van Ark, 1996. Adjustment factors are based on Van Ark and Pilat, 1993, for Japan and Germany relative to the United States, and on Van Ark, 1993, for France and the United Kingdom relative to the United States.

highest in the OECD area (Englander and Gurney, 1994), average skill levels of its manufacturing workforce – measured by the qualification levels of manufacturing workers – are not very different from those of other major OECD countries (Van Ark and Pilat, 1993; Table 4.8). In addition, the experience with transplant production suggests that companies are able to match the productivity of their parent company abroad by using local labour; this suggests that educational levels are not a binding constraint for achieving high productivity, as appropriate in-company training can reduce such differences (McKinsey, 1993; Baily and Gersbach, 1995).

Differences in labour productivity may also be the result of ***structural factors,*** *i.e.* differences in the composition of output in a particular industry or sector. The McKinsey studies (McKinsey, 1993) suggest that this factor plays a limited role in most industries, although it may be important for some. For instance, Japan is one of the few OECD countries that produces supertankers and has a high level of labour productivity in shipbuilding. In addition, the productivity leaders in the aircraft industry, France and the United States, are the main producers of large passenger aircraft. At the aggregate level, however, adjustment for industrial structure does not contribute much to the overall explanation of productivity gaps (Table 4.8). In fact, adjustment for industrial structure increases Germany's productivity gap with the United States, as the industrial structure of Germany is more geared towards industries with high levels of labour productivity (Van Ark and Pilat, 1993).

The combined adjustments for capital intensity, labour force qualifications, and industrial structure explain more than 45 per cent of the Japanese-US labour productivity gap, and almost 20 per cent of the UK-US labour productivity gap. For France and Germany, they fail to provide any explanation of the labour productivity gap with the United States, although adjustment for educational skills reduces the productivity gap somewhat.

More evidence on factors explaining productivity differences, which are, however, specific to individual countries, is available from the country-specific studies mentioned above, primarily the McKinsey studies (McKinsey, 1993; 1994; 1995). These studies generally confirm that differences in capital and skill intensity do not go very far towards explaining the productivity gaps in manufacturing. They also suggest that access to technology is not a major factor in productivity differences among OECD countries. Much technology is embodied in capital goods, which are readily available in the world market. There are, however, major differences in the degree to which the latest technology is incorporated in the production process, an indication that new technology diffuses slowly across countries.

Economies of scale do appear to play a role, at least for some countries. Comparing Japan and the United States, Van Ark and Pilat (1993) found that the small size of establishments in many Japanese industries contributed substantially to a lower level of average productivity. The McKinsey work presented similar evidence (Baily and Gersbach, 1995). These studies found that sub-optimal scale and craft production processes were still a substantial part of industries in Japan (*e.g.* food manufacturing) and Germany (*e.g.* beer production and metalworking) and contributed to low productivity levels in these industries. The McKinsey studies found that many differences across countries with regard to productivity actually resulted from the organisation of functions and tasks. These differences are often the result of an accumulation of small improvements over a long period of time, regarding both shopfloor organisation and the management of the firm (Baily and Gersbach, 1995).

If differences in productivity levels across countries are not simply the result of differences in factor endowments or structural effects, then the gap in productivity levels between countries can be explained in part as the gap between the best available (average) practice and average implemented practice in a particular country. This suggests considerable scope for catch-up. In addition, large variations in productivity in some countries indicate that catching up with US productivity levels has not been uniform across industries and that productivity growth in some sectors may have suffered from structural rigidities other than the availability of technology (Englander and Gurney, 1994). The evidence on productivity differentials also indicates that even within the United States, catch-up possibilities may exist in some sectors.

Variations in productivity levels across countries also appears related to the level of competition facing industries and sectors in different countries (Baily and Gersbach, 1995; Pilat, 1997*b*). International competition, both for trade and foreign direct investment, appears to be important for achieving high levels of efficiency, and case studies suggest that the highest levels of efficiency are achieved by industries competing with best (global) practice. Openness may also allow firms to learn from and benchmark their performance against that of their international competitors.

MICROECONOMIC DETERMINANTS OF PRODUCTIVITY GROWTH

Breaking down productivity growth: the role of micro data

The preceding analysis of productivity is at a relatively aggregate level. Despite some analysis at sectoral level, many of the insights into the determinants of productivity growth are derived from aggregate data, often involving data sets for many countries. Recent work based on microeconomic data suggests that aggregate-level analysis may miss some important determinants of productivity which cannot be measured at the macroeconomic level.

Analysis of productivity at the microeconomic level is based on longitudinal databases. These detailed data cover individual firms or establishments and make it possible to trace the performance of firms over time. Over 16 OECD countries have developed such databases. They generally cover the manufacturing sector and include variables such as output, value added, employment, wages, capital stock (or investment) and material inputs for individual firms or establishments. The years and sample covered differ by country. In some countries, longitudinal databases also include parts of the services sector, and in some they have been linked to surveys of technology, R&D, or worker characteristics. The data units covered may differ, with establishments (plants) surveyed in some countries, and firms in others.

Longitudinal data have a number of advantages compared with regular databases (McGuckin and Pascoe, 1988; McGuckin, 1995; Bartelsman and Doms, 1997). First, as they are based on micro-level data, they allow for addressing a host of new questions, while avoiding the risk of aggregation bias. Second, they cover a large sample of the business sector. Because the business sector is so heterogeneous, and the size distribution of establishments (or firms) is very skewed, it is important to achieve a representative and detailed sample for each industry. Third, they allow for tracing individual plants or firms over time. Their longitudinal character enables the study of dynamic phenomena, such as productivity growth or job creation and destruction. Fourth, they can be linked to other detailed surveys, such as wage, R&D and technology surveys, something that is often impossible at the aggregate level (Zeelenberg and Van Leeuwen, 1996). For instance, by combining the US Longitudinal Research Database (LRD) and technology surveys, it is possible to associate technology use at the plant level with changes in performance (McGuckin *et al.*, 1996).

Longitudinal databases have mainly been used for detailed analysis of productivity growth. They allow for breaking down productivity into various components. Two methods are generally used. A first, pioneered by Baily *et al.* (1992) and somewhat revised by Haltiwanger (1996), allows for distinguishing between productivity growth in existing (and continuing) firms, productivity growth resulting from increased market shares of high-productivity firms, and productivity growth resulting from the process of entry and exit (Annex II). A second method, attributed to Baily *et al.* (1996), can be used to break down productivity growth into the contributions of downsizing and upsizing firms (Annex II). It makes a distinction between four types (quadrants) of firms: those that increase employment and have positive productivity growth (successful upsizers); those that decrease employment and have positive productivity growth (successful downsizers); those that increase employment and have negative productivity growth (unsuccessful upsizers); and those that decrease employment and have negative employment growth (unsuccessful downsizers).

The role of reallocation

Thus far, the first method has been used for five countries (Table 4.9), although several others have been covered by closely related methods. In interpreting Table 4.9, several points should be noted. First, the US breakdown concerns TFP growth, whereas that of the other countries concerns labour productivity.[5] Second, the US breakdown is based on a slightly different method (Annex II). Third, the Finnish and US data cover establishments, but the Dutch, German and Japanese data refer to firms. Fourth, the data for Finland, Japan, and the Netherlands exclude some smaller establishments and firms. For Japan, the sample of firms is relatively small, as firms with less than 100 employees are not included.[6] Fifth, the US and Finnish breakdown includes the effect of exit and entry, while that for Japan, Germany and the Netherlands is based on a balanced sample.

The breakdown results provide useful insights. First, except for Germany,[7] most productivity growth is due to changes within plants or firms. This is particularly true for the Netherlands, where this factor explains almost all productivity growth. However, changes in market shares also play a role, and are the dominant feature of German productivity growth. The results for the United States for this term are the reverse of those for the European countries and Japan, although this may due to methodological differences. The interaction term (see Annex II) is particularly important in the United States and Germany, and again has different signs for the United States on the one hand and the European countries and Japan on the other. The positive sign for the United States implies that the data are characterised by plants whose market share and productivity increase and by plants whose market share and productivity decrease. The interaction term plays only a minor role in Japan. The effect of net entry is quite important for the United States and also plays some role in Finland.

The breakdown in Table 4.9 covers a relatively long time period for the five countries. To some extent, a long time period is needed to study the long-term effects of entry and exit. However, some interesting results can also be derived from a breakdown into shorter time periods. Table 4.10 shows such a breakdown for Finland, Germany, and the United States. The results are particularly interesting for Finland (Maliranta, 1997). They suggest that most of the increase in productivity growth in Finland since the mid-1980s is due to competitive effects, *i.e.* a positive contribution of net entry (mainly due to the exit of low-productivity plants) and of changing market shares. These results fit well with the massive restructuring of Finland’s industry over this period. The contribution of productivity growth in continuing plants changed little over the period 1975-94.

Baldwin (1995) uses a somewhat different method to break down productivity growth. He finds that almost 70 per cent of productivity in Canadian manufacturing over the period 1970-79 is due to productivity growth within plants. The remainder is due to the process of entry and exit. Within the continuing sector, Baldwin distinguishes between growth in plants gaining market share, growth in plants losing market share, and a displacement effect. Plants gaining market share account for 43 per cent of productivity growth within this segment, while the displacement effect accounts for almost 38 per cent. Growth in plants losing market share accounts for the remainder. Related studies of productivity growth have been made for some other countries. Griliches and Regev (1995) find that, over the period 1979-88, more than 80 per cent of all productivity growth in Israeli industry is due to productivity growth within firms and that the effects of net entry and changing employment shares are relatively minor. Roberts and Tybout (1997) report that, during an economic recession, plant exits in Chile improved labour productivity by more than a percentage point, whereas the entry of low-productivity firms during Morocco’s boom period reduced labour productivity growth by almost two percentage points.

The negative interaction term for the European countries and the positive term for the United States may indicate differences in the competitive process. Whereas productivity growth in the United States appears to be accompanied by a growth in output shares, it appears in Europe to be characterised by declining output shares. The data reveal another interesting difference between the United States on the one hand, and Europe (with the exception of Lower Saxony) and Japan, on the other. In the United States, productivity growth within firms explains just over half of productivity growth. Reallocation, as measured by the combined effect of changing market share, net entry, and the

Table 4.9. **Breakdown of manufacturing productivity growth**[1]

	United States[2]		Japan	Germany	Finland	Netherlands
	1972-87	1977-87	1987-94[3]	1978-94[4]	1976-95[5]	1980-91[6]
	Panel A: Annual average growth rates					
Productivity growth	1.6	1.0	9.2	2.4	6.4	2.9
Due to changing firm-level productivity	1.1	0.6	6.8	0.5	5.6	2.8
Due to changing market shares	0.5	–0.1	2.5	2.7	1.5	0.4
Interaction term	..	0.4	–0.1	–1.0	–1.4	–0.3
Net entry	0.0	0.2	..	..	0.6	..
	Panel B: Percentage contribution to productivity growth					
Productivity growth[5]	100.0	100.0	100.0	100.0	100.0	100.0
Due to changing firm-level productivity	69.1	55.6	73.9	19.6	87.5	96.6
Due to changing market shares	32.2	–10.9	27.0	113.4	23.4	13.5
Interaction term	..	38.6	–0.7	–42.9	–21.9	–9.5
Net entry	–0.4	19.1	..	..	9.4	..

1. Total factor productivity growth for the United States, labour productivity growth for the other countries. The first column for the United States is based on Baily *et al.,* 1992; the second on Haltiwanger, 1996.
2. Based on US LRD database for establishments.
3. Based on firm data. Excludes firms with less than 100 employees.
4. Based on firm data. Data cover Lower Saxony only.
5. Based on establishment data. Excludes plants with less than 5 employees.
6. Based on firm data. Excludes firms with less than 10 employees.

Sources: United States based on Baily *et al.,* 1992, and Haltiwanger, 1996; Japan provided by MITI, 1997; Germany from Wagner, 1997; Finland from Maliranta, 1997; Netherlands by Nieuwenhuijsen, 1997.

Table 4.10. **Breakdown of manufacturing productivity growth, by time period**

Annual average growth rates, by time period

	Aggregate productivity growth[1]	Productivity growth within plants	Effect of net entry	Effect of changing market shares	Cross-term
	Panel A: United States				
1977-82	0.5	–0.1	0.1	–0.3	0.7
1982-87	1.6	0.9	0.2	–0.3	0.8
1977-87	1.0	0.6	0.2	–0.1	0.4
	Panel B: Lower Saxony, Germany				
1978-84	2.3	0.7	..	2.0	–0.4
1984-94	2.5	0.4	..	3.1	–1.2
1990-94	1.4	0.6	..	1.3	–0.5
1978-94	2.4	0.5	..	2.7	–1.0
	Panel C: Finland				
1976-80	5.0	5.2	0.1	1.1	–1.6
1980-85	5.1	5.4	–0.1	0.9	–1.0
1985-90	7.6	6.2	1.3	1.7	–1.6
1990-95	7.8	5.7	1.0	2.3	–1.3
1976-85	5.0	5.3	0.0	1.0	–1.3
1985-95	7.7	5.9	1.1	2.0	–1.4
1976-95	6.4	5.6	0.6	1.5	–1.4

1. Total factor productivity growth for the United States, labour productivity for Finland and Germany.

Sources: United States based on Haltiwanger, 1996; Germany from Wagner,1997; Finland from Maliranta, 1997.

Table 4.11. **Exit and efficiency**

Exits between years as a percentage of all firms in initial year

	Firms with above-average productivity (top 50% of firms)	Firms with below-average productivity (bottom 50% of firms)
Germany (Lower Saxony)		
1978-84	17.7	30.2
1984-94	27.9	39.6
1990-94	12.8	21.1
1978-94	40.4	54.9
Canada[1]		
1970-79	21.4	29.4

1. The data for Canada refer to plant closures.

Sources: Wagner, 1997, for Germany; Baldwin, 1995, for Canada.

interaction term, is almost as important. In Europe and Japan, productivity growth within firms accounts for three-quarters or more of total productivity growth. This may mean that competitive factors play a greater role in the United States and also that the "representative firm" model is more appropriate for Europe and Japan than for the United States.

The entry and exit process can sometimes make a sizeable contribution to productivity growth. The main factor is less the entry of firms whose productivity is above average than the exit of firms whose productivity is poor. Baldwin (1995) and Wagner (1997) indicate that the productivity of exiting firms is likely to be below their industry average (Table 4.11). However, the productivity of new entrants to the industry is also typically well below the industry average (Baily *et al.*, 1992; Baldwin, 1995; Griliches and Regev, 1995). However, if the productivity of exiting firms is even poorer, the net contribution of the entry and exit process can be positive. The contribution of net entry is often not very large because new entrants typically do not account for a large share of output. In exceptional cases, such as the restructuring of Finland's manufacturing sector during the period 1985-95, exit may provide an important contribution to productivity growth (Maliranta, 1997).

Productivity and upsizing and downsizing

The second type of breakdown is available for only four countries (Table 4.12). Apart from a positive effect of net entry for the Netherlands, productivity growth is almost equally due to successful

Table 4.12. **Upsizing and downsizing in labour productivity growth**

Annual average growth rates, in per cent

	United States		Japan	France	Netherlands
	1977-87[1]	1987-92[1]	1987-94[2]	1985-91[3]	1980-91[4]
All firms/establishments	..	..	..	..	3.0
Continuing firms	3.4	2.4	9.2	2.3	2.0
of which:					
– Successful upsizers	2.2	1.7	9.1	1.2	1.2
– Successful downsizers	2.6	2.6	10.0	2.2	1.0
– Unsuccessful downsizers	–0.6	–0.5	–4.7	–0.6	–0.1
– Unsuccessful upsizers	–0.7	–1.3	–5.2	–0.5	–0.2
Effect of entry and exit	..	..	..	..	1.0

1. Based on establishment data.
2. Based on firm data. Excludes firms with less than 100 employees.
3. Based on firm data. Excludes firms with less than 20 employees.
4. Based on firm data. Excludes firms with less than 10 employees.

Sources: United States (1977-87) from Baily *et al.*, 1996; Netherlands from Bartelsman *et al.*, 1995. Other estimates by OECD based on national data.

upsizers and successful downsizers in Japan, the Netherlands, and the United States, but not in France. Successful upsizers added employment but increased productivity at the same time, perhaps because of increasing product demand, combined with increasing returns to scale, or technological innovation that allows the firm to lower the price of its output in the face of elastic product demand (Bartelsman *et al.*, 1995; Baily *et al.*, 1996).

The second group, successful downsizers, are representative of the view that productivity growth in manufacturing is associated with downsizing. The combination of rising productivity and falling employment may indicate technological innovations or efficiency improvements combined with falling or inelastic demand or, alternatively, lower barriers to entry and the lesser importance of economies of scale in expanding markets. The third and fourth group represent the less successful parts of the manufacturing sector. A combination of falling productivity and falling employment may indicate falling demand and increasing returns to scale, or falling demand and incomplete employment adjustment (Baily *et al.*, 1996; Bartelsman *et al.*, 1995). The combination of falling productivity and increasing employment may suggest negative productivity and increasing demand, or rising demand and diminishing returns to scale.

The breakdown presented above can be taken further in a number of ways (Baily *et al.*, 1996; Bartelsman *et al.*, 1995). For instance, it is possible to look at the size distribution of firms and study which size classes contributed most to productivity and employment changes. In addition, sectoral patterns can be studied and the links between productivity, downsizing and wages can be explored. Unfortunately, the sample of countries covered is still quite small, making it difficult to draw general conclusions. Nevertheless, these studies provide some interesting results and re-emphasize the enormous variation in productivity.

First, the relation between size and productivity growth appears very similar in the United States and the Netherlands (Bartelsman *et al.*, 1995; Baily *et al.*, 1996). In both countries, small and medium-sized firms (SMEs) are disproportionately represented among successful upsizers. Surprising, however, is the disproportionate representation of the largest plants (over 5 000 employees) among successful upsizers in the United States. In both countries, plants with over 500 employees are strongly represented among successful downsizers, in confirmation of the traditional view of downsizing. Among unsuccessful upsizers, small plants are disproportionately represented in both countries. However, among unsuccessful downsizers, small and medium-sized plants (less than 250 employees) are somewhat under-represented and large plants over-represented in the United States, whereas in the Netherlands small and medium-sized plants (below 500 employees) are over-represented and large plants under-represented.

The sectoral patterns are also quite interesting, but differ substantially between the two countries for which such data are available. For the United States, the following patterns can be observed. Among successful upsizers, electronic equipment has a relatively high share and basic metals a very low share. Among successful downsizers, petroleum refining and basic metals are strongly represented. The data appear to reflect the decline in the steel industry and the move towards minimills (Baily *et al.*, 1996). For the Netherlands,[8] the chemicals industry is important among successful upsizers, whereas the metal and electrotechnical industries are under-represented. The latter two groups are over-represented among successful downsizers, owing to the decline of the steel industry in the Netherlands and considerable restructuring efforts by the electronics industry (dominated by Philips).

The link to wages also produces interesting results. For the United States, Baily *et al.* (1996) found that downsizing plants had the highest initial wages, whereas successful upsizers had the lowest. Plants that increased productivity, both upsizers and downsizers, had the highest real wage growth. Plants with falling productivity also experienced a drop in real wages. For the Netherlands, Bartelsman *et al.* (1995) found a monotonic link between initial wages and contribution to productivity growth. However, the highest category of wages was disproportionately present in successful downsizers. Furthermore, firms with the lowest wages were over-represented among upsizers.

These results can be interpreted in several ways (Baily *et al.*, 1996). For instance, wage changes might be associated with changes in labour quality. Successful upsizers might add more skilled workers, whereas successful downsizers might retain their higher-skilled workers. Alternatively, wage increases for some types of workers might have led to some substitution of capital for labour and thus enhanced productivity growth. Also, plants increasing productivity might share some of their rents with workers in the form of higher real wages.

Have microeconomic data changed our understanding of productivity growth?

Work with longitudinal microeconomic data series (LMDS) has demonstrated the heterogeneity of firms as well as the persistence of productivity dispersion. Baily *et al.* (1992) found that an important determinant of a plant's productivity level in a given year was its level five years earlier. This persistence may be associated with differences in worker quality, but also with differences in management and organisation. Dwyer (1995*a;* 1995*b*) used the US Longitudinal Research Database (LRD) to analyse productivity dispersion in the US textile industry. He found that while a substantial part is transitory and disappears after three years, an important share is real and persists over time. Some plants are consistently more productive than others and force firms that perform less well out of business.

LMDS have also made it possible to identify some factors influencing productivity growth. Two types of processes seem to be at work. One is productivity growth within firms, which may be due to technical change and the accumulation of human capital with the firm,[9] but is also influenced by ''softer'' production factors, such as management, ownership and organisation. The other is productivity growth among firms. This is often linked to competition and creative destruction.

The role of technology

Much of the productivity literature identifies TFP growth with technical change. To some extent, this reflects the difficulty of measuring technology and advances in technology. Work with LMDS – in combination with technology surveys – offers some fresh insights. The most extensive work on this issue has been done for the United States. In a first study, Doms *et al.* (1995) constructed a database for the period 1987-91 for more than 6 000 manufacturing plants on the basis of the 1987 Census of Manufacturers (CM), the 1988 Survey of Manufacturing Technology (SMT), and the 1991 Standard Statistical Establishment List (SSEL). The 1988 SMT data distinguish 17 advanced (manufacturing or information) technologies used by a plant, whereas the CM and SSEL data provide information on size, age, productivity, capital use, and growth and failure variables. The authors found that increases in the capital intensity of the product mix and in the use of advanced manufacturing technologies are positively correlated with plant expansion and negatively with plant exit.

A follow-up study (Doms *et al.*, 1997) shows the interaction between technology, skills and wages. It finds that plants that use more sophisticated equipment employ more skilled workers and that workers that use more advanced capital goods receive higher wages. An inter-temporal analysis showed that the most technologically advanced plants paid higher wages prior to adopting new technologies and were more productive, both prior to and after the adoption of advanced technologies.

McGuckin *et al.* (1996) also examined the link between technology use and productivity, based on the US LRD database and the 1988 and 1993 Surveys of Manufacturing Technology. They found that firms that use advanced technologies exhibit higher productivity, even when controlling for factors such as size, age, capital intensity, labour force skills, industry and region. More productive plants used a wider range of advanced technologies and used them more intensively than other plants. Like Doms *et al.* (1997), they found that while the use of advanced technologies can help improve productivity, plants that perform well are more likely to use advanced technologies than those that perform poorly. They also found that the process of technology adoption was not smooth and was characterised by substantial experimentation. In addition, the diffusion of particular technologies was very diverse.

Similar studies have been made for other countries. Studies for Canada (Baldwin and Diverty, 1995; Baldwin *et al.*, 1995*a*) link panel data from the Census of Manufacturers to data from a technology survey. Baldwin *et al.* found that establishments using advanced technologies gain market share at the expense of non-users. Technology users also enjoy a significant labour productivity advantage over non-users, except for establishments that only use fabrication and assembly technologies. Relative labour productivity grew fastest in establishments using inspection and communications technologies and in those able to combine and integrate technologies across the different stages of the production process. Technology users were also able to offer higher wages than non-users. Baldwin and Diverty (1995) found that plant size and plant growth were closely related to the incidence and intensity of technology use, an indication that technology use is closely linked to the "success" of a plant.

A study of the Netherlands (Bartelsman *et al.*, 1996) is also based on firm-level longitudinal data. It found that adoption of advanced technology is associated with higher labour productivity, higher export intensity, and larger size. Firms that employed advanced technologies in 1992 had higher productivity and employment growth in the preceding period. On the basis of longitudinal data covering Swedish multinational firms, Fors (1997) demonstrated that the productivity-enhancing effects of R&D are influenced by the nature of technology transfers due, for example, to intra-firm trade in goods and own R&D by foreign affiliates.

Human capital

A number of longitudinal studies also address the interaction between technology and human capital and their joint impact on productivity (Bartelsman and Doms, 1997). Although few longitudinal databases include data on worker skills or occupations, some address human capital through wages, arguing that wages are positively correlated with worker skills. For the United States, Baily *et al.* (1992) found a positive link between wages and productivity, although there is no clear evidence of causality. For France, the results are somewhat clearer, as the French data include details about worker characteristics. Entorf and Kramarz (forthcoming) found strong complementarity between skills and technology and hence between skills and productivity. For Swedish multinational firms, Andersson *et al.* (1996) demonstrated a close link between training and R&D expenditures, on the one hand, and labour productivity, on the other, although the impacts may differ among various parts of a firm (for example, domestic operations versus foreign affiliates).

For Canada, Baldwin *et al.* (1995*b*) found that use of advanced technology was associated with a higher level of skill requirements. In Canadian plants using advanced technologies, this often led to a higher incidence of training. They also found that firms adopting advanced technologies increased their expenditure on education and training. A follow-up study (Baldwin *et al.*, 1997) found that plants using advanced technologies pay higher wages to reward the higher skills required to operate these technologies. Thus, most micro-level studies confirm the complementarity of technology and skills in improving productivity, a result that has also been found in other recent work (OECD, 1996*h*).

Management, ownership and organisation

Management and related factors are often difficult to capture in productivity analysis. However, LMDS provide some insights. For the United States, Baily *et al.* (1992) found that plants that are part of a high-productivity firm will also have high productivity (where the plant in question is not included in the firm's productivity level). According to the authors, multi-unit firms can improve performance across the whole range of plants, as they can easily transfer skills, technology, product design and production methods.

Lichtenberg and Siegel (1992*a*) examined a sample of large establishments in the LRD and found that plants that undergo ownership changes tend to have below-average productivity prior to the change, and that their productivity increases at a slightly higher than average rate following the change. A related study (Lichtenberg and Siegel, 1992*b*) found that ownership changes were often accompanied by a reduction in the share of employment at auxiliary offices.

However, a study by McGuckin and Nguyen (1995), which focused on only one industry, food processing, and covered a broader sample of establishments found that plants with above-average productivity are more likely to change owners and that the acquiring firms also tended to have above-average productivity. Plants that changed owners generally improved productivity following the change.

According to the authors, ownership changes appear associated with the purchase or integration of advanced technologies and better practices into new firms. These results were confirmed by Baldwin (1995), in a study for the Canadian manufacturing sector.

A follow-up study (McGuckin and Nguyen, 1997) analyses ownership changes from the perspective of acquiring firms. It finds that acquisitions have a positive effect on acquiring firms' productivity growth when single-unit firms are included in the analysis, but that there is no significant effect if multi-unit firms are included. In addition, productivity increases in acquired plants are higher than in non-acquired plants, for both single and multi-unit firms.

The impact of competition

Analysis based on LMDS provides some important insights into the competitive process. As discussed above, it shows the high degree of turnover in the manufacturing sector, the success of some firms, the failure of others, and the role of entry and exit. It also shows that intra-industry dynamics make an important contribution to productivity growth (Baldwin, 1995). New entrants are generally more productive than firms that close down, and firms that exit an industry tend to have below-average productivity. The effects of entry take time to appear, however, as plants gain market share and become more productive as they mature. Furthermore, firms that gain market share contribute significantly to overall productivity growth.

Analysis based on LMDS reinforces the view that competition and dynamism are central to productivity, a view that is confirmed by other recent studies (Nickell, 1996; Pilat, 1997*a*), but they also make possible more detailed insights into the process of competition and creative destruction and allow quantification of some effects of competition.

CONCLUSIONS

Productivity growth at the economy-wide level remains disappointing in most OECD countries, although a few have been able to improve their performance over the past years. Analysis at the sectoral level shows that many parts of the economy – in both manufacturing and services – have achieved significant productivity gains over the past decade. Measurement problems – for instance in financial services – may also disguise some improvements made. However, productivity growth in other parts of the economy – and in many parts of the services sector – has been slow over the past decades.

Analysis of ***productivity levels*** leads to some broad conclusions. First, productivity levels are a main determinant of real incomes, and improving productivity is thus an essential element of policies aimed at higher incomes. Second, inefficiency and low productivity levels appear to be widespread in both manufacturing and services throughout the OECD area, so that there would seem to be substantial potential for further productivity growth in many countries. The great variation in the speed of catch-up across industries may indicate that structural factors inhibit productivity growth in some sectors. Third, variation in productivity levels and growth rates across countries appears to some extent related to the degree of competition facing industries and sectors in different countries. In the services sector, government-imposed regulation often seriously restricts competition, as it prevents entry and reduces the benefits of competition.

The economic literature appears in broad agreement on the principal ***determinants of productivity growth***: private investment in physical capital, training and technology, as well perhaps as public investment in education, research and infrastructure. The organisation and management of these production factors within the firm also affect productivity. Framework conditions, such as openness to trade and investment and the degree of competition prevailing in the economy, are also important.

Productivity analysis based on ***longitudinal data*** has added considerably to our understanding of productivity growth and has demonstrated the enormous diversity of experiences in individual industries. In the United States, industry-specific factors explain less than 10 per cent of the cross-sectoral variation, a sign that firms react very differently to changing conditions and aggregate shocks. Aggregate trends, drawn from industry-level data, may thus fail to allow for a proper interpretation of behaviour. Analysis of microeconomic patterns may be needed to understand changes in macroeconomic patterns.

This insight affects the analysis of productivity in a number of areas. First, longitudinal analysis shows that ***competitive effects,*** such as entry and exit of firms and changes in market shares, make an important contribution to productivity growth. Technology-driven strategies to enhance productivity growth within firms may have to be embedded in a competitive framework, where a process of ''creative destruction'' enables entry and exit, growth of successful firms, and failure of unsuccessful ones. Policies that unduly restrict this process risk lowering productivity growth.

Analysis of a number of OECD countries suggests that productivity growth is almost equally due to ***upsizing*** (firms adding employment) as to ***downsizing*** (firms shedding employment). Firms that increase productivity and add to their workforce are often in markets with increased product demand and increasing returns to scale or in markets characterised by technological innovation which allow firms to reduce output prices in the face of elastic product demand. Firms that reduce employment while increasing productivity are often in markets with inelastic or falling demand, with technological improvements in the industry allowing them to increase efficiency.

Furthermore, the breakdown of productivity growth suggests positive effects from ownership changes and the growth of firms, suggesting that policies should not unduly restrict the expansion of firms. Longitudinal analysis also provides some fresh insight into the role of ***small and medium-sized enterprises.*** It suggests that SMEs, where the process of creative destruction is greatest, are a dynamic component of the economy.

Work with microeconomic data also raises new issues. Principal among these is the diversity of ***firm behaviour.*** Analysis suggests that most productivity growth is the result of growth within firms. The use of advanced technologies and investment in skills are often associated with productivity growth within firms, but longitudinal studies also suggest that firms that adopt these technologies and invest in skills already perform better than the average firm. This suggests the need for a better understanding of why some firms do well and why others fail. Recent analysis (OECD, 1996*b;* Government of Canada/OECD, 1997) indicates that a flexible workplace organisation may be important to a firm's success. Flexible firms appear to have a greater ability to adapt and to enhance the contribution of intangible assets, such as workers' skills, to their performance.

Currently, work with longitudinal databases primarily covers the manufacturing sector. Although some databases include parts of the ***services sector,*** less work has been done on these data, partly because of measurement problems. Further work on longitudinal data on services would be very important, however, as it would extend the analysis of microeconomic data to the largest part of the economy, thus improving the understanding of productivity growth at the macroeconomic level. As productivity growth in parts of the services sector has been more sluggish than in manufacturing, better understanding of the drivers of productivity in services would be very important.

Productivity in OECD countries remains a concern to many OECD governments. The analysis in this chapter – and in other work by the OECD – suggests that there is no simple way to boost productivity growth. Attention to framework conditions, including the degree of competition and market openness, appear as areas where ***government policy*** can contribute. Attention to education and training, physical capital formation and public infrastructure, as well as the promotion of technological change, are also important areas where governments have a role to play. However, private industry remains the principal actor for achieving high rates of productivity growth.

Annex I

PRODUCTIVITY GROWTH IN SERVICES

Annex Table 4.1. **Productivity in services**[1]

Compound annual growth rates, in per cent

	Wholesale, retail trade, restaurants and hotels			Transport, storage and communication			Finance, insurance, real estate and business services				Community, social and personal services	Producers of government services	Total services
	Total	Wholesale and retail trade	Restaurants and hotels	Total	Transport and storage	Communication	Total	Financial institutions	Insurance	Real estate and business services			
Australia													
1974-79	–0.1	0.0	..	4.6	4.3	5.1	1.2	..	..	..	1.3[1]	0.9	1.1
1979-84	1.6	1.6	..	3.9	2.9	7.2	–0.7	..	..	..	–0.1[1]	0.6	1.0
1984-93	–0.7	–0.4	–1.8	4.5	3.1	8.7	0.9	3.1	..	–0.2	0.6	2.4	1.0
Austria													
1973-76	1.5	1.8	0.3	4.4	..	..	1.6	..	..	..	0.4	0.3	1.5
1976-79	1.1	1.6	–0.5	4.1	..	..	1.5	..	..	..	–1.1	0.8	1.4
1980-83	2.3	2.8	0.7	1.4	..	..	1.0	..	..	..	–0.2	0.8	1.4
1984-94	1.1	1.4	–0.3	3.2	..	..	0.7	1.8[2]	..	0.1	1.6	–0.3	1.0
Canada													
1973-79	–0.8	–0.4	–2.1	2.9	1.2	6.9	–0.4	–0.8	3.8	–0.7	0.5	–0.2	0.2
1979-85	0.2	1.4	–4.1	2.8	1.9	4.2	–0.4	–4.1	3.1	–0.3	–2.3	0.5	0.1
1985-92	0.6	1.3	–2.1	3.0	0.7	6.2	0.5	–0.7	1.6	0.5	–0.5	0.2	0.7
Denmark													
1973-79	2.7	2.8	1.9	0.3	0.0	5.2	–0.8	–4.7	–7.7	0.5	1.4	–0.3	0.6
1979-85	0.6	0.8	–0.9	–2.6	–3.0	–1.7	–3.9	–2.5	–0.9	–4.4	–0.3	–3.1	–2.0
1985-94	2.8	3.3	–1.3	2.8	1.7	7.6	1.2	–0.1[3]	–7.8[3]	0.4	0.1	2.6	2.2
Finland													
1973-75	1.9	–4.3	2.7	1.5	0.2	6.9	–0.4	–2.1	..	0.0	0.4	0.4	2.2
1975-79	2.1	2.2	1.5	1.4	1.5	1.2	1.4	–0.6	5.1	1.5	1.6	0.3	1.6
1979-85	1.8	2.0	1.2	2.0	1.2	5.2	0.3	4.0	1.2	–1.5	3.2	0.2	1.5
1985-94	1.7	1.6	2.3	5.0	4.1	7.4	1.6	2.0	11.0	0.4	3.2	0.3	2.0
France													
1980-85	..	..	0.3	3.5	2.3	7.4	..	–1.6	6.7	..	..	..	1.8
1985-95	0.9	1.3	–1.1	4.3	1.9	8.9	1.0	4.7	–0.4	–0.1	1.6	0.8	1.4
Iceland													
1973-80	0.7	1.0	–2.0	3.4	2.8	5.9	–0.3	2.7	1.4	–2.0	1.2	0.6	1.2
1980-89	0.3	0.5	0.5	3.0	0.2	10.4	–1.0	1.1	2.5	–3.2	2.9	2.0	1.2
1990-92	–3.1	–1.9	–8.5	0.3	–0.5	3.5	–1.5	1.7	4.9	–3.5	0.1	–0.6	–1.1
Italy													
1973-79	2.0	2.3	0.7	3.3	3.3	3.3	–0.9	..	..	..	..	0.0	1.0
1979-85	–1.0	–0.9	–1.7	1.4	0.2	5.2	–3.4	..	..	..	..	0.0	–0.9
1985-94	1.7	2.1	–0.3	3.7	2.5	7.1	0.9	..	..	..	..	0.2	1.2

Annex Table 4.1. **Productivity in services**[1] *(cont.)*

Compound annual growth rates, in per cent

	Wholesale, retail trade, restaurants and hotels			Transport, storage and communication			Finance, insurance, real estate and business services				Community, social and personal services	Producers of government services	Total services
	Total	Wholesale and retail trade	Restaurants and hotels	Total	Transport and storage	Communication	Total	Financial institutions	Insurance	Real estate and business services			
Japan													
1973-79	4.9	4.9	..	0.7	..	..	2.0	3.5	..	..	0.0	2.6	1.6
1979-85	2.7	2.7	..	4.3	..	..	1.6	3.3	..	..	1.9	1.8	2.8
1985-94	4.1	4.1	..	2.2	..	..	2.6	4.7	..	..	0.2	0.8	1.9
Mexico													
1980-85	–0.4	..	..	–1.2	..	..	–0.9	..	..	..	2.1	–0.5	0.1
1985-93	0.0	..	..	2.5	..	..	2.4	..	..	..	0.5	0.2	0.9
Netherlands													
1982-87	3.3	3.5	2.1	4.6	4.7	4.6	2.7	5.7	3.6	1.1	2.4	2.1	3.2
1987-92	1.6	1.2	4.7	3.3	2.7	5.0	2.5	1.6	2.8	2.2	2.5	2.9	2.8
Sweden													
1980-85	2.3	3.3	–5.1	0.5	–0.6	2.6	0.1	2.0	3.1	–0.7	0.6	0.0	0.8
1985-91	2.2	2.6	–1.2	5.6	4.7	8.0	–2.7	1.7	2.0	–4.3	0.5	1.1	1.6
1991-94	3.9	4.2	2.1	3.5	2.6	7.2	3.8	4.1	2.9	3.8	–1.3	1.4	2.7
United States													
1973-77	–0.1	–0.1	0.1	2.7	1.5	5.3	–0.4	0.1	0.4	–0.9	0.3	0.0	0.3
1977-87	1.5	1.6	–1.1	2.5	1.0	4.9	–1.5	0.0	–2.2	–2.8	–0.6	0.2	0.5
1987-93	1.8	1.7	3.1	2.6	2.3	3.9	0.1	2.1	2.1	–0.7	–1.3	0.1	0.6
West Germany													
1973-79	2.1	2.4	0.4	4.1	3.2	6.0	3.1	3.7	2.3	..	0.5	0.4	1.9
1979-85	0.0	0.5	–2.1	2.9	2.0	4.4	1.7	0.4	2.1	..	1.4	0.3	1.2
1985-93	1.2	1.6[4]	–0.8	3.1[4]	1.8	4.8	2.1[5]	2.4	2.8	..	2.1	0.7[4]	1.9[4]

Productivity = constant price value added/employment.
1. Includes restaurants and hotels.
2. Includes insurance.
3. 1985-92.
4. 1985-95.
5. 1985-94.
Source: OECD, Services database.

Annex II

BREAKING DOWN PRODUCTIVITY GROWTH – METHODOLOGY

There are several ways to break down productivity growth. A first method, pioneered by Baily *et al.* (1992), allows a distinction between productivity growth in existing (and continuing) firms, productivity growth resulting from increased market shares of high-productivity firms, and productivity growth resulting from the process of entry and exit. The last two components reflect the competitive process underlying productivity growth, *i.e.* creative destruction, whereas productivity growth within firms is often identified with technological progress. If the effect of entry and exit is excluded, this breakdown is as follows:

$$\Delta \ln TFP_{t1} = \sum_{continuers} \theta_{it0}\, \Delta \ln TFP_{it1} + \sum_{continuers} \ln TFP_{it0}\, \Delta\theta_{it1} + \sum_{continuers} \Delta \ln TFP_{it1}\, \Delta\theta_{it1}$$

where θ_{it} is the share of gross output for plant *i* in period *t* for the industry, and where productivity growth ($\Delta \ln TFP_t$) is measured between the periods 0 and 1.

The first term of the breakdown represents productivity growth in continuing plants (or firms) based on plant-level changes, weighted by initial market (employment) shares. This part of productivity growth is independent of any change in market shares. The second term reflects changing market shares weighted by the levels of TFP in the initial year. This component captures by how much productivity would have changed had there been changes in market shares, but none in productivity of individual plants. The third term is the "covariance" term. It is positive when plants that increase productivity also increase market share, and vice versa (Conference Board, 1997*b*). The effect of entry and exit can also be incorporated in this breakdown (Maliranta, 1997). An entering plant will contribute positively to productivity growth only when it has higher productivity than the initial average, whereas an exiting plant will have a positive contribution to productivity growth if its productivity is below the initial average.[10]

Haltiwanger has recently proposed an alternative method (Haltiwanger, 1996). His formula is:

$$\Delta \ln TFP_{t} = \sum_{continuers} \theta_{it-k}\, \Delta \ln TFP_{it} + \sum_{continuers} (\ln TFP_{it-k} - \ln TFP_{t-k})\, \Delta\theta_{it} + \sum_{continuers} \Delta \ln TFP_{it}\, \Delta\theta_{it}$$
$$+ \sum_{entrants} \theta_{it}\, (\ln TFP_{it} - \ln TFP_{t-k}) - \sum_{exits} \theta_{it-1}\, (\ln TFP_{it-k} - \ln TFP_{t-k})$$

where θ_{it} is the share of gross output for plant *i* in period *t* for the industry, and where productivity growth ($\Delta \ln TFP_t$) is measured between the periods $(t-k)$ and *t*. The first term of the breakdown is similar to that of the first formula. The second reflects changing output shares weighted by the deviation of initial plant productivity from initial average productivity in the industry. This component captures the gains in productivity from high-productivity plants that capture market share, or the losses due to low-productivity plants that lose market shares. The third term is also similar to that in the first formula, while the final two terms capture the impact of entry and exit. An entering plant will contribute positively to productivity growth only when it has higher productivity than the initial average, whereas an exiting plant will have a positive contribution to productivity growth if its productivity is below the initial average.[11]

A second method, attributed to Baily *et al.* (1996), can be used to break down productivity growth into the contributions made by downsizing and upsizing firms. A distinction is made between four types (quadrants) of firms, namely firms that increase employment and have positive productivity growth (successful upsizers), firms that decrease employment and have positive productivity growth (successful downsizers), firms that increase employment and have negative productivity growth (unsuccessful upsizers) and firms that decrease employment and have negative employment growth (unsuccessful downsizers). This breakdown uses the following notation (Baily *et al.*, 1996):

$$\Delta \ln TFP_t = \sum_q \phi_{t-1,q} \Delta \ln TFP_{t,q} + \sum_q \Delta \phi_{t,q} (\ln TFP_{t-1,q} - \ln TFP_{t-1}) + \sum_q \Delta \phi_{t,q} \Delta \ln TFP_{t,q}$$

where ϕ_q is $L_q/\Sigma_q L_q$, the share of manufacturing employment in quadrant *q*. The interpretation of this breakdown is similar to the first one. The first term reflects productivity increases within individual plants, the second one those arising from shifts in employment shares between plants, while the third terms captures the cross-term, and is positive or negative depending upon whether plants with positive productivity growth have increasing or decreasing employment shares, or vice versa.

The equation indicates that successful upsizers contribute to productivity growth not only by the rise in productivity within such plants, but also through their increased employment share (the cross-term). Successful downsizers mainly contribute to productivity growth by their performance within plants and have a negative cross-term (their employment share is falling). Unsuccessful upsizers and downsizers provide a negative contribution to productivity growth, with unsuccessful downsizers having a positive cross-term and unsuccessful upsizers having a negative cross-term.

NOTES

1. Productivity growth in the business sector is also influenced by the primary sector (agriculture and mining). In most OECD countries, this sector makes only a modest contribution to GDP and productivity growth.
2. All comparisons are relative to the OECD average. See Conference Board (1997*b*) for more details.
3. The high productivity level of the Mexican PTO is due to the use of economy-wide PPPs to convert revenues. These are likely to overstate real output considerably, as Mexican price levels are considerably below those in most other OECD economies.
4. The ''explanation'' of productivity levels in Table 4.8 is based on a simple Cobb-Douglas production function with constant returns to scale. See Van Ark and Pilat (1993) for details.
5. It is not clear whether this difference could affect the productivity breakdown. Wherever both TFP and labour productivity are measured, heterogeneity in labour productivity is often accompanied by heterogeneity in TFP (Bartelsman and Doms, 1997). Unfortunately, none of the studies discussed here provides both measures.
6. Productivity growth for the sample of firms amounts to 9.2 per cent on an annual basis, whereas that for total manufacturing is only 3.2 per cent annually over the same period (OECD, STAN database). The sample of firms accounted for just over 10 per cent of manufacturing value added in 1987 and for almost 17 per cent of value added in 1994. It accounted for about 10.5 per cent of manufacturing employment in both years.
7. It should be noted that the German data cover the State of Lower Saxony only.
8. The breakdown for the Netherlands is less detailed than for the United States. Baily *et al.* (1996) present some results for US 3-digit industries and indicate that there is considerable variation within the 2-digit categories.
9. If the focus is on labour productivity, physical capital accumulation may also be an important factor driving productivity growth within firms.
10. The breakdown by Baily *et al.* differs slightly from the one shown here, and uses output shares instead of employment shares. This difference may influence the result (Maliranta, 1997).
11. Haltiwanger's methodology differs from that used by Baily *et al.* (1992). An important difference is that, by using end-level plant productivity, the share term in Baily *et al.*'s breakdown combines the between plant and the covariance term in Haltiwanger's breakdown. Furthermore, the between and net entry terms in Baily *et al.*'s study do not incorporate deviations of plant-level productivity from the initial average level of productivity in the industry.

REVITALISING MATURE INDUSTRIES: THE ROLE OF ADVANCED TECHNOLOGY

INTRODUCTION

This chapter examines the impacts of new technologies, including advanced manufacturing technologies (AMT) and information technologies (IT), on the performance of a number of mature industries. It focuses on four industries: textiles, steel, automobiles, and construction. Output and employment in these industries has stagnated and sometimes declined, and, over the past decades, all have been faced with the need for substantial restructuring, owing to rising energy prices, saturated demand, changes in demand patterns, and greater international competition (globalisation).

To cope with the changing circumstances, these sectors have introduced a wide range of new technologies, such as AMT and IT, which have generated profound changes in industry performance, although sectors and countries differ. In aiding these sectors to make timely adjustments to internal and external factors, these technologies have generally had a positive effect. They have enabled productivity improvements and better product quality, have helped to restore international competitiveness, and have led to considerable structural change.

TEXTILES

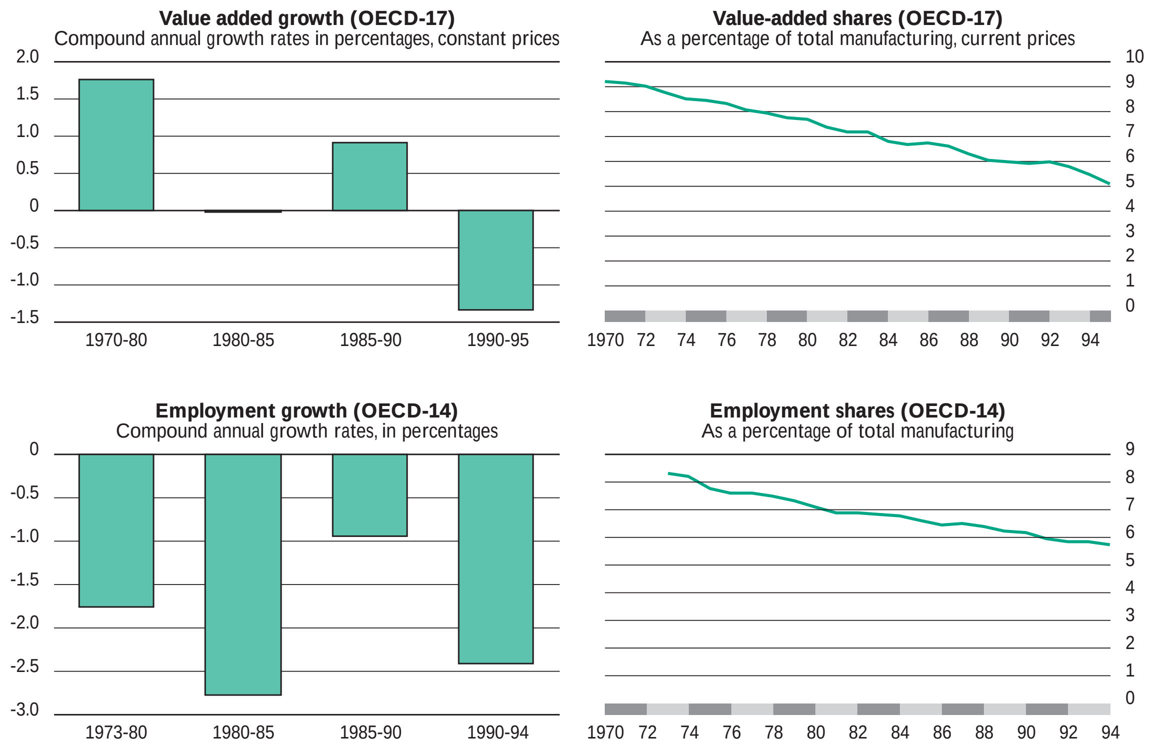
Introduction

The textile industry ushered in the modern industrial era two centuries ago, and was already a mature industry at the start of the post-World War II period. At that time, the growth rate in production was slower than the manufacturing average and indeed had been since the beginning of this century (OECD, 1983). Over the past decades, structural trends in the OECD area exhibit stagnating or declining production and employment and a fall in share in total manufacturing (Figure 5.1). This decline reflects saturated demand in the OECD area and increased competition from outside the area (Table 5.1).[1] Given current demographic trends, future demand for textiles in the OECD area cannot be expected to grow significantly.

Despite its increasing technological sophistication, the industry spread easily outside the OECD area owing to the availability of standard technology, the absence of large entry costs, and the industry's labour-intensive nature. Shifts in production to non-OECD areas started before 1970 and accelerated during the 1970s and 1980s, partly owing to ongoing trade liberalisation. Despite a range of multilateral and bilateral trade agreements, such as the Multi-fibre Arrangement, which aimed to ease the effects of the relocation of textile production, the textile industry in OECD countries inevitably underwent drastic structural adjustment. As protective arrangements are phased out, international competitive pressure is increasing again and restructuring becomes more urgent. Technological advance has already played a major role in boosting industry productivity (Figure 5.2) and may also play a crucial role as restructuring continues. The OECD-area textile industry will need to stress product innovation and high-quality goods in order to remain competitive.

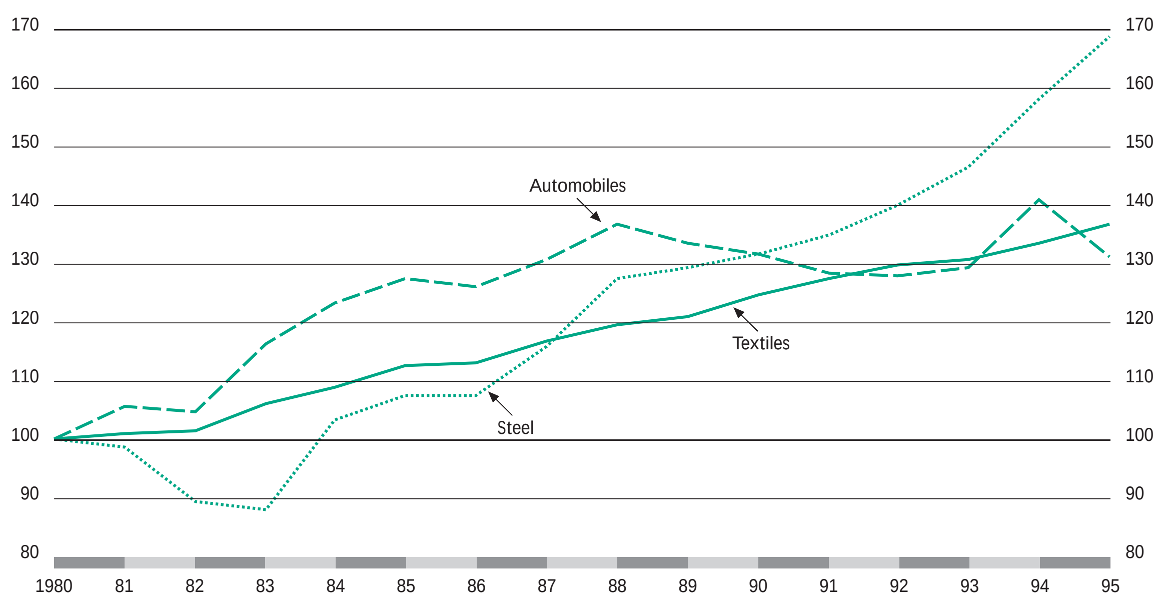
Although the structural adjustments implemented have varied, some general trends can be observed. At first, the OECD-area textile sector increased concentration. The aim was to achieve scale economies and enable the industry to meet competition from low-cost countries with mass-produced goods. When this strategy failed, production was reoriented towards high value-added goods, and the advantages of small- and medium-sized enterprises (SMEs) were reconsidered (OECD, 1988). While

◆ Figure 5.1. ***Trends in the textile industry***



Source: OECD, Main Industrial Indicators database, August 1997.

◆ Figure 5.2. ***Labour productivity in mature industries***
Index: 1980 = 100



1. Labour productivity = constant price value added/number engaged.
2. Data cover 14 OECD countries.

Source: OECD, Main Industrial Indicators database, August 1997.

Table 5.1. **Import penetration and export shares in the textile industry**

In per cent

	Import penetration[1]			Export shares[2]		
	1975	1985	1994	1975	1985	1994
United States	7.2	19.5	29.3	3.4	4.2	9.5
Canada	23.1	28.4	41.4	5.0	7.1	32.0
Japan	5.2	9.8	19.6	10.0	9.1	6.0
Australia	22.0	30.8	41.4	5.7	16.2	32.0
New Zealand[3]	26.3	38.9	49.9	28.3	54.2	53.8
Austria	38.9	57.3	70.4	36.9	53.3	60.6
Belgium/Luxembourg	61.2	81.5	83.4	64.0	82.8	85.1
Denmark	51.5	66.8	76.7	39.3	58.9	70.0
Finland	32.9	44.6	63.0	33.3	44.8	44.5
France	17.7	31.6	44.5	20.3	26.7	37.0
Germany	31.2	47.7	61.6	21.4	36.2	45.1
Greece	10.2	26.1	52.1	15.0	34.7	56.8
Iceland[3]	53.9	60.8	65.2	28.7	42.7	22.8
Italy	7.0	13.6	19.0	20.7	31.0	38.6
Netherlands	81.7	102.4	135.1	76.5	104.1	152.3
Norway	57.4	76.5	80.1	19.0	27.6	32.7
Portugal	6.5	16.4	33.8	21.2	38.7	52.0
Spain	4.0	8.2	27.0	10.4	21.9	24.3
Sweden	51.2	73.6	87.3	26.8	50.1	65.9
United Kingdom	20.1	36.7	48.7	17.1	23.9	32.1
OECD-14[4]	14.8	23.8	32.6	13.0	16.4	21.3

1. Import penetration = imports/domestic demand (domestic demand = production – exports + imports).
2. Export share of production = exports/production. Exports can exceed production for the following reasons:
   a) Exports include re-exports.
   b) Production data are normally based on Industrial Surveys which record establishments' primary activities. Thus, activities that are mainly secondary may be understated in terms of production because they are not allocated to the relevant ISIC code while exports of related commodities are recorded.
   c) A bias may be introduced by the conversion from product-based trade statistics to activity-based industry statistics for certain sectors for certain countries.
3. 1993 instead of 1994.
4. Excludes Austria, Belgium/Luxembourg, Greece, Iceland, New Zealand and Portugal.

Source: OECD, Main Industrial Indicators database, August 1997.

some countries, such as France, focused on domestic measures to improve investment in the textile industry and stabilise the workforce, others, notably Japan, actively pursued an outward-oriented investment strategy.

The textiles industry is fragmented and has three major segments: fibre production, fabric manufacturing, and production of finished goods. Fibre production includes natural fibres, such as cotton, wool, silk and linen, and synthetic fibres, largely manufactured by large chemical companies in OECD countries. Fabric manufacturing, which takes place in textile mills, involves three relatively distinct operations: yarn spinning, fabric forming, and fabric finishing. In yarn spinning, the fibres are separated and disentangled, spun into yarns, and chemically treated using specialised textile machinery and equipment. In addition, yarns now can be produced by ''throwing'', a process of combining and twisting filament strands into a yarn, and then ''texturing'', which gives the yarn elasticity and bulk (OECD, 1983). Yarns are then formed into fabrics by weaving, knitting, or using ''non-woven'' techniques to manufacture products such as tufted carpets. The formed fabrics are then subjected to various finishing processes, such as permanent press treatment, bleaching, and dyeing. Fabric manufacturing can be performed by specialised machinery and equipment. This segment of the textile industry consists of large firms – which produce a wide range of fabric products – and small producers, who specialise in a limited range of products. In the finished goods segment, fabrics are transformed into wearing apparel, home furnishings, or industrial goods. Apparel manufacturing, the largest part of this segment, involves designing garments and making patterns as well as cutting and sewing. This is the most labour-intensive and fragmented part of the textile industry, and is mainly comprised of small enterprises.

Technological change in the textiles industry

Technological advances have led to radical changes in traditional textile mill processes, especially for yarn and fabric production. Technological change has increased both the speed of individual operations and the mechanisation and automation of every phase of textile manufacturing, from carding,[2] spinning, weaving and knitting to finishing processes (Box 5.1). These changes are due to improvements in textile machinery and have led to significantly better product quality. This is also a result of greater use of man-made fibres, which are much more resistant than natural fibres and enable high-speed processing without reducing quality. The technological changes have been paralleled by better management and control of the production process through the use of information technology, which has also helped reduce inventories and increased production flexibility. The latter trend is very important, as the structure of demand in the OECD area is shifting to smaller volumes of a greater variety of high value-added products.

Box 5.1. **Main technological changes in the textile mill industry**

In ***spinning,*** improvements in ring-frame machines doubled process speed between 1950 and 1975, while upgrading yarn quality. As this technology approached its limits, it was partially replaced by open-end (OE) spinning machines, used for spinning short-staple fibres. These machines could operate at three times the speed of ring spindles. Moreover, open-end spinners made two "pre-spinning" operations (winding and rowing) unnecessary, thus reducing capital requirements. These machines diffused unevenly, however, since they are unsuitable for producing very fine yarn (Table 5.2). However, in general, OE rotors are being modernised more rapidly than ring spindles. Several other processes, such as opening and lap forming, were also merged and automated. Similar increases in speed, process integration, and automation also took place in the throwing and texturing processes.

Table 5.2. **Diffusion and modernisation of spinning machinery**

	1995 installed spinning capacity[1] (thousands)			Cumulative shipments 1987-96 (thousands)			Modernisation rate[2] (in per cent)		
	Spindles		O-E rotors	Spindles		O-E rotors	Spindles		O-E rotors
	Short-staple	Long-staple		Short-staple	Long-staple		Short-staple	Long-staple	
Africa	8 130	232	192	1 192	119	86	14.7	51.3	44.9
North America	10 664	913	1 092	1 473	149	982	13.8	16.3	90.0
South America	12 480	696	309	1 810	117	186	14.5	16.8	60.3
Asia and Oceania	113 353	7 749	1 906	23 911	2 112	987	21.1	27.3	51.8
Eastern Europe	11 407	1 538	2 940	1 902	582	1 891	16.7	37.8	64.3
Western Europe	7 003	5 105	602	3 311	1 108	507	47.3	21.7	84.3
Other Europe	4 489	743	250	1 849	249	328	41.2	33.5	130.9
Not specified	0	0	0	592	13	25			
World	167 526	16 976	7 291	36 041	4 449	4 992	21.5	26.2	68.5

1. In technological terms, one O-E rotor is equivalent to 4.5 ordinary spindles.
2. Cumulative shipments 1987-96 compared with 1995 installed capacity.

Source: International Textile Manufacturers Federation, 1996.

In ***fabric manufacturing,*** speed and efficiency have increased considerably in both weaving and knitting. Higher-speed knitting has replaced weaving where possible, and there has been a steady expansion of "non-woven" technologies. In weaving, the loom was automated, but the breakthrough was the replacement of the shuttle with shuttle-less technologies, such as water and air jets, rapiers and missiles. These

(continued on next page)

(continued)

technologies trebled weft insertion speed and increased loom width substantially, while consuming less energy. However, like OE spinning machines, shuttle-less looms are limited in that improved output performance comes at the cost of product flexibility. Shuttle-less looms have diffused more rapidly than shuttle looms over the past decade (Table 5.3).

Table 5.3. **Diffusion and modernisation of weaving machinery**

	1995 installed weaving capacity (thousands)		Cumulative shipments 1987-96 (thousands)		Modernisation rate[1] (in per cent)	
	Shuttle-less looms	Shuttle looms	Shuttle-less looms	Shuttle looms	Shuttle-less looms	Shuttle looms
Africa	21.3	123.7	8.0	1.5	37.6	1.2
North America	85.3	61.2	35.7	0.3	41.9	0.6
South America	45.1	155.9	17.9	1.8	39.6	1.2
Asia and Oceania	242.0	1 422.2	303.0	130.1	125.2	9.1
Eastern Europe	204.0	48.7	58.3	1.4	28.6	2.9
Western Europe	70.5	12.5	79.2	0.2	112.4	1.3
Other Europe	13.5	42.0	14.1	0.1	104.8	0.2
Not specified	0.0	0.0	2.9	0.7		
World	681.7	1 866.2	519.2	136.1	76.2	7.3

1. Cumulative shipments 1987-96 compared with 1995 installed capacity.
Source: International Textile Manufacturers Federation, 1996.

Knitting became more attractive than weaving in the 1960s because of faster fabric production rates, cost advantages resulting from greater use of man-made fibres, ability to combine fabric and garment stages, *e.g.* for seamless hosiery, and greater flexibility in the product range compared with weaving machines. However, limits to consumer acceptance of knitted synthetic fibres set an upper limit to the substitution of knitting for weaving. Technical progress also expanded the range of ''non-wovens'', which offer possibilities for significant cost reductions since they combine fibre and fabric production processes. Increases in speed and product upgrading also took place as a result of technological advances in finishing processes, such as the use of computers to design fabric and print patterns on material (OECD, 1983). Furthermore, computer-controlled dyeing equipment helped reduce the minimum length of a lot considerably (from 10 000 to 500 yards) while improving quality.

Computers are now used extensively in the textile industry and play an important role in the increased efficiency of these processes, since automation, operation linkages, and production flexibility are achieved by using computer controls and robots to replace manual operations such as materials delivery and splicing of broken yarn. Precision controls have also helped to minimise defects and improve quality. The use of IT to achieve better management and control of production has also contributed to productivity gains. In addition, IT permits better control of the stock and flow of parts and products throughout the production process and makes it possible to cut inventory costs and increase flexibility. With further technological advances in textile machinery, the speed of individual operations is likely to increase. Automation will be used more widely for transportation, handling, inspection, and fault detection. Systemic IT-based automation does not yet exist, but textile mills are moving towards fully automated systems that integrate spinning and weaving with minimum labour inputs and greater flexibility. Such integrated systems require improved machinery, as well as technologies to control and co-ordinate separate operations, *i.e.* information-based technologies.

In the clothing industry, technological advances have taken place in two ways, in both of which IT and AMT play an important role. The first is the development and diffusion of computer-aided design and manufacturing systems (CAD/CAM) in the pre-assembly stage (Box 5.2). The second is a change in production organisation, which is now geared towards greater demand for variety and flexibility

Box 5.2. **Technological changes in the clothing industry**

So far, new technologies have mainly been integrated in the pre-assembly stage of clothing production, thereby radically changing the nature of the operations involved. Computer-aided design systems have facilitated the design process. By digitising information on the shape and size of garments, these systems speed up grading and marking operations and replace formerly needed manual operations by highly skilled workers. Another computer-based innovation introduced in the pre-assembly stage is the computer numerically controlled (CNC) automated cutting system which use digitised information from CAD systems to guide high-speed precision cutting.

These advanced manufacturing systems offer substantial benefits, including materials saving (15 per cent over previous techniques), lower labour requirements (resulting in substantial productivity improvements), increased speed and accuracy in operations such as grading, marking and cutting, and increased flexibility, such as the capacity to perform rapid alterations to styles. Because CAD and CNC systems are expensive, they tend to benefit large firms that can take advantage of scale economies. However, competition among suppliers has brought prices down and made the technology more accessible to small firms (OECD, 1988; Hoffman, 1989). CAD and CNC cutting machines allow firms to set up large factories and achieve substantial economies of scale. These technologies also permit flexibility in planning, sourcing and design of products (OECD, 1996*h*) and make it possible to produce smaller quantities of a large variety of products without raising cost.

Box 5.3. **Changes in the organisation of production in the clothing sector**

Market-oriented innovations in the organisation of production, in which information technology plays an important role, have had as much impact as technological changes in the pre-assembly stage. "Quick response" and "just-in-time" technologies belong to this category. Over the past decades, changes in market conditions induced by the changing demographic structure of OECD countries have caused a shift in consumer taste towards individual choice, greater variety and fashion-designed clothing. Successful retailing has increasingly come to depend on retailers' ability to offer a wider variety of novel and rapidly changing products. These developments have contributed to new co-operative relationships among retailers, clothing manufacturers, and textile firms, often via more stable contractual relationships. This stability has enabled retailers to demand from their upstream suppliers greater variety in product lines, shorter production runs, and shorter lead times. The competitive base of the clothing industry is thus shifting from price to variety, style, flexibility and rapid response (Hoffman, 1989).

The US-born "quick response" technology is an innovation in production organisation along these lines. Information technologies are used to provide information upstream about exactly what is demanded downstream, thus enabling the production of optimal quantities of the type of product demanded by the market. An obvious advantage is that "quick response" technologies can keep inventories low and avoid overstocking. "Quick response" has reduced the period required from fibre production to the sale of a piece of garment from almost a year to a few months at most. The shorter production cycle also means that what is produced is what sells. This has helped to reduce the incidence of forced mark-downs (Office of Technology Assessment, 1987). In combination with "just-in-time" manufacturing and delivery techniques which promote rapid deliveries of products from supplier to customer on very short lead times, this innovation can improve the competitive position of the OECD textile sector, since closeness to the market and availability of a good transport infrastructure are important to making the technology work.

(Box 5.3). For instance, new production management methods such as quick response and just-in-time delivery systems – which are extensively computer-based – have been introduced. They have reduced the role of the wholesaler and the intermediary and strengthened that of the retailer and thus changed the industry's structure.

Clothing manufacture comprises the following stages. First, the piece of clothing to be produced is designed and its production method is defined. Then follows the pre-assembly stage, in which patterns are made and the components are cut from cloth (grading, marking, and cutting). These operations are creative, sophisticated, and require high skills. In the next stage, the components are assembled or sewn together to produce a piece of clothing. In the final finishing stage, the garment is pressed, folded and packaged. These stages, especially the assembly stage, are very labour-intensive and account for a major part of value added. However, skill requirements are relatively low, as compared with those required for the pre-assembly stage.

In contrast to the technological advances for the pre-assembly stage, systemic use of IT-based manufacturing systems has yet to appear for the labour-intensive assembly stage. The difficulty stems from the fact that machines made of metal cannot handle limp material easily. Advances to date have been incremental improvements in machinery and the organisation of production, such as attachment of microelectronics-based control units to the sewing machine. Such improvements speed up and increase the accuracy of operations such as attaching belt-loops and buttonholing and result in some productivity gains. However, they have not changed the basic work organisation, nor have they affected the labour-intensive material handling operations at the assembly stage.

Efforts have been made to develop fully automated CIM (computer-integrated manufacturing) systems, but with little success. Such systems would require techniques to handle limp material for two- and three-dimensional operations and fully automated handling and transport of material through the assembly stage: these would have to be integrated with the pre-assembly and finishing stages. The development of such systems would concern not only traditional textile equipment manufacturers, but also the electronic firms that supply pre-assembly CAD systems and large clothing producers.

Some initiatives in this area have received public support. The US Textile/Clothing Technology Corporation (TC2), funded by the Department of Commerce and involving a group of fibre, textile and clothing firms, aims to develop a computer- and robotics-integrated system which automatically handles and sews fabric into a finished piece of clothing. The original project – started in 1979 – has set up a robotics centre and research has continued to this decade. The National Apparel Technology Centre functions as a technology demonstration and training centre and seeks to stimulate innovation in the sector (Finnie, 1990; Hoffman, 1989).

In Japan, the Ministry of International Trade and Industry (MITI) sponsored the ‘‘Automated Sewing System’’ project, initiated in 1982 and involving a consortium of enterprises from all segments of the textile complex and research institutes. Its objective was to halve manufacturing time by developing elements of a flexible manufacturing system covering all stages of clothing production. The project’s focus was the development of assembly automation technology for sewing in three dimensions, using a flexible, movable sewing head. At the conclusion of the project in 1990, all process elements had been demonstrated for the production of a specific type of garment, but the cost of the required investment makes commercialisation of the fully integrated system unlikely. However, certain elements of the technology are likely to be adopted by the Japanese textile industry (Hoffman, 1989; Berkowitch, 1996).

The European Commission originally sponsored research on flexible materials handling in its Basic Research in Industrial Technologies for Europe (BRITE) programme. The last of these projects was completed in 1997. It aimed to develop an automated tracking and handling system for sewing two-dimensional flexible material sheets into three-dimensional end-products. The goal was to take an important step towards developing ‘‘intelligent’’ sewing stations. However, work on this technology is not part of the new Basic Research in Industrial Technologies for Europe/European Research on]Advanced Materials (BRITE-EURAM III) programme (http://apollo.cordis.lu).

The impact of technological change

The technological changes in the textile and clothing industries outlined above have led to profound changes in productivity, quantity and quality of labour input, product quality, and organisation and flexibility of production. The following patterns have emerged:

- The most obvious change has been the quantitative reduction in the textile labour force, and the dramatic rise in ***productivity.*** The productivity gains are a natural outcome of the enormous increase in the speed of the newer generations of textile machinery, such as open-end spinners and shuttle-less looms. The automation of associated handling and processing in textile mill production has also contributed to the productivity gains, as has the use of CAD and CNC systems in clothing manufacturing.

- The diffusion of newer generation technologies has not only led to quantitative productivity gains but also to improvements in ***product quality.*** Defect-free, higher quality products can now be produced more rapidly. Even more important, the new technologies allow for greater flexibility in production, which is gaining in importance. New technologies in the textile mill process can respond to rapidly evolving market trends that require frequent style changes, emphasize design and styling, and require shorter production runs. In the clothing industry, CAD and CNC systems in the pre-assembly stage can be adapted to the need for greater variety, high style, smaller lots, and shorter runs without increasing labour input. The flexible manufacturing elements of the newer assembly technologies have the same characteristics.
- Because the new technologies can respond to the demand for greater ***flexibility,*** the OECD-area textile industry can shift from mass production of standardised products to ***small lot production*** of a wider variety of products. Technological change allows the OECD-area textile industry to pursue such a strategy and may have enabled it to survive competition from non-OECD countries, which rapidly gained competitiveness for standardised products owing to low labour costs. Despite increased import penetration in the textile sector, most OECD countries have continued to show strong export performance (Table 5.1).
- The impact of technological changes on ***skill requirements*** in the textile industry is quite similar to that observed in other industries (OECD, 1996*h*). There has been deskilling in specific operations, such as cutting in the pre-assembly stage of clothing manufacturing. The general trend has been towards higher skill requirements, however, as workers are now required to operate increasingly sophisticated and versatile machines and equipment, and need to have a broader basic knowledge and skills base.
- Increased flexibility has also enabled innovation in the ***organisation of production,*** as firms took advantage of this flexibility to shorten the production cycle and increase responsiveness to market trends, as demonstrated by the "quick response" strategy. Organisational innovations such as this have strengthened the competitive base of domestic producers and upstream suppliers such as fibre producers. Recent trends show that for processes for which foreign processing is advantageous, such as the labour-intensive assembly stage of clothing production, the demand for shorter product cycles favours geographically close locations, such as the Caribbean for the United States or North Africa and Eastern Europe for EU countries.
- The new technologies have also changed ***concentration patterns*** in various segments of the textile industry. As textile firms in OECD countries become unable to take advantage of scale economies for mass-produced standardised goods, concentration in the conventional sense is becoming an anachronism. However, in segments where new technologies are expensive, *e.g.* the CAD and CNC systems used in the pre-assembly stage of clothing manufacture, concentration may offer some advantages in terms of economies of scale. Moreover, the current trend towards variety, versatility and flexibility suggests that specialised small firms will be able to target specific market niches.

In the textile industry, market trends play a great role in determining the direction of technological change. In a recent analysis of publicly supported research and development (R&D) programmes to develop automated and integrated sewing systems, such as the US TC2 programme, Japan's MITI-supported automated sewing system programme, and the flexible materials section of the European BRITE programme, Byrne (1997) found that their mediocre success was due not only to technical difficulties and the high price of such systems, but also to the increasing realisation that such integrated systems – generally geared to mass production – would not strengthen the competitive base of the OECD textile sector, which faces markets increasingly oriented towards greater variety, higher design content, and rapid response. Market trends exert considerable influence on the direction of R&D in textile and clothing technologies.

There are substantial national differences in textile sector restructuring in OECD countries. In Germany, the textile mills sector has continued to perform well, and the clothing sector is using a mixed sourcing strategy to lower production costs while retaining flexibility and the ability to respond to market developments. The German clothing industry increasingly relies on processing in Eastern Europe and North Africa. Firms in these countries process German textile mill products and have become Germany's largest source of clothing. Both foreign processing and direct imports of finished clothing continue to rise while domestic clothing production continues to fall (Schild and Ern, 1995).

Despite a crisis in the 1970s, the Italian textile and clothing sector is one of the most competitive in the OECD area. Both large and small firms have survived the restructuring process, and several appear to have been revitalised. This may be due to Italian tax and labour market regulations, which tend to favour small enterprises, to success in international marketing of highly styled Italian products, but also to local industrial support mechanisms that facilitate collaboration in product and process innovation, training and marketing (Locke, 1995; Rigby, 1993). The success of the Italian textile industry also shows that market niches can be targeted by small firms.

In contrast, the Japanese textile sector still has areas that are geared toward mass production, but these face increasing competitive pressures (Tsushosangyosho Seikatsusangyokyoku, 1995). There is, however, a trend towards closer integration of the different segments of the textile industry. In the United States, the recovery in certain segments of the textile and clothing industry may be due to the retail sector, which has helped producers become more responsive to market trends by developing quick response and just-in-time operations suited to customer needs (Finnie, 1995).

STEEL

Introduction

The steel industry has long occupied a place of special importance in the manufacturing sector, as it historically supported growth in other industries. However, since the 1970s, the OECD-area steel industry has been forced to undergo considerable restructuring. This was largely prompted by the economic downturn of the 1970s and by the effects of energy price increases on the steel and steel-consuming industries. These developments not only obliged the industry to intensify efforts to reduce production costs, but also resulted in stagnating demand for steel products. In addition, changes in the availability and prices of other inputs, rising labour costs, changing product quality requirements, increased competition from emerging steel industries in the non-OECD area, and the need to reduce environmental pollution all forced the industry to restructure (Gold, 1982; US International Trade Commission, 1991). Technological changes within the industry facilitated the on-going restructuring process and have created a far more efficient and automated iron and steel industry.

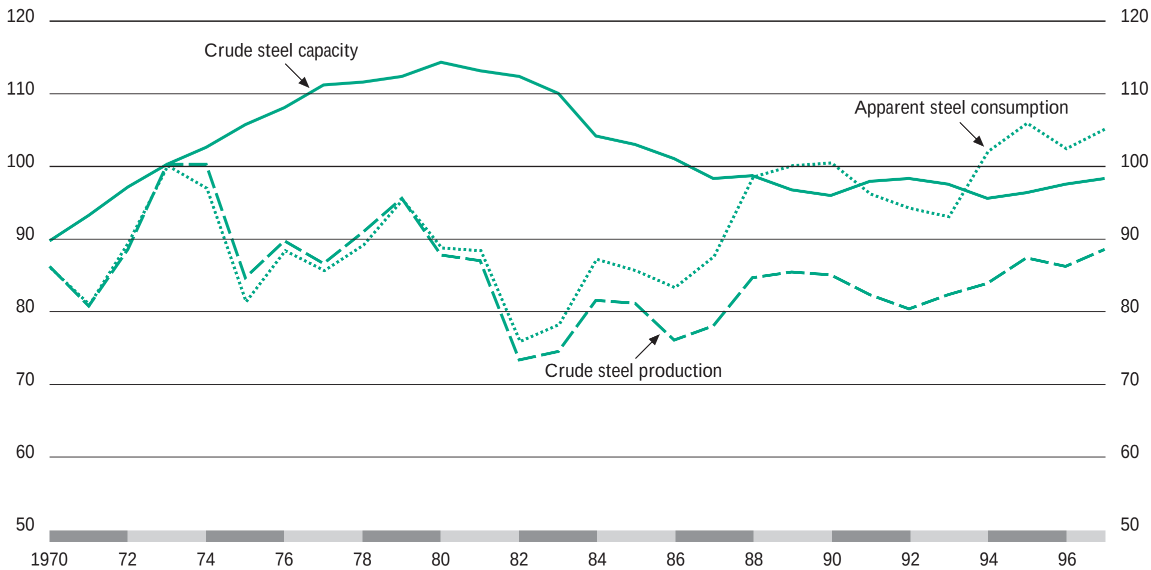
Iron and steel production has fallen in the OECD area since 1973, and consumption declined until the mid-1980s (Figure 5.3). During the 1970s, the industry had a high level of excess capacity, as the new capacity planned prior to the petroleum crisis came on line at a time of weak demand. Restructuring entailed a shedding of capacity in the 1980s. Further aggravating the industry's situation was the increasing competition from steel industries outside the OECD area, which resulted in increased import penetration of steel products, slower growth in production than in consumption since the mid-1980s, and a considerable loss of market share to non-OECD economies. As a result of restructuring, employment in the industry decreased drastically in many countries (Figure 5.4), while the modernisation of production facilities has contributed to sharp labour productivity gains (Figure 5.2).

Technological change in the steel industry

Technological changes in the iron and steel industry in the last quarter century include fundamental changes, with the replacement of some traditional processes, and incremental changes, which modified and improved basic processes. Some changes were specific to the industry, while others were due to the application to the steel-making process of more general advances in electronic and information technologies (Box 5.4).

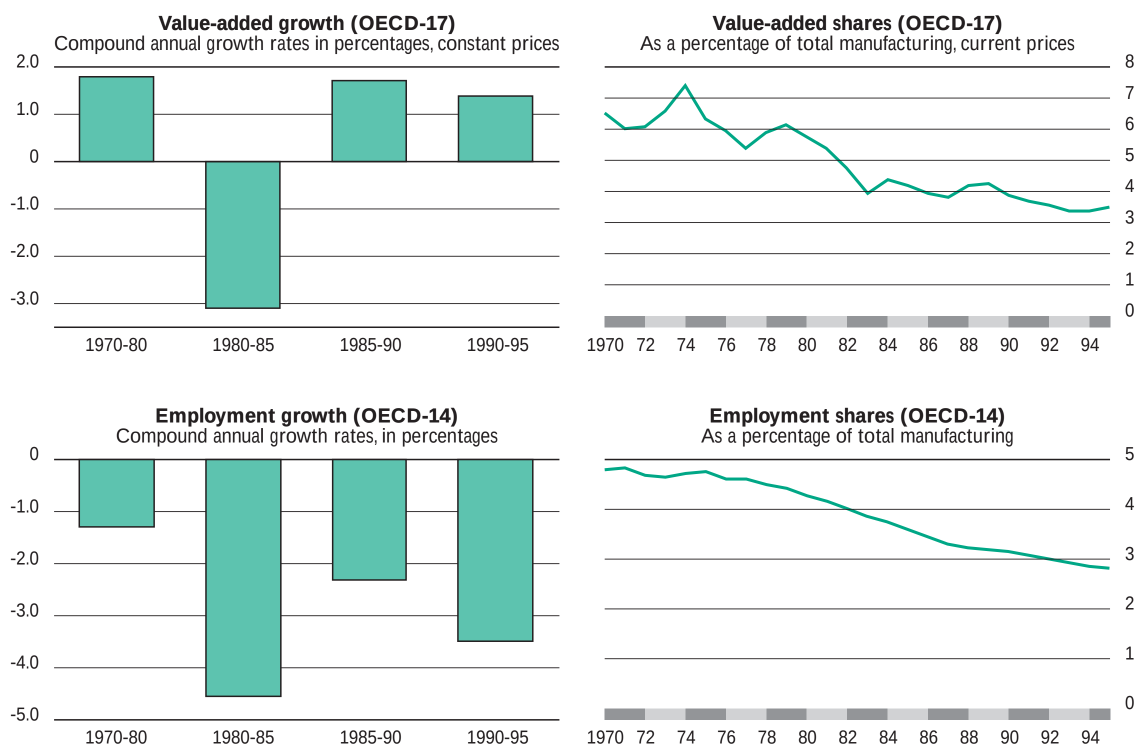
◆ Figure 5.3. ***OECD crude steel capacity, production and apparent consumption, 1970-97***

Index: 1973 = 100



Source: OECD, 1996*l*.

◆ Figure 5.4. ***Trends in the steel industry***



Source: OECD, Main Industrial Indicators database, August 1997.

Box 5.4. **Main technological changes in the steel industry**

The past quarter century has seen steady growth of steel produced in the ***electric arc furnace*** (EAF) or "minimills" (Figure 5.7*b*). Whereas the minimum efficient scale of an integrated mill is in the range of 3-4 million tons, minimills are efficient from 100 000 tons. Because they do not incorporate the labour-intensive iron-making process of the integrated process, and because their range of products can be more limited than the integrated product range, minimill productivity is considerably higher than that of the integrated mill. One study estimates that a minimill's labour productivity in terms of value added per hour worked is twice that of an integrated mill (McKinsey, 1993).

Recent developments in minimill technology have expanded the product range at the lower efficient scale, thus presenting further challenges to the integrated process. A notable recent development in this respect is the 1989 start-up of a thin slab casting plant by Nucor, a US minimill, to produce steel sheet products. This plant's success has stimulated new investments in this technology in the United States, and has contributed significantly to the industry's revitalisation in the 1990s (Schorsch, 1996). In addition, the minimill technology itself has become considerably more efficient through the introduction of improved furnace technologies such as ultra-high power furnaces and a high use of oxygen (Cyert and Fruehan, 1996). The distinction between EAF and integrated processes has increasingly become less clear, as some EAF mills have invested in facilities to make DRI (directly reduced iron) or other iron-based feeds as a supplement to scrap. These mills now produce flat rolled and heavy structural products which were previously produced exclusively in integrated mills. The cross-application of some of the techniques used in the integrated process in the EAF process and vice versa is blurring the difference between the two processes.

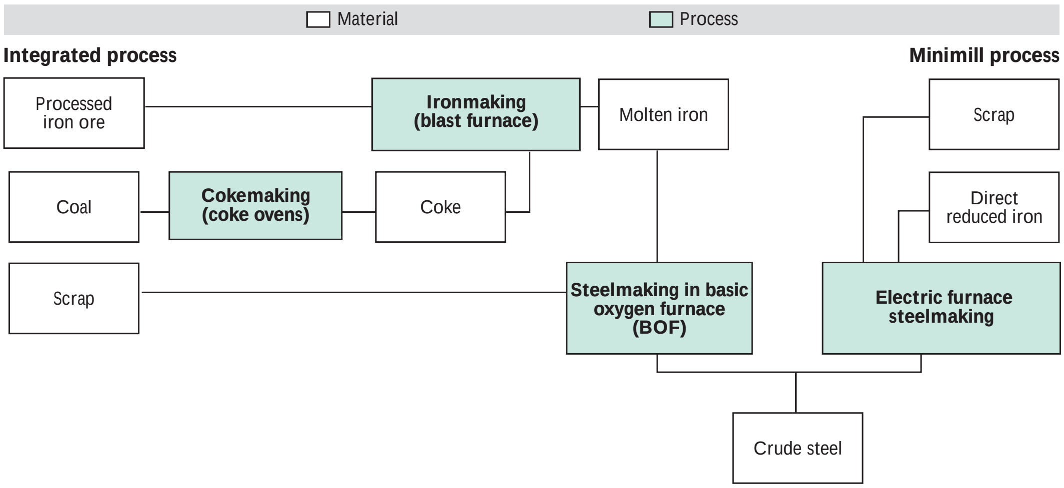
Energy conservation requirements have stimulated the adoption of ***continuous casting technologies,*** in which the several steps in the conventional ingot casting process are replaced by casting steel directly into semi-finished shapes. In the traditional ingot casting method, the steel is allowed to solidify in moulds and is then reheated for rolling, while in the continuous casting technology, molten steel is poured into a reservoir and then passed into the moulds of the casting machine. As the steel is cast and descends through the moulds, the cast steel is water-cooled and allowed to solidify into semi-finished shapes. This process reduces energy consumption by making fuller use of the heat contained in the molten steel, increases yield, improves product quality and reduces pollution. Figure 5.7*a* shows trends in the adoption of the continuous casting method.[1]

Computer controls have been applied to most stages of the steel-making process and have facilitated and enhanced automation. Once incorporated in steel-making equipment, the benefits of these technologies include reduced labour requirements, improved energy use, higher yields, productivity and quality. The use of advanced computer controls increases the speed of some processes, reduces inventories, and enables more precise production controls and tailoring to order. Computer control systems have become more sophisticated and comprehensive. Computers have also permitted process linkage. For example, the continuous cold mill complex originally developed at Nippon Steel combines five separate processes (pickling, cold reduction, annealing, temper rolling and inspection). Thanks to main frame computers, process time has been reduced from 12 days to under one hour, quality has improved, and costs have been reduced (Burger, 1990). On the management side, the use of computers has enabled the development of increasingly effective production planning, control, and inventory systems (US International Trade Commission, 1991; Barnett, 1996; Gold, 1982).

1. The diffusion of continuous casting technology is unlikely to reach 100 per cent, as it is not applicable for very small-scale operations for the production of speciality steel.

Today, steel is produced either in integrated mills or in "minimills". The former integrate the iron-making process by smelting processed iron ore and coke in a blast furnace to produce molten iron, then making steel in the basic oxygen furnace, where scrap and alloy materials are also added. Minimills produce steel by melting steel scrap and in some instances directly reduced iron in an electric arc furnace (EAF). The molten steel then goes through a refining process to remove certain chemical elements and give the steel the appropriate chemical makeup, and the temperature is adjusted for optimum casting. The casting is done either by the traditional ingot-teeming method or by the newer continuous casting process. The resulting semi-finished shapes (slabs, blooms and billets) are then hot-rolled into coils, bars, rods, rails and structural shapes. Some of these products are subjected to further

◆ Figure 5.5. ***Steelmaking flowchart***



Source: US International Trade Commission, 1991.

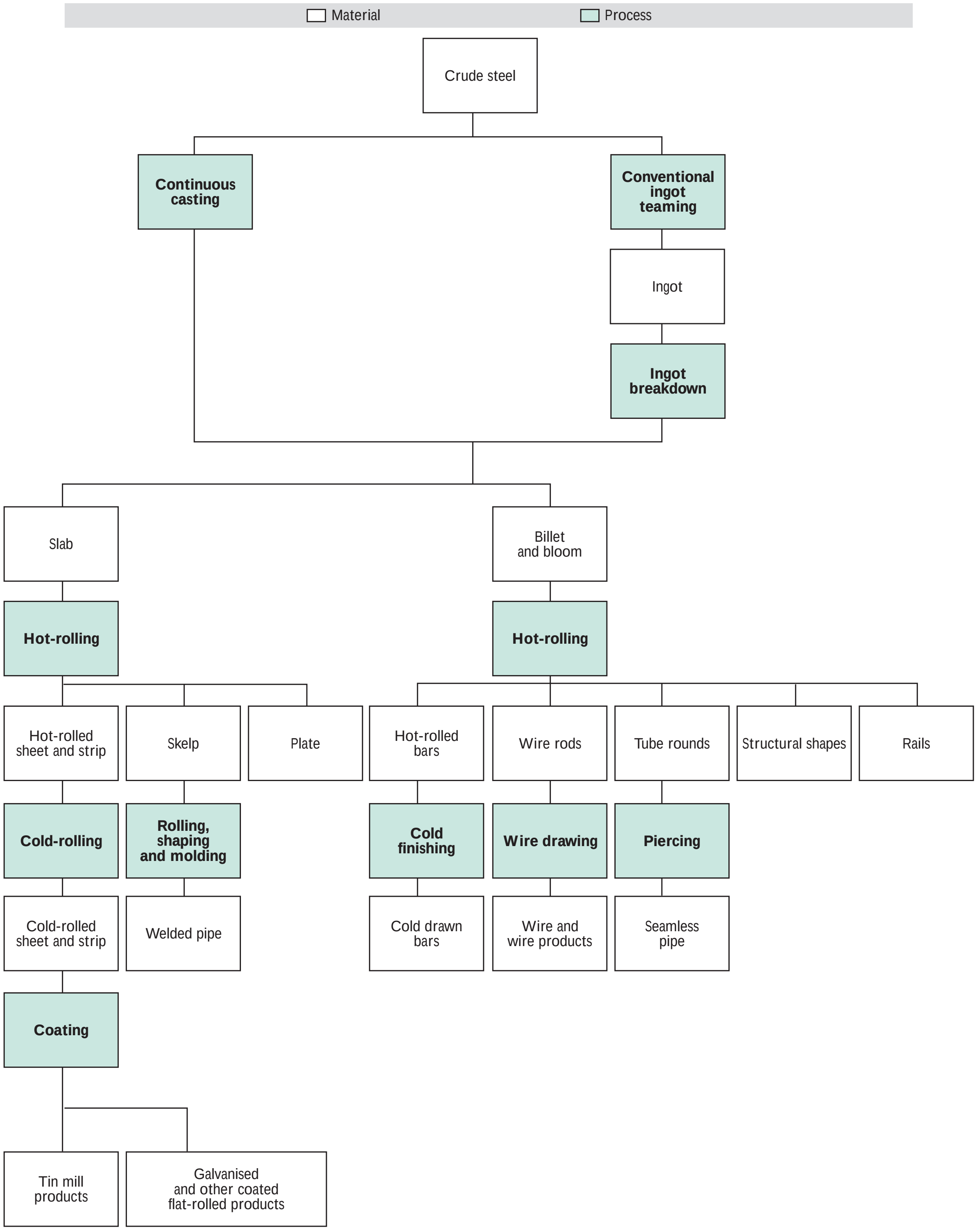
processing, such as cold rolling, coating, slitting and welding, to form a variety of end products. Figures 5.5 and 5.6 illustrate the two steel-making and finishing processes; some of these processes represent major technological innovations that were developed before 1970 but subsequently improved. They have been progressively adopted since 1970.

While EAF minimills represent a major technological advance, it should be noted that diffusion of this technology depends on the availability and price of steel scrap and electricity. Its success in the United States is due to favourable circumstances for these factors and to a range of environmental regulations that have made integrated steel making more expensive. Moreover, although minimills are advantageous in terms of initial capital requirements, they are more costly than the integrated process in terms of non-fixed production costs. Direct iron-smelting technology, which is mostly still in the experimental stage, may eventually replace blast furnace iron making; because it is more cost-effective and efficient than the blast furnace and also more environmentally friendly since it eliminates coke ovens, it may help maintain the competitiveness of the integrated process.

Automation, including computerisation, constitutes an important part of steel sector investment. In the latter half of the 1980s, US steel makers spent about 5 per cent and other steel makers on average 11 per cent of total capital investment on automation (US International Trade Commission, 1991). Computerisation seems to have started as early as the 1960s and progressed most rapidly in the integrated steel plants of Japan. It was part of the giant integrated mills built at the time. One early analysis (Gold, 1978) attributed this to the steel makers' commitment to long-term performance targets, to government support, to the availability of graduate engineers, and to a high commitment to R&D. Computerisation in Japanese integrated mills has reduced unit labour requirements in production, increased capacity relative to investment, improved product yields, extended and improved comprehensive planning and control systems, thereby enabling optimum material flows and lower inventories, enhanced energy conservation, and reduced office manpower requirements. As the CIM systems have become more sophisticated, considerable reduction of process cost has been achieved owing to lower inventories, while non-price competitiveness – in terms of delivery and services provided – has been strengthened (Tomiura, 1997).

Computerisation has penetrated practically all of the world's steel plants. Korea's Pohang Iron and Steel Co. Ltd. (POSCO) has invested in computer-integrated information systems for its plants since

◆ Figure 5.6. ***Steel products and processes***



Source: US International Trade Commission, 1991.

1972. All of POSCO's operations, from planning, production and emission control to management functions are now computerised. The company plans to integrate advanced computer and communication systems, such as electronic commerce, satellite communications, and CALS (continuous acquisition life-cycle support). Steel mills in Germany are currently modernising their computer-aided planning system (CAP). This will improve just-in-time production, increase capacity utilisation, minimise inventory levels, and speed up the production flow. The French steel maker, Usinor Sacilor, has developed two information technology systems, one for production control and decision making and another for business management (International Iron and Steel Institute, 1997).

Further application of computers remains an important area of innovation in the steel industry. Information systems, which integrate databases and simulation and decision-making support systems, are being developed to facilitate customisation. To reduce delivery time and to respond to the need to produce small quantities of a broad range of products, flexible manufacturing systems (FMS) also need to be integrated into steel mills' CIM systems. The development and application of artificial intelligence (AI), such as expert systems, is well under way and may facilitate decision making and control of production processes. As the demand for steel products moves toward higher-performance products and production of smaller lots of a wider range of products, process controls, such as temperature control and flow timing, become more difficult. Expert systems can simulate the attributes and abilities of the human experts who make such decisions. With the use of AI-based expert systems, operating practices and procedures can be optimised and standardised. In many cases, computer-based expert systems appear to perform better than human experts (Dorn, 1996).

In addition to these major technological changes, many processes have undergone various modifications or improvements. These refinements include: *i)* injection of pulverised coal into the blast furnace, increased injections of oxygen and natural gas, and higher blast furnace pressures and temperatures, which have reduced coke use rates and increased blast furnace productivity; *ii)* improved oxygen-blowing practices in the basic oxygen furnace, which have improved stirring and homogeneity of the furnace bath and resulted in improved steel quality and productivity; *iii)* a shift to more hot charging, higher charge temperatures, and greater power and temperature controls, which have improved hot strip mill throughput; and *iv)* more continuous cold finishing, higher-power hydrogen batch annealing and more continuous annealing, which have improved pickling and cold mill productivity (Barnett, 1996; US International Trade Commission, 1991). Moreover, the technological changes have resulted in reductions in process discontinuities and have increased process linkages, thereby improving productivity and reducing cost.

It should also be noted that steel plants have had to develop and adopt various technologies to reduce emissions of pollutants to meet environmental regulations, especially in the iron-making phase of the integrated process. The steel industry is both energy- and pollution-intensive. It accounts for a major portion (more than 10 per cent in the United States, for example) of air and water pollutant emissions associated with industrial production. Investments to meet pollution control requirements accounted for a major share of total industry investment over the past decades. In the Japanese iron and steel industry, for instance, environment-related investment accounted for 11 per cent of total investment between 1971 and 1987. In 1976, it accounted for as much as 21 per cent (Keizai Koho Center, 1989).[3] Much of the pollution abatement investment was for developing and installing end-of-pipe equipment, but some of the technologies, such as continuous casting and pulverised coal injection technologies, also made major contributions to lower energy consumption and reduced pollutant emissions. Pollution abatement requirements also redirected much of the industry's R&D activity.

The impacts of technological change

Technological change has profoundly affected the steel industry in terms of productivity and structure. New processes and incremental technical changes have increased yield, speeded up process time, saved energy and resources, improved product quality, and reduced production costs. In structural terms, productivity has improved substantially, while employment levels have fallen and competition has increased. In addition, the industry has diversified considerably in terms both of process scale and product range, and this in turn has changed skill requirements. The following impacts can be observed:

- The most dramatic change has been the reduction in employment and sharp rise in labour productivity. ***Productivity gains*** have occurred in all phases of the steel-making process. Man-hours required to produce a ton of finished product in both the integrated and the EAF processes have decreased significantly (Table 5.4). According to a recent study, more than 50 per cent of the productivity increase in the steel industry in Germany, Japan and the United States, and can be attributed to technical change (Barnett, 1996). Increased outsourcing and innovative use of human resources – often directly or indirectly made possible by the adoption of new technologies – have also helped to improve productivity. Comparisons of sample steel production lines in a number of US steel mills, some of which use a set of innovative work practices, including incentive pay, teams, and flexible job assignments, showed that lines using these innovative practices achieved substantially higher levels of productivity than those using more traditional approaches (Ichinowski *et al.*, 1997).
- Technological changes have also enabled improvements in ***product quality*** and ***diversification.*** First, steel has become lighter and stronger, and production of high-performance steel has increased. Consequently, steel-based structures can now be built with less steel and car bodies, for example, have become lighter. Second, the use of computerised controls has facilitated customised production and production of a broad range of products in smaller batches. Third, as a result of the use of information technology in steel-making operations, some steel companies have diversified into equipment that integrates information technology and information technology products. This development is probably most pronounced in Japan's integrated steel mills. For example, at Kobe Steel Ltd., an integrated steel producer, 33 per cent of sales in 1996 were in its machinery and information sector. About 13 per cent of these sales represented information technology, integrated machinery and computer software, and advanced materials. Nippon Steel also produces information systems and equipment and has diversified into the production of semiconductors (Kobe Steel Ltd., 1996; Nippon Steel, 1997). This diversification appears to be an important aspect of the competitive strategy of Japan's large integrated mills.
- ***Reduction of the steel workforce*** has taken place in all OECD countries and has been achieved by a variety of means, even within the European Union. In the United Kingdom, the steel workforce was reduced through massive layoffs, while recourse to layoffs was minimal in the countries of continental Europe, where early retirement with compensation was often the principal strategy, complemented by severance pay for voluntary departures, *i.e.* job buyouts, work-sharing and transfer schemes, including the contracting out of workers to subsidiaries and other

Table 5.4. **Estimated man-hours per tonne of finished product, 1980-95**[1]

	United States	Japan	EU-12
A. Integrated mill, production of wire rod (from coke)			
1980	7.1	4.6	6.9
1985	6.5	4.1	5.5
1990	..	3.7	4.8
1995 est.	..	3.3	3.9
B. Mini-mill (EAF[2]), production of wire rod (from EAF)			
1980	3.5	3.8	4.3
1985	2.5	3.0	3.3
1990	2.1	2.4	2.7
1995 est.	1.7	1.9	2.0

1. All integrated plants assumed to be supplying their own coke and semi-finished steel. Data include all plant and overhead employees and contract workers.
2. EAF: electric arc furnace.

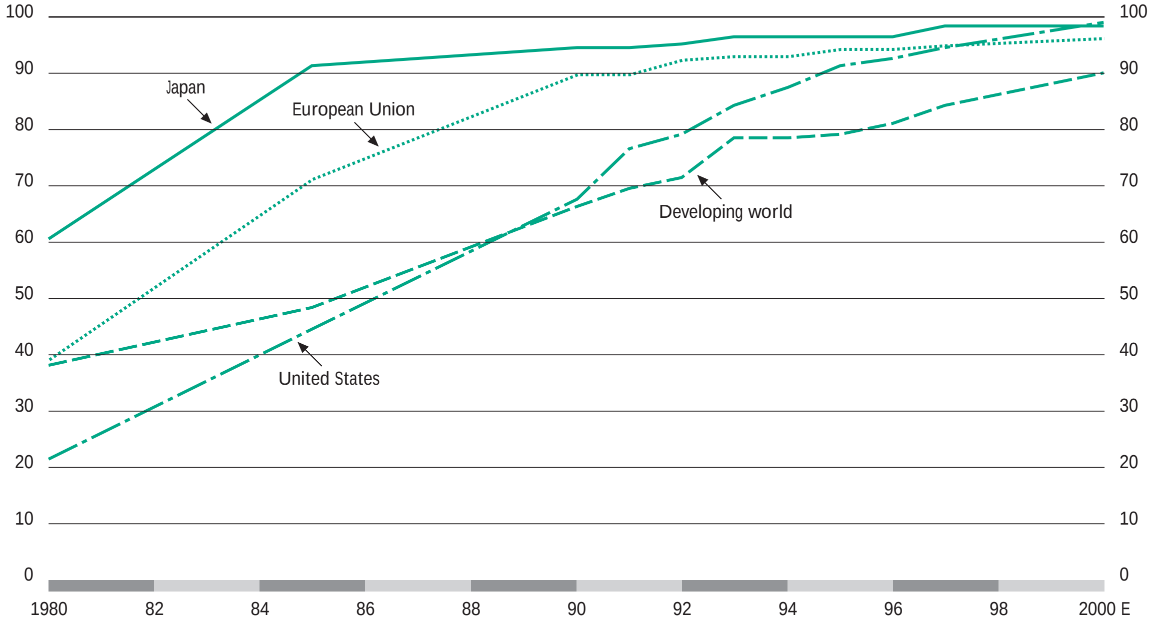
Source: Barnett, 1996.

companies. In addition, retraining and job placement programmes were launched. In some cases, wage cuts were involved, but most of these schemes avoided forced layoffs (Houseman, 1991).[4]

- As important as the quantitative change is the qualitative change in the workforce. First, there is a clear trend towards ***upskilling.*** In the integrated mill, low-skill jobs and jobs associated with obsolete or declining technologies, such as open hearth operators, have disappeared. In turn, the number of high-skill jobs and jobs associated with newer technologies, such as thin-slab casting and computer control systems, has increased. On the factory floor, manual labour is rapidly disappearing and is being replaced by computer-operated systems. The increasing presence of computers means that steelworkers need to have a higher level of basic skills in reading, mathematics and scientific knowledge than in the past. This suggests that the steel industry's knowledge base is becoming more sophisticated. In fact, new recruits to the industry appear to be better educated than in the past. For example, half of the new employees in some start-up minimills in the United States had post-secondary level degrees (Schriefer, 1996).
- Technological changes in the steel industry are destroying the traditional rigid skill distinctions and increasing requirements for ***versatility,*** flexibility and trainability associated with higher general skills. The modern steelworker needs to master many skills, to be able to perform many jobs, and to have the flexibility to change from one job to another. The diffusion of the minimill process has given an impetus to this trend. In the minimill, a worker needs to be competent but flexible and versatile, "switching from job to job (or even plant to plant), from operating to maintenance jobs, or even damage control" (Barnett, 1996). The trend is therefore towards multi-skilled workers and fewer job classifications.
- The change in skill requirements is increasing the need for ***training*** and retraining of employees in the steel industry. New job skills cannot be learned on the job from older workers as in the past, but need to be transmitted more systematically. Steel mills are improving and standardising training procedures and increasingly employ classroom instruction based on textbooks and computer-based training materials. Computers play a greater role. For example, one US minimill, North Star, set up computer learning centres at each of its mill locations, where workers could go through self-paced training and retraining in basic skills and in technical, regulatory and safety operations. Not only firms but also trade unions take an active part in training. In 1989, the United Steelworkers of America and some steel-making firms created the Institute for Career Development (ICD). Its programmes supplement firm-level training to improve workers' personal and basic skills and help workers who have lost their jobs retrain for new ones. Steel mills have also set up training courses jointly with local community colleges in the United States (Schriefer, 1996).
- The growth of EAF steel making has had far-reaching effects on the ***structure of the steel industry.*** This is probably the single most important development and will continue to change the industry. As pointed out before, the most significant effect of the minimill has been the reduction in the minimum efficient scale of steel making, which has eased entry requirements. Minimills will continue to present a major competitive challenge to the integrated mills, while the low entry requirement suggests that competition among minimills may increase further. This is already happening in the United States and Japan and is also likely to affect the steel industry in other countries as their integrated mills restructure. Competition among the major steel-making processes may stimulate innovation and efficiency improvements in minimills as well as in integrated mills.

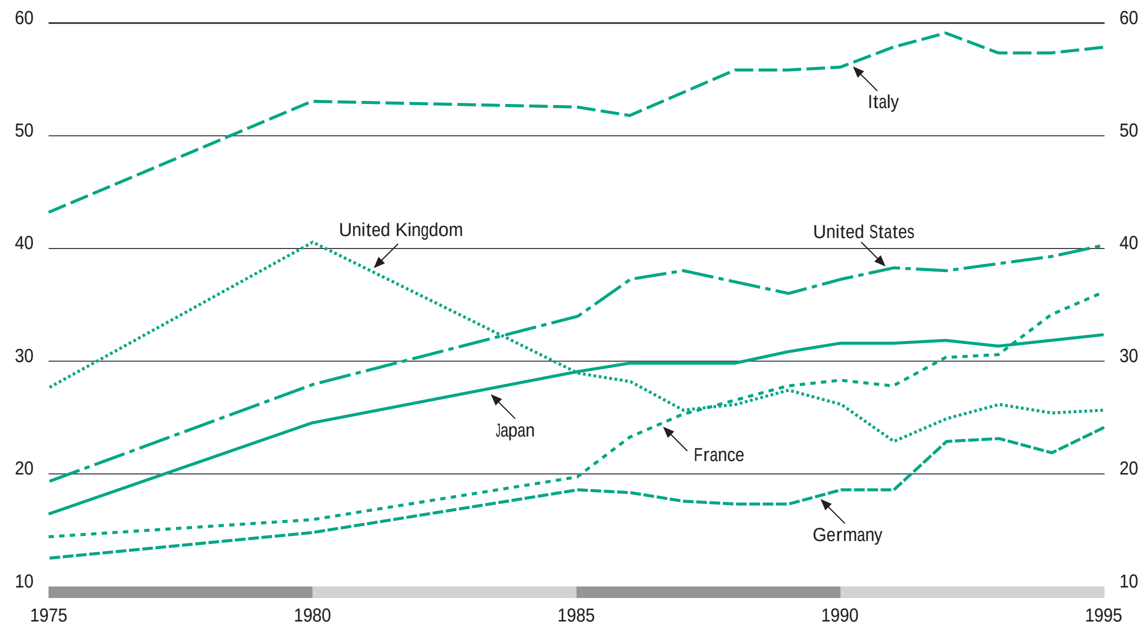
In the OECD area, the diffusion of certain types of technology has not been uniform. This difference contributes to the competitive position of the industry relative to other countries. For example, the EAF minimill process has spread rapidly in the United States and Italy, but slowly in Japan and some European countries (Figure 5.7*b*). There seem to be a number of reasons for the difference. First, electricity prices are much higher in Japan and Europe than in the United States. This is a decisive factor for the adoption of the EAF process. Moreover, regulatory barriers have affected the entry and exit of steel producers in some parts of the OECD area, where the government has intervened to support

◆ Figure 5.7*a*. ***Diffusion of the continuous casting technology***
As a percentage of total crude steel



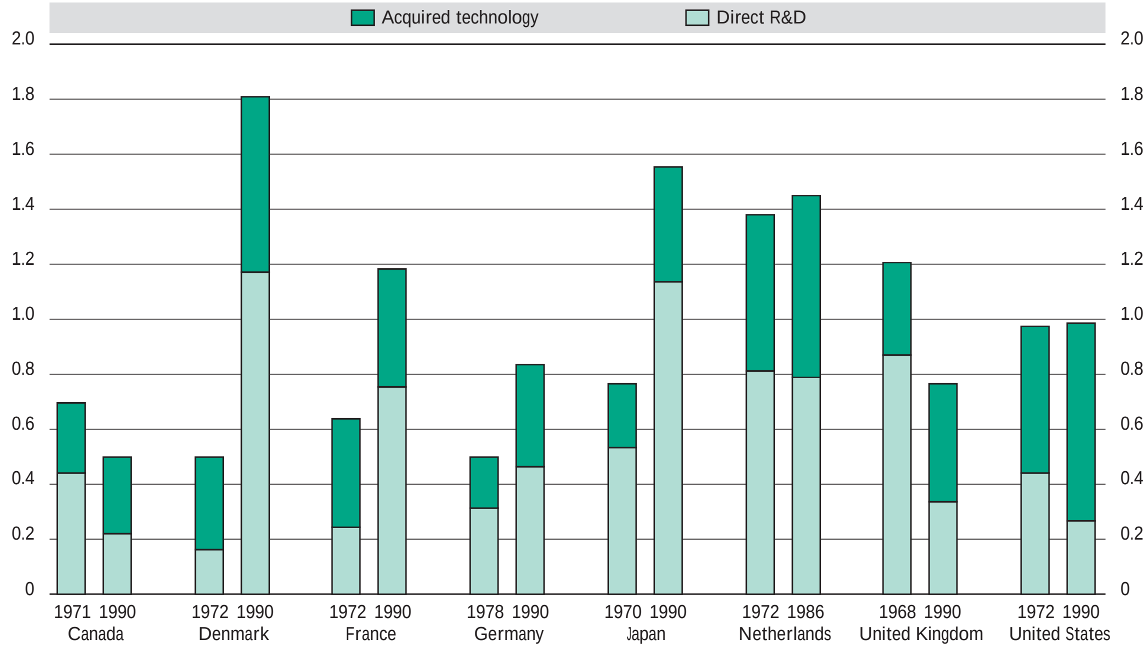
Source: Marcus *et al.*, 1997.

◆ Figure 5.7*b*. ***Diffusion of the Electric Arc Furnace technology***
As a percentage of total production



Source: OECD, 1996*m*.

◆ Figure 5.8. ***Technology intensity in ferrous metals, 1972-90***
As a percentage of total output



Source: OECD, calculations from Input-Output and ANBERD databases, September 1997.

existing producers, often in order to prevent large-scale job losses. Such regulations, especially if accompanied by government subsidies and other protective measures, have functioned as disincentives to investment in the more efficient minimills.

Diffusion of technology is also influenced by other factors, such as the financial resources available for investment. This could explain the differing speed at which continuous casting was adopted (Figure 5.7*a*). In general, Japanese steel makers were quicker than others to introduce sophisticated computer control systems in the integrated mills. Information technology has penetrated the Japanese steel industry both for process and product innovation. The United States has been slow to adopt the continuous casting technology. Furthermore, although a US firm (Armco) pioneered the development of the pulverised coal injection technology in 1963, the US steel industry has lagged behind other OECD countries in diffusing it. These differences in diffusion patterns are likely to diminish in view of increased foreign direct investment (FDI) and inter-firm alliances in the steel industry. Increased FDI already appears to have contributed to greater diffusion.[5]

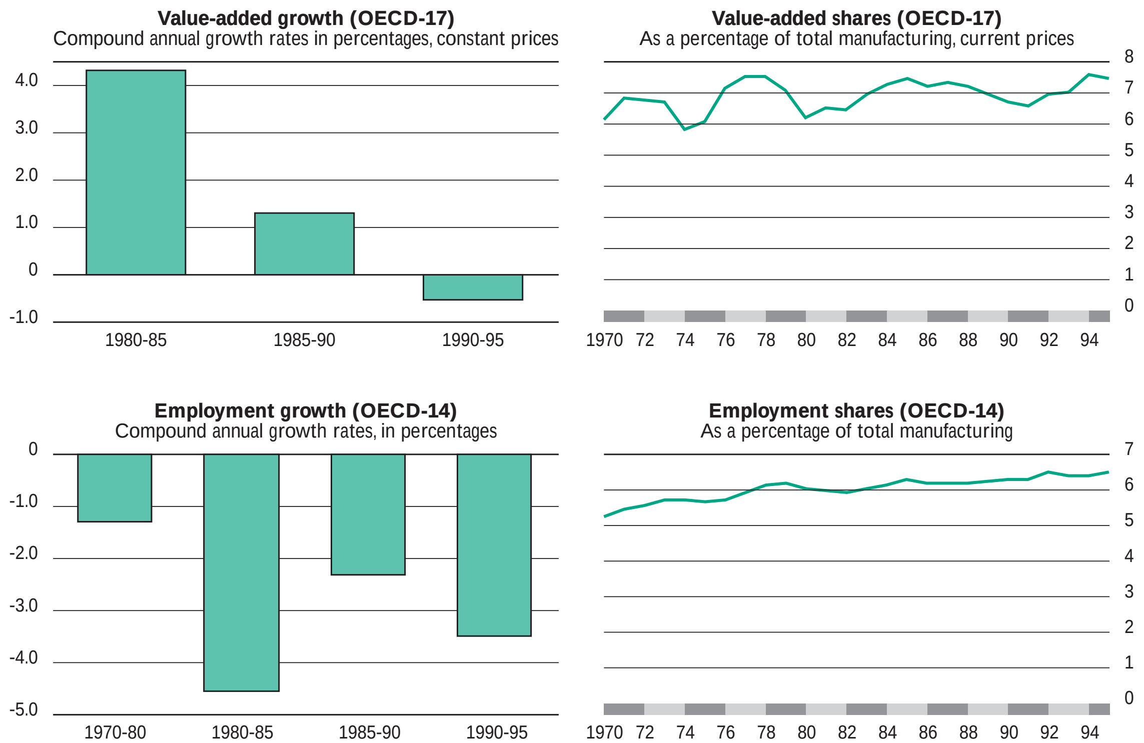
Technological changes and their effects on the steel industry point to an increasingly important role for technology. Investment intensities per unit of production and per employee have either increased or held steady since the 1970s, while labour intensity has decreased drastically. The industry's technology and R&D intensity have increased substantially, however, indicating that – in contrast to the conventional notion of a mature industry – the steel industry has become a relatively advanced industry in technological terms (Figure 5.8).

AUTOMOBILES

Introduction

The automobile industry is less mature than the steel and textile and clothing industries. Its share in total OECD-area manufacturing production is still increasing in terms of value added, albeit at a

◆ Figure 5.9. ***Trends in the automobile industry***



Source: OECD, Main Industrial Indicators database, August 1997.

slower rate (Figure 5.9). However, employment is falling in the automobile industry, although its share in total manufacturing employment is still growing. Labour productivity increased rapidly in the 1980s but has levelled off since (Figure 5.2). Moreover, unlike steel or textiles, production is still concentrated in the OECD area. The push for industry restructuring results less from competition from non-OECD countries and more from competition among OECD automobile producers as well as from technological change.

The automobile industry's technological evolution is well known. After the first customised ''handicraft'' automobiles of the end of the nineteenth century, the industry came to symbolise the age of mass production and consumption with the advent of ''Fordist'' mass assembly production, which dominated the US automobile industry in the 1920s. The mass production technology diffused first to Europe and then to Japan. As the industry has matured and growth in demand has slowed, this production technology has increasingly been challenged by the ''lean'' production system which originated in Japan. The diffusion of this flexible production system, combined with greater use of advanced manufacturing systems based on information technology, is revolutionising the industry, given its capacity for boosting productivity and increasing flexibility of production. The competitiveness of those firms and countries that were quick to adopt this new production method has led to a global restructuring of the industry.[6] The new technologies are also radically changing the labour processes involved in automobile manufacturing.

Technological change in the automobile industry

The basic processes involved in automobile manufacturing have changed little since the first few decades of this century. Following the design and engineering phase, there are a number of steps. In the automobile assembly plant, purchased components and materials are inspected; then the material inputs are formed into various shapes by casting, forging, stamping or moulding. Some of these shapes are tempered and strengthened by heat treatment and are then machined into components. These components, some of which may be supplied by external suppliers, are sub-assembled into gearboxes, axles, engines, etc., usually at another assembly line in a separate building. The chassis and body are built by welding the metal parts and then the resulting body is painted. At this stage, the various components and sub-assembled parts are brought together and assembled into the final product. The finished automobile is inspected, stocked and shipped to customers. While these basic processes have remained unchanged throughout the century, automation has steadily replaced manual labour. What has changed radically in some automobile plants, however, is the organisation of the production process with the move from mass to "lean" production.

From mass production to the "lean" paradigm

The mass production of automobiles, developed by Henry Ford in the first two decades of this century, relied on three key principles: product standardisation, use of special-purpose equipment, and elimination of skilled labour on the assembly line (Tolliday and Zeitlin, 1986). The first mass-produced Model T Ford came in a single model and colour. The original intention was to facilitate repair, but the standardisation of the model and its components also permitted a dramatic reduction in costs, owing to the use of special-purpose machinery and the division of labour. Ford also simplified each component as much as possible, and then developed special-purpose machines to assemble them. Ford's tools and machines could be operated by unskilled workers, and the subdivision of tasks further reduced skill requirements. The deskilling of assembly operations allowed faster throughput and led to Ford's invention of the moving assembly line in 1913. The result of these innovations was a dramatic rise in productivity and a significant reduction in the cost of the finished car. Furthermore, capital requirements were low compared to those for the early customised production.

Ford's mass production technology was complemented in the 1920s by a range of marketing and management innovations introduced by Alfred Sloan of General Motors (GM). Sloan saw weaknesses in the management of Ford's operations, including the combination of a vertically integrated production structure and centralised decision making and an inflexible production organisation centred on a single standardised product. Sloan therefore decentralised management and introduced four different models and price categories to satisfy a broader market. However, these innovations did not change the technical or the organisational aspects of the assembly line. Even when the Fordist technology diffused to Europe, the strong European tradition of customised production did not modify it. Instead, the two systems co-existed: custom producers specialised in luxury products, while mass producers aimed to satisfy the emerging, broader European market for automobiles.

Despite some drawbacks, the Fordist mass production technology dominated most of the century. First, the deskilling of assembly line work meant that specialists (*e.g.* die changers) had to be employed to support the assembly workers, whose work consisted of monotonous operations. Second, keeping the assembly line going meant that defects tended to go unnoticed, so that the final product often had to be "reworked" to rectify them. Third, large inventories of parts and components were needed to keep the assembly line moving. Finally, because of the inflexibility of the Fordist tools and machines, standardised components and sub-assembled parts had to be produced in large quantities to achieve economies of scale.

These drawbacks of the Fordist paradigm were recognised by Japanese auto makers in the 1950s, when the automobile technology reached Japan. Their resources were too limited and their market too small to accommodate mass production. The changes made by Toyota, the main Japanese automobile manufacturer, created the "lean" production system (Womack *et al.*, 1990) which has since revolutionised the automobile industry. The original motive for the series of organisational innovations made at the Toyota factory in the 1950s and 1960s was to remove what seemed wasteful or useless in the mass assembly system, but also to devise a method suited to available resources, as well as to the market structure of post-war Japan, which was tiny by US standards but required a wide range of products. The "lean" system has four key organisational concepts (Monden, 1983): *i)* just-in-time production, which aims to produce the optimal amount of components as they are needed, thus eliminating large inventories; *ii)* autonomation, or the autonomous control of defects; *iii)* flexible workforce, or adapting the number of workers as demand fluctuates; and *iv)* creative thinking and inventive ideas, or capitalising on workers' suggestions. These concepts resulted in an innovative production method able to achieve cost reductions, improved quality, flexible production, and "humanised" labour practices.

The just-in-time – or "kanban" – method, is probably the best-known aspect of the lean production system. It is a means of organising assembly line operations without having recourse to large inventories. Information systems continuously inform assembly line workers about the precise quantity of parts required from the immediately preceding step in the assembly line or from external suppliers. The just-in-time method requires an appropriate reorganisation of the components supply chain so that the needed quantity of each component is delivered as required to the assembly line. Also, in order to make the method work, the delivered parts must be free of defects. "Autonomation" allows assembly workers to alert or stop the assembly line whenever defects are detected, to look for the cause, and to rectify the problem. This reduced defects drastically and eliminated the frequent "reworking" of defective products at Fordist mass assembly plants (Womack *et al.*, 1990). The reduction in reworking not only saved labour and material inputs, but also saved floor space for parking defective cars awaiting reworking.

Workers who are allowed to detect and correct defects are no longer the interchangeable unskilled workers of the mass production line. In a fundamental departure from the mass production system, the lean system eliminated the hordes of unskilled assembly workers and specialist operators and replaced them with "teams" of workers who could perform varied tasks and specialist operations (*e.g.* changing dies) and who co-operated in solving problems. This marked an important first step towards a multi-skilled, flexible workforce. For mixed assembly and manufacturing, workers had to be able to handle rapid machine set-ups, as well as frequent changes of task. The manufacturing process in turn became adapted to producing smaller volumes of a large variety of products. The lean system also institutionalised improvement engineering by encouraging workers, through "quality circles", to suggest ways to improve the production process. The effectiveness of quality circles was reinforced by the "creative tension" in the flexible work organisation but also by labour management practices (*e.g.* a high degree of job security) (Womack *et al.*, 1990). The lean system contributed to a dramatic improvement in productivity over the mass production system.

Lean production and advanced manufacturing systems

The diffusion and effects of IT-based advanced manufacturing systems in the automobile industry should be placed in the context of the "lean" revolution outlined above. When examining the automobile industry, a preoccupation with the lean system seems to have overshadowed interest in the effects of new technologies. However, the automobile industry is a leading user of robotics and other aspect of AMT. Microelectronics-based and more advanced IT-based technologies were eventually integrated and have become powerful complements to the lean system. While automation and robotics may account for about a third of productivity gains when comparing different plants, adoption of the lean system is a prerequisite for capturing the full benefit of advanced technology equipment (Womack *et al.*, 1990). Once the lean system is adopted, advanced manufacturing systems facilitate information flows and enhance manufacturing flexibility while increasing productivity. Hence, advanced information technology and manufacturing systems are steadily penetrating the automobile industry (Box 5.5).

The impacts of technological change

Adoption of the "lean" system and of microelectronics and IT-based AMT have radically affected performance in the automobile industry. It has helped to increase productivity and to lower production costs, has affected labour requirements, improved product quality, and facilitated flexibility of automobile production. These changes have affected the competitiveness of the automobile industry in different OECD countries and regions and have led to considerable restructuring efforts to regain

Box 5.5. **The use of advanced technologies in the lean system of automobile production**

The diffusion of the just-in-time method to other automobile manufacturers in Japan led to an increased ***use of computers*** to manage the system. In order to achieve variety of production while maintaining productivity, Japanese automobile manufacturing firms gradually replaced simple automating devices with numerically controlled (NC) tools, industrial robots and flexible transfer machines. These provided the flexibility needed for cost-effective production of small volumes while maintaining high productivity levels. These machines diffused more rapidly in Japan than in the United States and were continuously upgraded as the demand for product diversification intensified. Moreover, they were increasingly included in computer-integrated production systems. Therefore, although the lean system and IT-based advanced manufacturing systems evolved separately, their interaction and interdependence have increased over time. Computer-integrated production systems have also enabled production engineering techniques such as "modular assembly", in which sub-assembled components delivered by external suppliers are assembled with minimum adjustment by robots (Hoffman and Kaplinsky, 1988).

Computer integrated manufacturing systems for flexible automation also involve computerised control of production scheduling and relations with suppliers. This involves the co-ordination, by computer, of all aspects of production: the assembly line, production scheduling, ordering of components from external suppliers and just-in-time production within the plant. Systems such as Nissan's Action Plate Method are in essence a CIM version of Toyota's "kanban" method, designed to streamline production and handle customised production.

In addition, ***electronification*** is changing product technology dramatically, as components become electronics-based. This is changing product development strategies and the direction of R&D, especially in automobile component manufacturers. Microelectronics- and IT-based innovations are appearing not only in Japan but also in US and European automobile manufacturers and component firms. Firms in the United States and Europe are also devising various combinations of the lean system and IT-based advanced manufacturing systems to increase their competitiveness, and in both regions more emphasis is being placed on incorporation of IT-based design, process and product technologies.

One of the latest innovative developments in the automobile industry is the implementation of the lean and IT-integrated system in ***retailing.*** The problem here is matching production to customer demand. Obviously, electronic data systems can facilitate the required information flows. The US car retailing sector already has some innovations that make extensive use of information technology. For instance, a successful second-hand car chain, CarMax, uses inventory control and computer technology to control costs and to guide and inform customers about the products offered. GM's Saturn Corporation has adopted a customer-pull marketing strategy and uses IT to monitor market trends and to integrate retailers in the corporate decision-making process. This is intended to ensure customer feedback into manufacturing. Another successful retailing innovation is the multi-brand retailer. This type of retailing uses information and communication technologies to provide the customer with a variety of services such as toll-free numbers for information and ordering, or a wide range of financing purchase and lease options. This method uses ICT to gather information about products from a large number of factories and matches factory supply to customer demand by creating sophisticated forecasting and inventory management systems (Fine and St. Clair, 1996).

competitiveness. Because in many cases adoption of the lean system and investment in IT-based equipment proceeded simultaneously, it is difficult to separate the effects of these two process innovations. Moreover, as mentioned above, the two processes have become interdependent. Contemporary automobile technology can be seen as the integration of two originally distinct innovations.

The impact of the lean production system is summarised in Table 5.5. The first two columns represent plants that have become "lean" and have also rapidly adopted automation, although in varying degrees, while the last two columns represent latecomers to these changes. The performance-enhancing impact of the lean system is clear and striking:

- There are considerable improvements in ***productivity,*** in terms both of the length of time required to produce an automobile and of quality, as measured by frequency of defects. Also significant is the reduced space needed to produce a vehicle and the amount of space that needs to be reserved for repairs. Associated with these trends is a drastic reduction in inventories, particularly in Japan's automobile assembly plants. A recent study (McKinsey, 1997) confirms the importance of the lean system in achieving high productivity levels. It attributes most of the productivity difference between France and Germany on the one hand, and Japan on the other, to the widespread adoption of the lean system in Japan. Another important technological factor contributing to productivity differences is the greater degree to which Japanese car producers have been able to design their cars for efficient manufacturing. The Japanese practice of offering more options as standards reduces variability, smoothes the production process, and allows complex cars to be built efficiently. The McKinsey study confirms that major differences in productivity continue to exist in the OECD area, suggesting that restructuring may continue for some time.

- Equally striking is the radical change in the ***organisation of the workforce.*** More workers are organised in teams and there are considerably higher rates of job rotation within the team. In the lean system, new workers are subjected to significantly more intense training, and there are fewer job categories; however, there are considerable regional differences on this point. Differences in labour practices indicate that workers in the lean system are trained to be ***multi-skilled.*** They have to change tasks more frequently on the factory floor, and must therefore be flexible and versatile. In other words, the lean method has led to a definite and pervasive upskilling trend in the automobile assembly labour force, a trend also observed in the steel and textile/clothing industries. The requirement for multiple skills and greater flexibility appears to improve worker motivation, to judge by the reduced absenteeism rates. The lean system may also motivate workers by institutionalising improvement engineering and incorporating workers' suggestions.
- Perhaps the most significant impact of the lean system and the adoption of AMT is greatly enhanced ***flexibility*** in production, which has been accompanied by high product quality but has not raised the unit cost of production.

The lean system has also affected the way in which innovation is generated in the industry. It is not so much the intensity of the R&D effort that distinguishes the lean system from the traditional Fordist

Table 5.5. **Summary of assembly plant characteristics, volume producers, 1989**

Averages of plants for each region

	Japanese producers in Japan	Japanese producers in North America	American producers in North America	All producers in Europe
Performance				
Productivity (hours/veh.)	16.8	21.2	25.1	36.2
Quality (assembly defects/100 vehicles)	60.0	65.0	82.3	97.0
Layout				
Space (sq. ft./vehicle/year)	5.7	9.1	7.8	7.8
Size of repair area (as a % of assembly space)	4.1	4.9	12.9	14.4
Inventories (days for 8 sample parts)	0.2	1.6	2.9	2.0
Workforce				
Percentage of workforce in teams	69.3	71.3	17.3	0.6
Job rotation (0 = none, 4 = frequent)	3.0	2.7	0.9	1.9
Suggestions/employee	61.6	1.4	0.4	0.4
Number of job classes	11.9	8.7	67.1	14.8
Training of new production workers (hours)	380.3	370.0	46.4	173.3
Absenteeism	5.0	4.8	11.7	12.1
Automation				
Welding (% of direct steps)	86.2	85.0	76.2	76.6
Painting (% of direct steps)	54.6	40.7	33.6	38.2
Assembly (% of direct steps)	1.7	1.1	1.2	3.1

Source: Womack *et al.*, 1990.

Table 5.6. **Trade in automobiles (finished and parts)**[1]

Major exporters	1980		1993		Major importers	1980		1993	
	Value (US$ bn)	Share (%)	Value (US$ bn)	Share (%)		Value (US$ bn)	Share (%)	Value (US$ bn)	Share (%)
Japan	19.1	19.7	69.0	23.1	United States	24.6	27.0	78.8	27.2
Germany	22.8	23.5	55.2	18.5	Germany	7.6	8.3	28.1	9.7
United States	12.8	13.2	38.3	12.8	Canada	10.4	11.5	25.7	8.9
Canada	6.7	6.9	27.4	9.2	United Kingdom	6.7	7.4	21.5	7.4
France	11.4	11.7	22.5	7.5	France	5.7	6.3	16.6	5.7
Belgium/Luxembourg	5.6	5.7	16.2	5.4	Italy	6.2	6.8	12.3	4.2
Spain	2.1	2.2	12.9	4.3	Spain	1.1	1.2	11.1	3.8
United Kingdom	6.2	6.4	11.9	4.0	Belgium/Luxembourg	6.5	7.1	10.3	3.6
Italy	4.8	4.9	9.4	3.2	Japan	0.6	0.6	6.6	2.3
Mexico	0.0	0.0	7.6	2.5					
Sweden	2.4	2.5	5.3	1.8					
Republic of Korea	0.1	0.1	4.4	1.5					
Rest of the world	3.2	3.3	18.8	6.3	Rest of the world	21.8	24.0	78.9	27.2
World	97.0	100.0	298.7	100.0	**World**	91.2	100.0	289.9	100.0

1. SITC Revision 2: 7132 + 7783 + 781 + 7841 + 7842 + 7849.
Source: OECD, 1996*a*.

system, but the organisation of innovative efforts. In fact, R&D intensity in the Japanese automobile industry has changed little since 1970 and is below that of a number of other major car producers (OECD, 1997*c*). In the lean system, innovation is not an isolated activity, reserved for specialised R&D departments, but something that occurs in all parts of the system. For instance, the lean system encourages workers to be creative, and resulting minor innovations can contribute to productivity gains in the production process. Furthermore, the lean system ensures that R&D efforts are closely linked to the needs and realities of production and marketing, as R&D engineers have experience in assembly operations, production and marketing as well as engineering and design. Innovation thus plays a central role in the lean system, sometimes characterised as the ''innovation-mediated production'' model (Kenney and Florida, 1993).

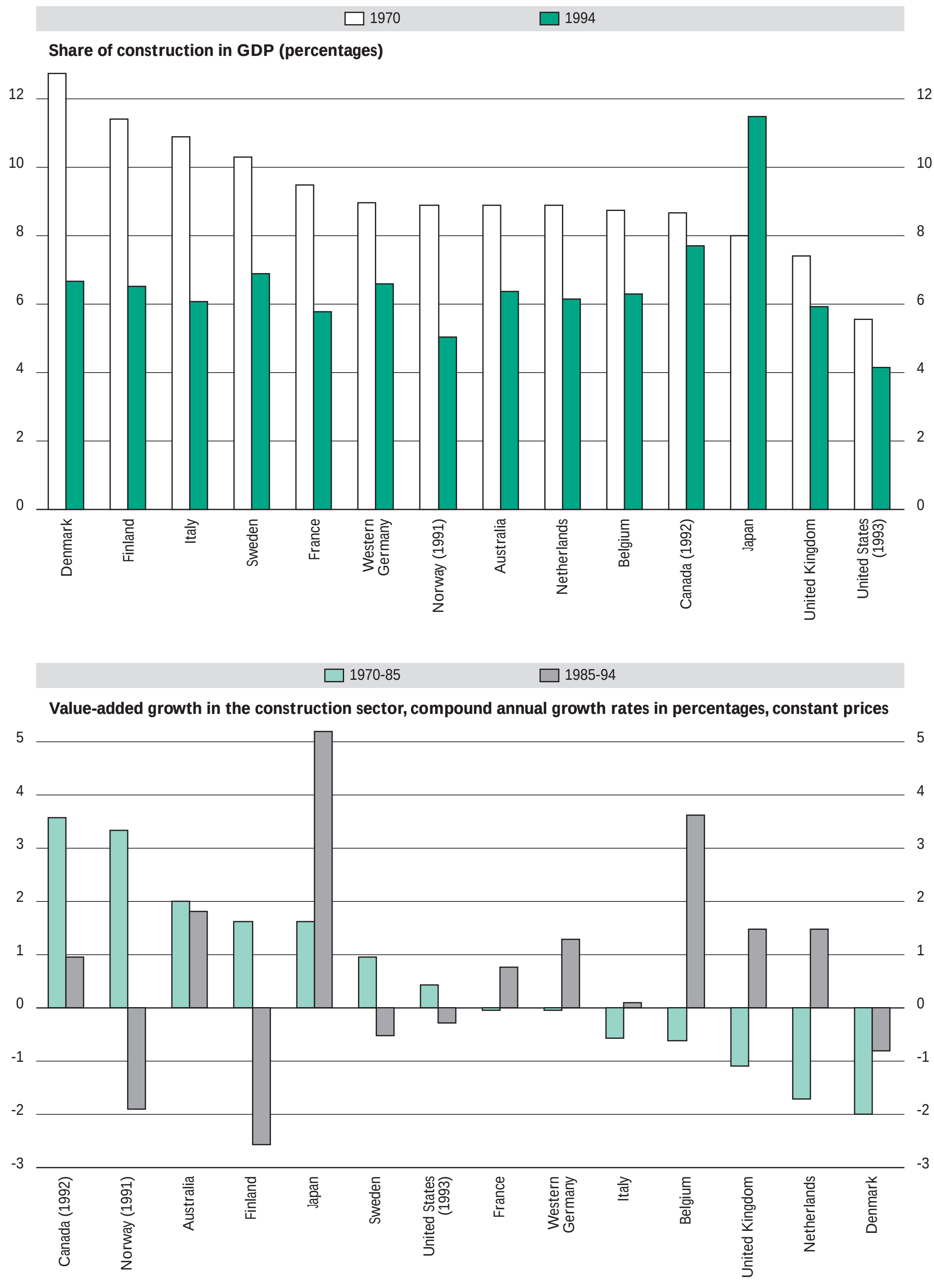
The lean system developed and diffused rapidly in Japan at a time when the demand for smaller and fuel-efficient cars – for which the lean system was designed – suddenly increased as a result of petroleum price increases. This amplified the competitiveness of Japan's automobile industry over the past two decades, as its increased share in world automobile exports indicates (Table 5.6). The automobile industry has become a truly globalised industry. FDI, particularly by Japanese firms, has increased substantially over the past decade and newly industrialising countries are also increasing market share in the automobile industry. Globalisation is not only taking place through FDI, but also through the development of intricate inter-firm networking and alliances for external and internal sourcing, R&D and design (OECD, 1996*a*). The globalisation trend is likely to facilitate the diffusion of the lean system and make its adoption a necessity for survival. The spread of the lean system to US firms has significantly improved productivity performance and has helped to restore the competitiveness of the US car industry in the face of Japanese competition. The European car industry is still lagging behind, although substantial progress has been made (McKinsey, 1996).

CONSTRUCTION[7]

Introduction

The construction sector differs in several ways from the manufacturing industries discussed in the previous sections. It is substantially larger, and in most OECD countries, it contributed some 6-7 per cent to GDP (gross domestic product) in 1994 (Figure 5.10). In Japan and Korea, where investment in infrastructure and housing remains high, the figure is about 12 per cent and over 11 per cent,

◆ Figure 5.10. ***Trends in the construction sector***



Source: OECD, ANAN database, October 1997.

respectively. The construction sector is also an important employer. In 1994, the construction sector accounted for 8 to 9 per cent of economy-wide employment (OECD, 1997*w*). It has declined, however, in relative terms, as its share in economy-wide output and employment was substantially higher in 1970 than it is today. The construction sector is the main producer of investment goods and thus underpins production, distribution and consumption of other goods and services. Up to 65 per cent of all investment goods in the economy – comprising residential buildings, non-residential buildings and structures, and other construction goods – are produced by the construction sector (OECD, 1997*w*). About half of this investment is in residential buildings.

Construction is a highly cyclical industry. In several market segments, construction activities are demand-led, particularly where large facilities and infrastructures are concerned. Government procurement policies also strongly affect demand for construction products and play an important role in guiding technological change in the sector. Demand for buildings and structures therefore tends to fluctuate with business and investment cycles. Construction's significance to wealth creation and quality of life extends far beyond its direct economic contribution. The products and services provided by construction create an infrastructure which supports existing and newly emerging social and economic activities.

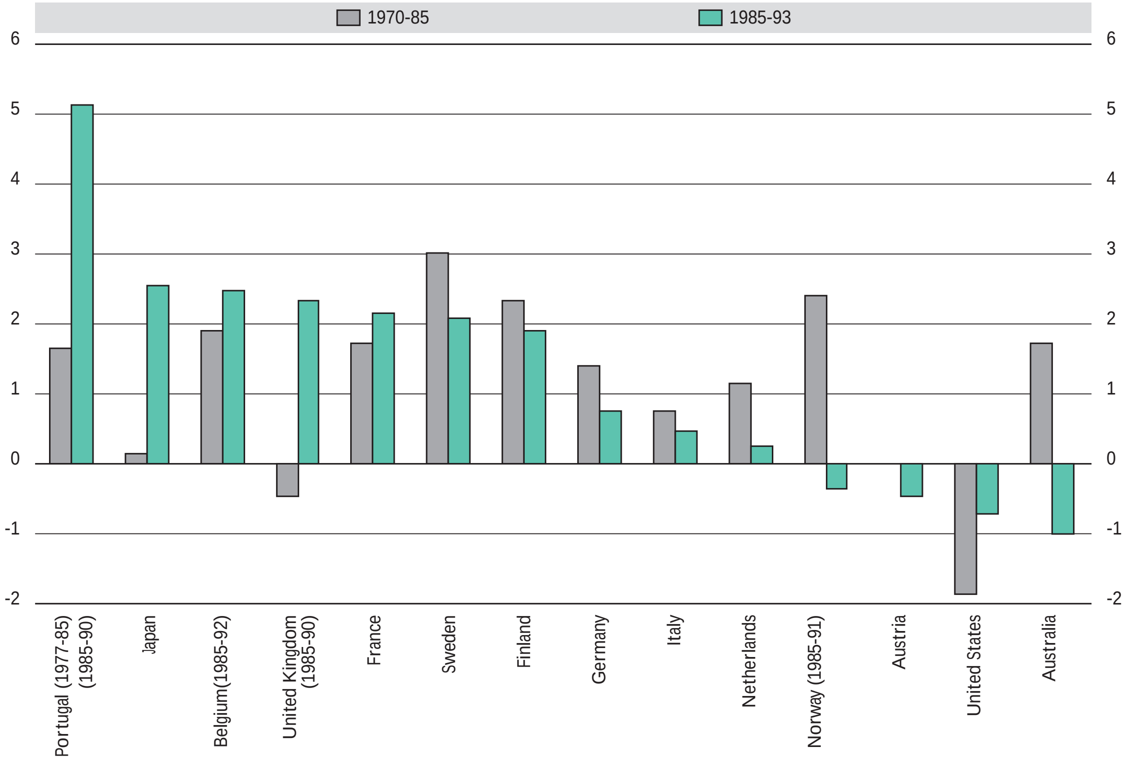
Relative to other industrial products, buildings and structures have become more costly to purchase and operate. Lower rates of productivity growth in construction compared with manufacturing have contributed to a relative increase in construction costs. Construction has failed to keep pace with the performance improvements realised in other industries. For example, in the period 1970-85, productivity in European construction increased at an average rate of 0.9 per cent a year, *i.e.* less than in other industries (KD/Consultants, 1991).[8] Over the period 1985-94, productivity growth was modest in most OECD countries, and a number – including the United States – experienced negative productivity growth (Figure 5.11).

Clients' expectations of the construction industry are based not only on perceived improvements in cost and performance, but also on comparisons with those of other products and services. Slow relative price decreases in buildings and infrastructures may create pressure for investors to substitute one type of capital good for another, such as information and communication equipment for buildings (Barras, 1995). This may explain why larger clients are demanding lower construction prices, which may in turn lead to long-term problems of profitability in construction firms. This in itself hinders investment in new techniques and has resulted in extreme forms of price-based competition, which has put further pressure on profit margins and created opportunities for new entrants from other industries.[9] Because of these developments, there is scope for increased competition from firms in other countries with more efficient design, engineering, construction, and supply.

The relatively weak performance of construction firms is reflected in a number of other indicators. For example, construction has a worse health and safety record than most sectors, and share prices of construction and building materials firms under-performed those of most other industries during the recession of the early 1990s. These aspects of the economics of construction indicate the need for technical change to reduce costs and improve quality. Furthermore, buildings and structures are usually long-lived and often have to be adapted to meet different and changing needs. Products designed and built to cope with change and whose long-term costs are considered in the design process may therefore offer greater utility.

Here, construction is viewed as a *process* rather than as an *industry*. It includes designing, constructing, maintaining and adapting the built environment. These activities involve many organisations from a range of industrial sectors, temporarily working together on project-specific tasks. These functions involve design, engineering, supply and integration, erection and installation of a diverse array of materials, components and increasingly complex technical systems. The project-based nature of the work implies that firms have to manage networks of complex interfaces. Competitiveness depends not on the single firm but on the efficient functioning of the entire network. The project-based nature of construction creates discontinuities in the development of technical knowledge and its transfer within and between firms, and from one project to the next. A technology support infrastructure (professional institutions, industry organisations, etc.) and mobility of personnel aids learning. Firms' technology

◆ Figure 5.11. ***Labour productivity growth in the construction sector***[1]
Compound annual growth rates, in percentages



1. Labour productivity = constant price value added/number engaged.
Source: OECD, Main Industrial Indicators database, October 1997.

strategies need to extend beyond their immediate boundaries if technologies are to be managed effectively. This raises questions about the management of technical know-how in projects and the management of business and inter-organisational processes within and between firms (Lorenzoni and Baden-Fuller, 1995).

Markets for project-based industries are often highly institutionalised and frequently politicised, and selection mechanisms are usually far more complex than in markets associated with mass consumption goods, upon which much of the conventional wisdom is based. In some construction markets, investments are extremely lumpy and may cover several years.

The construction industry is also affected by many regulations on land use and rent, and by building standards and planning permits (Høj *et al.*, 1995). To some extent, these regulations and standards are necessary to protect consumers and create a level playing field for suppliers. However, excessive or unnecessarily complicated standards contribute to high price levels or restrict consumer choice. They may also be used to discriminate against foreign contractors or serve as a barrier to trade in construction materials and services. Within the single market of the European Union, a lack of harmonisation of standards and technical specifications represents a significant barrier to the free circulation of construction products in the EU area (European Commission, 1995).

Traditionally, construction has been a local and regional activity in which local materials and labour have been combined to meet particular market needs, and it often reflects local geological and climatic considerations. For example, research on earthquakes is a high priority in the United States, particularly in California, and in Japan. Cold-weather construction is important in the Nordic countries and in

Canada. The structure of industry is such that most firms are very small. In the EU countries, 97 per cent of the 1.8 million construction firms employ less than 20 people (Atkins, 1994). Markets are segmented according to product types: housing, commercial and industrial buildings, civil engineering structures and infrastructure, public works and repair, maintenance and improvements. The smallest firms are usually active in local markets, where much of their work involves "traditional" technologies. Some SMEs specialise in particular technical areas, and some are innovative. Medium-sized firms usually work in regional and national markets. Large firms work nationally and internationally.

Technological change in the construction industry

Forces driving technological change

Technological innovation in construction arises for many reasons (Box 5.6). It may result from imitation or emulation, from the transfer and adaptation of techniques used elsewhere, or from various forms of problem-solving. It may also result from radical attempts to develop new products and processes. Here, two simplified levels of innovative activity are considered:

- Small *ad hoc* changes to and adaptations of materials and components are continuously being made by supply and construction firms. The site-based nature of production, with an increasing number of specialities, the relative uniqueness and changing use of final products, and the great variety of production processes constantly throw up problems that need to be solved. This often leads to unstructured innovation, where improved quality and speed and reduced costs are not necessarily the goal. Incremental innovation may also not result in major changes to overall

Box 5.6. **Major changes in the demand for construction work**

Transformations in economic and social activities create demands for new construction work and renewal of the built environment. Processes of production, distribution and consumption across the OECD countries are changing, so that new facilities are needed for extraction of raw materials, processing, manufacture, retail and services sector activities. New infrastructure is required to transport people, goods and services and to provide basic utilities such as water, sanitation and power. Environmentally clean buildings and structures are also increasingly in demand. In Europe and the United States repair, refurbishment and modernisation programmes generate a need for better construction technologies.

Some markets for construction are becoming more globalised, *e.g.* specialist construction of engineering-intensive projects such as silicon-chip fabrication plants. Furthermore, technologies upstream in the supply industries are being produced by large firms operating in international markets. As a result, technologies used by the project-based construction industry are increasingly international, as more design and technical know-how migrates upstream in the value chain. In general, there are signs that production and markets are becoming global, although this is not necessarily the case in design and research (Patel and Pavitt, 1991; Pavitt, 1992; Hu, 1992). These changes are stimulating a situation where technical knowledge is embodied in products which are assembled quickly on the site rather than prepared using traditional craft skills.

The public sector in OECD countries has traditionally been a major customer for construction goods and services. In recent years, its role in procuring constructed products and services has changed. In many OECD countries, privatisation and deregulation have led to new ways of procuring major projects involving new institutional players, such as financial institutions. The general trend is also for public sector institutions to divest themselves of their former technical competencies. The increasing complexity of local, national and international political and financial regimes may force more rapid development, with shorter lead times for tendering and design work, and may put more pressure on the need to manage technical choices. Furthermore, changes in planning and regulatory frameworks affect the conditions under which construction technologies are developed and used. For example, a shift to performance-based building regulations – enabled by better methods of measuring building performance – may increase opportunities to apply new components in construction (Gann *et al.*, forthcoming).

performance, because small changes may only stretch an existing, inefficient practice a little further.

- Major changes to materials, components and equipment result from planned R&D. These generally lead away from traditional craft practices and towards improved engineering and assembly methods. Such radical innovations are usually accompanied by major structural change, new forms of competition and industrial upheaval. Design innovations, such as CAD, may play a role in this type of innovation.

Not all construction firms are passive recipients of changes emanating from other sectors. Some function as systems integrators and intermediaries in the transformation of component technologies. They can adapt and shape new technologies and convey crucial feedback from upstream producers to downstream clients and eventual users and vice versa. In this project-based environment, the ability to innovate in terms of organisation is often as important as the ability to introduce new technologies. Forces for change are particularly strong among materials and components manufacturers who are able to invest in long-term research and product development. Many major technological changes aimed at improving construction processes take place away from construction sites and seek to reduce skill requirements on-site. Value added in construction is increasingly being produced upstream in the supply chain, *e.g.* by component manufacturers. Customers for large projects may also feed the innovation process and often fund new developments.

The nature of constructed products and the organisation of construction processes constrain technological change. The site-based nature of erection, assembly and installation, together with the need for durability, means that firms often prefer techniques they consider "tried and true". Moreover, buildings and structures are becoming more complex and often need to integrate expensive systems. The legacy of sunk costs in existing buildings may reduce the viability of major technical advances, as new systems may be too costly to integrate. This may also slow innovation, because architects and designers are often reluctant to specify materials and components that do not have a proven track record. The risk of failure, the need to take account of public safety, and the potential for legal conflict all help to perpetuate conservatism (McCutcheon, 1975). While such risks retard development in one direction, they may also act as a stimulus to change.

The longevity of many building components puts pressure on suppliers to maintain stocks of spare parts. This reduces incentives for manufacturers to change product lines. Longevity and the need for durability create problems for testing new materials and components, and the costs involved may make innovation prohibitively expensive. Prototypes of buildings are rarely constructed and tested in the way automobiles or planes are, although computer simulations are beginning to help in this respect.

Product and process innovation

Growth of new markets and demand for radically new types of buildings and structures periodically result in demand-induced technical change. Over the long term, this has been one of the most significant forces for innovation. For example, previous periods of high demand for new infrastructure, such as railways, factories or tall buildings, have been accompanied by major technological innovation. In OECD countries today, the demand for constructed products is changing. People and businesses want greater choice and flexibility in how they live and work, and their expectations for the built environment are also changing. Innovations such as IT, new materials, genetic and biochemical engineering create a need for new working environments: for example, silicon chip fabrication plants, pharmaceutical research laboratories, biotechnology plants, transport and communications facilities, and digital control centres for network industries.

Demand is shifting towards more functional buildings which integrate more sophisticated equipment and structures. Users are preferring engineered solutions that offer greater flexibility and choice of layout, finishes and aesthetic qualities. Some large clients are demanding increased quality and functionality and lower capital and operating costs, so that earlier buildings become obsolete (Barlow and Gann, 1995; Gann and Barlow, 1996). A poor understanding of users' and clients' new product requirements and lack of investment in new techniques to provide this infrastructure can result in inefficiencies that drain resources from the rest of the economy. It can also reduce the functionality of infrastructure and may erode users' competitiveness *vis-à-vis* those in other countries where innovative new constructed products are being developed.

In all countries, construction processes range from those rooted in indigenous craft methods using local materials, to modern international engineering and assembly approaches. The type of project organisation has consequences for co-ordination, communication and decision making. Many management approaches developed in modern manufacturing are being adapted for use in project-based environments. These include concurrent engineering, value management, just-in-time delivery, waste reduction and business process re-engineering. International benchmarking, using case studies, is providing better understanding of how to improve performance. Organisational forms vary significantly across the OECD and affect the development and introduction of new technologies. There are three main types:

- ***Relatively stable partnerships between firms.*** These are characterised by long-term inter-organisational networks and create environments in which firms can transfer technology and collaborate on long-term R&D. Their response to changes in demand is relatively inflexible and they have integrated decision-making capabilities (*e.g.* Japanese, East Asian, some French approaches)
- ***Unstable market-based, temporary coalitions of firms.*** These are characterised by great uncertainty and adversarial hierarchical networks. They respond very flexibly to cyclical markets. Interdependent problems and independent actors make long-term investment in R&D difficult (*e.g.* US and many UK approaches)
- ***Hybrid forms of organisation.*** These are characterised by strategic partnering for transfer and development of critical technologies. They aim to provide flexibility and develop core technical capabilities in critical areas (*e.g.* some UK and North European and North American approaches).

Process innovations are often closely associated with product innovations (Box 5.7). In many cases, a new technology embodies both product and process innovation. For example, new types of pre-assembled components such as packaged air conditioning, prefabricated pipework, wall cladding systems, total-roof systems, or pre-fitted bathroom modules can result in improved product quality for

Box 5.7 **Main product innovations in the construction sector**

The main product innovations in the construction sector are:

- ***Changes to on-site plant and equipment,*** automation systems and programmable machines (robotics). Mechanical handling equipment has been developed for use for a wider range of situations. Smaller, more powerful hand-held tools have become widely available to increase speed and accuracy of construction and reduce the need for manual dexterity and lifting.
- ***New materials,*** including plastics and mastics, composite board products, alloys, ceramics, chemicals, cleaning reagents, paints and protective substances. Biochemical materials are also being developed for use in bioremediation and cleaning processes. New materials tend to be lighter and easier to manipulate on site and often improve aesthetic and physical durability of the final product.
- ***New fixing technologies.*** There is a trend towards standardised universal fixings that provide quick-fit, clip-together assembly of parts, rather than honing, filling and shaping joints on-site. They aim to provide quicker jointing, improved accuracy and tolerance for interchangeable parts. The development and use of strong, rapid-hardening adhesives is another important area of innovation.

New construction component technologies are usually developed by manufacturers. Detailed design work is migrating upstream into manufacturing firms with the capability to engineer and test standard component parts pre-assembled in factories. More building and structural elements are being produced in this way to minimise on-site work and improve accuracy, speed and quality of construction.

clients and faster, more accurate installation processes for contractors. Technical change in construction processes needs to be seen in the context of these organisational innovations.

From the builder's point of view, these technical changes, together with more efficient project organisation, mean that value added in construction depends on the ability to co-ordinate and integrate technologies developed elsewhere. Work packages from a wide range of firms need to be managed simultaneously. The supply of appropriate, accurate information to the right people when and where it is needed is crucial to success. For this reason, the development and use of information systems has become the most important technology for improving construction processes. There have been many technical and implementation problems associated with the introduction of IT to the construction process, but successful cases indicate the following benefits: better integration of information flows among firms involved in projects; automation of routine information processing and communication activities within project teams; production of new information and new levels of transparency about processes which lead to further improvements via the ability to acquire new knowledge, generate feedback and learn.

Moreover, the use of simulation techniques – such as virtual reality – can be helpful in early project stages. These techniques can be used to brief clients or to involve interest groups in planning. They also aid information flows between producers and users and may make it possible to meet user needs better. They have been shown to reduce risk and uncertainty and improve predictability in design decisions, thereby leading to fewer changes and thus lowering costs and saving time. Some firms have used information systems to expand their markets (Gann *et al.*, 1996). The use of IT systems in combination with new business processes can radically alter the performance of construction firms. In best-practice examples, decisions are made more rapidly, information becomes available when and where required, and the process becomes more transparent (Groák *et al.*, forthcoming).

The impacts of technological change

To date, the impact of advanced technologies in construction has been limited. While the nature of demand and the structure of production have changed, performance has improved little. Productivity growth has been limited in most countries, and construction prices have risen compared to those of manufactured goods. Construction companies have, however, integrated many new technologies in the production process, thereby improving product quality and allowing the construction sector to meet changing demand. Individual companies have shown that significant gains can be achieved by introducing advanced technologies. For instance, evidence from successful demonstration projects illustrates major performance gains when new IT systems have been implemented for co-ordination and control, together with new component-based approaches to construction.

New technologies could – if combined with significant organisational change and skills development – substantially improve the performance of the construction sector. A shift from a labour-intensive craft industry, in which materials are adapted on site to meet often insufficiently specified requirements, to an engineering and assembly process, which integrates the systems needed for modern life, could have the following impacts:

- ***Productivity and the production process.*** There is enormous room for improvement in the overall process. Various benchmarking studies in Japan, North America and the United Kingdom suggest that many on-site construction processes are highly inefficient. Current levels of inefficiency and wasted materials, labour and time, as well as pollution, could be substantially lowered by streamlining supply chains and by introducing better management practices. Increased use of standardised and pre-assembled components, linked with new IT management systems, could improve performance further. Moreover, IT systems could be used to help integrate briefing and design decision making, so as to improve flexibility and meet customers' needs better.
- ***Quality of products***. Constructed products generally do not enjoy a high reputation for quality in comparison with goods and services produced by other industries. Clients are beginning to demand more value from construction, and this is driving changes in quality. Construction

activities are a long way from producing zero-defect buildings and structures; there is much room for improvement. Furthermore, technical changes in materials, components and systems integration could improve physical and aesthetic durability and reduce embodied energy and life-cycle energy costs. They could also lead to greater initial flexibility in design choice, together with adaptability in use and the potential to recycle parts during demolition, thereby improving environmental performance.

- ***Employment***. Technological innovation aimed at improving performance is likely to have significant consequences for employment. Productivity improvements are unlikely to be achieved without a reduction of traditional on-site construction work. It is unlikely that construction markets can expand sufficiently quickly in most OECD countries to counterbalance the employment lost through productivity-improving technical change.
- ***Labour force skills***. Greater use of technology in the construction sector will require considerable upskilling of the workforce. Currently, the construction sector is usually seen as a source of low-skill, low-wage, insecure, and dangerous employment. Migrant labour is often relied upon to increase flexibility. The construction sector generally fails to recruit higher-skilled staff, and this creates difficulties for firms that wish to develop and implement new technologies. Moreover, training programmes are often not geared to equipping new entrants with the type of skills needed for deploying innovative, modern technologies. Adherence to outdated craft practices and job demarcation lines, or to traditional professional disciplines, hinders the development of a workforce capable of working with different technologies and integrating systems to provide low-cost, high-performance buildings and structures.[10]
- ***International competitiveness.*** An international construction market exists for large construction projects and specialist development projects. Moreover, there is a well-developed international market for construction materials and components; manufacturing firms in this segment tend to be much larger than contractor and design firms. The development of further technical capabilities in international design and engineering firms for construction and consulting could increase exports to markets outside the OECD area. The integration of European markets and the gradual harmonisation of standards, together with privatisation, have been accompanied by a number of mergers, acquisitions and takeovers. Cross-border trade in construction services has increased in Europe in recent years. This is changing the nature of competition and creating an environment where there is a need to improve performance through technical and organisational innovation in the domestic sector. However, the effective integration of the European and world-wide construction market remains obstructed by a number of barriers, including differences in domestic rules, regulations and standards.
- ***Changing industrial structure***. Only a small number of large construction firms in OECD countries are capable of operating internationally and developing and using new technologies. In many countries, some medium-sized enterprises are also able to innovate and improve performance. However, all have a large tail of very small firms. Most of these operate using antiquated practices, and it is extremely difficult to improve their performance through the introduction of new technologies. Nevertheless, some specialist small firms are innovative, and mechanisms need to be found to support the development of new technologies in this part of the sector. In general, there are signs that the industry structure could be shifting, with detailed design moving upstream into component manufacturing firms and specialist technical subcontractors. New project management and systems-integrating firms are emerging for procurement and co-ordination of site-based activities. In some sectors, financial institutions and clients are becoming more involved. Construction firms are partnering with clients, suppliers and finance organisation in order to spread the risks and rewards of implementing new technologies.

Encouraging signs of improvements in understanding the role of technology in construction appeared in the early 1990s in Canada, Europe, Japan and the United States. Structured approaches to promoting innovation in construction have emerged, involving collaboration between industry, government, and academic organisations. Systematic management of innovation can help to close the performance gap between construction and other industries and provide users with higher-quality buildings and infrastructures, thus resulting in better value for investments in the built environment and higher levels of profitability in construction firms.

Construction firms can play a key role in improving their use of existing technologies, and this can lay the foundations for further technological innovation. For example, a low-cost starting point for firms wishing to improve their performance through technology could be the employment of technology managers, gatekeepers, and facilitators to co-ordinate the use of existing (latent) technical know-how in the firm (Gann and Simmonds, 1993). Many larger construction organisations already have formal technical support functions, with responsibilities for technical troubleshooting, problem-solving and R&D. The work of these departments can be improved by: mapping ways in which technical resources are mobilised, fed back and developed within and between firms engaged in projects; measuring the types of activities carried out within formal R&D and technical support groups in these firms and identifying best practices for further support; developing best-practice models for use of technical support and feedback between firms' central technical services and their project teams. Firms that develop these capabilities generally find that they can recognise and exploit benefits of technical change and are therefore in a better position to invest in R&D and the new skills that will be required to guarantee future success.

CONCLUSIONS

The three mature manufacturing industries have substantially improved performance as a result of the adoption of advanced technologies. They have achieved significant productivity gains thanks to the automation of labour-intensive work and the improvement of production processes and better product quality. They have moved towards higher quality goods and services. Greater flexibility in production has enabled them to adjust to changing demand.

Technological change has been accompanied by other important changes in the production process. The use of advanced technologies has led to greater demand for higher-skilled and more versatile workers. Furthermore, the implementation of advanced technologies in the production process has often been accompanied by considerable organisational change, such as the "lean system" in the automobile industry. In addition, more flexible production processes have given smaller firms, particularly in textiles and steel, a more prominent role.

The construction sector has not been able to achieve similar results, although it has improved productivity somewhat and has become more flexible and responsive to changing demand. Among the main barriers to innovation in construction are the project-based nature of construction work, which leads to a good deal of unstructured innovation but to little systematic improvement in working methods and technologies. However, a strong potential for improved performance exists, which could, if realised, help improve productivity and reduce prices.

Technological change has emerged from many sources. The dominant sources of technology are upstream suppliers, such as producers of specialised machinery. However, information technology has affected the production process in all four industries. In the consumer goods industries, such as clothing, the retail sector plays an increasing role in determining the direction of technological change; car distributors have also guided technological change in the automobile industry. In the construction sector, large clients and upstream suppliers of materials and components have been important sources of innovation. In most industries, increasing co-operation among firms, suppliers and customers, and closer integration among them, has helped to further innovation and technological change. In some sectors, particularly textiles, government-funded R&D programmes have played a role, although there is some doubt about the effectiveness of these programmes. In most of these industries, the technologies themselves – *i.e.* machinery and equipment – have been available in the world market, a sign of the mature nature of the industries.

The restructuring process has differed substantially among OECD countries. While variations in industry structure and comparative advantage play an important role, so have government policies. For instance, protective measures, such as restrictive trade measures (*e.g.* the Multi-fibre Arrangement) and government subsidies, have restrained competition in the textile and steel industries and have slowed the restructuring process. In automobiles, although the situation is changing somewhat, international competition has been mostly among OECD countries, and types of protection, such as voluntary export restraints, have influenced the restructuring process. Such protective measures have reduced trade flows and slowed restructuring in several markets but have also stimulated growth in transplant assembly and components production, thus enhancing the global character of the industry. In the construction industry, differences in the rules and regulations in OECD countries continue to be a significant barrier to the free flow of construction goods and services.

The rapid restructuring of these mature industries has led to employment losses in some sectors, particularly in textiles and steel.[11] This has created adjustment problems for workers who have had to seek jobs elsewhere. Several countries have used early retirement programmes to deal with loss of employment for older workers. Such sectoral employment losses are inevitable in a dynamic economy, where decline in some sectors is accompanied by growth in others. Governments can contribute to the relocation of workers to other sectors by improving the economy's capacity to adjust, for instance by implementing the policies set out in the *OECD Jobs Study* (OECD, 1994*b;* 1997*l*).

Government policies can also play an important role in the promotion and support of technological development in the four industries discussed in this chapter. A number of policies should be considered (and are the subject of other OECD work; see OECD, 1998*c*), including:

- ***Promotion of R&D and diffusion programmes.*** It may be difficult to foster a research base restricted to the private sector. Governments need to support fundamental research, for instance in building or materials science. Governments may also want to promote the capability to understand future markets and technologies, *e.g.* through foresight activities. Shaping an environment that is conducive to technology diffusion is also an area where government policies can contribute to improved performance.
- ***Skills development.*** Training programmes need to be modernised and working practices changed in order to enable the adoption of new technologies. The fragmented nature of some sectors, such as construction, means that governments may need to play a part in facilitating skill development and promoting lifelong learning. Training programmes can also play an important role in relocating workers to growing sectors of the economy (OECD, 1997*l*).
- ***Strengthening the competitive framework and promoting market integration***. The experience of many of these sectors suggests that firms adopt advanced technologies to respond to increased competitive pressures, particularly from abroad.
- ***Procurement policies.*** In the construction sector, governments remain major customers for goods and services, and these projects can be used to stimulate better performance through technical and organisational change. Such policies should be used in a competitive framework, however.
- ***Regulatory policies.*** Appropriate regulations can stimulate better performance, for example in areas such as health and safety, environmental protection, and energy use. However, regulations and standards should be used with care and in a way that promotes competition and innovative behaviour. This also requires further efforts to harmonise regulations across countries and to ensure that they do not act as barriers to international competition.

Firms remain the main actors in promoting technological change. While governments can create framework conditions and play a role where clear market or systemic failures are at stake, private industry remains the principal engine of technological change and economic growth.

NOTES

1. A narrow definition of the textile industry would include only the textile mill process. However, the term textile industry usually points to the entire range of related industries: from fibre and textile mill production to clothing (or apparel) and other finished goods production. This range is normally described as the "textile chain" or "textile complex". This section discusses technological change and its impacts in both the textile mill and the apparel industry. The combination of these industries is termed the textile industry.
2. Carding is the process that prepares fibres for spinning.
3. Anti-pollution investment has had a significant effect on emissions. In the case of the United States, the discharge of air and water pollutants was reduced by over 90 per cent over the past 25 years (http://www.steel.org/information).
4. The *OECD Jobs Study* (OECD, 1994*b*) has criticised the broad application of such early retirement schemes, however, as these programmes reduce economy-wide labour supply, often at the cost of higher public expenditures.
5. A recent OECD publication lists recent FDI and inter-firm alliances in the OECD steel sector (OECD 1996*a*).
6. The globalisation of the automobile industry is documented and discussed in OECD (1996*a*).
7. This section is largely based on a paper written for the OECD. Details are available in Gann (1997).
8. It should be noted, however, that output measurement in the construction sector is more difficult than in any of the other industries discussed in this paper.
9. The nature of competition in the construction sector often involves protection of market share, which may lead to bidding below cost for large projects.
10. Demand for modern skills varies in different construction market segments. In general, specialist technical skills are needed in larger new projects, while craft and multi-skilled workers are needed in smaller projects. In repair, maintenance and work on existing buildings, there is great demand for multi-skilled workers who can work with new and earlier technologies.
11. Some employment losses may also be due to the outsourcing of certain activities, *e.g.* cleaning services or business services. Outsourcing has gained in importance over the past years (OECD, 1998*b*), but its precise impact on employment losses in the sectors discussed in this chapter remains unclear.

TRENDS AND TIME HORIZONS OF RESEARCH

INTRODUCTION

This chapter examines changing trends in research and development (R&D) investment in OECD countries. Concern has recently been expressed about changes in government policies and business behaviour with respect to R&D expenditure. Owing to fiscal constraints and reduced defence expenditures, many governments have cut back their R&D expenditures, and an economic slowdown led the business sector to reduce expenditure on R&D during the first half of the 1990s. There has thus been a relative decline in R&D expenditures, particularly in the United States, but also in several European economies.

At the same time, concerns have been expressed about a reorientation of research from basic research to applied research and product development, and about a shortening of the time horizon for research. Government policy in many OECD countries increasingly emphasizes the economic relevance of research, possibly at the expense of basic research, and firms seem to be shifting their research strategy towards applied R&D, in order to obtain more rapid payback from their investments.

Other factors may have contributed to these changes. Technology development is increasingly interdisciplinary and international. Innovations arise from many sources and at any stage of the process of research, development, marketing and diffusion; they result from the interaction of all actors in the national systems of innovation – governments, universities and private enterprises. Consequently, knowledge flows and the diffusion and absorption of technology have increased in importance. More rapid diffusion, partly resulting from developments in information and communication technology (ICT), may also have affected firms' ability to appropriate the benefits of investments in R&D and thus reduced their incentives to engage in it.

Moreover, changing business sector behaviour seems related to greater competitive pressures, which are due in part to globalisation, regulatory reform, and a shift in R&D expenditures towards sectors with shorter product and research cycles, such as computer equipment. All these factors may suggest that basic research is being cut back and that expansion of the knowledge base, and therefore technological change and economic growth, are in danger.

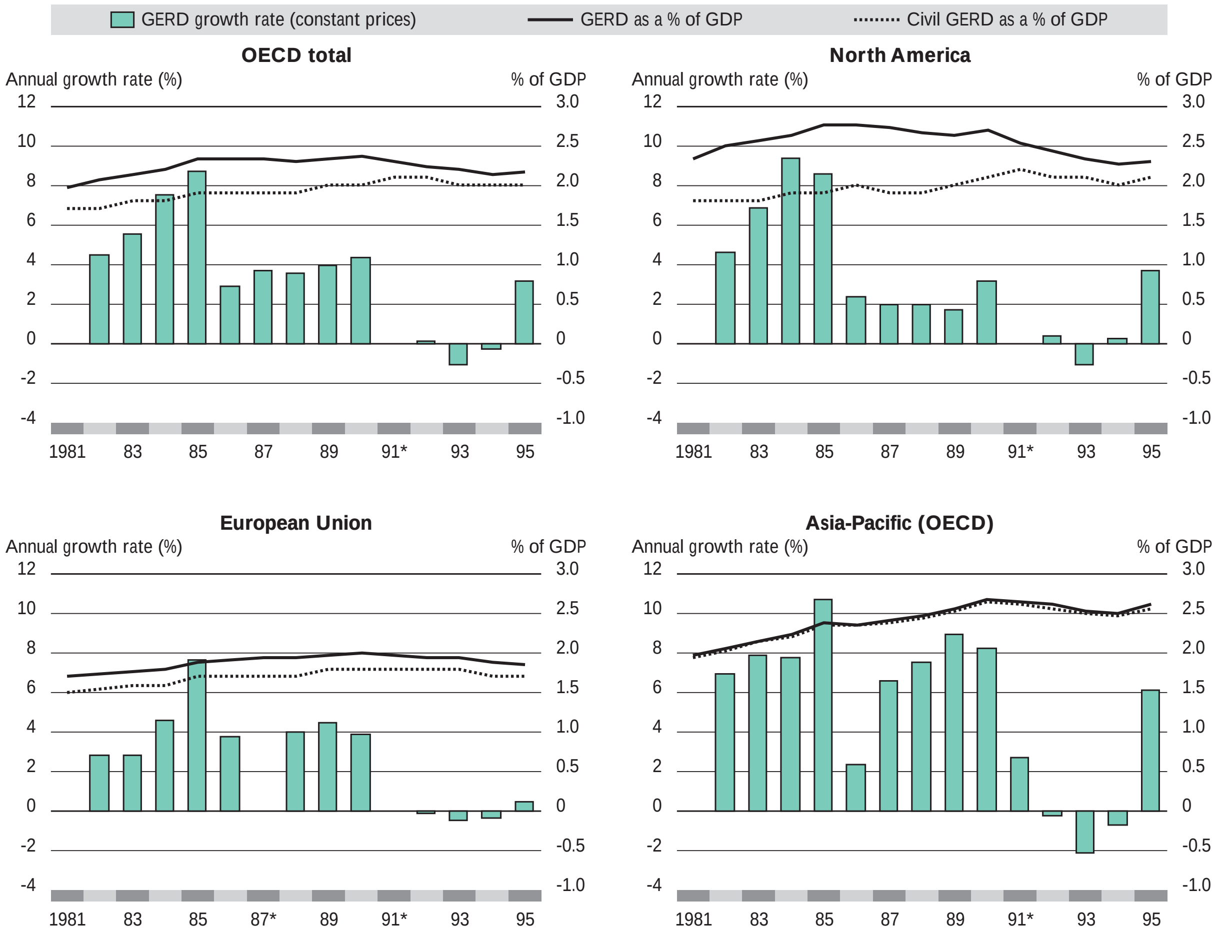
This chapter reviews these issues. It first provides a brief overview of trends in resources allocated to R&D and of the funding and performance of R&D. It then turns to the role of government in national research systems and examines factors affecting the level and composition of government-funded research. It next looks at the changing role of university research in the context of declining government funding. A discussion of the role of the private sector and its changing strategy towards R&D expenditures follows. Finally, it draws conclusions and discusses some implications for policy.

OVERALL R&D TRENDS

Expenditures

After growing strongly through the 1980s, gross domestic expenditure on R&D (GERD) in the OECD area experienced slow and even negative growth in the early 1990s (Figure 6.1).[1] Given that the United States accounts for over 40 per cent of OECD R&D expenditure, the downturn is closely related to the slowdown in the growth of R&D expenditure growth in that country. Growth in R&D expenditure also

◆ Figure 6.1. ***Gross domestic expenditure on R&D (GERD)***
Growth and percentages of GDP



* Year for which the growth rate cannot be calculated due to a break in series.
Source: OECD, MSTI database, March 1997.

slowed substantially in France, Germany, Italy, and Japan. However, this was not the case in Australia, Canada, Denmark, Iceland, and Ireland, and in some of these countries growth in fact increased (Table 6.1).

Due to slow growth in R&D expenditure, the share of R&D expenditure as a percentage of GDP (gross domestic product) in the OECD area fell from its peak of 2.4 per cent in 1990 to a low of 2.1 per cent in 1994. Over 1995, R&D intensity increased slightly to 2.2 per cent of gross domestic product (GDP), mainly owing to higher expenditure in the United States and Japan, which account for almost 65 per cent of OECD-wide R&D expenditure. However, US data for 1996 indicate a further decline in R&D intensity. Government budgets suggest that some growth is likely in Japan and the United States, but that the decline will continue in the larger European economies and Canada, although a business cycle upturn may lead to higher private R&D expenditures in some of these countries. Higher expenditures in smaller countries such as Australia, Finland, and Ireland have resulted in a notable increase in their R&D intensity, although the effect on OECD-wide R&D intensity is negligible. In consequence, overall OECD-area R&D intensity is likely to remain stable over the coming years.[2]

Table 6.1. **Gross domestic expenditure on R&D (GERD)**

	Compound annual growth rate (based on constant prices)			As a percentage of GDP			
	1981-85	1985-90	1991-96	1985	1991	1995	1996
United States	7.3	2.2	0.5	2.9	2.8[11]	2.6	2.5
Canada	6.7	3.1	3.9	1.5	1.5	1.7	1.7
Mexico	..	..	..	..	..	0.3	..
Japan[1, 2]	8.5	6.7	0.4	2.6	2.8	2.8	..
Korea			..	..	2.7	..	
Australia[3]	8.3	4.9	7.6	1.3	1.6[12]	1.6[13]	..
New Zealand[2]	..	..	3.6	..	1.0	1.0	..
Austria[2]	4.0	5.3	1.8	1.3	1.5	1.5	1.5
Belgium	..[11]	..[11]	0.5	1.7[11]	1.7	1.6	..
Czech Republic	..	..	–10.3	..	2.1	1.2[11]	..
Denmark[2]	7.0	6.9	5.2	1.3	1.7	1.9	..
Finland[2]	10.5	7.3	4.4	1.6	2.1[11]	2.4	..
France	4.9	4.5	0.4	2.3	2.4	2.3	..
Germany[4, 5, 6]	4.3	2.8	–1.3	2.7	2.6[11]	2.3	2.3
Greece	..	..[11]	..	0.3	0.4	..	..
Hungary	..	..	..	2.4	1.1	0.8	0.7
Iceland	5.9	9.4	6.9	0.7	1.2	1.5	1.5
Ireland[2]	5.6	6.3	17.1	0.8	1.0	1.4	..
Italy	8.3	5.9	–0.8	1.1	1.2[11]	1.1	1.1
Netherlands[2, 7]	4.5	4.0	2.5	2.1[11]	2.1	2.1	..
Norway[2, 8]	..[11]	2.5	3.6	1.5[11]	1.7	1.7[11]	..
Poland	..	..	..	..	..	0.8	..
Portugal[9]	7.5	14.0	3.9	0.4	..	0.6	..
Spain[6]	8.7	13.9	0.5	0.6	0.9	0.9	0.8
Sweden[2, 8]	8.2	3.0	6.5	2.9	2.9	3.6[11]	..
Switzerland	..[11]	..[11]	..	2.9[11]	2.7[12]	..	..
Turkey[2]	..	..	–4.4	..	0.5	0.4	..
United Kingdom[2]	1.3	2.8	1.3	2.2[11]	2.1	2.1	..
North America[2]	7.3	2.2	0.8	2.8	2.5[11]	2.3	2.3
Asia-Pacific (OECD)[2]	8.3	6.7	0.7	2.4	2.6	2.6	..
European Union[2, 5]	4.4	4.3	–0.1	1.9	2.0[11]	1.9	..
Total OECD[2, 5, 10]	6.5	3.7	0.5	2.3	2.3[11]	2.2	..

1. Overestimated, or based on overestimated data.
2. 1991-95.
3. 1986 instead of 1985; 1981-86, 1986-90 and 1990-94.
4. 1987-90.
5. Figures for Germany from 1991 onwards refer to unified Germany.
6. 1992-95.
7. 1982-85.
8. 1985-89
9. 1982-86, 1986-90 and 1990-95.
10. Total OECD includes Mexico from 1991 onwards, but excludes the Czech Republic, Hungary, Korea and Poland.
11. Break in series from previous year for which data are available.
12. 1992.
13. 1994.

Source: OECD, MSTI and S&T databases, April 1998.

In the major OECD economies, declining R&D expenditures are closely linked to the decline in government-funded R&D in North America and Europe. In all regions, the business sector has taken a greater role in the funding of R&D. In 1995, the business sector financed almost 60 per cent of OECD R&D expenditure, up from just over 50 per cent in the early 1980s (Table 6.2; OECD, 1997*c*). In most OECD economies, and particularly in North America, the increase is due less to an increase in private expenditure than to the decline in government funding. However, a few countries, including Australia and Finland, have experienced a simultaneous increase in business and government funding of R&D.

The breakdown of R&D by sector of performance reveals that by the mid-1990s, the business sector accounted for two-thirds of OECD-area R&D (Table 6.2). Industry's role has declined somewhat,

Table 6.2. **R&D expenditures by source of financing and performing sector in 1996 (or closest year)**

In per cent of national total

	Source of financing				Performing sector		
	Business enterprise	Government	Other national sources	Abroad	Business enterprise	Government	Higher education
United States	61.4	34.6	4.0	..	72.7	9.8	14.6
Canada	48.2	33.7	5.4	12.7	62.2	14.9	21.7
Mexico[1]	17.6	66.2	9.5	6.7	20.8	33.0	45.8
Japan (adj.)[1]	72.3[5]	20.9	6.7	0.1	70.3[5]	10.4	14.5
Korea	76.3	19.0	4.7	0.0	73.7	17.0	8.2
Australia[2]	46.3	47.5	4.2	2.0	47.0	26.5	24.6
New Zealand[1]	33.7	52.3	10.1	3.9	27.0	42.2	30.7
Austria	49.4	47.6	0.4	2.6	55.9[3]	8.9[3]	35.0[3]
Belgium[1]	64.2	26.4	2.5	6.9	67.4	3.8	27.3
Czech Republic	59.6	35.5	2.9	1.9	59.9	31.1	8.9
Denmark[1]	46.7	39.2	4.1	9.9	57.4	17.0	24.5
Finland	59.5[1]	35.1[1]	1.0[1]	4.5[1]	66.2	15.8	18.1
France	48.3[1]	42.3[1]	1.3[1]	8.0[1]	61.5	20.4	16.8
Germany	60.8	37.0	0.3	1.9	66.3	18.1	15.6
Greece[3]	20.2	46.9	2.6	30.3	26.8	32.0	40.7
Hungary[1]	43.0	47.9	0.2	4.8	43.4	25.6	24.8
Iceland	31.6	62.9	2.3	3.2	31.1	40.9	24.0
Ireland[1]	67.4	22.6	1.8	8.2	70.5	9.7	19.2
Italy	49.5	46.2	0.0	4.4	57.7	19.9	22.4
Netherlands[1]	46.0	42.1	2.6	9.3	52.2	18.1	28.8
Norway[1]	49.9	43.5	1.6	4.9	56.7	17.3	26.0
Poland[1]	31.5	64.7	2.1	1.7	38.7	26.3	35.0
Portugal[1]	18.9	65.2	4.0	11.9	19.8	26.7	33.7
Spain	44.5[1]	43.6[1]	5.2[1]	6.7[1]	48.6	31.8	18.5
Sweden[3, 4]	61.2	33.0	2.3	2.9	69.9	4.1	25.7
Switzerland[6]	67.4	28.4	2.3	1.9	70.1	3.7	25.0
Turkey[1]	30.8	64.5	2.7	2.0	23.6	7.4	69.0
United Kingdom[1]	48.0	33.3	4.3	14.3	65.5	14.5	18.8
North America	60.3	34.8	4.1	..	71.6	9.5	15.7
Asia-Pacific (OECD)	70.3	24.6	6.8	0.3	68.4	11.7	15.3
European Union[1]	52.7	39.1	1.7	6.5	62.0	16.1	21.0
Total OECD[1, 7]	59.1	34.5	3.9	..	67.3	17.7	12.2

1. 1995 instead of 1996.
2. 1994 instead of 1996.
3. 1993 instead of 1996.
4. Percentages do not sum to 100 because of an incomplete breakdown.
5. Overestimated.
6. 1992 instead of 1996.
7. Excluding Czech Republic, Hungary, Korea and Poland.

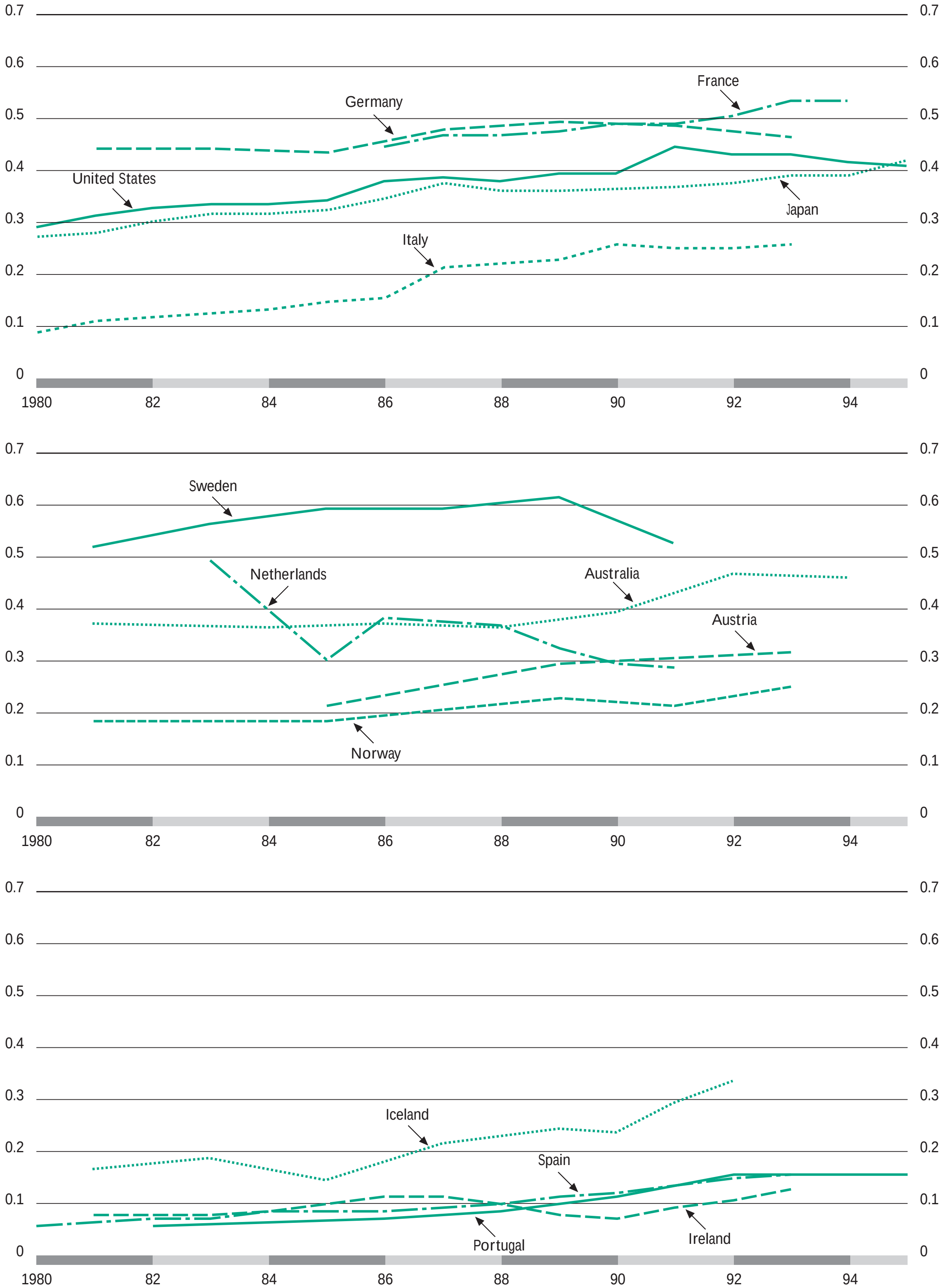
Source: OECD, MSTI and S&T databases, April 1998.

however, in countries such as Belgium, Germany, Norway, Portugal, and Spain (OECD, 1997*c*). The government sector currently performs over 12 per cent of R&D in the OECD area, and more than 20 per cent in Australia, Mexico and several European countries (Czech Republic, France, Hungary, Iceland, Italy, Poland, Portugal and Spain). Institutions of higher education (mainly universities) perform most of the rest.

The composition of R&D

In some OECD countries, the decline in government funding has contributed to a fall in the share of basic research in GDP (Figure 6.2), although not in the share of basic research in total R&D expenditure. While the business sector increasingly emphasizes applied research and product development, the

◆ Figure 6.2. ***Basic research as a percentage of GDP, 1980-95***



Source: OECD, S&T databases, January 1998.

Box 6.1. **Types of R&D**

Traditionally, a distinction is made between basic (or fundamental) research, applied research, and experimental development. *The Frascati Manual* (OECD, 1994*c*) defines basic research as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view". Applied research is defined as "original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective". The third category, experimental development, is defined as "systematic work, drawing on existing knowledge gained from research and practical experience, that is directed to producing new materials, products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed".

These distinctions reflect various dimensions of research, including the time horizon, the degree of uncertainty and risk involved, economic relevance, and the appropriability of outcomes. In principle, basic research has a long time horizon, has uncertain outcomes, and is not directly economically relevant or applicable. Indeed, much is not aimed at economic outcomes, but pursues other values. In addition, as basic research helps to build the general knowledge base, it has large social but limited private benefits. It is therefore difficult for private firms to appropriate the results.

However, the multi-dimensional character of these distinctions implies that there are many border cases. For instance, much economically relevant research (*e.g.* gene research, cancer research, mathematics) is risky and uncertain, and may have a long gestation period, as it aims for a fundamentally new understanding of certain problems. However, such basic research may have direct and marketable applications once results are obtained. In new fields, such as biotechnology, the distinction between basic and applied research may have lost much of its meaning. In such fields, technological development can almost be considered basic research (OECD, 1998*c*).

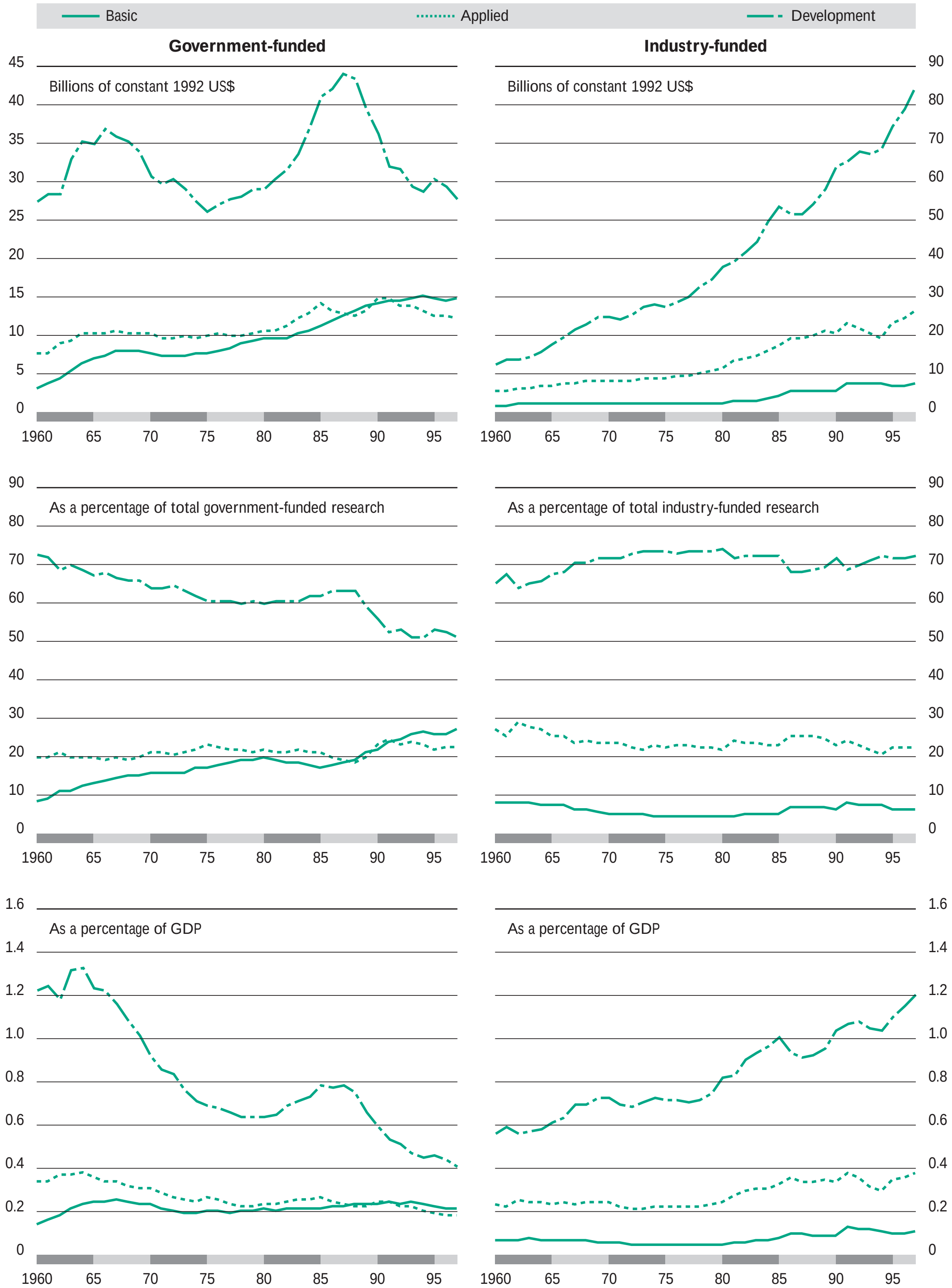
These distinctions also have implications for R&D funding. Basic research is more likely to receive government support than applied research or development. Some risky but economically relevant research may also require government support (Council on Competitiveness, 1996), although well-developed venture capital markets may also be able to fund some of this research. However, it is not easy to delimit the respective responsibilities of government and the private sector for different types of research. In practice, both government and the private sector fund basic research, applied research, and product development, although governments finance more basic research and private firms more development-related R&D. Yet, governments finance more applied work, for instance to develop infrastructure or energy technologies, or for military purposes. The various rationales for government funding of R&D are further discussed below.

available data suggest that it still supports basic research, albeit at a very low level. It should be noted that it is difficult to distinguish among the various types of research, including from a statistical point of view (Box 6.1; OECD, 1994*c*).

OECD data indicate that the share of basic research as a percentage of GDP has edged up in most OECD countries, but has fallen in some, notably Germany, the Netherlands, Sweden, and the United States (Figure 6.2). In most, basic research represents 15 to 20 per cent of total R&D expenditure. In some of the larger ones, including France, Italy, Japan, and the United States, the share of basic research in total R&D expenditure has risen slightly over the past decade. Its share has fallen somewhat in some smaller OECD economies, including Australia, the Netherlands and Sweden. In the United States – the only country for which detailed data are available – the share of basic research as a percentage of total GDP has remained relatively stable since the mid-1970s but has risen somewhat as a share of government-funded R&D. The share of basic research in business-funded R&D has edged up slightly from 5 per cent in 1985 to 6 per cent in 1997 (Figure 6.3).

Governments fund most basic research in OECD countries, and most of this research is performed in the higher education sector. Given the role of government in funding basic research, if the slowdown in total government R&D expenditure were accompanied by a significant shift away from expenditures for basic research, this might be cause for concern. However, available information for a number of

◆ Figure 6.3. ***R&D expenditure in the United States by type of research, 1960-97***



Source: *National Science Foundation*, 1996*b*; 1998.

Table 6.3. **Growth of gross domestic expenditure on R&D, by type of research**
Compound annual growth rates in per cent, constant prices

	Basic	Applied	Development
Australia (1984-94)	5.6	5.9	9.4
France (1986-94)	4.2	0.9	3.4
Ireland (1985-93)	7.1	7.3	12.2
Japan (1985-95)	5.8	3.7	3.5
Norway (1985-93)	4.7	4.2	0.0
Portugal (1986-95)	11.7	9.8	4.4
Spain (1985-93)	12.0	9.4	10.9
United States (1985-97)	3.4	2.0	1.5

Source: OECD, S&T databases, August 1997; National Science Foundation, 1998.

OECD countries suggests that basic research has been less affected by the decline in funding that other types of R&D (Table 6.3). There are nonetheless signs that the character of basic research is changing, as it increasingly has a technological aspect (OECD, 1998*c*).

GOVERNMENT-FUNDED RESEARCH

Trends in government R&D

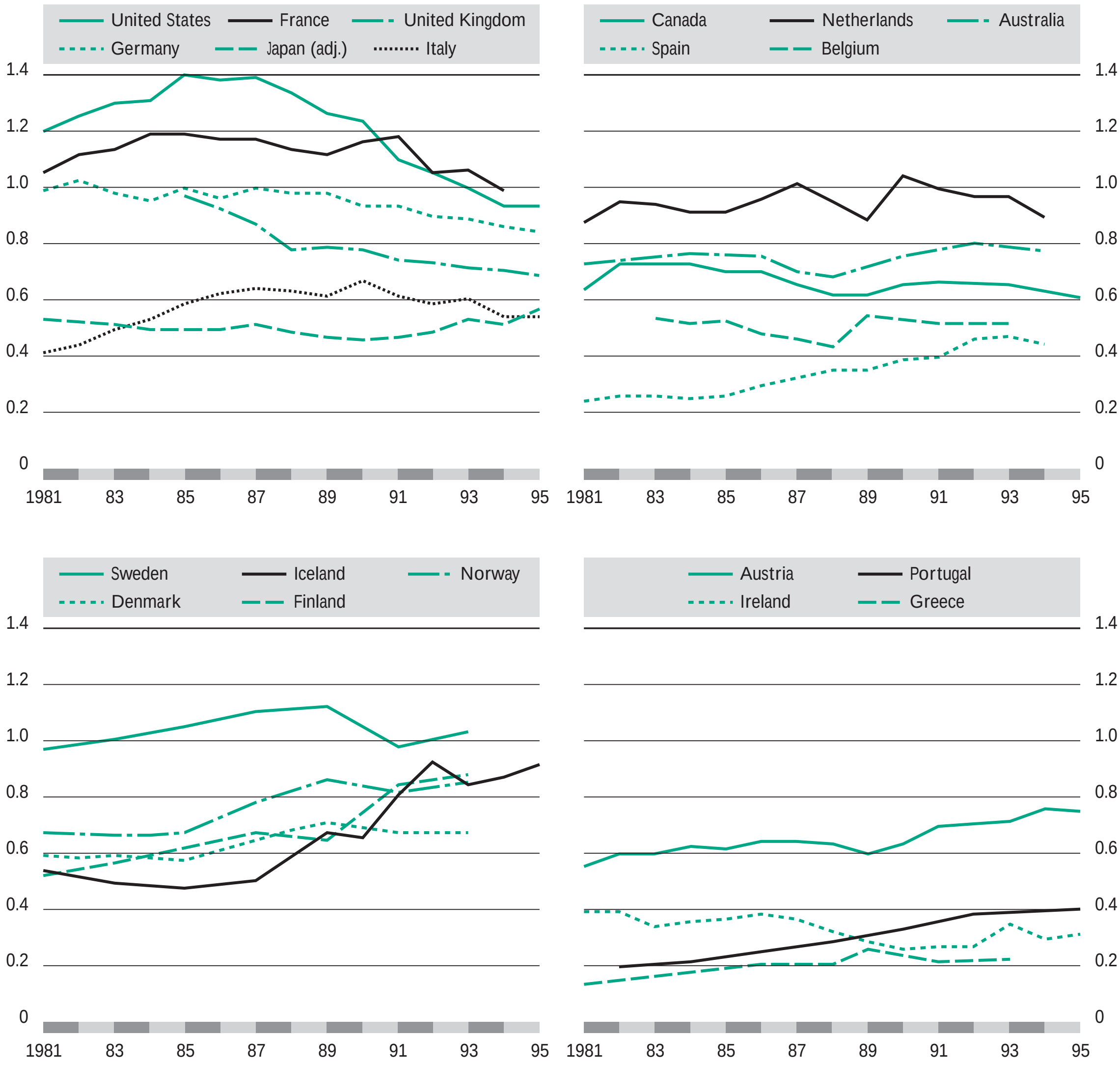
While governments continue to play an important role in R&D funding, their share has declined significantly since the early 1980s in most OECD countries and is likely to continue to fall in the near future owing to falling defence expenditures in several major OECD economies and increased fiscal constraints. However, increased competition and globalisation may also have affected the decline in government funding. Government involvement in R&D increasingly emphasizes partnerships with the private sector, development of commercially applicable technologies, and indirect incentives, such as tax incentives or the promotion of venture capital markets (OECD, 1996*g;* 1996*n*).

Governments support research for a number of reasons (Science Policy Research Unit, 1996; Wong, 1996). First, research has a public good character. Because firms are unable to appropriate all the benefits of their expenditure on R&D, and because there is a significant gap between private and social returns to R&D investment due to spillovers, they may under-invest in R&D (Jones and Williams, 1997). Market failures, such as inadequate information and market distortions, may also discourage firms from investing in R&D. Second, much scientific knowledge is "embedded" in individuals and is transmitted through their interaction, and for this reason, the benefits of science mainly accrue through training and networks. This suggests that the role of governments is to encourage the development of (fundamental) knowledge and the diffusion of research results and scientific knowledge to other parts of the national innovation system.

Government investment may also be justified in areas such as mission-oriented research (defence, health and energy); basic research that supports business competencies (*e.g.* mathematics); and research towards path-breaking and enabling technologies with the potential to create new industries, but which are risky and long-term (*e.g.* fusion power and nanotechnologies). Other types of market failure may also justify government investment (Branscomb and Parker, 1993). In the past, government-funded research often played a vital role in developing new technologies and in emerging industries. Once the technologies were well established and further development became less risky, industry R&D increased dramatically (computers, biotechnology). Governments have made major contributions to several technologies that have only recently found major economy-wide applications, such as the Global Positioning System, Windows, parallel computing, and the Internet (National Academy of Sciences, 1995; National Research Council, 1995).

In 1995, the share of R&D expenditure ***financed*** by government varied between 20 and 65 per cent, with an OECD average of almost 35 per cent (Table 6.2). During the 1990s, government-financed R&D as

◆ Figure 6.4. ***Government-financed R&D as a percentage of GDP, 1981-95***



Source: OECD, S&T databases, January 1998.

a percentage of GDP decreased in North America, and to a lesser extent in the major European countries (Figure 6.4). In several countries (Austria, Finland, Greece, Hungary, Iceland, Mexico, New Zealand, Poland, Portugal, Spain and Turkey), government is the largest single source of R&D funds (Table 6.2).

Growth rates for government-funded R&D have been negative or near zero (in real terms) since the late 1980s in North America, and since the early 1990s in the European Union. Over the 1991-95 period, government expenditure on R&D fell in the Czech Republic, Germany, Italy, the Netherlands, Turkey, and the United States, and was stable in Canada and the United Kingdom. Japan is one of the few countries (and the only major OECD economy) where growth in government-funded R&D has increased since the 1980s. The OECD area as a whole has seen a slight upturn in since 1992, due to a slowing decline in government funding in the United States.

Changes have also occurred in sectors ***performing*** government-financed R&D (OECD, 1998*c*). In most OECD countries, the higher education sector remains the main performer (almost 40 per cent of the OECD total in 1994), followed by the government sector, which in 1995 performed the largest share of government-financed R&D in Japan and several European countries (Czech Republic, France, Iceland, Poland). The United States is the only country where the business enterprise sector performs the largest share of government-funded research (almost 37 per cent in 1995), perhaps owing to the high share of defence-related R&D, much of which is performed by private industry. In Europe and North America, the higher education sector has increased its share from 35 and 24 per cent, respectively, in 1985, to 45 and 32 per cent, respectively, in 1995, mostly at the expense of the business sector (OECD, 1997*c*). In Austria, Belgium, Sweden, Switzerland and Turkey, two-thirds or more of government-financed R&D is performed in the higher education sector.[3]

Factors affecting government R&D

Given that a large part of military expenditures is R&D-related, the fall in government-funded research in several large OECD economies appears closely tied to reductions in defence expenditure. The end of the cold war and the collapse of the former Soviet Union have had a significant impact on military spending in these countries. Data from the US Arms Control and Disarmament Agency (ACDA) show that military expenditures declined as a percentage of central government expenditures in the OECD area from 12.5 in 1985 to 8 per cent in 1995 and in the United States, the largest military spender, from 25.7 per cent to 17.4 per cent, respectively (Arms Control and Disarmament Agency, 1997).

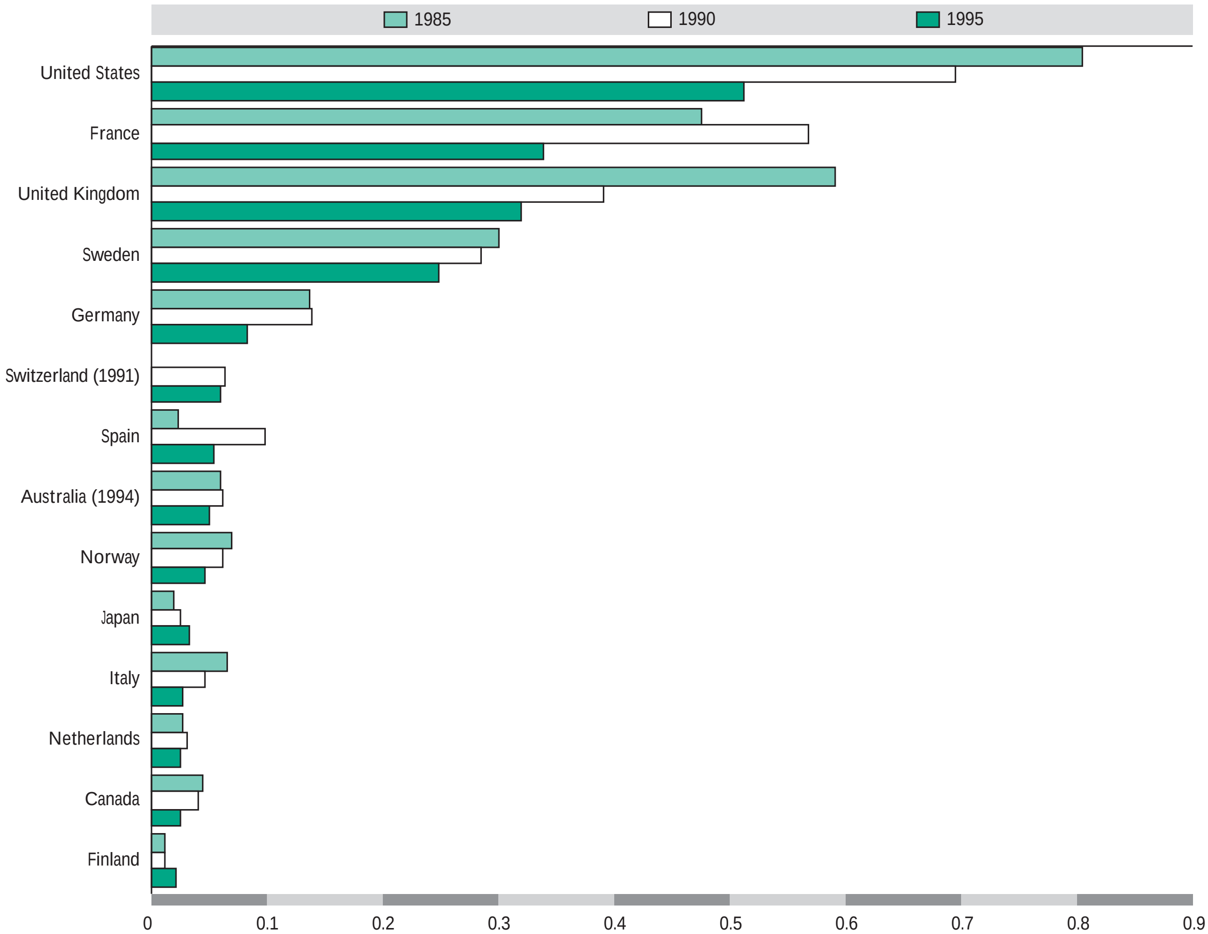
Public defence budgets in OECD countries have fallen in real terms since 1990, except in Japan, where they increased by more than 50 per cent between 1990 and 1996, in Korea, where they increased by about 16 per cent in real terms between 1990 and 1995, and to lesser extent in the Netherlands, where they have remained stable. Outside the OECD area, defence expenditure has dropped particularly sharply in the Russian Federation and other former Warsaw Pact countries: between 1985 and 1995, military expenditures for these countries fell in real terms from US$448 billion to US$96 billion (1995 prices). Military expenditure by the North Atlantic Treaty Organisation (NATO), which includes a large number of OECD countries, continued to decline in 1996, led by a further reduction of defence expenditure in the United States (Stockholm International Peace Research Institute, 1997).

Defence R&D as a percentage of GDP in OECD countries dropped significantly between 1990 and 1995, except in Australia, Japan, and Korea (Figure 6.5; Stockholm International Peace Research Institute, 1997). Data on the share of defence and civil R&D in government budget appropriations or outlays for R&D (GBAORD) suggest that the fall in government R&D spending in France, the United Kingdom, and the United States over the period 1987-95 was almost entirely due to the fall in defence-related R&D (Figure 6.6). The process of military conversion has significantly affected the level and nature of research activities in the Russian Federation, where R&D expenditure as a percentage of GDP dropped from 2.0 per cent in 1990 to 0.8 per cent in 1993; the share of R&D in total military expenditure dropped from 19.8 per cent in 1989 (the former Soviet Union) to about 7.2 per cent in 1993 (Russian Federation) (United Nations Educational, Scientific and Cultural Organization, 1996). At the global level, military R&D expenditures continued to decline over 1996 (Stockholm International Peace Research Institute, 1997).

The extent to which the drop in defence-related R&D spending will affect the knowledge base remains unclear. There are considerable doubts about the usefulness of military research for commercial purposes (Branscomb and Parker, 1993). Although some defence research is basic research, and although there are some – admittedly impressive – examples of commercial spin-off from military research, such as Internet, this only reflects a small part of military R&D expenditure. Recent US government efforts are aimed at developing dual-use technologies (Mowery, 1996), for instance by encouraging greater use of commercially available components in defence procurement and by increasing R&D and technology development programmes in dual-use technologies.

Lowered defence expenditure is only one reason for the cuts in government funding of research over the past years, and one that has not affected all countries equally (OECD, 1996*c*). Another

◆ Figure 6.5. ***Defence R&D as a percentage of GDP in 1985, 1990 and 1995 (or closest year)***[1]



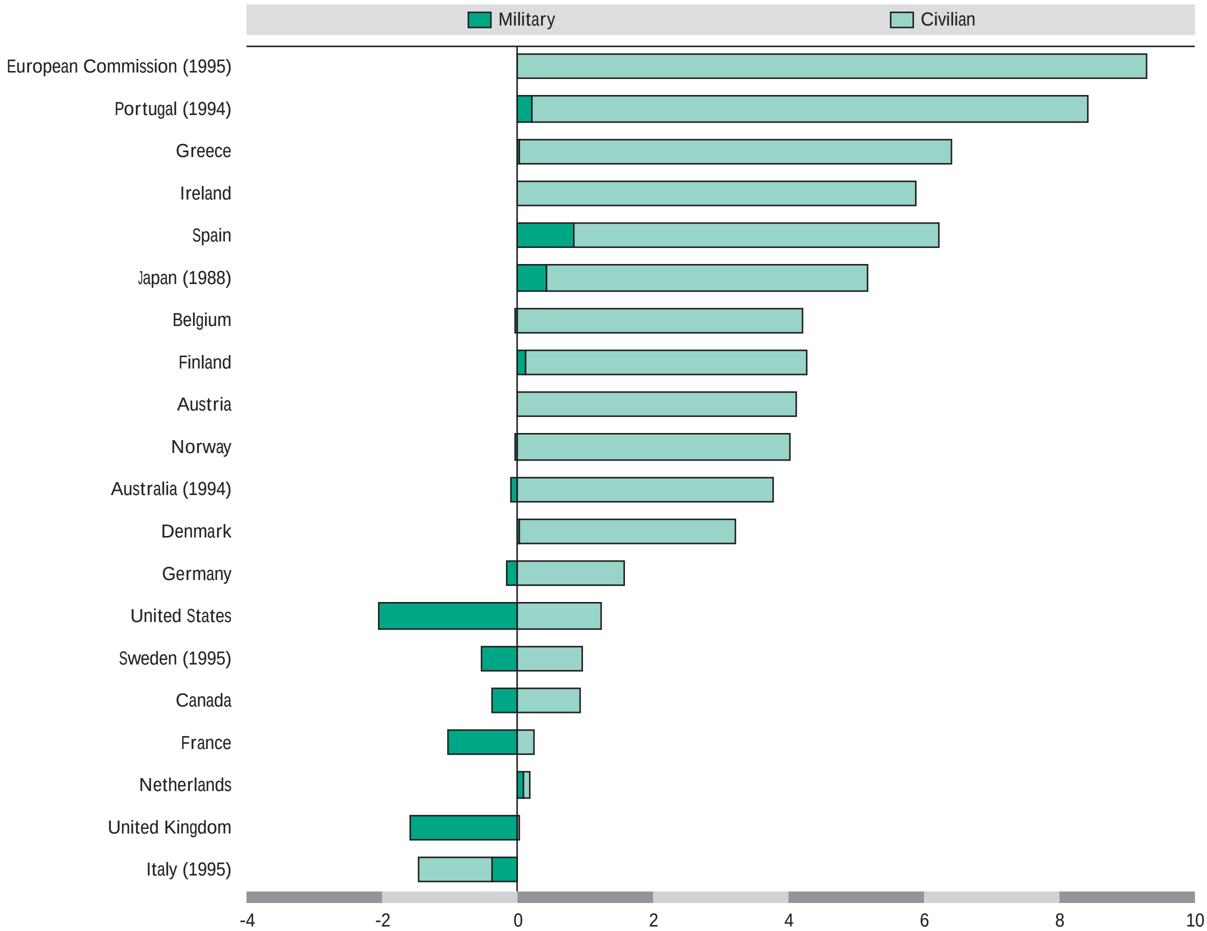
Note: Only countries where defence R&D as a percentage of GDP was greater than 0.02 per cent in 1995.
Source: OECD, S&T databases, July 1997.

important, and more generally applicable, reason is the state of public finances. Many countries face high and sometimes rising debt burdens and budget deficits. In the European Union, the desire to meet the Maastricht criteria for monetary union has increased budget constraints (OECD, 1997*f*).

Although most OECD governments acknowledge the "public good" character of some types of research, research budgets have felt the pressure of the need to consolidate public finance and to eliminate or reduce activities of lesser importance. As research is among the few areas of discretionary spending in government budgets, research budgets have declined more than overall government expenditure in most large OECD countries, except Japan (Figure 6.4). This reduction has also come at a time of calls for greater public accountability and of government demands for more direct and specific results from their investments (Science Policy Research Unit, 1996).

As a result, governments have taken a closer look at the efficiency of publicly funded research. Priorities have been re-evaluated, duplication of effort has been reduced, and funding has concentrated on areas judged to be in the country's strategic interest. The evaluation process has also been driven by a need to understand the complexities of allocating R&D funds and to improve the policy-making

◆ Figure 6.6. ***Contributions of defence/civilian R&D to the growth of government budget appropriations or outlays for R&D, 1987-96***
Compound annual growth rate in percentages, constant prices



Source: OECD, S&T databases, January 1998.

process (OECD, 1997*x*). Governments have also shifted some of their efforts to indirect stimulation of research and innovation, such as tax credits,[4] although the impact on total R&D spending appears limited.[5]

To some extent, governments have also reacted to financial pressures by seeking closer co-operation with the private sector. There has been a sharp increase in the number of technology partnership programmes and other collaborative structures (*e.g.* centres of excellence, co-operative R&D centres, joint R&D programmes, and science parks) across the OECD area (see also Chapter 3).

Other factors may have affected government-funded research as well: technology diffusion from abroad has become a major source of technology for many countries, particularly smaller ones such as Canada, Denmark and the Netherlands (OECD, 1997*g*). The increasing globalisation of OECD economies means that domestic research efforts can increasingly be captured by foreign companies (Office of Technology Policy, 1997). These developments affect the ''national character'' of R&D policies and may in some cases have led to reduced support for public funding of research.

For strategic or competitive reasons, access to public R&D programmes is sometimes restricted for domiciled foreign firms (those with an R&D or production facility in the country) and is rare for nondomiciled foreign firms (OECD, 1997*s*). Although the aim of such restrictions is to capture R&D spillovers at national level, they impede international technology co-operation, which is of increasing importance to most OECD Member countries. Inter-government co-operation is particularly important in areas where governments have common global concerns (*e.g.* health, ageing, the environment), where research is very costly (*e.g.* high energy accelerators), or where international comparisons are an important part of the research effort (National Academy of Sciences, 1995). Much of this is "basic" research.

The increasing importance of diffusion has also created a new role for government, which increasingly goes beyond the funding of research to include ways to improve access to research performed abroad and integrate it into the knowledge base. Governments in small OECD countries have considerable experience in this area, but governments in larger OECD economies may still need to adapt to this new role.

UNIVERSITY RESEARCH

Trends in university research

University research trends and time horizons are also changing. Government funding of university research is declining and is only somewhat offset by increased funding from the business sector.[6] The relative importance of basic funding, which covers researchers' salaries, operating expenses, etc., has also declined in recent years. Continued pressure on government R&D budgets and the inherent limits to business sector support suggest that university research will remain under pressure. In addition, government funding of university research in several OECD countries is becoming more mission-oriented, contract-based and dependent on output and performance criteria. This may lead to more short-term and market-oriented university R&D (OECD, 1997*e*). Universities are facing greater demands for relevance and are being required to contribute more to their country's innovative and economic capacity. Business funding of university R&D is also mainly commercially oriented.

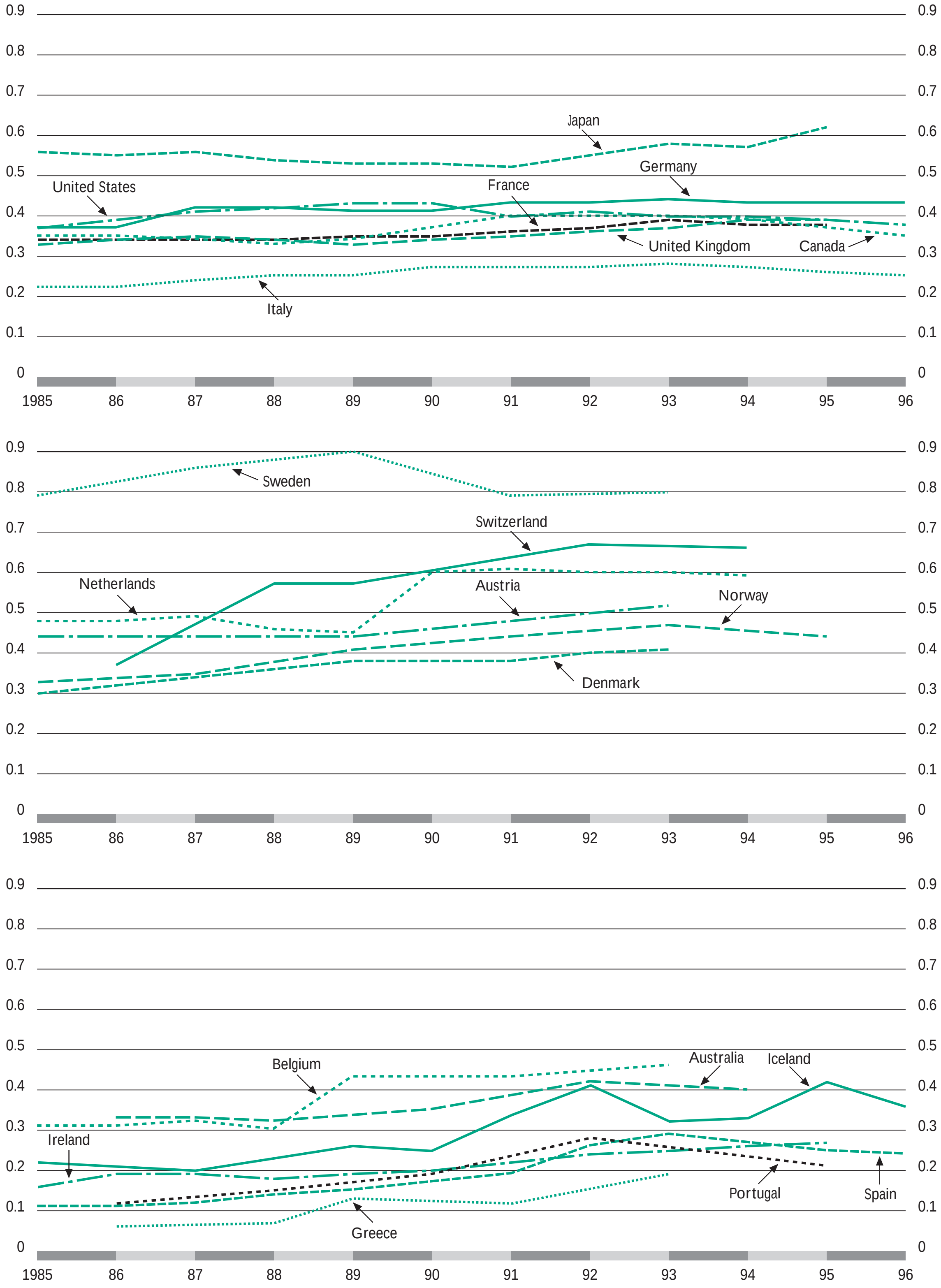
The share of university research in R&D expenditure increased slowly in most OECD countries in the second half of the 1980s but flattened out, or even declined in some countries, in the first half of the 1990s. The share of higher education R&D (HERD) in GDP has declined somewhat in recent years in the G7 economies, after increasing steadily to the beginning of the 1990s (Figure 6.7).

Industry funding of university research remains modest at less than 5 per cent in half of the OECD countries. Industry funding is relatively high in Belgium, Canada, Germany, Ireland, Poland, Sweden, Turkey, and the United Kingdom (OECD, 1997*c*). The higher education sector also performs a small share of business-funded R&D (less than 3 per cent in all G7 countries except Canada). Lack of adequate R&D infrastructure may contribute to high use of university facilities by business in small and less developed OECD economies: in 1995, 29.3 per cent of business R&D was performed by the higher education sector in Turkey.

Universities continue to fulfil an essential function as performers of basic research, since about 50 per cent of all university research is basic (OECD, 1997*c*). However, wide differences in institutional systems exist. In English-speaking countries, universities conduct most basic research and coexist with public research institutes focused on national interests (defence, energy, medicine). In the large continental European countries, university research co-exists with public sector laboratories which perform basic research but also engage in technical, applied and mission-oriented activities. Somewhat different institutional arrangements exist in smaller European and East Asian countries (OECD, 1997*e*).

Universities also contribute indirectly to innovation by adding to the overall stock of knowledge, by linking research to education and training of engineers and scientists, by co-operating with industry to solve specific problems, by creating scientific research networks, and by developing spin-offs (Science Policy Research Unit, 1996).[7] Innovation surveys conducted with firms (*e.g.* the Yale survey) point to basic research, much of it originating in universities, as a major source of technological opportunities.

◆ Figure 6.7. ***R&D performed in the higher education sector as a percentage of GDP, 1985-96***



Source: OECD, S&T databases, January 1998.

Factors affecting university research

The university research environment has changed rapidly in recent years. Universities have become increasingly linked to other actors in the national system of innovation. These links include joint ventures, co-operative research projects with industry, use of government laboratories, and international research networks. US data suggest nonetheless that increased support from the private sector cannot be expected to compensate significantly for cutbacks in federal funding (Baldwin, 1996; Hill, 1996). As government support declines, universities will be forced to search for alternative sources of R&D financing, including income from patents. In a knowledge-based economy, university-industry links are likely to strengthen further, through new and evolving organisational arrangements, although they will be under more scrutiny.

On the industry side, it is clear that firms in high-technology, science-based industries are finding co-operative R&D with research universities an increasingly attractive option. Several studies confirm that firms affiliated with university-based technology incubators have experienced higher productivity and higher rates of return to R&D than firms not engaged in such links (OECD, 1997*p*).

Research links between universities and industry strengthened during the 1980s (Geiger, 1992). On the industry side, this is partly due to the emergence and expansion of science-based (high-technology) industries such as biotechnology and microelectronics. For their part, universities' attitudes towards industry-sponsored research have changed, owing to cutbacks in government funding for academic research and to new opportunities to benefit from these ties through increased knowledge exchange (*e.g.* personnel flows) and commercial relationships (patent licensing, research parks, business incubator programmes, technical assistance).

Several areas of friction exist between universities and private business, however, due to sometimes conflicting interests. Universities are often opposed to restrictions on flows of information, as researchers need to have their research published and require some degree of academic freedom. In spite of these problems, higher education institutions have continued to set up external structures to manage increasingly complex links with firms, such as co-enterprises and trading companies that commercialise products developed by institutions of higher education, science parks, incubators that encourage the creation and development of small technology-based firms, and consortia that enable long-term research projects.

Links between universities and business enterprises range from highly diversified university-industry relations in Canada and the United States, to growing yet unevenly developed systems in some European countries (France, Germany, United Kingdom), to as yet undeveloped links in smaller countries. Governments have facilitated such interaction through a variety of mechanisms, such as the establishment of national or international financing programmes, funding for collaborative projects, as well as the removal of legal obstacles and constraints on personnel mobility and academic rules (Box 6.2).

Differences in patent systems may affect these links and the commercialisation of university research. In most OECD Member countries, inventions by academic staff are not exempt from the general principle that assigns patents to the employer. One of the main exceptions is the first-to-invent system in United States. Since the passage of the Bayh-Dole Act in 1980, universities are allowed to patent the results of federally funded research. In Japan, recent legal changes assign publicly funded researchers 50 per cent of the patent rights for their inventions. Such differences may have important implications for the conduct and exploitation of research.[8]

Analysis of university patenting data reveals the increasing propensity of universities to patent research believed to have a direct commercial application. A recent study of patenting by American universities (Henderson *et al.*, 1995) examines the 15-fold increase in the number of patents granted between the mid-1960s and the early 1990s. An examination of citations of new patents suggests that high citation rates until the mid-1980s are closely related to an increasing focus by universities on commercial technology development. After that, a decline in the relative "importance" of university patents appears partly the result of increased patenting by smaller institutions, most of which produce less-cited patents.

Box 6.2. **The growing role of industry in university research: some examples**

Australia. There has been a recent emphasis on personnel mobility to facilitate knowledge transfer. Due to increasing demands for accountability, an evaluation of the three main Australian Research Council programmes dealing with industry links is currently being conducted by the Centre for Policy Research (University of Wollongong). These three programmes are: the Collaborative Research Grants Scheme (estimated 1997-98 budget: A$ 146.2 million); the Key Centres of Teaching and Research Programme (15 centres will receive an average grant of A$ 360 000 in 1997, with most obtaining additional funding from other sources); and the Australian Postgraduate Awards (Industry) Scheme (580 awards giving a stipend of A$ 20 180 in 1997, with additional funds from industry partners). From 1998, the Collaborative Research Grants Programme and the Australian Postgraduate Awards (Industry) Scheme will be merged into a single programme, the Strategic Partnerships with Industry-Research and Training Scheme (Australian Government Publishing Service, 1997).

Canada. The National Science and Engineering Research Council (NSERC) has combined various university-industry partnership programmes under the Research Partnerships Directorate, whose 1997-98 budget was C$ 118.5 million. For every dollar invested by NSERC's Research Partnership Programme, an additional dollar and a half is leveraged from industry, universities or government. Industry has also helped Canadian universities establish more than 200 NSERC Industrial Research Chairs to assist in developing research areas for which there is a clear need in industry. Other efforts are taken outside the NSERC. For instance, the Canadian Network for the Advancement of Research, Industry and Education, a consortium with more than 140 members, performs research and develops applications related to the information highway (Association of Universities and Colleges of Canada, 1996).

Germany. Between 1991 and 1996, some 350 joint projects were funded in various areas such as medicine, pharmaceuticals, food industry, and environmental biotechnology. These projects aimed to transfer research results rapidly to industry and to increase the R&D activities of small- and medium-sized enterprises (SMEs). Collaborative research (government support is only available at a pre-competitive stage) has contributed to more rapid technology transfer and the commercialisation of new products (*e.g.* in the biotechnology industry). The German Ministry for Education, Science, Research and Technology (BMBF) has established programmes focused on increasing the innovative capacities of small and medium-sized firms and supports application-oriented co-operation between SMEs and universities, *Fachhochschulen*, and other tertiary institutions. Activities covered by these programmes include subcontracting in joint research projects of enterprises, contract R&D work for enterprises, and temporary exchange of research personnel.

Japan. The 1996 "Basic Plan for Science & Technology" calls for measures to promote university/industry joint research, including personnel exchange, joint use of R&D facilities and equipment, and the strengthening of R&D centres such as Tsukuba Science City. The Japanese government also wishes to engage in broader evaluations of these joint research programmes and a review of restrictive regulations concerning academic leave of absence and secondment of industrial researchers to universities. Although industry funding of university research has historically been low in Japan, bibliometric studies suggest that Japanese firms collaborate more with Japanese academic institutions than with foreign universities (Hicks, 1993).

Sweden. Since the early 1970s, various institutional forms of interaction between higher education and the private sector have been developed, including science parks, liaison offices in universities, and technology bridge foundations. Material consortia, competence centres, and interdisciplinary graduate schools are considered important structures for research with industrial relevance and involvement, and particularly useful in facilitating the movement of students and researchers between universities and industry.

United States. Initiated in the mid-1970s, Industry-University Co-operative Research Centers (IUCRC) were the first American experiment in government-sponsored industry-university co-operation. Currently there are over 50 of these centres, 12 of which are self-sufficient (Geisler, 1995), receiving an average of US$ 60 000 per year. The Engineering Research Centers, based on a 1985 programme, receive over US$ 2 million per year. Industrial firms subscribe to these centres as members (with an average of 12 partner firms per centre) for an annual fee and are in return allowed to influence the R&D portfolio and share in the results. Firms are also allowed to enter into proprietary R&D agreements with these centres. Finally, the National Science Foundation (NSF) initiated the Science and Technology Centers programme in 1987, which is modelled on the previous programme, but is accessible to university science departments in general, not just to engineering departments.

A recent study of references cited in US patents (Narin *et al.*, 1997) reveals that patents increasingly rely on basic, publicly supported research. Patent-science links have tripled from 17 000 in 1987-88 to 50 000 in 1993-94. Among the papers cited in US patents in 1993-94, 73.3 per cent draw on publicly supported science at academic, governmental and other public institutions (both in the United States and abroad). In the case of the pharmaceuticals industry, almost 80 per cent of the science citations are based on publicly funded science. This study also shows that the links have a strong national component and that the papers cited are published in mainstream, basic scientific research journals.

Universities in OECD countries have also engaged in closer co-operation with other universities at both national and international level. Budget cutbacks at national level have led to the concentration of research capabilities in a limited number of institutions, which increasingly specialise in particular fields. The need to pool resources and the decreasing barriers to international co-operation, due in part to ICTs (see Chapter 7), have intensified ties among OECD country universities through bilateral links, complex multidisciplinary networks, twinning arrangements, and consortia. These links may help universities face their budget constraints and may also help diffuse research findings across the OECD area.

THE BUSINESS SECTOR

Trends in business enterprise R&D

OECD expenditure on business enterprise R&D fell substantially over the period 1992-94 (Figure 6.8), particularly in France, Germany, Italy, Japan, and the United States. It rose substantially, however, in Australia, Canada, Finland, Iceland and Ireland. Available data for 1995-97 suggest a resurgence in business R&D, mainly due to higher expenditures in the United States and Japan, which together account for between 60 and 70 per cent of total OECD business R&D. Owing to the decline in business R&D spending in 1992-94, the R&D intensity of private industry has fallen across most of the OECD area.

Over the same period, concerns were voiced about a shift to more short-term research in the composition of business R&D. Pressure to develop products more rapidly and reduce the time to market for new products could further shift the focus of business R&D from basic and "long-term" research, often performed in central corporate laboratories, to "short-term" and applied research and to product development (Institute for the Future, 1995). Given government cutbacks in R&D expenditure, this would mean limiting growth in the stock of knowledge. These concerns were particularly marked in the United States (*R&D Magazine*, 1997*a*).

The driving factor behind these changes is firms' desire to see more concrete results from their R&D expenditure, to reduce product development time and costs, and to integrate technology development with expenditure on R&D (Rotman, 1994; Larson, 1996). Large firms, in particular, are cutting back on R&D expenditure. Some are transferring R&D responsibilities from central laboratories to smaller business units, thereby integrating research, more closely with product development.

A survey of leading US firms for the Industrial Research Institute found that most industrial research is now financed by business units, rather than by corporate (centrally controlled) funds. Corporate funding in the budgets of business unit laboratories fell from 40 per cent in 1988 to less than 10 per cent in 1993 (Council on Competitiveness, 1996). Moreover, the survey indicated that the share of firms' expenditure on "basic" research fell from 6 per cent in 1988 to 2 per cent in 1993, while that of "applied" research fell from 20 per cent to 15 per cent over the same period, to the benefit of expenditure on product design and development. However, National Science Foundation (NSF) data, with broader coverage, found that the share of basic research in business sector funding of R&D rose from about 5 per cent in 1985 to 6.5 per cent in 1996 (National Science Foundation, 1996*a*). The share of applied research fell somewhat over this period, from 22.8 per cent in 1985 to 19.2 in 1996.[9]

Structural changes in OECD economies may also suggest that research time horizons are shortening. The composition of the business sector and of R&D has shifted from traditional industries (steel, chemicals) with long product cycles and an emphasis on process R&D to more innovative,

◆ Figure 6.8. ***Business enterprise R&D as a percentage of GDP, 1981-96***

Source: OECD estimates and MSTI database, April 1998.

faster-changing industries, often with short product cycles (*e.g.* computer equipment). However, such a structural effect only explains a change in the average time horizon of research, it does not explain why time horizons in a particular industry may have shortened.

There is in fact little hard evidence to show that the time horizon of research has changed substantially, although a recent survey of American firms suggests that the average length of research projects fell from 21.6 months in 1991 to 16.7 months in 1996. This may suggest a more applied focus, but may also be a sign of greater efficiency.[10] However, many R&D managers in private firms indicate that their research portfolio has shifted towards more short-term research.

Factors affecting business sector R&D

The diversity of growth of business R&D suggests that various factors contribute to expenditure decisions. Recent OECD research suggests that the slowdown in business-financed R&D expenditure over the early 1990s can be largely explained by the slowdown in OECD economic growth, lower government funding of business R&D, particularly for defence-related purposes, high real interest rates, and changes in the sectoral composition of R&D expenditures (Box 6.3) (Guellec and Ioannidis, 1998; OECD, 1998*c*).

The effect of the ***business cycle*** on R&D spending is closely related to the financing of such expenditure by firms. Much of firms' R&D expenditure, particularly that of small firms, is financed from retained earnings, depreciation allowances, and other internal sources of funding (Goodacre and Tonks, 1995). When cash flows diminish during a downturn in economy activity, internal financing dries up and R&D expenditure, particularly for short-term development work, is likely to fall. Thus, current low levels of R&D spending in Europe may rebound with the projected economic upturn, while the resurgence in US business spending may be short-lived if the economy slows in the near future (OECD, 1998*a*).

The second factor in the fall in business R&D spending is declining ***government expenditure on research.*** In 1995, governments contributed about 12 per cent to funding of firms' R&D, down from almost 15 per cent in 1991 and over 20 per cent in 1981. Over the 1991-95 period, the decline in government funding of business R&D was particularly sharp in France, the UnitedKingdom, and the United States, much of it due to a decline in defence -related R&D. Moreover, in addition to its direct effect, government funding also has a leveraging effect on private research, particularly for high-risk projects with uncertain outcomes. Government backing allows firms to share risk and recover some of the fixed costs of research, so that additional funding from within the firm is possible. Government support may also make it easier for firms to find complementary external sources of finance, as public support may be taken as an implicit guarantee. Guellec and Ioannidis (1998) investigated the impact of fluctuations in government-funded business R&D on privately funded business R&D and found a strong and significant correlation; this suggests that leveraging may be quite important in certain contexts (Box 6.3).

Investment decisions, involving either tangible or intangible capital, are related to the availability of capital at reasonable cost. ***Real interest rates*** are an important determinant of the cost of capital. Although real interest rates have come down somewhat over the past few years, they remain at a high level, particularly compared to the period before 1970. Guellec and Ioannidis (1998) found that high real interest rates over the past decade may have depressed R&D spending.

Structural factors may also have contributed to the fall in business R&D over the past five years. Business R&D is highly concentrated in a few high-technology industries, notably pharmaceuticals, computers and office machinery, communication equipment, motor vehicles, aerospace, and scientific instruments. The decline in some sectors over the early 1990s, notably those that are defence-related, may have contributed to the overall fall in R&D expenditures. One indication is the sharp decline since 1987 of the share of high-technology industries in total US business R&D. In addition to shifts within the manufacturing sector, OECD economies have also seen a shift from manufacturing to services. As services are currently less R&D-intensive than manufacturing, the latter shift could reduce the overall R&D intensity of the economy. However, services are becoming more R&D-intensive, and services R&D is still insufficiently captured by R&D statistics (OECD, 1997*c*). It is therefore unclear to what extent the

Box 6.3. **Modelling the determinants of business R&D expenditure**

In the context of the "Technology, Productivity and Job Creation" project, the OECD has analysed the levelling off of business R&D spending over the past years (Guellec and Ioannidis, 1998; OECD, 1998*c*). The authors estimated an error-correction model covering 11 OECD countries over the period 1965-96. The model assumes that firms' R&D expenditure is influenced by both short- and long-run factors. Short-run shocks affect expenditure in the same (or next) year, while long-run factors determine the long-term relationship between privately funded R&D expenditure and the explanatory variables. When firms' R&D expenditure "overshoots", it will be pushed back to its equilibrium level. The model aims to explain the increase in business R&D financed by firms, taking the GDP of the business sector (in volume terms), business R&D financed by government, interest rates, and a structural variable as explanatory factors.

In the estimated model, business sector GDP plays both a long- and a short-term role. In the short run, fluctuations in GDP growth affect firms' cash flow and thus their ability to finance R&D, particularly R&D relating to sales, such as product development. The short-run elasticity of this factor is around 0.8. In the long run, higher GDP implies a greater ability to finance R&D, while common factors may drive both GDP and R&D. GDP alone explains a considerable part of the fluctuations in R&D spending.

Government-financed business R&D is also an important explanatory variable. A 1 per cent decrease in government funding of business R&D induces a long-term fall of privately funded business R&D of about 0.26 per cent.

Real interest rates also affect firms' R&D spending, although with a time lag. The negative effect of high real interest rates on R&D spending appears particularly relevant for the second half of the 1980s. During this period, a 1 per cent rise in real interest rates would lower R&D spending by almost 3.5 per cent. The effect of real interest rates is not as significant as the first two effects, however.

Structural factors also appear to play a role. A slowdown in the growth of technology-intensive sectors relative to the rest of the economy explains some of the variation in R&D expenditure.

Together, these four variables explain about 30 per cent of the variation in business-financed R&D. They can also explain the acceleration of firms' R&D expenditure in the mid-1980s and the slowdown of the early 1990s.

shift towards services can explain a slowdown in R&D performance. Guellec and Ioannidis (1998) included a structural variable in their estimation and found it to be positive and significant (Box 6.3).

Private R&D expenditures may also have fallen because ***global and domestic competition*** has increased or because governments have pushed regulatory reform in the services sector. Greater competition might pressure firms to reduce overhead costs and R&D expenditure. There is some limited evidence from a wide variety of sources, most of it involving the United States, on how these developments have affected R&D expenditure (Box 6.4).

The literature on competition and expenditure on R&D suggests a complex link that is partly dependent on ***market structure.*** Low-technology firms are more likely to lower R&D expenditure in response to increased competition from imports or changes in ownership than high-technology firms. The latter might in fact increase R&D expenditure, which is an important part of their competitive strategy, to meet competitive pressures. Deregulation and privatisation appear sometimes to have led to reduced R&D expenditure by monopoly firms in specific sectors, but may also have helped to improve the efficiency of R&D spending. In addition, other dynamic benefits of regulatory reform, such as productivity gains and technology diffusion, may compensate for any fall in R&D expenditure in deregulated sectors.

Increased competition may not have affected the volume of research expenditure, but appears to have had a substantial impact on the composition of research and the ***role of research in the commercial strategy of firms.*** A major aspect of this change is a shift from an inward focus on firms' own R&D and innovative efforts to a more outward orientation. With greater competition and globalisation, new technologies and innovative concepts have a wider variety of sources, most of them outside the direct

Box 6.4. **The impact of competition on business R&D**

The debate on the link between competition and innovation dates back to Schumpeter (1942), who argued that large firms, operating in concentrated markets, are the main engines of technological progress. This implies that greater competition would probably lead to lower R&D expenditures. Recent work by Symeonides (1997) finds little evidence for such a link. However, in some R&D-intensive industries, high concentration may be inevitable, due to the high fixed costs of R&D and indivisibilities in large R&D projects.

The debate on competition and R&D goes beyond this issue, however. First, import competition may affect expenditure on R&D, although the evidence on this point is quite limited (Scherer and Huh, 1992; Zietz and Bayissa, 1992). Scherer and Huh found that increased import competition led to a short-run decline in R&D. However, over the long run, firms increased their expenditure on R&D and became more aggressive in response to import competition, although the response differed considerably across firms. Large diversified firms in concentrated markets reacted much more forcefully than smaller, non-diversified firms. Zietz and Bayissa (1992) also found that the response differs according to market structure. High-technology firms react by increasing R&D, as R&D expenditures are an important part of their defensive strategy. Low-technology firms react much less, as R&D is much less important for their competitive strategy.

Second, deregulation may affect research expenditure. Evidence for this is often based on the deregulation of network-related industries (electricity, telecommunications). For instance, R&D expenditure in the US electricity sector fell by 33 per cent in real terms between 1993 and 1996 (Jones, 1997), apparently in line with a move towards greater competition. In their efforts to cut costs, utilities often see R&D as a prime target for budget cuts; remaining R&D investments are increasingly tied to a shorter payback time. Furthermore, deregulation may limit the ability to pass R&D costs on to consumers and taxpayers (Hirsch, 1996). Utilities also react to deregulation by seeking more R&D collaboration, although there are difficulties when some potential collaborators are competitors. However, utilities are likely to continue to invest in some long-term research, albeit increasingly through collaborations with privately and publicly funded research institutes.

The drop in R&D expenditure in specific firms may give a biased view of overall R&D expenditure in a deregulated market. Among the objectives of deregulation is often the entry of new competitors, many of which may undertake R&D efforts. For instance, R&D expenditure in the telecommunications market has moved beyond the core public telephone operators (PTOs) and now also involves equipment suppliers, software companies, and service companies. The 1996 R&D expenditure of the four main US manufacturers of Internet equipment (3Com, Bay Networks, Cabletron Systems, and Cisco Systems) amounted to almost US$1 billion (OECD, 1997*v*). Furthermore, deregulation may promote technical change in the broader sense, by giving firms greater incentives to innovate or create new goods and services, and by making firms more responsive to consumer needs.

Third, mergers and acquisitions may affect R&D expenditure. A number of studies of the United States focus on this issue (Hall, 1988, 1990; Lichtenberg and Siegel, 1992*b;* Miller, 1990). Most find little evidence that takeover activity led to a decline in R&D spending. Lichtenberg and Siegel analysed the impact of ownership changes on corporate overhead, including R&D, for a large sample of US manufacturing firms. They found that change in ownership had no significant effect on R&D. Hoskisson and Johnson (1992) found that firms that reduced diversification during restructuring increased R&D intensity, whereas firms that diversified further experienced a decline in R&D intensity.

The increased focus on short-term objectives has sometimes been linked to cross-country differences and changes in corporate governance (Miller, 1990). Stronger shareholder representation in the United States and some other countries would help to explain the greater emphasis on short-term results. Hall (1990) presents some evidence that stock markets react favourably to announcements that firms plan to increase R&D expenditure, an indication that financial markets take account of some of the long-term impacts of R&D. A number of other studies (McConnell and Muscarella, 1985; Chan *et al.*, 1990; Hall and Hall, 1993) also found that stock markets do not systematically undervalue investment in R&D. The emergence of venture capital markets in some countries also suggests that R&D-intensive firms can find external finance on stock markets.

control of firms. The challenge to firms is to manage the complex interactions with other firms, universities, governments, and other actors in the national – and increasingly international – innovation system. Many of these interactions pose new challenges with regard to property rights, and often involve a wide range of proprietary arrangements, *e.g.* licensing agreements.

For instance, firms are increasingly engaging in ***joint ventures*** (Larson, 1996). This type of collaborative structure is one way for firms to continue to invest in (basic) research. As basic research often has a more long-term focus and its outcomes are more uncertain, this is an area where firms seek to share costs. In the United States, two-thirds of joint ventures announced over 1993-94 were in high-technology industries (communications, computers, software and pharmaceuticals), while more than a third of all domestic joint ventures focused on R&D or the development of new products (Institute for the Future, 1995).

The increase in R&D joint ventures and other types of collaborative structures may have other causes as well. First, the costs for innovations such as a new generation of semiconductors or aircraft have skyrocketed and may now be beyond the means of any single firm (Institute for the Future, 1995). Second, highly skilled researchers are scarce in several important areas, and firms may want to share these resources. Third, some key technological developments, including biotechnology, cross traditional scientific and firm boundaries, reinforcing the need for co-operation. Fourth, joint ventures may reduce duplication of research and thus improve its efficiency (Katz and Ordover, 1990).

Firms are also ***relying more on external sources*** – universities and government laboratories – to fill the gap left by reductions in their own basic research (Rotman, 1994). Increasing co-operation between universities and private industry, and between government and private industry, are signs of these developments. However, firms often require some in-house research capability for such joint work. In addition, universities are not always sufficiently equipped to co-operate effectively with the private sector, and there may be conflicting interests in several areas (see above).

There are also signs that relationships among firms have changed. Large firms increasingly engage in collaborative arrangements with small technology-driven firms. Many of these small firms are now able to finance R&D through venture capital markets, particularly in the United States, where small firms attracted a record US$10.1 billion in venture capital in 1996, up 53 per cent from 1995 (Larson, 1997).

Changing research strategies in the private sector may also be linked to the more rapid diffusion of technologies. This has made it more difficult for firms to appropriate the benefits of R&D expenditure and may have reduced their incentive to engage in own R&D. Such "free riding", as practised by some producers of personal computers, may deter R&D investment by more research-oriented firms. The returns to R&D may also diminish if competition squeezes prices and profit margins or if more rapid product development reduces product life cycles (Institute for the Future, 1995). Firms are also less sure of being able to turn a major scientific breakthrough into a commercial success (Buderi, 1997).

Changing R&D behaviour in the private sector and the closer integration of research with business strategies has helped companies to overcome one of their main problems, namely the translation of good research into successful products (Buderi, 1997). Furthermore, if research departments were not integrated more closely with business strategies, they might not survive at all. A recent study (Iansiti and West, 1997) argues that the turnaround of US firms in many high-technology industries since the early 1990s is due less to a greater innovation effort than to greatly improved technology integration. This has probably become more important because the range of technologies has expanded rapidly, making it impossible for a company to cover all main disciplines, as IBM and AT&T were able to do in the 1970s. The sources of technology have also proliferated, and monitoring other companies across the world and in different markets has become an essential part of firms' innovative effort.

Industry analysts also suggest that simply looking at business R&D spending may give a misleading picture of their actual innovative efforts. Spending large amounts does not guarantee success and may even be a sign of poor planning (Buderi, 1997). Large budgets may disperse the research effort and may even suggest a lack of focus. IBM reduced its research expenditure from about US$5 billion in 1991 to US$4 billion in 1996, but received 1 867 patents in 1996, up from only 679 in 1991. While there is a certain lag between R&D expenditure and patenting, this suggests that IBM's research output has not (yet) suffered from the cutback in expenditure. Moreover, changes in the volume or composition of R&D are imperfect measures of total innovative effort. Innovation surveys suggest that only part of innovation is attributable to expenditure on R&D, and that innovation costs also include marketing activities, product design, and diffusion efforts.[11] A recent OECD survey (OECD, 1997*j*) suggests that R&D represents some 30 to 50 per cent of the total costs of innovation, but with considerable variation among countries.

Several major companies (Microsoft, NEC, Intel, Hewlett-Packard), most of them active in the ICT industry, have increased their R&D expenditure over the past years, often with a focus on long-term research, as they find that existing product lines do not generate sufficient revenues (Buderi, 1997). Several of these companies are leading the way towards a new approach to R&D in the private sector, characterised by a closer integration of R&D policies with business strategy and more intensive co-operation with other parties in the national innovation system. The outcome of these developments for innovation and growth remains to be seen.

CONCLUSIONS

The discussion above suggests some broad conclusions. First, in many OECD countries, declining ***government expenditure*** on R&D has resulted in lower R&D intensity. With a few exceptions, the available data offer little evidence that the share of basic research in GDP or in government funding has declined. Pressures for fiscal consolidation suggest that government funding of R&D is unlikely to increase much in the short term. This is confirmed by budget projections for the major OECD economies (see Chapter 3).

At the same time, the science and technology policies of many OECD economies tend to give greater emphasis to the funding of research programmes that are aimed at near-term applications and are closely linked to the private sector (Skoie, 1996). A major shift in this direction would risk eroding basic research and ignoring its long-term value. Basic research seeks a deeper understanding of nature and society and poses fundamental questions, many of which are not related to economic values. While the results are often not foreseen – many important discoveries are made unexpectedly – they may lead to major technological breakthroughs. Continued public support for R&D, particularly for basic research, remains important. Governments are the main and often only possible source of funding for basic research.

The situation for ***universities*** is possibly more challenging (OECD, 1997*e*). Reduced public funding, in combination with greater demands for economic relevance and increasing student enrolments, mean that universities need to adjust to changing circumstances. Universities continue to play an essential part in national innovation systems, and increased demands for economic relevance have boosted their role in transferring knowledge to the private sector. However, although the importance of co-operation with the private sector is growing, there is a limit to the amount of financing that universities can expect from the private sector. Many aspects of university research have few, if any, commercial applications, even in the long run. Support for university research will thus continue to be largely the responsibility of governments. In addition, governments will need to find a balance between protecting the fundamental nature of university research and encouraging the interaction between science and industry.

Greater competitive pressures in the ***business sector*** have led to increased emphasis on applied research and product development. However, firms are not turning their back on basic research. The share of basic research in funding of R&D by the business sector appears quite stable (at about 6 per cent in the United States), and firms are increasingly creating links with universities and public laboratories to gain access to basic research. In some countries, the rapid development of venture capital markets may help ease the financial situation of research-intensive firms, although there is evidence that small technology-based firms still face funding constraints. Furthermore, competitive pressures and better integration of technological resources within firms have helped make more effective use of R&D resources and could help reduce overlapping R&D efforts, encourage the diffusion of technologies, and lead to the entry of new R&D-performing firms. Competition has forced firms to integrate R&D more closely with business strategies; consequently, research results are now much more likely to be used to generate new products and processes.

The pressures on governments and the private sector to reorient R&D efforts come at a time when the traditional model of technological development is increasingly considered obsolete. In the traditional linear model, the science system is the sole initiator of innovation and an increase in science inputs (R&D expenditure or other resources) will directly increase the rate of innovation and technological development (OECD, 1997*r*). Systemic approaches paint a much more complex picture of the innovation process: innovation has many sources and occurs at any stage of the process of research, development, marketing and diffusion; it is the result of the interaction of all actors in the ***national system of innovation,*** including government, universities, and private enterprises. Furthermore, bibliometric analysis suggests that knowledge is increasingly developed internationally, in a multidisciplinary way, and by various actors.

This has important implications for policy. It turns attention away from an exclusive focus on investment in R&D, either directly by government or indirectly by incentives to the private sector, and towards systemic failures that may affect innovation and technological change, as well as towards other sources of innovation. In responding to the challenges outlined above, governments need to pay sufficient attention to R&D, and in particular to basic research, and to improving the interaction and knowledge flows within the national innovation system.

Governments thus face a number of fundamental challenges (see also Chapter 3):[12] increasing the support for government funding of R&D; enhancing the efficiency of government spending; increasing the focus on the core competencies of governments (particularly the funding of basic research); and improving collaboration with other partners in the national system of innovation (in particular the private sector) and with other governments. Moreover, government policy should not ignore other sources of innovation, as R&D expenditures are only part of the innovative effort. Greater attention to technological diffusion, both within and across countries, will also be required in many countries.

Governments also play a crucial role in establishing a framework for research and innovative activity. Measures in this area include the establishment and protection of intellectual property rights; support for raising skills and competencies, particularly those related to science needs; facilitating the mobility of researchers between different parts of the national innovation system; and the establishment of infrastructure and regulatory frameworks that stimulate innovation and growth. The increasing focus on interaction and collaboration among the different actors in the national system of innovation may also require governments to facilitate such collaboration. The objectives and instruments of these policies will differ according to the specific characteristics of each country, including size, industrial structure and institutional arrangements. For instance, effective policies to integrate technology developed abroad are more important to small countries than to large ones.

NOTES

1. Trends in R&D expenditure may give an incomplete indication of changes in the total innovative effort. R&D statistics may insufficiently capture activities in emerging sectors such as software development, do not provide complete coverage of the services sector in most OECD economies, and do not always sufficiently cover R&D efforts by SMEs. Furthermore, innovation surveys at the firm level indicate that R&D is only one component – albeit an important one – of the total innovative effort by firms. Nevertheless, R&D expenditure remains the best and most broadly available indicator for studying trends in innovative activity.

2. A decline in government funding of R&D could potentially affect business expenditure, as government-funded R&D appears to have a leveraging effect on privately funded R&D (see below). However, the sharp increase in US business R&D over the past few years, despite reduced government funding, suggests that this may not be the case in all countries or situations.

3. Measuring R&D expenditure in the higher education sector remains problematic (OECD, 1998*c*). It is generally estimated by combining data on "separately budgeted R&D" with an estimate of the R&D content of general university funds – covering teaching, administration and research – to universities. The R&D content of these block grants is usually estimated by applying a standard percentage, based on available benchmark surveys or a rule of thumb. This procedure may lead to biased estimates of R&D expenditure by the higher education sector, particularly because the weight of teaching and administration appears to have increased, so that academics may be spending less time on R&D than in the past.

4. Doubts can be raised about the efficiency of tax credits, however. Empirical evidence suggests that a universal tax credit may only be appropriate in industries where R&D expenditure has high rates of social return. In industries with low social rates of return to R&D, a high tax credit may be too generous. Some countries have therefore moved towards a more targeted policy of R&D promotion through tax incentives (OECD, 1996*g*).

5. Work at the OECD suggests that by the end of 1980s the cost of fiscal R&D incentives corresponded to only 1 per cent of government-financed R&D in Japan, about 3 per cent in France, Germany, and the United States, and 10 per cent in Australia and Canada. In France, Germany and the United States, funding by fiscal incentives fell more rapidly than funding by contracts and grants, but growth in R&D spending in Australia and Canada over the 1989-95 period would have been higher if fiscal incentives had been included (OECD, 1998*c*).

6. University research may also receive funding from other sources. In the United States, in particular, state governments and the institutions themselves finance a significant proportion of university research.

7. Universities also play an important role in safeguarding scientific standards.

8. These issues are discussed elsewhere in more detail (OECD, 1997*y*).

9. The definitions of the various types of research are somewhat different in the two studies.

10. Unfortunately, little hard evidence on this issue is available for other OECD countries.

11. OECD's *Oslo Manual* (OECD, 1997*z*) proposes guidelines to collect and interpret data on innovation.

12. There are also some broader issues that may affect research policies in the long run. There are signs of decreasing returns to investment in several fields of science, and there are studies that point to the "end of science" (Horgan, 1996). If this were the case, the expansion of the knowledge base and long-term economic growth might be affected. A counterweight to this trend is the possible increase in productivity in science and research over the past decades. The rapid spread of ICTs, in particular the use of computers, may have significantly enhanced the productivity of researchers. This remains a contentious issue (see Chapter 7).

THE GLOBAL RESEARCH VILLAGE: HOW INFORMATION AND COMMUNICATION TECHNOLOGIES AFFECT THE SCIENCE SYSTEM

INTRODUCTION

As information and communication technologies (ICT) have become essential tools for science, governments need to understand their role in the science system in order to develop appropriate science policies. This chapter looks at how the use of ICT has influenced science in five areas and the implications for the science system. This chapter addresses both the widespread use and growing capabilities of computers and the linkages they make possible in the areas of communication among scientists, access to scientific information, scientific instruments, electronic publishing in science, and science education and training. It discusses the potential of experimental applications as well as more mature ones. Overall effects on the science system will depend on how use of ICT evolves in terms of the specific characteristics of each field of science.

While this chapter seeks to describe the impact of ICT on the science system, it does not seek to provide detailed policy advice to OECD governments. It draws on the international conference on the Global Research Village held in Denmark in 1996 (OECD, 1996*o*), which was organised jointly by the Danish Ministry for Research and Information Technology and the OECD and examined the implications of ICT for world science and the science policy implications. At the 1996 Conference, the OECD was asked to prepare a report on quantitative and qualitative trends in the development of information technology (IT) infrastructure and the impact on the science system. A follow-up conference will be held in Portugal in 1998. This chapter is intended as a contribution to the ongoing discussion.

TECHNOLOGIES UNDERLYING THE CHANGING SCIENCE SYSTEM

A wide range of developments in ICT, covering hardware, software and networking technologies, underlie ongoing changes in the science system. They include significant improvements in computing power and storage capacity and better networking and search technologies. Such developments have allowed scientists to make rapidly increasing use of Internet and ICT tools. However, there are concerns that the Internet is becoming inadequate for certain scientific purposes. Several governments and universities have recently taken initiatives to develop faster networking technologies to meet the needs of science.

ICT-related changes underlying the evolving science system have three main sources: technological change in the ICT industry (mostly driven by needs unrelated to science); scientists' efforts to develop their own tools; and government programmes specifically designed to foster developments in ICT and apply them to scientific needs, *e.g.* the US High-Performance Computing and Communications (HPCC) programme.

Main technological developments

Conventional computers solve problems by performing programme instructions one at a time in a strict sequence. Electronics manufacturers have provided users with increasing computing power at decreasing cost for many years, essentially by squeezing a greater number of ever smaller transistors and other components onto chips, thanks to continuous advances in lithographic techniques (*Science*, 1996*a*). They have also found alternative ways of getting more processing power from computers, for example by using reduced instruction set computer chips (RISC) or special purpose chips to perform designated tasks faster than a general-purpose processor (*New Scientist*, 1996).

The supercomputers used for research generally have custom-made, expensive processors which provide better performance. Up to the late 1980s, vector supercomputers were the most powerful computers. They were the only option for researchers with truly large problems, who used them to perform calculations simultaneously on long strings of numbers, *i.e.* vectors (Pool, 1995). The research potential of parallel computers has been demonstrated more recently. These multiprocessor machines break major programming tasks down into smaller problems which they solve simultaneously. This method remains quite difficult, however, and cannot be used to solve all problems.

Cheaper off-the-shelf components and software have generally contributed to increased use of information technology. A new generation of extremely powerful off-the-shelf commodity chips is also at the heart of an emerging standard parallel architecture (Matthews, 1996). These chips, which can function equally well alone and in concert (a requirement of parallel architectures), are perfect for low-cost parallel computers. Even working on their own, these chips attain speeds of up to 200, 300 or 600 million flops (floating point operations per second). Many off-the shelf components are also available for certain scientific instruments. Plug-in circuit cards allow new features to be added to personal computers (PCs) without much adjustment. Complex software, increasingly available for Windows '95, contributes to the use of technology by non-specialists at lower cost.

Various storage and information delivery technologies continue to co-exist. Traditional storage systems such as the CD-ROM (compact disk – read only memory) are still being used by publishers, particularly where current Internet access limitations would result in very slow access, *e.g.* when the package contains great quantities of data. New products that combine CD-ROM data with information on the World Wide Web (WWW) or on-line services give publishers the opportunity to deliver huge amounts of data on CD-ROM and then use the Internet to offer updates or transactions. The Digital Video Disk (DVD) can store seven times as much data as a CD-ROM and deliver a moving picture quality that outshines laser disks. It is particularly useful for multimedia publishing and will enable educational software, in particular, to incorporate more video. The mass-storage industry continues to develop technologies that can handle increasing quantities of data, thereby satisfying the needs of scientists carrying out large-scale simulations, experiments and observation projects.

Electronic networks constitute the infrastructure which provides scientists with new means of communication that gives them access to data, information and software in cyberspace, allows them to share and control remote instruments, and which links distant learners to virtual classrooms and campuses. Scientists currently have access to various types of networks, including campus, national and international research networks, which are increasingly interconnected. For instance, in early 1997, the French RENATER network connected 1 200 laboratory networks to 300 campus networks and to 20 regional networks. A national interconnection network links the regional networks to Europe and the rest of the world.

The main network, the Internet, began in the late 1960s as a network providing a limited number of researchers with shared interactive communication among computing systems at different locations. It has become a network of networks that can be accessed by anyone with a computer and a modem. Since 1991, the WWW has been a very powerful and convenient way to navigate through the world's collection of networked computers. Through hypertext links, it connects information on the network to other sites. Special graphical interfaces known as Web browsers, such as Netscape Navigator, Microsoft Internet Explorer and Netcom NetCruiser, allow users to read hypertext.

Rapid advances in computing power and the explosive growth in network connectivity have generally enhanced the use of distributed systems. The potential of networking several computers to perform tasks similar to those performed by supercomputers is also being tested. In addition, systems capable of co-ordinating different types of computers, including traditional supercomputers, parallel computers, workstations and PCs, are emerging (*Economist*, 1996*a*). Hardware and software for using a network of workstations as a distributed computing system on a building-wide scale are being developed (National Science and Technology Council, 1995).

The development and use of digital data and information rely on a broad range of technologies. Non-digital data requires data acquisition technology, such as optical character recognition, while direct use of data collections requires database management systems. Text analysis and information retrieval techniques (including text, index and image compression, indexing, routing, filtering and visualisation techniques) sometimes enhanced by artificial intelligence, are needed to index, search, retrieve and present desired information. Furthermore, data mining technologies can be used to sift large amounts of data for useful patterns.

Methods for handling information help users more effectively search, learn about, organise and use data and information. Search tools, for example, can go through millions of articles from current and back issues of electronic journals in almost any discipline. They help users navigate on-line services and save time. Search engines such as Altavista, Excite, Infoseek, Lycos, Web Crawler and Yahoo constantly burrow through and catalogue Internet documents. There are also limited area search engines that index only Internet resources relevant to a specific subject and thus raise the speed and efficiency of searches. Internet search technology is still, however, in its infancy.

Many ICT applications used by scientists, such as access to databases, information services and e-mail, were originally based on narrowband technologies;[1] broadband technologies were only needed for video applications. However, the growth of the Internet and new interactive – often multimedia – applications have led to a rapidly growing demand for high bandwidth technology, which may also be needed to process large amounts of data.

Some indications of ICT use

While there is little systematic analysis of ICT use rates, various studies include estimates that broadly indicate how usage varies. It varies significantly by field of science and by region. For example, mathematicians and physicists make significant use of e-mail, with respectively 34 per cent and 24 per cent reporting e-mail addresses as early as 1991, when experimental biologists had yet to adopt this technology in large numbers. Ornithologists in North America still had low rates of e-mail use by 1993 (Walsh, 1997; Table 7.1).

However, by then, the technology was beginning to diffuse rapidly. Almost 74 per cent of aerospace engineers in industry, government and academia used a network by 1993, although only 50 per cent had access to external networks such as the Internet. Use among academics (rather than industry or government employees) and scientists (rather than engineers or managers) was nearly universal (Table 7.2). Analysis, database work and word-processing were the most common uses in 1993. There were still significant differences in usage by field. Internet use by chemists, sociologists, political scientists and philosophers at Jesuit colleges and universities in the United States varied from 82 per cent for chemists to 55 per cent for philosophers (Table 7.1).

By 1993, 30 per cent of the value of the US stock of scientific instruments consisted of computers and data handling instruments. Furthermore, 29 per cent of all chairs of academic science and engineering departments surveyed ranked some type of computer as their highest priority in terms of instruments needed (National Science Foundation, 1996*a*).

In France, more than half of all scientists and university professors used a computer by 1993, a significant increase from 1991 (Table 7.2). Use was higher for researchers and teachers in higher education. In Japan, 76 per cent of all researchers and engineers used the Internet and electronic mail in 1993, primarily for communication with other researchers, conferencing, and retrieval of information, data and software (Japan Science and Technology Agency, 1996). Computer use was even higher in Canada, with almost all science and engineering workers using computers in the workplace by 1994. The rapid expansion of Internet since the time of these surveys suggests that e-mail and Internet use by scientists has expanded sharply. In many scientific disciplines, Internet and e-mail use may now be almost universal.

Table 7.1. **E-mail use across scientific disciplines**

Discipline	Region	Year	E-mail use (in per cent)
Experimental biology	United States	1991	9
Mathematics	United States	1991	34
Physics	United States	1991	24
All fields	Australia United States United Kingdom	1992	39
Ornithology	United States	1993	15
Aerospace	United States	1993	74
Engineering/chemistry	United States	1994	82
Sociology	United States	1994	75
Political science	United States	1994	67
Philosophy	United States	1994	55

Source: Walsh, 1997.

The Internet itself continues to expand rapidly. While commercial and personal uses now grow faster than research uses, the number of host names at US universities (*.edu) also continues to grow rapidly (Figure 7.1). Unfortunately, these data say little about Internet diffusion to universities outside the United States. However, trends in Internet use in the workplace across the OECD area suggest a rapid increase, which may suggest that Internet use by scientists is also rapidly expanding.

Towards faster computer and communication technologies

The growing accessibility of the Internet has raised some problems for science users. Quality has sometimes been affected and congestion has increased. As scientists may require high-speed access and considerable bandwidth to transmit large volumes of data, these problems have become quite serious for some science applications. In the short run, congestion can be eased by a mix of technical solutions and pricing schemes (OECD, 1997*d*). In the longer run, further research may be required to solve the congestion problem and improve Internet access for science users.

Some efforts are already under way to develop a faster network. Three US initiatives will provide participating universities with new network services and on-line connections about 100 times faster than the present Internet's. The Very High Speed Network Backbone Service (VBNS) of the National Science Foundation (NSF) is the cornerstone of the US government's effort to upgrade the existing Internet's backbones, the primary hubs of data transmission. Internet 2 is a co-operative effort by universities to create a faster and better computer network among their institutions and will add to the capabilities of the VBNS by developing software for the new network and by upgrading campus networks. Next Generation Internet (NGI) is a US government proposal to support efforts for both advanced networking and applications research.

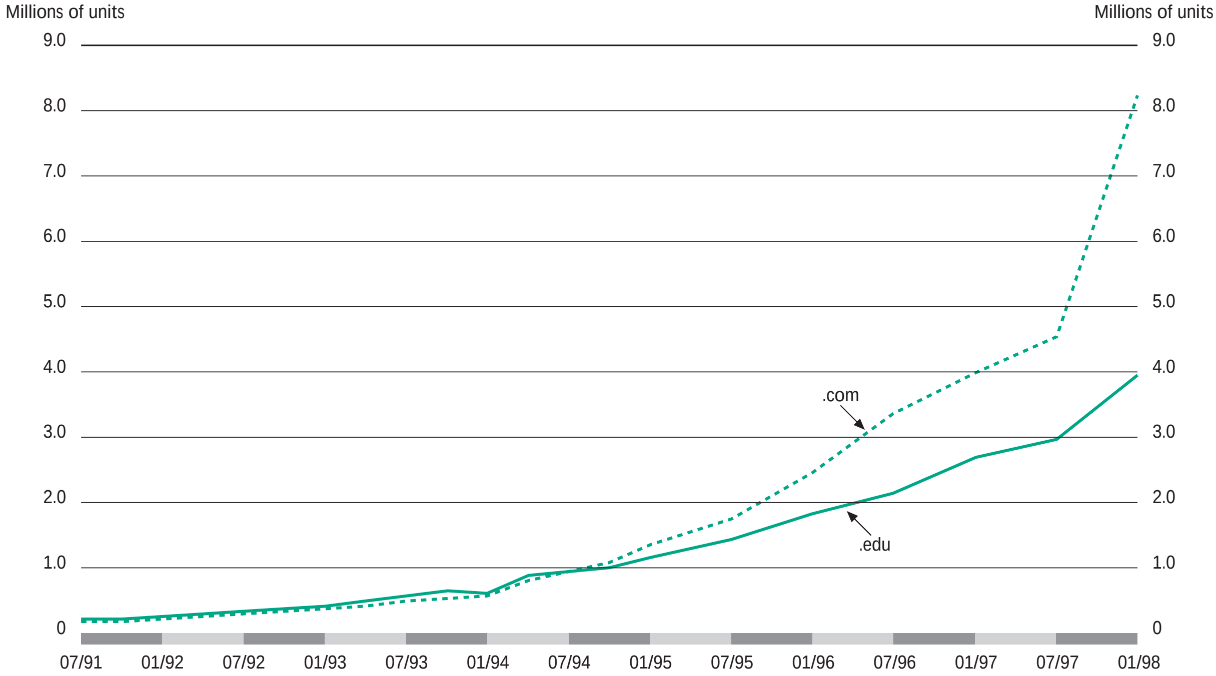
In May 1997, there was a significant breakthrough in European research networking, with the launch by the European Commission of TEN-34 (the trans-European network). This project seeks to strengthen electronic gateways between national research networks in EU member states with a high-speed infrastructure. It is supported by the European Union's Telematics Applications and European Strategic Programme for Research and Development in Information Technologies (ESPRIT) programmes. The TEN-34 network intends to upgrade the 2 megabit/s international links among national research networks to 34 megabit/s, the capacity of most national networks. At the same time, many national research networks are being upgraded through high-speed research network initiatives. While the initial target

Table 7.2. **Computer network use across scientific disciplines**

Occupation	Total	Total	Analysis	Communications	Database	E-mail	Graphics	Programming	Spreadsheet	Word-processing
	United States									
	1989	1993								
Mathematical and computer scientists	92.8	95.7	63.2	57.8	60.9	57.5	43.0	58.4	47.6	65.9
Natural scientists	73.0	85.0	51.2	27.7	42.0	28.2	25.4	12.7	30.1	54.8
Engineers	81.6	84.8	39.4	32.9	35.6	31.0	34.3	24.8	36.3	48.9
Engineering and science technicians	62.4	66.4	25.6	17.3	24.4	15.2	18.8	13.0	16.0	24.2
All occupations	43.2	40.7	11.0	13.6	14.8	9.2	7.3	5.6	10.2	19.1
	France									
	1991	1993								
Professors and scientists	47.0	55.5								
Higher education lecturers and researchers	71.0	..								
All occupations	34.0	39.3								
	Canada									
	1989	1994								
Science and engineering workers	77.6	95.0								
All occupations	33.8	48.0								

Source: US Department of Commerce, 1989 and 1993; ministère du Travail, de l'Emploi, et de la Formation professionelle, 1993 and 1994; Statistics Canada, 1994.

◆ Figure 7.1. ***Number of Internet hosts worldwide***[1]



1. The survey method was changed in January 1998. Earlier data are not strictly comparable.

Source: Network Wizards, April 1998.

for all national networks in Europe is 34 megabit/s, some already aim for 155 megabit/s, *e.g.* Germany's *Breitband-Wissenschaftsnetz* and SuperJanet in the United Kingdom. There are similar initiatives in OECD countries outside Europe, such as CA*netII in Canada and NACSIS in Japan.

In several OECD countries, HPCC programmes develop technologies and applications and constitute the principal force behind efforts in these areas to meet the challenges of science and engineering. The US HPCC programme started in the early 1990s as the cornerstone of a planning process involving government, industry, and academia. It focuses on the following areas (National Science and Technology Council, 1995):

- world-scale information infrastructure technologies that create advanced application building blocks and widely accessible information services;
- high-performance and scaleable systems to support high-performance and low-end applications seamlessly;
- high-confidence systems that provide availability, reliability, integrity, confidentiality, and privacy;
- virtual environments and simulations, which may transform scientific experimentation and industrial practice and play an increasingly important role in education and training;
- user-centred interfaces and tools to provide easier development, navigation, "mining", and general use of information resources;
- human resources and education, to educate the next generation of industrial and academic leaders in information science and technology and to establish a foundation for new learning technologies.

These research and development (R&D) efforts have already achieved much and will continue to do so over the next decades. For example, while computation speeds of 250 billion flops have already been achieved, the next performance goal for large scientific and engineering problems is a trillion operations per second (teraflops). For software, substantial investments in a broad range of advanced technologies are leading to developments in systems software, programming languages and compilers, application tools, computational techniques, software performance measurement, software sharing, and visualisation. A combination of gigabit speed (billions of bits per second) networking technology and computational science have already demonstrated that massive scientific calculations can be executed across parallel processing systems located more than 1 000 miles apart. These speeds represent a thousand-fold improvement over the fastest networks in existence in 1991. The information infrastructure is also being extended into the mobile environment with wireless technologies (National Science and Technology Council, 1995).

COMMUNICATION AMONG SCIENTISTS

Researchers have used ICT-based communications – or the Internet – mostly as a natural extension of other communications tools. Apart from greatly enhancing the quantity, quality and speed of communication among scientists, ICT use has also had various effects on the organisation of work in science. Collaboration patterns have changed, the science base has widened as more scientists are able to participate, and scientific hierarchies have sometimes been affected. However, for the most part, scientific work has not been revolutionised (Walsh, 1997).

The growth of collaborative arrangements

Improved communication due to ICT may contribute to an increase in the size of professional networks. For example, among oceanographers, intensive e-mail users report larger professional networks. In biology, chemistry, mathematics and physics, collaborations have also increased in size, apparently in association with the use of ICT. In experimental particle physics, Internet has facilitated experiments in which a large number of people collaborate effectively.

A more significant change in the organisation of science has been the increase in remote collaboration, particularly at international level (Table 7.3). Computer networks have reduced the need for co-workers to be at a single location. Consequently, a new form of scientific work has emerged, the "extended research group". This is typically a large, unified, cohesive, co-operative research group that is geographically dispersed, yet co-ordinated as if it were at one location and under the guidance of a single director. It provides access to colleagues and to equipment, software and databases that are traditionally part of laboratory organisation, without regard to geography. These "collaboratories" rely heavily on ICT for co-ordinating their work (Box 7.1).

Table 7.3. **Publications with international collaborators**

In per cent of total publications

Field	United States			France			Netherlands
	1981	1986	1991	1982	1990	1995	1993/94
Mathematics	8.8	13.4	17.1	45.5	50.9	40.0	17.9
Physics	8.5	10.5	16.1	36.0	37.3	43.3	28.9
– Astronomy and astrophysics[1]						45.7	
Biology	4.8	6.5	10.0				17.7
– Basic				19.2	23.2	18.1	
– Applied and ecology				19.7	25.8	24.4	
Medical research				8.6	11.0	10.9	11.7-19.3
Chemistry	4.7	6.1	9.1	22.3	27.3	20.1	14.5
Earth sciences				32.6	34.1	39.7	18.8
Engineering				25.1	28.0	30.6	7.2-18.9
All fields	8.8	7.5	11.0	19.9	22.9	21.6	17.0

1. Estimate influenced by frequent collaborative use of research and observation facilities in other countries.
Sources: National Science Foundation, 1993; Observatoire des sciences et des techniques, 1997.

Box 7.1. **Examples of collaboratories**

Atmospheric and space science

Upper Atmospheric Research Collaboratory (UARC): ground-based observation of ionospheric phenomena using the Sondrestrom Upper Atmospheric Research Facility, at: http://www.sils.umich.edu/UARC/HomePage.html

Collaborative Visualization Project (CoVis): scientific visualisation for K-12 students studying the Earth's atmosphere, at: http://www.covis.nwu.edu

Biology

Worm Community System: data about the *C. Elegans* genome, at: http://csl.ncsa.uiuc.edu/CSLWWW/WCS.html

BioMOO: on-line discussions about biology, at: http://bioinformatics.weizmann.ac.il:70/0/biomoo

Chemistry

Collaboratory for Environmental and Molecular Science: remote access to nuclear magnetic resonance (NMR) spectrometers, at: http://www.emsl.pnl.gov:2080/docs/collab/CollabHome.html

Medicine

Medical Collaboratory: synchronous and asynchronous remote consultation over radiographs and ultrasound videos, at: http://www.sils.umich.edu/~weymouth/Medical-Collab/index.html

Distributed Health Care Imaging: storage and retrieval of coronary angiograms from Kaiser Permanente's Cardiac Catheterization Laboratory in San Francisco to six Bay Area Kaiser Permanente hospitals, at: http://george.lbl.gov:80/Kaiser/LBL.CRADA.NII.html

InterMED Triad Collaboratory: dictionaries for disease description, at: http://www.cpmc.columbia.edu/intermed_proj.html, http://camis.stanford.edu/projects/intermed-web http://dsg.harvard.edu/public/intermed/InterMed_Collab.html

Teledermatology Program: remote diagnosis of skin lesions in rural Oregon and Kansas, at: gopher://gopher.hpcc.gov/00/grants.contracts/awards/hpcc.health.care.awards.txt

Telemanagement of Neuro-Imaging: remote consultation of computer tomography (CT) and magnetic resonance imaging (MRI) of the brain and spinal cord, at: gopher://gopher.hpcc.gov/00/grants.contracts/awards/hpcc.health.care.awards.txt

Physics

LabSpace: remote access to electron microscopy tools (Argonne) and to an object-oriented programming project at CERN, at: http://www-itg.lbl.gov/DCEE/Overview.fm.html

Remote Experimental Environment: real-time participation in experiments conducted at the D-IIID tokamak at General Atomics, at: http://www.nersc.gov/Projects/REE/

Beamline 7 Collaboratory: remote access to the Advanced Light Source at Lawrence Berkeley Laboratory to obtain spatially resolved chemical information, at: http://www-itg.lbl.gov/~deba/ALS.DCEE/project.html

Source: Finholt and Olson, 1997.

One example of ICT-based international collaboration is a collaborative research project in atmospheric physics consisting of scientists at five Canadian sites, two US sites and two sites in another country. All members of the group have Internet addresses and most reported sending several e-mail messages a week to other members. E-mail was preferred to the telephone because scientists who travel may be hard to reach by phone, but can be contacted at their virtual address, because written messages allow time for formulating answers before responding, and because colleagues whose native language is not English preferred written communication.

E-mail over the Internet enables researchers to overcome many barriers to communication due to geographic distance, such as time, costs and language. This seems especially important to researchers in Australia and New Zealand who make much use of the Internet to improve their access to research communities in Europe and North America. E-mail is considered next best to face-to-face interaction and a good medium for facilitating collaboration among scientists. However, many scientists emphasize the importance of establishing common understanding of the research problem through intensive, face-to-face interaction before engaging in computer-mediated collaboration.

With tighter links among geographically dispersed scientists, the international community of scholars is becoming denser. For a given research topic, ICT allows the creation of more complex work groups with more fluid structures. Virtual research teams can be formed and link a variety of scientists, each of whom contributes his or her skills to the project. Projects take advantage of networks to obtain access to the precise skills needed, and researchers gain access to projects that demand their skills. As a result, the research topic, rather than geographical proximity, determines collaboration decisions.

For the most part, collaborative arrangements have not yet been revolutionised. ICT-based communication has been adopted in a way that reproduces local social relations and research practices. Thus, while the social structure has changed somewhat owing to ICT use, the reorganisation seems largely limited to changing (expanding) participation, with only minor changes in the content of participation. The existing work organisation is reproduced over a wider geographic area and ICT-based communication serves as the link formerly served by face-to-face communication in local collaborations.

There is some debate over whether the variety of new work arrangements made possible by computer networks constitute a net benefit to those affected. While ICT may facilitate cross-disciplinary collaboration, it may also lead to the fragmentation of research. This might lead to ‘‘balkanisation’’ of science, with researchers using limited communication time to interact only with those in their speciality (Van Alstyne and Brynjolfsson, 1996). While this might be beneficial and achieve economies of scale in certain scientific areas, it might also reduce cross-fertilisation of ideas among disciplines. However, the overall impact of these new forms of organisation on scientific outcomes is not yet clear and whether balkanisation is indeed an issue remains to be seen.

Increased frequency of communication

There is evidence that ICT-based communication contributes to an overall increase in the amount of communication during a research project (Walsh and Bayma, 1996*a*). This may be particularly important in the context of long-term experiments, shift work, and different time zones. Increased communication may increase attachment to the research group, job satisfaction, and commitment, by alleviating feelings of isolation due to irregular hours but also to concentration on a highly specialised endeavour that may not interest local colleagues.

In high energy physics, for example, ICT has allowed researchers to remain involved in long-term experiments even when they are not physically present, thanks to distribution lists, bulletin boards and e-mail and the electronic distribution of pre-prints and other crucial (informal) information. This method of communication allows all members of the collaboration to stay ‘‘in the loop’’. However, the combination of technologies used and the ways they are used affect the outcome.

By passing research work back and forth, collaborators in different shifts and time zones can have a project that never sleeps. Chemists and biologists, with their loosely coupled and lengthy experiments, also find that the frequent communication permitted by ICT means that the various elements of the research project tend to remain well co-ordinated (Walsh, 1997).

On the other hand, there is evidence that e-mail communication does away with many of the socialising that generally accompanies face-to-face or even phone conversations, thereby resulting in less collegiality and a more alienating work environment. Some scientists view the increased focus of communications on business matters as an advantage of e-mail (reduced time costs) and use it for both remote and local communications (Walsh and Bayma, 1996*b*). Indeed, ICT-based communication may simultaneously integrate and isolate individuals. The result could be a work environment, or community, where the individual is linked to more colleagues but the links are more instrumental or less satisfying.

Effects on status and hierarchy

ICT-based communication can lead to greater decentralisation or less difference in status, because interaction over the Internet provides fewer clues to status, rank, and gender than face-to-face or even mail or phone communication (Walsh, 1997). Group decisions are consequently less influenced by the status of those proposing particular solutions.

Moreover, by its informal nature, e-mail reduces lower-level researchers' reticence about contacting higher-level ones. It may facilitate the creation of new ties among remote collaborators and give scientists with lower status easier access to their more eminent colleagues with whom they may eventually publish results jointly. On the other hand, it may create even greater disparity in publication rates as top scientists become attached to a greater number of research projects via e-mail contacts. E-mail communication may also allow scientists who previously lacked the access necessary to keep up to date to become active participants and possibly core scientists. So far, no significant correlation has been found between age or institutional prestige and ICT use as a predictor of productivity (Cohen, 1995).

To the extent that status distinctions remain, however, individuals with high status will continue to exert more influence on group decisions. As the technology has been developed, more status cues are being inserted into the communication. E-mail addresses, for example, are evolving from a nondescript assembly of letters and numbers to a combination of family name, institution or company, and country of registration. Also, other mechanisms for introducing the status-reinforcing procedures of earlier communication technologies (mail, telephone) are beginning to appear. For example, high-level scientists increasingly use gatekeepers to screen their e-mail just as they screen letters and calls. Similarly, if ICT violates existing work norms or status distinctions, it may not be used.

New technology can also change part of the basis for existing status distinctions. ICT can, for example, enhance the status of younger colleagues who are more familiar with the latest technology. It may also provide peripheral scientists with wider access to crucial resources – such as computing facilities, software or databases – which have traditionally been unequally distributed. Improved access could reduce the gap between more and less eminent scientists.

The evidence is conflicting, however. A recent study of network use in oceanography found that younger oceanographers who were intensive users of networks were more likely to receive professional recognition than others of their age group who used networks less. Similarly, inland oceanographers who made greater use of networks had more publications than those who used them less (Hesse *et al.*, 1993). On the other hand, another study, which replicated this study, found no evidence of democratisation effects from ICT, such as advantages accruing to those at less prestigious institutions or to younger scientists (Cohen, 1995).

In general, ICT has allowed more scientists to have access to the latest information and thus remain up to date. This has been particularly meaningful for those at less prestigious institutions. However, there is a significant difference between having access and being present. Researchers at top institutions have access to oral information and seminars as well as research papers. They also have access to specialists who know which information and papers are important. The filtering provided by local and informal communication is an important part of the process of finding scientific information. Researchers at large institutions usually also have better access to funding and equipment. Overall, while ICT helps improve access to information, it does not overcome disadvantages due to a lack of direct contact with top scholars in the field. ICT use may thus lead more to a broadening of the science base than to a change in the hierarchy of scientific institutions.

While ICT can be used to provide broad access to resources, it can also be used to limit access. Netnews bulletin boards are generally open to many users and are used to announce new findings, discuss substantive issues, and get answers to questions from unknown colleagues. More field-specific distribution lists may be announced through direct contact with existing research ties, thus enabling a more specialised exchange of information.

Some fields seem to have more potential to benefit from technology than others. Those where interdependence is high, with frequent interaction between collaborators, and those where collaborators are likely to be dispersed – such as mathematics, physics and aerospace – are most likely to benefit. In fields such as ornithology, on the other hand, technical limitations related to the transmission of non-textual information and a relatively slow pace of discovery may limit benefits.

ACCESS TO SCIENTIFIC INFORMATION

Rapid advances in ICT have made it possible to handle digital data and information in large volumes at ever-increasing speeds and have resulted in sharp reductions in the cost of storing, filtering, processing, compressing, and retrieving data for interpretation and retransmission. ICT has increased researchers' ability to access information by supplying them with increasingly powerful tools at decreasing cost and thus enabling new ways of working. Researchers have frequently been the first to use ICT in a new or comprehensive way, as in the case of the Internet. On the whole, this has significantly improved the efficiency of information-based work.

Digital resources for scientists

In the past, traditional libraries held the keys to research and knowledge. Today, "digital libraries" store and manipulate large collections of material in electronic form. The development of digital libraries is closely linked to that of network information systems, which increasingly allow access to resources when and where users desire it. Prodigious quantities of general and sector-specific information are now available off-line on CD-ROMs and on-line, increasingly over the Internet. With ICT, access to this information can already be obtained at low incremental cost. As systems become more sophisticated, users will benefit from a growing capacity to navigate among information resources at low cost.

Databases

The value of scientific and technical databases to research organisations continues to increase. Estimates suggest that both the amount of data they contain and their total number expand by about 10 per cent a year. Internet tools, in particular, have made information more readily available to a growing base of scientists and engineers, as database service providers have started moving to Web-based systems. Web browsers such as Netscape are excellent database interfaces; their broad acceptance has extended the potential user base to the research community (*R&D Magazine,* 1997*b*).

Scientists in many fields now produce data sets which are accessible via the Internet to colleagues around the globe. The Internet also provides new opportunities for scientists in different countries to combine local data sets into global ones. This is useful for research projects requiring data from around the world, notably in biological and Earth-related sciences, *e.g.* the Human Genome Project, the International Geosphere-Biosphere Programme. One notable, if experimental, example was the immediate release of data collected by the Hubble Space Telescope (HST) to any astronomer wishing to study it. Standard procedure in astronomy would have been for researchers making the observations to withhold the data for about a year while they analysed them and published the results (*Science,* 1996*b*).

Several factors help make data sets collected by scientific projects available to broad communities of users. Since the tools used to collect, transmit, and analyse data generate or require digital signals, the data are already in digital form and are therefore easily communicated over digital networks in a timely way to scientists world-wide. Furthermore, when scientists have public support for major research projects, they are encouraged to disseminate data widely so as to maintain that support.[2]

On-line databases are now among biologists' main resources. Electronic databases, which have accumulated huge quantities of gene sequence data, enable microbiologists to complete relatively quickly research tasks that they could hardly imagine before the computer (Box 7.2). Whether in centralised archives or decentralised databases, these resources play a catalytic role in advancing research (Waldrop, 1995). The sequence databases double in content every 12 to 18 months, have about 100 000 Web hits per day from 4 000-5 000 different sites, and usage is increasing seven-fold each year. These databases are financed in various ways: from the public budget, according to usage on the

Box 7.2. **Major databases for biologists**

GenBank is a nucleotide database in the United States that has been a fixture of molecular biology for more than a decade. It started as a simple archive. Since its transfer to the National Center for Biotechnology Information, where many staff members are themselves active researchers in laboratories of the National Institutes of Health, it has evolved into an intricately cross-linked array of databases, where molecular biology researchers can search for similarities among gene and protein sequences. Recent new features are a database of DNA codes for protein, links to MEDLINE, a browsing system, and the possibility to submit queries or add sequences over the World Wide Web (WWW). Software takes each new sequence added and computes its "distance" from each of the existing entries. This allows identification of homologues, which can provide valuable information about the functioning and evolution of the original gene.

Genome Sequence Data Base (GSDB), created in the early 1990s, is an experimental, relational version of GenBank. It allows users to make complex queries. The queries follow links between chunks of information, which might be distributed over several files or even databases. This federation of autonomous and distributed databases creates an environment where researchers can pursue more complex questions than with GenBank.

The *European Molecular Biology Laboratory* and the *DNA Data Bank of Japan* are two other major nucleotide sequence databases. All four major databases exchange newly submitted sequences regularly.

Researchers around the world have been filling a common database with the outcome of sophisticated DNA analysis (sequences of base pairings in a gene common to all cells) of thousands of organisms, including microbes. While the main goal of this database, maintained by researchers at the University of Illinois at Urbana-Champaign, is to gauge evolutionary relationships between organisms, it is also proving to be a useful catalogue of microbial diversity.

basis of either transactions or connect time, or through sale of physical products such as CD-ROMs and print or subscriptions or a combination thereof.

Images constitute an important part of research data in astronomy. The Astronomy Digital Image Library aims to support astronomers' productivity by providing easy access to data via the Web. Its collection of fully processed images permits researchers planning new projects to access previous observations as an aid to sensitivity calculations or exploring new questions. New data may also be compared with previous observations to allow a multi-frequency study of particular objects. Astronomers may also use the library to archive their final processed images and related data and share them with collaborators and colleagues without having to use their own disk space or as a way to present results in a manner that complements the presentation in printed journals (National Center for Supercomputing Applications, 1997).

Many smaller databases cater to projects that are smaller in scale and geographic coverage. An example from the medical sciences is the CD-ROM, *Encyclopaedia of Clinical Practice* (EPIC). This database contains more than 4 million anonymous UK patient records and can aid in general or preliminary medical research by an epidemiologist or primary health care researcher.

Bibliographic databases provide information on published research. By providing citations, summaries of original research material (abstracts), and various indexes to scientific research literature, they allow scientists and researchers to identify published articles appropriate to their needs. They range from the more than 20 million records contained in On-line Computer Library Center (OCLC) to the millions of citations in on-line databases for specific disciplines such as MEDLINE, EMBASE, INSPEC and NTIS.[3]

ICT has expanded delivery methods for bibliographic databases and has created better options for storage, search and retrieval. Bibliographic databases were first made available to scientists and researchers in electronic format via commercial on-line hosts and search service vendors and then via the Internet and the WWW, as well as off-line on CD-ROM. The different electronic delivery modes continue to exist, as their attributes and the needs of users vary, but the Internet is expected to become the primary means of delivery. On-line access has many advantages. It is more affordable for academics and librarians, who are often unable to purchase entire databases on CD-ROM. Internet also enables cross-searching of databases. Nevertheless, many larger institutions continue to purchase databases on CD-ROMs, sometimes to bypass Internet traffic jams. Commercial providers, such as the Chemical Abstracts Service (CAS) and Knight-Ridder International (KRI), two of the largest database service providers in the United States, provide access both via traditional on-line services and via the Web. A wide range of options and formats are available (Box 7.3).

Reliability, security and speed of access do not seem to be an issue for most users of Web-based systems (*R&D Magazine*, 1997*b*). Nevertheless, KRI also offers an intranet Web-based database service, KR@Site, which maintains database content at a local site and does not permit external access from the

Box 7.3. **Database delivery formats and content**

STN International (Scientific and Technical information Network, CAS) is a traditional fee-based on-line search service that provides information from more than 200 scientific, technical, business and patent databases and includes business, regulatory and supplier information. It is aimed at information specialists experienced in command line searches. Dialog and DataStar (KRI) which focus on American business and technology and on European business, medical information and pharmaceutical sources, respectively, provide combined on-line access to more than 600 databases, with a very powerful search language that would be difficult for the uninitiated.

The Web-based version of STN, STN Easy, introduced at the end of 1996, provides access to selected databases and only includes core bibliographic information. It has no connect-time charges. The Web-based ScienceBase, launched in mid-1996 by KRI, allows users unfamiliar with its search language to access a collection of databases compiled especially for scientists. Dialog Web gives users desiring a more complete Web-based database the capability to browse through all the Dialog databases by topic and supports users with a database directory. Dialog Select, due to be launched in mid-1997, is similar to ScienceBase but allows users access by application or subject matter, *e.g.* patent information. DataStar Web gives users access to more than 350 of the DataStar databases.

STN has recently added SWETSCAN, a current awareness database offering the tables of contents of more than 13 000 international scholarly and research journals, including publications on technology, medicine and science. The database holds 300 000 records going back to 1993. It has also added WCSA, a bibliographic database containing citations to the world-wide research, technical and trade literature on all aspects of paint and surface coatings. It has 200 000 records dating back to 1976, is updated monthly, and is based on the printed *World Surface Coatings Abstracts* produced by the UK Paint Research Association.

Cambridge Scientific Abstracts has published abstracts and indexes to scientific literature for over 30 years. In addition to its traditional print journal, it now makes its databases available through 13 different commercial on-line hosts and five CD-ROM vendors. CSA's Web-based Internet Database Service provides access to all its databases and to those of several publishing partners.

The US-based Institute for Scientific Information (ISI) has released The CompuMath Citation Index, previously only available in print, on CD-ROM. The rolling five-year file, to be updated bimonthly, covers close to 350 computer science and mathematics journals, and selected items from 7 300 science, social science, art and humanities journals. Another CD-ROM database on novel organic compounds, the Index Chemicus, offers features such as the ability to zoom on graphical abstracts. The ISI has also begun offering the Web version of its citation databases for delivery via companies' intranets. Called the Web of Science, this new version provides access to the Science Citations Index Expanded, the Social Sciences Citations Index and the Arts and Humanities Citation Index, which collectively index the full text of over 8 000 journals.

UnCover is an on-line article delivery service, a table of contents database, and a keyword index to nearly 17 000 periodicals. It holds more than 7 million references which are available through a simple on-line order system and 5 000 citations are added daily. UnCover covers the periodical collections of some of the major university and public libraries in the United States; coverage has been extended to libraries in Europe and Australia.

Web. The service is for users who find the Internet too slow, or those who want to protect their own database. Some Web-based services offer access to journals from various publishers at a single point. This reduces difficulties related to software incompatibility, administration, and management of passwords for users who typically access information from many publishers.

The new technologies also allow information providers to address scientists directly. Biosys, for example, has provided abstracting and indexing services to the life science community for about 70 years. It has changed significantly over the decades, evolving from an organisation relying on volunteers to one with more than 300 paid staff on both sides of the Atlantic. In the 1970s, mainly owing to the advent of on-line technology, its target audience shifted from scientists to librarians. Further technological innovation, notably networking, has enabled Biosys to focus again on the scientist. It offers its databases to all UK universities via the Joint Academic Network (JANET) and has similar arrangements – 50 in all – around the world. Networks have thus allowed the company to reach the scientific researcher directly. The company is planning to use the Internet, first by working with its vendor partners and then by directly offering content on the Web.

The situation differs substantially among disciplines, however, for both numeric and bibliographic databases. For materials engineering, ICT-based distribution of information seems to be generally lagging, with numeric databases on materials available only in-house, notably in universities and in companies. There is insufficient demand for broader distribution of the data. In terms of bibliographic information, the cost of CD-ROMs as compared to hard-copy directories and of investment in technology for what are mostly small manufacturers limits the market for these products (*Information World Review*, 1997).

As information providers turn to the Web, they also add new features to their services. The Web site of the Institute of Physics – which covers 31 journal titles – includes a virtual filing cabinet which enables physicists to annotate, label and store articles from journals to which they subscribe. Users can personalise the menu, pre-set search facilities, configure PostScript downloads, and create a table of contents. An intelligent client-server application, SciFinder, allows users to build structures with a new structure editor, to access chemical databases and more than 1 900 journals through an Internet

Box 7.4. **Some textual databases**

The French on-line service Questel-Orbit includes trademark and company information. The Community Marks database covers all EU trademarks applied for via the OHMI (*Office d'harmonisation des marchés intérieurs*), including full trademark details.

IRLMARK contains the full text of all Irish trademarks. The company has recently upgraded its Imagination software to enhance document display, allowing items of interest to be reprocessed to a format closely resembling the original document, and enabling searches without prior knowledge of commands or database structures.

In Japan, the Patent On-Line Information System is provided by the Japan Patent Information Organisation and the Japan Information Center of Science and Technology (JICST). It involves a comprehensive database of documents available on-line.

Bowker-Saur has made its European Research and Development Database available on-line via a new EU-funded on-line business support system, Alpha-DIDO. The database contains information on companies and individuals – 85 000 research professionals – actively involved in R&D in 39 European countries.

The Community of Science is building a Web-based information service that covers it own database and that of other vendors. This Expertise, Inventions and Facilities database consists of 50 000 first-person narratives by scientists about their research. Other databases provided are Funding Opportunities, an international database on research grant information, Medline, and the US Patent Citation Database. In addition to increasing the quantity of information made available to users, it customises delivery to the end-user who receives a daily e-mail providing details of new additions to databases that may be of interest.

connection to CAS, and to search the CHEMCATS database which has information on 370 000 commercially available chemicals from more than 40 catalogues. Users of MicroPatent can use a new patent-searching tool, PatentSearch, which allows combining a search on a CD-ROM with document delivery via the Internet.

Other types of textual information have also been compiled and stored in databases. Information on patents and trademarks as well as on research activities are valuable for scientists (Box 7.4). Some full-text databases of classic works no longer copyrighted are also being assembled and made available on-line.

In future, users will increasingly benefit from the incorporation of visual and multimedia information into databases; while this will add substantially to storage requirements, falling storage costs will probably keep this from becoming a problem (*R&D Magazine*, 1997*b*). Users will also benefit from improved database search capabilities due to software developments, including systems for gathering and indexing documents using Web crawlers, and from indexes that support actual scientific data as well as documents (Taubes, 1995).

Digital library initiatives

There are vast numbers of projects for developing digital libraries. They currently focus on issues of access costs and digitisation technology (Box 7.5). The key technological issues, however, are how to

Box 7.5. **Digital library programmes**

In the United States, the NSF, the Advanced Research Projects Agency (ARPA) and the National Aeronautics and Space Administration (NASA) are funding a four-year Digital Library Initiative (DLI) with roughly US$1 million per year for each of six projects. Each project spans a wide range of research topics related to large-scale digital libraries, all focused on infrastructure issues. One project looks at receiving materials in electronic format directly from publishers, while another looks at receiving them in paper format and automatically transforming them into digital form. Other projects look at the manipulation of new media such as video and maps, which were previously impossible to index and search. The projects involve university-led consortia, with active participation of client groups, such as specific research communities. They also include commercial enterprises involved in the commercialisation of digital library systems, such as publishers, software houses, stock exchanges, equipment manufacturers, communications companies, libraries, and information and data service providers.

A project at the *Bibliothèque nationale de France* (BNF – National Library of France) involves the provision of 100 000 documents (30 million pages) to academic users in digital form by the end of 1998. Contrary to the practice adopted by the Colorado Alliance of Research Libraries in the United States and the Electronic Document Interchange between Libraries in Europe, where digitisation depends on demand, the French initiative is based on a pre-selected range of manuscripts for digitisation. Researchers will be able to access the digitised documents via computer-assisted terminals located in the BNF (Bouchard, 1996).

The Initiatives for Access project of the British Library was launched in 1993 to investigate hardware and software platforms for the digitisation and subsequent networking of a range of library materials. In addition to enhancing library services and facilitating access, the programme was to establish standards for storage, indexing, retrieval and transmission of data, and to examine copyright issues. One of the projects made the library's major catalogues, which hold over 6 million bibliographic records detailing items from the beginning of printing up to current scientific journals, available over the United Kingdom's Joint Academic Network (JANET) (Purday, 1995).

The US Library of Congress is continuing digitisation efforts begun in 1990. It is digitising core collections of material in the public domain or for which it has permission to disseminate at little or no cost. The Library, which is also the home of the US Copyright Office, is also working on issues of copyright through the Electronic Copyright Management System, which will allow automated copyright registration, and through an electronic journal project which will focus on free journals but ask for the publisher's agreement as if it were a for-fee publication (Becker, 1995).

search and display desired selections from large collections on the Internet. Research on digital libraries concentrates on how to develop the necessary infrastructure to manipulate effectively the massive amounts of Internet information (*Computer*, 1996).

Many traditional libraries which are not yet involved in large-scale digitisation of publications are nevertheless increasing their holdings of electronic documents. These can be powerful tools for research and may reduce subscriptions to printed publications by enabling electronic access to other libraries' holdings. A ''free-rider'' problem may arise, however, if all libraries follow this policy.

Access to unpublished student research stored at universities is generally limited, thereby reducing the transfer of knowledge contained in unpublished scholarly work. It is estimated that over 10 per cent of all research performed in the hard sciences each year had already been done. Providing electronic access to this data source might improve scientists' productivity by enabling them to focus on the appropriate issues. In the United States, the federal government and the ICT industry are collaborating on the preparation of a digital library of unpublished research. As of the 1997-98 academic year, all graduate students in designated programmes at the Virginia Polytechnic Institute will be required to submit their dissertations/theses in digital form. This project will serve as a prototype for all 400 000 doctoral dissertations/theses written by science and engineering students at American universities each year (Koprowski, 1996).

The Digital Library Initiative (DLI) is the flagship research effort of the US National Information Infrastructure Initiative (Box 7.5). Ultimately, the digital library would involve an entire network of distributed repositories where objects of any type can be searched within and across indexed collections. With its many partners and large testbeds, the DLI is structured to encourage technology transfer. Once the DLI has stimulated basic research in various enabling technologies and enabled several digital library testbeds, it is expected that IT companies, traditional libraries, publishers, organisations, and users will join forces to develop the knowledge repositories that will play an essential role for all of society in the 21st century. Earlier similar government initiatives such as those for information retrieval technology spawned Dialog and Lexis/Nexis in the 1970s and Lycos and Yahoo Web searchers in the 1990s (*Computer*, 1996).

Software sharing

Scientific analysis increasingly involves complex software. Technologies such as satellite imaging systems and particle accelerators collect huge amounts of data, the interpretation of which often requires specialised software. Computer networks can provide wider access to such software. For researchers, one of the most important changes wrought by the Internet, and particularly the WWW, has been the ability to upload specialised software code readily. Transfer and use of software via the Internet has become as essential to many researchers as e-mail. Given the increased sophistication of software and the considerable investment required to develop it, the incentive to share software is increasing.

Programmes that earlier would have been written solely for personal use are now made available over the Internet, where libraries of free software for scientific purposes are growing. With the soaring popularity of the WWW, use of Netlib, which has operated since the mid-1980s, has grown tremendously. There were more than 3 million requests to download programmes in the first six months of 1996, compared with 5 million in all of 1996 and 250 000 in 1993. The Web site contains the source code for scores of programmes relating to research in mathematics and computational science. The HPCC programme funded the National HPCC Software Exchange in September 1994, in order to collect software or software descriptions for high performance computing systems and make them available on the Web. The exchange also contains a hardware and software vendor catalogue and information about reports, journals and professional associations (National Science and Technology Council, 1995).

Software sharing presents some difficulties, however. Those who borrow programmes need to know how the software works, as this affects the results they obtain. Relevant documentation is often not available, so that scientists tend to write their own programmes instead of using existing ones. Applying software obtained from another sources to the data of interest is also problematic, since most scientific software is prepared for specific purposes and the data must be formatted to meet its requirements. However, these are minor problems compared to the tremendous advantages software sharing can bring.

Implementation issues

Sharing the exponentially growing volume of accumulating scientific data presents many challenges. In all disciplines, extensive electronic distribution of scientific data has made it more difficult to categorise data according to quality, including the degree of review and certification. Gaps in quality control, incompatible data streams, inadequate documentation, and difficulties in retaining data over the long run have been particularly acute in observational sciences. In the biological sciences, the variety of attributes and qualifiers relevant to individual observations, combined with differences in terminology and usage, make it increasingly difficult for data suppliers to describe data precisely enough to prevent misinterpretation. The problems are also serious in laboratory physics. The need for qualified support personnel in library systems presents an additional challenge.

The extensive use of ICT has also raised various technical, economic, and legal issues related to data access, many of which cross national boundaries. These issues include congestion on the Internet, the rapid obsolescence of information processing tools, and the vulnerability of networks and data repositories to damage. In addition, as the quantity and use of scientific data have grown, and as budgetary constraints have increased, some governments have begun to privatise the generation and distribution of scientific data, raising fears that the scientific community's access to data could be limited by new pricing practices. Current attempts to expand intellectual property rights models to cover the content of electronic databases may also affect the international flow of scientific data, if the special needs of libraries, educators and researchers are not taken into account (National Research Council, 1997).

It is essential that digital databases of scientific information remain accessible to researchers and educators. Various proposals concerning the international distribution of scientific data are currently being examined by the World Intellectual Property Organisation (WIPO), the European Union, and the US House of Representatives. There are concerns that these proposals do not provide adequate safeguards for the "fair use" of data by the scientific and educational communities. Many would prevent databases that are not copyrighted or patented from being copied to other computers without the permission of those who own or maintain the data. The National Research Council (NRC), a private organisation which provides advice to the US government, recently indicated that these proposals could jeopardise basic scientific research and education (National Research Council, 1997). The access to international databases may also be affected by problems of language and translation.

Network funding disparities in different sectors and countries may also threaten equitable participation in development, a concern relevant for all services that will be provided by information infrastructures. For example, access to the Internet among US academics was nearly universal in the early 1990s but was much less uniform in other countries. Researchers in developing countries also need access to electronic communications, both to acquire information and to provide the data they generate in fields dealing with inherently global issues such as food production, biodiversity, and the prevention and cure of communicable diseases. Increased networking has also uncovered various problems related to identification and authentication of users of networks and library systems which delay co-operation and collaboration in service developments. Progress on copyright issues concerning fair use by libraries of digital materials has been slow.

SCIENTIFIC INSTRUMENTS

ICT developments have also significantly influenced scientific instruments and the way scientists use them. The main development is undoubtedly the ever faster and more powerful computers which make it possible to attack scientific problems that were out of reach until a few years ago. Computers aside, the ICT-based tools used vary by discipline. In some disciplines, greater computing power has allowed better visualisation of results and has significantly improved modelling, simulation and analysis. In others, scientific instruments have been revolutionised by miniaturisation or the development of virtual instruments. This has significantly lowered the costs of some instruments and has also made them more flexible.

Computational research

Computers are now among the most important instruments used by scientists. Many research problems, such as modelling the global climate, forecasting the weather, molecular modelling to enable new drug therapies, and simulating automobile crashes, require enormous numbers of calculations. Increasingly powerful computers have significantly contributed to the ability of scientists to solve the equations used in this type of research and enabled them to perform repetitive computations on huge data sets. Computational research involves complex tasks that force the limits of the most advanced computer systems and permit achievements that would have been impossible without them. Computers have, in this respect, revolutionised science.

Key problems in the theory of elementary particles, so complicated that they would have required many years of continuous operation to resolve with the fastest computers available in the early 1980s, have led researchers to design and construct a supercomputer dedicated solely to these issues. In 1995, after about a year of continuous computation, a large 11 gigaflop supercomputer produced its first results, including values for the masses of the proton and seven other hadrons. By that time, the HPCC programme had demonstrated a capability of more than 140 gigaflops, and was on its way towards demonstrating technologies capable of sustaining 1 trillion operations per second (one teraflop) (National Science and Technology Council, 1995). A teraflop machine being built by the Sandia National Laboratories of New Mexico will carry out its calculations with 9 000 off-the-shelf Pentium Pro chips working in concert (Matthews, 1996).

The tasks that push back the frontiers of scientific research remain the domain of HPCC systems at national research laboratories, government defence centres and weather forecasters. Nevertheless, less complex versions of these tasks can be carried out on (networked) PCs and workstations in combination with increasingly sophisticated software. The speeding up enabled by increasingly powerful computing systems is also evident in high-technology industry. Computers have allowed industry researchers to carry out tasks they could not have performed otherwise, thereby enabling more rapid product development cycles and lower design costs. Computer modelling, simulation and visualisation are the main applications driving this process.[4]

The rapid development and proliferation of computer technology has been an important catalyst for several evolving technologies – robotics, computer control and tracking, molecular modelling, and high-speed database search tools – that together have enabled combinatorial chemistry. Combinatorial chemistry makes a large number of new chemical compounds and then screens them for chemical activity in order to build a library. Without computer technology, tracking the novel compounds created during the synthesis and screening procedures would not be feasible (Box 7.6). Combinatorial techniques are one way in which the pharmaceutical industry can cut costs and development time. Researchers have rapidly adopted them, and this has contributed to strategic alliances between equipment and software suppliers. The techniques also hold promise in areas such as the discovery of new materials.

Changing system interfaces and improving access speeds are also contributing to make chemical development modelling faster. Computer simulations of molecular dynamics have proved extremely useful in biochemistry, notably in drug development. The complexity of such simulations and the enormous computational requirements push today's massively parallel computers to their limits. Many prospective drugs that might harm patients can now be identified and discarded by tinkering with images of molecules on computer screens rather than testing the molecules on animals or in time-consuming cell-culture processes.

Visualisation has also grown in importance. Graphics, the core of visualisation activity, require a great deal of computation and memory. Computer graphics can help scientists working on large-scale scientific problems to visualise large amounts of numerical data and find new relationships. Rapid, 3-D

Box 7.6. **Some applications of computational research in science**

Chemistry and pharmacology

- Combinatorial chemistry raises the probability that a new compound will usefully react to a molecular target, such as an AIDS virus, thus shortening the time to market for pharmaceutical products. Previously, researchers trying to create new chemical compounds assembled molecules one at a time in a laboratory in individual test tubes and then screened them against a molecular target, again one at a time (Studt, 1997).
- The ''chemically aware Intranet'' is a Web-enabling infrastructure and tool kit consisting of servers and Java-based applets.[1] The applets can be used to develop interfaces for established computational-chemistry software modules. Consequently, a broader range of scientists, on a wider variety of computer platforms, are able to use a company's drug discovery software at an individual Intranet site. The system's simple graphical user interfaces can be used to launch modelling calculations on the network server and allow all members of the research team to retrieve the results (*R&D Magazine,* 1997*c*).
- Clinical studies suggest that inhibitors of an enzyme responsible for degrading a neurotransmitter may be useful in enhancing memory in patients with Alzheimer's disease. Designing inhibitors requires an understanding of the active site where binding occurs, including the mechanism of product entry and substrate release. Researchers use simulation to understand the mechanics of the molecular dynamics involved (Concurrent Supercomputer Consortium, 1995).
- Researchers at the University of Surrey have created images of six key enzymes used by the human liver or gut to break down foreign substances. These enzymes degrade 90 per cent of the foreign substances entering the body. By manoeuvring 3-D images of molecules on their screens, they can subject prospective drug molecules to encounters with the enzymes. They can then predict whether a molecule will be broken down by one of them, how fast it will be flushed by the body, and by what chemical mechanism (Coghlan, 1996).

Clinical medicine

- A system using virtual imaging and high-performance computers to improve radiation treatments now takes only 20 minutes instead of hundreds of hours to calculate how radioactive particles and related products interact with cancerous matter. The system gives doctors a better idea of dose distributions.
- Standard bronchoscopy is being augmented with non-invasive imaging of the human bronchial tree. The technique, which combines CT and specialised software to create accurate 3-D images, can identify lesions on the bronchial wall and helps doctors make precise measurements of bronchial size. It may substantially reduce the number of regular bronchoscopies, which are less accurate and may cause internal bleeding.

Earth and related environmental sciences

- A synthetic aperture radar aboard NASA's Space Shuttle recently returned almost 32 terabits of data on the Earth's surface. These are being used by the international science community to gain better insights into the Earth's ecosystem, climatic and geological processes, the hydrologic cycle and ocean circulation (Concurrent Supercomputer Consortium, 1995).
- Analytical tools for satellite imagery have generated accurate 2-dimensional maps of ground displacement – used to study earthquake activity – for 40 000 pixels (picture elements), and plans are under way to boost this number to 4 million. In contrast, technology for workstations can only provide information about ground displacements for a few hundred pixel locations scattered throughout an image (Concurrent Supercomputer Consortium, 1995)
- The ability correctly to image complex geologies is a key to reducing the risk and cost associated with oil and gas exploration. It is expected that predicted processor performance improvements over the next several years should make it possible to process such data in real time (*R&D Magazine,* 1997*c*).
- Atmospheric data gathered by sensors at surface stations, on weather balloons, in aircraft, on ships, and on satellites are collected by the World Meteorological Organisation in Geneva and made

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available to member researchers via the Internet. A special programme, Unidata, was conceived as a means to enhance participating universities' ability to acquire and use atmospheric data.

Engineering

- Computer visualisation techniques have also been used to create a 3-D reconstruction of the microstructure of materials. This may contribute to the understanding of microstructural development and to the design of new materials. Previously, the principal tools for probing microstructures in materials were electron microscopes and conventional optical examination.
- In the area of product design, Caterpillar is currently using virtual reality (VR) to design new earth-moving equipment. It once took a year to put together a new prototype, but it now takes only three weeks. Caterpillar's 1996 new backhoe loader was almost entirely designed using the computer animated virtual environment (CAVE). General Motors' engineers are building car interiors using computer code and use the virtual environment to evaluate various aesthetic, ergonomic, and engineering aspects of prototype designs.

Physics

- Physics researchers often use cluster models to analyse interactions of atomic or molecular species with gallium arsenide (GaAs) crystals. These can be of technical importance in modern manufacturing processes such as digital etching, surface cleaning, and atomic layer growing. A recent high-performance computer programme, in combination with newly developed software, has allowed significant improvements in this type of modelling, thus enabling researchers to do experiments on the interaction of free GaAs clusters with ammonia (Concurrent Supercomputer Consortium, 1995).

1. Java applets are small programmes that execute specific files and are platform-independent.

high-resolution colour display is essential for understanding simulation results. Enormous quantities of remote-sensing data about the Earth's environment are being created and stored at an increasing rate. Computers have always played a prominent role in the visualisation of high-resolution imagery supplied by remote sensing. In order for this valuable information to be disseminated, it must be delivered in useable form to those who interpret it. High-performance computers and fast networks can be used to provide animated, customised data quickly.

Powerful new analytical tools for satellite imagery, which may contain millions of pixels, can now extract information about physical processes that previously remained buried within the large data sets. The enormous computational demands of these tools are satisfied by the computational power of high-performance computers and recent developments in the fields of machine learning and data mining. The same tools and techniques can be applied to problems such as global change, monitoring of tectonic activity, and measurements of land-cover dynamics due to urbanisation and global climate change. Images are also an important part of biomedical knowledge. New computational technologies that provide three-dimensional images to supplement traditional two-dimensional biological and medical images, including computer tomography (CT) and magnetic resonance imaging (MRI), are currently being developed (Box 7.6).

Virtual reality technology creates computer-generated simulations and 3-D visualisation of the physical world, with which the operator can interact directly. CAVE (computer animated virtual environment) is used for a wide range of applications, including molecular modelling for drug and product design, medical imaging, manufacturing, cosmology and education.[5] It consists of a multi-person, room-sized, surround-screen, surround-sound, projection-based virtual reality (VR) environment. Images are projected in 3-D onto the walls and floor and viewed with stereoscopic glasses by users who are immersed in computer-generated simulations of data. More than 20 CAVEs or related systems have been installed, one of which is at the German National Research Centre for Information Technology in Bonn. CAVE systems have also already been commercialised.

In engineering, modelling software developed over the past decade has made it possible to computerise the prototype process, allowing researchers to design and analyse complex products using information technology before producing actual parts. Components can now be evaluated on a computer for fit, function, interference with other parts, strength, and cost and production aspects. VR is helping in the design of automobiles, aircraft interiors, submarines and factories (Box 7.6). It can enhance product quality and reduce time to market, and plays a significant role in ensuring the cost-effective manufacture of products. However, VR cannot be used to model all aspects of a product. The databases that underlie VR increase in complexity and size as more product attributes and their interactions are included. Most road holding characteristics of vehicles remain beyond the capabilities of current VR technologies.

Virtual laboratories

The "collaboratory" is an integrated, tool-oriented computing and communications system which supports scientific collaboration. It allows researchers to concentrate on the purpose and results, rather than the mechanics, of communication. It has been defined as "a centre without walls in which ... researchers can perform their research without regard to geographic location, interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information in digital libraries" (National Research Council, 1993). It is an environment in which networked facilities permit all of a scientists' instruments and information to be virtually local, whatever their physical location.

Collaboratories provide new ways to co-ordinate large-scale research projects and to access remote data and researchers. ICT has already made collaborative research possible by wire, as demonstrated by the operation of complex experimental devices such as the Tokamak Test Fusion Reactor at Princeton University in the United States. Video-conferencing has also existed for a number of years. However, the state of the art of video communications, telecommunications and data-exchange tools will need to advance further to create seamless electronic platforms for collaborative research. The basic technical requirements for a collaboratory relate to data and software sharing, control of remote instruments, and communication with remote colleagues.

Scientists increasingly use remotely controlled instruments. Remote control improves researchers' access to scarce scientific equipment and may contribute to more efficient use of resources in a time of budget restraint. For example, browser software allows researchers anywhere to use instrumentation at the University of Illinois. They can conduct MRI scans from their PC or laptop. The system (NmrScope) is available on the Web through a University of Illinois server. Once a sample has been delivered to the university, an authorised researcher can connect to the server, which shows a form indicating instrument settings and a menu of possible functions (move slice forward, zoom on, etc.). The experiment is carried out at the click of a screen button and the resulting image is returned to the researcher's computer screen (*Inside R&D*, 1996).

Controlling instruments through a computer network and collecting data regardless of the instruments' location is particularly beneficial in cases where instruments are inaccessible and the environment is unfriendly for collecting data. This is important in space physics, for example, where ground-based instruments are positioned in remote locations and space-based instruments may need to be repositioned while a mission is in progress. In physical oceanography, the ability to perform real-time reading of remote instruments can save time and money and result in a greater volume of higher-quality data.

Many projects involving remote control of instruments are under way, of which the Hubble Space Telescope is a classic example. The HST must operate most of the time autonomously, since it is not in direct communication with its controllers for more than half of its orbit. It must be able to receive occasional instructions from the ground and transmit data to Earth when communication links are available. Other sharable instruments include electron microscopes, particle accelerators and colliders, autonomous underwater vehicles, pilot-less aircraft and autonomous land rovers.

Several collaboratories involving remote control of instruments are also under way. In the United States, the Pacific Northwest National Laboratory in Richland, Washington, has developed an environmental and molecular sciences collaboratory which permits remote operation of the laboratory's two nuclear magnetic resonance (NMR) spectrometers and other instruments. The US Department of Energy has launched the Diesel Combustion Collaboratory Project, which links researchers at three government laboratories and the University of Wisconsin, Madison, the aim of which is to design diesel engines that produce less pollution.

A system provided by the Upper Atmospheric Research Collaboratory, University of Michigan, Ann Arbor, links researchers in six American universities with a US-funded radar in Greenland that continuously monitors the upper atmosphere, allowing researchers to observe the interaction between the solar wind and the Earth's atmosphere. In the past, the researchers had to fly to the station, sit in a trailer with instrument displays, record the data on computer tapes or disks, take these back to their laboratory and analyse them over the next few months. Since 1993, researchers observe the data over the Internet directly from instruments connected to a radar. The software on the researchers' home computers includes a text-based chat window through which the researchers can discuss the data and send instructions to technical staff in Greenland.

Network characteristics currently constitute an important obstacle to wider introduction of remote instrument control and collaboratories. The current lack of bandwidth means that scientists often cannot use the Internet to send data to participants in a collaboratory.[6] Owing to transmission problems, not only may a crucial instruction fail to reach a remotely controlled instrument, but the instrument may even be damaged (National Research Council, 1993). Another difficulty is the need to ensure that all participants update their software as changes are made in software on the collaboratory's central computer. Java, the new Internet computer language, is expected to solve this problem, as Java "applets" can be automatically updated from a central library.

Virtual instruments

A scientific instrument typically acquires data by collecting the output of a sensor, turning the readings into an electrical signal, analysing the signal – usually with the help of a microprocessor inside the instrument – and presenting the analysed data in a meaningful way. Until recently, this required dedicated benchtop instruments for each of several types of measurement (temperature, pressure, voltage, etc.). During the 1990s, multipurpose workstations and PCs, together with software systems that provide graphical programming capabilities, replaced many of these dedicated instruments.

The instruments become "virtual" as the user, rather than the instrument maker, determines precisely what the equipment does by matching the software to the sensor needed for each measurement. Technicians who required expensive instruments for each specific test can now create their own by changing programme settings. This dispenses with many of the costly parts of a traditional instrument. For example, a combination of chip-testing equipment that only performed a limited number of tests at a cost of US$220 000 could be replaced by a more versatile virtual instrument built from off-the-shelf parts at a cost of US$8 000. Similarly, ventilation systems built for factories and offices can be tested with a single piece of equipment that can be reprogrammed endlessly to mimic the demands of different buildings (*Economist*, 1996*b*).

The tremendous increase in the processing power of PCs has contributed to the realisation of "virtual" instruments. It has supported extensive software-based developments that have simplified complex tasks such as data acquisition and monitoring, modelling and visualising. Visual programming software technologies have allowed faster development of software which is also more easily understood and easily reused in different problems. New software and regular upgrades add functionality without requiring users to learn new programming techniques and also allow faster execution. The latest version of the instrument programming language LABVIEW, for example, provides multithreading, distributed computing tools, graphical differencing tools and instrument wizards to set them all up (*R&D Magazine*, 1998).[7] Software is now frequently compatible with Microsoft's Windows. Graphical output can increasingly be embedded in standard word processors, PowerPoint presentations, Web pages, lab notebooks, reports or other graphics programmes.

In addition, new user-friendly custom interfaces and simple menu choices and control buttons now enable users to view results from many test stations. One of the next stages will be to use such software to access, monitor, and control remote data locations, possibly over an Internet with expanded bandwidth capabilities, since current capabilities may not permit real-time control and debugging (*R&D Magazine*, 1997*c*).

More simply, virtual instruments can reduce the number of sensors required for a given task. This is useful in hostile environments where the tendency is to use multiple temperature probes and average readings to compensate for degradation of calibration and accuracy. For instance, the self-verifying sensor (SVS, from AccuTru) ties the basic probe to an electronics package that constantly monitors temperature calibration against established references. Real-time temperature displays and software diagnostics readily identify probe failures when they occur. SVS eliminates the need for multi-sensor units because the sensor's accuracy is monitored constantly. It could contribute to energy savings, improved quality control, reduced waste and lower maintenance costs and has potential applications in many energy-intensive manufacturing processes (Crowford, 1997).

More complex virtual instrumentation may combine various technologies, such as high-speed digital recording and massively parallel computing. In the case of radio astronomy, for example, conventional special-purpose analog filter bank spectrometers and auto-correlators used in pulsar astronomy, which typically took years to design and develop, were replaced by a general-purpose, software-based digital system implemented in as little as nine months (Concurrent Supercomputer Consortium, 1995).

Miniaturisation

Miniaturisation is a driving force in the development of electronic, biomedical and electromechanical systems. Instrument packages and measurement tools continue to shrink in weight, volume and energy needs and augment in performance, sometimes by orders of magnitude. Over the next decade, the capability of microanalytical instrumentation may be further revolutionised, as technologies of chemistry, biochemistry, micro-machining, electronics, and microelectronic fabrication are combined. Currently, micro-instrumentation is developing along two lines: biomedical, chemical and micro-fluidics systems on the one hand; and physics-based systems on the other.

ICT is not the only source of miniaturisation, but the growth in micro-instrumentation does depend in part on developments in micro-machined, micro-electromechanical systems (MEMS) components which contribute to size reductions for sensors and electronics. Systems "on-a-chip" are being developed and tested for many applications, with many more envisaged. All the manipulations typically carried out by a chemist with beakers and test tubes can now be performed on a very small platform. These tiny micro-machined devices, which look like microscope slides, are capable of sophisticated chemical analysis. Chemists and biochemists are increasingly applying new micro-chemical processing to on-a-chip integration of sample treatment, chemical processing, separation, detection and analysis.

The principles that have shrunk the chemistry lab to the size of a chip are the same as those that for decades led the way in the miniaturisation of electrical circuits. The new device is an optical version of the common computer microchip, but it uses tiny lenses and filters instead of transistors and diodes. It is typically made of glass, silicon, or quartz and is etched with hairline pathways for sample liquids or powdered solids, rather than for electricity. Depending on the chip coating, different materials can be analysed. Tiny amounts of test samples are examined under laser light, which turns the chip into an inexpensive sensor. The moving samples interact with a fluorescent dye in a separation channel on the chip and the fluorescent glow given off by the sample is analysed on a computer, giving quick, reliable results (Cable News Network, 1996 and 1997).

Early chip-level diagnostic and micro-fluidic systems are currently being refined for quantitative and qualitative chemical analysis, multi-component blood analysis, flow cytometry, and even DNA replication. A specific chip (the GeneChip by Affymetrix), which contains tens of thousands of different fragments of DNA, can now be used to identify any known DNA sequence. It can accomplish in about an hour a procedure that took days or even months using the traditional process of gels, glass plates, and electric charges (Mercury Center, 1996). Combined with the Oak Ridge National Laboratory's chemical lab-on-a-chip technology, a polymer fabrication technology developed at Harvard University will soon enable chemical analysis and medical diagnostics with minimal use of reagents and much shorter lab time. The ability to produce polymer lab chips will greatly extend the potential applications of this technology, both inside and outside the laboratory. A portable version of the lab-on-a-chip is also being developed for field testing, using a portable computer linked to the lab-on-a-chip.

There are also physics-driven applications of the lab-on-a-chip, such as the laser Doppler anemometer on a chip developed for measuring Martian wind velocities. Miniaturised planetary probe/instrument assemblies permitting surveys of large areas of planetary surface have also been designed for future Mars missions. Units weighing less than 2 kg will be deployed from the mother ship, land like bomblets, and penetrate up to 0.5 m into the Martian surface. They can be tethered to a package near the surface, from which an antenna can be extended to transmit data to an orbiting relay above.

These systems have a broad range of other applications, in addition to those in medicine (clinical operations, drug discovery) and crime lab testing (including forensics). These include environmental applications (detection of pollutants) and military applications (detecting biological warfare agents). Tests to identify bacteria, which currently take 36 to 45 hours, could be done in four or five hours with one of the chips recently developed and thus contribute, for example, to detection of potentially deadly bacteria in food processing.

ELECTRONIC PUBLISHING AND SCIENCE

Electronic publishing can significantly increase the speed of communicating scientific results. It may broaden access to scientific research and allow the inclusion of electronic links. While it might reduce publication costs, this remains unclear and depends on how electronic publication is used. The development of electronic publishing differs significantly among disciplines. The implementation of electronic publishing faces important problems involving peer review, protection of intellectual property, and the archiving of electronic media.

The advantages of electronic publishing

Electronic publishing has been acclaimed as a major advantage of the Internet, and information technologies in general, to the science system. The cost of scientific journals has risen sharply over the past decade, and many universities find it difficult to obtain sufficient funding for their libraries. Electronic publishing has been hailed as a potential solution to this problem, while having additional benefits that make electronic media attractive. Other possible benefits include a shorter time between submission and publication, the enabling of multimedia presentations and tailored reading, the inclusion of hypertext links to other relevant material, and the possibility of publishing for oneself.

The claim that electronic publishing can significantly reduce publishing costs has been made in various quarters. Several claim that electronic publishing costs are a quarter of those of print publishing. Many of these estimates, however, do not cover all the costs of operating full-service electronic information services. In fact, commercial publishers discover unexpected costs when establishing electronic journals (Kling and McKim, 1997). For instance, Johns Hopkins University Press is licensing more than 40 humanities journals to universities under a programme called Project Muse. The project has still to break even, despite several hundred university subscribers. About 50 per cent of Muse's costs arise from the development and maintenance of software to validate subscribers and ensure the system's integrity. MIT Press found that while certain costs, such as printing, fell sharply, software costs were substantial; also, they had to engage in greater efforts to market the electronic journals. While these two examples refer to mixed journals, which are distributed both in print and electronic format, the costs of purely electronic journals are also not as low as they may seem: many are effectively subsidised. The problem of recovering their costs is particularly acute for non-commercial publishers such as scientific societies, many of which derive a large portion of their operating income from journal sales to libraries.

Moreover, the costs of consuming electronic media are not zero (Kling and McKim, 1997). Consumers of science journals are often supported by state-of-the-art networking and computer systems, as well as technical staff. These resources are not free, and many professional users and scientists face difficulties in using electronic media effectively because the social and technical infrastructure of the workplace is underdeveloped. These problems are compounded if research requires collaboration across many different technological standards and systems.

While electronic publishing might also reduce the time between manuscript submission and date of publication, this would depend greatly on the character of the electronic publication (Kling and McKim, 1997). Table 7.4 gives an illustrative example of the time lags involved. The first column shows the conventional scenario, in which all communication is by mail. The second scenario reduces time lags somewhat by using courier mail to send manuscripts and in the peer review stages. In the third scenario, the manuscript is sent by e-mail, thereby cutting down transmission time a little more.

The fourth scenario assumes an electronic journal, but one for which a package of articles needs to be available before a new issue is published. Compared with the conventional scenario, this scenario has cut the total time lag by about one month. More gains are made if the editor does not wait for a complete package but allows articles to be published individually in electronic form. The total time lag under this scenario is similar to that of a pre-print system, as used in sub-disciplines of physics, where articles are printed and distributed once they have been accepted by a journal. The shortest time lag – a few days – between sending a manuscript and publication occurs when articles are pre-printed at the time of submission.

The importance of scientific working practices

The appropriateness of systems of electronic publishing differs sharply among disciplines (King and McKim, 1997). The most extreme example, with pre-prints made available at the time of submission to a journal, is in high energy physics. This type of research evolves around a limited number of expensive instruments and involves large collaborative research groups, sometimes with over 400 scientists. Working practices for this type of science differ sharply from those of other disciplines. The collaborative structure of the work and the long time horizons involved mean that the research has been extensively reviewed before it becomes a manuscript submission to a journal. A reviewer is unlikely to find major conceptual errors and is also unlikely to add much in terms of editing. Furthermore, there is little risk of plagiarism. The scientists involved are few and well known, access to the equipment is extremely restricted, and the time to publication is very short.

This is very different from a discipline like biology. Biological research is quite fragmented and involves many small research groups and individual researchers. Biological research is also easier to extend or copy, and research facilities are common and relatively cheap. Biology researchers are therefore more reluctant to share research prior to publication. Some areas of biology, such as cancer and AIDS research, are also closely linked to commercial applications, and researchers in these fields often work with the private sector. These researchers are often unwilling to share research methods, materials and results, as the work can be lucrative and is often highly competitive. Publication in biology is centred around peer-reviewed journals, and pre-prints are quite rare.

A recent editorial in the *British Medical Journal* proposed a system which treats print publication as the final medium in a process based on significant electronic pre-publication (Delamothe, 1996):

> "Researchers might begin a study by posting their protocol on a Web site for review by their peers, possibly followed by a call for collaborators and for assistance in recruiting research subjects. After the research is completed, early drafts of papers would be posted for comments and criticisms, which could then be taken into account in further drafts. At some point the paper would be transferred to a journal 's Web site (if the editors thought it had a chance of eventual publication). It might be made available on limited access (to specialist referees and statisticians) or on open access (for anyone to make comments). At some point the raw data from the study would also be posted on the Internet.

Table 7.4. **The speed of scientific communication under different scenarios**[1]

In days

	Conventional scenario	Courier scenario	E-mail attachment scenario	Electronic journal, with issue packaging	Pure electronic journal, with individual articles	Pre-print system, article sent at time of acceptance	Pre-print system, article sent at time of submission
Transmission of manuscript[2]	10	4	2	2	2	2	2
Peer review[3]	63-93	51-81	47-77	47-77	47-77	47-77	0
Journal issue packaging[4]	30-120	30-120	30-120	30-120	0	0	0
Journal production	20-80	20-80	20-80	20-80	4	0	0
Delivery of journal[5]	5	5	5	1	1	1	1
Total	128-308	107-287	104-284	100-280	54-84	50-80	3

1. The table shows an illustrative scenario of the impact of electronic publishing, in the time between the sending of an article by the author to a journal, until its delivery in published form to the author. The scenarios assume that the paper is accepted by the chosen journal.
2. This combines the time from author to the editor, and that from editor to production manager.
3. This measures the time between the editor's receipt of the manuscript and its acceptance.
4. This is the time taken by the journal editor to produce a sufficient package of articles and send them to production.
5. This measures the time it takes for a subscriber – or the author – to receive the completed journal issue.

Source: Based on Kling and McKim, 1997.

> After further revisions the electronic version of the paper would be given the journal's imprimatur and made available simultaneously in hard copy and electronic form. The time elapsing between submission and the journal's offer to publish and between ultimate acceptance and publication could dwindle from the current months to days (or even hours)."

Crucial factors determining scientific communication in each discipline are collaborative practices (team composition, sharing of data, commercial character of the research), the use of pre-journal publication formats (pre-prints, working papers or conferences), and the way in which research journals are used (Kling and McKim, 1997). Research journals should be viewed as a package of communicative properties, including announcement, access and trust. The move from print to electronic format may erode these properties and thus erode the (perceived) value of the journal. Pure electronic journals may, for instance, take insufficient steps to announce the journal's availability or may limit access, thus making the journal unavailable to Internet search engines.

Electronic publishing is thus likely to develop a range of formats, depending on each discipline's working practices, in particular differences in peer review. The practice of high energy physics, which is often used as a model by advocates of electronic publishing, is unlikely to be adopted by scientists in other disciplines. This also implies that the time lag between sending a manuscript and its availability in electronic form is unlikely to be reduced to "a few days". However, electronic publishing is likely to speed up scientific publication.

Implementation issues

A number of problems may affect the move to electronic publishing. The first is the potential impact on intellectual property rights. Two issues are critical in this respect, namely how to validate authorship and the date of publication, and how to enforce intellectual property rights (Bates, 1994). The problem for governments is to balance the public good character of scientific research and the need for open access to scientific results with the intellectual property rights held by various stakeholders. Enforcement of property rights is severely handicapped in the case of electronic information, as it is easier to plagiarise ideas, text and graphics stored in this format (Bates, 1994).

Another problem is archiving. Rapidly changing hardware and software may substantially reduce the longevity of electronic information. It remains unclear where responsibility for archiving lies.

There is also a risk that the public might trust unreliable articles. A major point of controversy over electronic media is the extent to which scientists (or others masquerading as scientists) can or will publish unreliable research reports that many people will wrongly trust. This risk is reflected in periodic reports of fraud in biomedical research or in the way that cold-fusion physics was promoted largely by bypassing rigorous research reviews (LaFollette, 1992). Others worry about the risks of "junk science".

These problems may be difficult to resolve. However, electronic journals can indicate whether the papers they publish have undergone a proper peer review process. For instance, the Association for Computing Machinery (ACM) has established a digital database for its electronic journals. The database accommodates pre-print practices and allows readers to attach comments to disclosed documents. A subset of the documents in the database is marked as "published", certifying that they have passed a peer review process (Denning, 1996). The ACM also guarantees that it will protect authors from copyright infringements. The ACM procedures suggest that the success of electronic publishing will depend greatly on a proper and rigorous process of peer review. Leading scientists may be reluctant to embrace the electronic medium unless proper peer review is guaranteed.

EDUCATION AND TRAINING OF SCIENTISTS

ICT contributes directly to teaching, learning, and research and provides a support function to researchers by enabling access to digital libraries, archives, databases and information services. ICT can have positive effects on learning by opening up access to educational resources, by supporting the learning process, and by supporting skill development. However, this requires efficient planning, and learners, teachers, and institutions that are willing and able to adapt. The enhanced use of ICT in teaching may also help to improve academic productivity, thus enabling scientists to spend more time on research. So far, there is little evidence that this is so. Scientists may also need better education and training to use ICT efficiently for scientific work.

ICT opens up access to education by removing many of the temporal and spatial constraints to information and knowledge. Furthermore, the availability of learning materials based on ICT can greatly improve learning resources. Computers support the learning process by helping to create a student-centred rather than a teacher-centred environment, one which is more flexible and adaptable to individual needs. Working groups formed around the computer can also help prepare learners for a world in which many problems are addressed by teams. Nevertheless, this potential can only be realised with high-quality software and significant efforts by all those involved (OECD, 1997*d*).

Efficient use of ICT allows students to develop the kinds of skills and competencies that many educational reform panels have viewed as essential (OECD, 1997*d*). Basic skills such as arithmetic can be mastered with computer-aided drill and practice, while writing skills can be developed with word processing, which makes writing and revising easier. A deeper understanding of complex scientific concepts in mathematics and science – particularly where experiments are not feasible or are dangerous – can be gained through computer simulations. Last but not least, the use of these technologies for learning may establish familiarity with technologies that are increasingly needed by individuals living in a technology-driven society.

Use of ICT in science education and training

Many of the uses of ICT described in previous sections also apply to education and training. Communication between teachers and students is facilitated by these technologies, and both benefit from sharing resources in digital format. ICT may also help science students as it helps researchers, for instance by providing increased computational possibilities and access to remote scientific instruments from the classroom, or by enabling students to participate in actual research.

Two distinctive uses are particularly relevant to science education and training. ICT-based course material (content) usefully supports the understanding of complex scientific phenomena, although it can also supplement conventional classroom activities for many other subjects. This is also true for ICT-based distance education. The use of these technologies for lifelong learning, although not for higher education, was covered extensively in an earlier report (OECD, 1997*d*).

Successful deployment and use of ICT in the classroom still largely depends on pioneering principals and teachers. Nevertheless, data from a recent US survey indicate that it has moved beyond early adopters in higher education institutions into the ranks of mainstream faculty. While data for 1995 reveal that use of ICT in courses is gradually moving beyond routine use, the 1996 survey only found modest gains in the proportion of college courses using such resources, possibly owing to efforts to consolidate earlier gains or implementation issues (Table 7.5).

In the United States, a third of higher education institutions offered distance education courses in the fall of 1995 and another quarter planned to do so over the following three years, whereas 42 per cent neither offered such courses nor had plans to do so (US Department of Education, 1997). About half of both two-year and four-year public institutions offered distance education courses, but among private institutions, only 2 and 12 per cent, respectively, did so.

To supplement the classroom

Technology-mediated instruction can be implemented in various ways. It may simply be included in conventional lecture-centred instruction. ICT can significantly enrich the range of resources traditionally available in a classroom: computer software, videos, resources on the Internet, and hypertext links to relevant reference materials. ICT-based content make lecture content more vivid than textbooks, and also can be used for practice and testing. Technology-mediated instruction appears to provide positive results in learner productivity, as indicated by higher mean examination scores and shorter instructional time than in traditional teaching, but may increase the instructor's workload (Gifford, 1997).

Table 7.5. **Results from the US survey of IT use in higher education**

In per cent

	1994	1995	1996	1997
Planning				
Strategic plan for role of IT			43.4	48.4
Financial plan for IT purchase and replacement[1]	22.0	22.0	28.1	28.9
Technology use				
Proportion of courses using IT resources:				
E-mail	8.0	20.1	25.0	32.8
Computer classrooms	16.0	24.0	24.0	22.6
Computer simulations/exercises	9.0	14.0	14.4	14.5
Presentation handouts	15.1	25.7	28.4	33.0
Commercial courseware	11.0	18.5	18.5	16.9
Multimedia resources	4.0	8.4	11.0	13.4
CD-ROM-based material	4.0	9.0	8.9	11.4
WWW pages		6.2	9.2	24.0
Internet resources		10.9	15.3	24.8
In institutions:				
WWW and Internet				
On site		55.2	79.4	
Plan for use in instruction		24.4	30.1	34.2
Plan for use in distance education		12.5	17.5	24.8
Plan for use for off-campus promotion (marketing)		38.1	56.8	58.3
Recognising IT in tenure and promotion committees			12.2	12.2
Mandatory IT requirement for all students[2]		33.1	40.0	40.3
Considering Internet2 access essential by 1999				
Universities				> 50
2- and 4-year colleges				< 33
Single most important IT issue confronting institution over the next 2-3 years				
Assisting faculty to integrate IT into instrumentation			27.3	29.6
Providing adequate user support			24.1	25.0
Enhancing/expanding user networks			17.6	11.8
Financing the replacement of hardware and software			17.4	20.4
Using IT effectively in distance education			4.1	11.8
Providing universal access to the Internet			5.8	3.4
Mandatory technology/computer fee for students		28.3	36.9	38.5
Campus systems connected to the network		62.5	70.8	81.1

1. 15.1 in 1990.
2. 31.4 in 1992.

Source: Green, 1994; 1995; 1996; 1997.

More and more educational software has become available in recent years. Content-specific computer or video software used for directed instruction is known as courseware (Box 7.7). It may be created for education and/or aimed at professional scientists and academics involved in both teaching and research. The *Atlas of the Oceans*, for example, can be used in education to illustrate basic principles by taking a point on the globe and comparing data about that point over the year. For the research community, its advantages are the open format of the data, the inclusion of hyperlinks to references, data and video sequences, and the search capabilities available (*Information World Review*, 1996).

When integrated into the curriculum, computer-based integrated learning can offer extensive instructional activities, cover a range of subjects and grades, and be used to teach core academic skills. However, it requires extensive adaptation of teaching methods and organisation. It is difficult to develop such courses and involves a broad range of resources and capabilities. The "mediated learning" model, for example, is designed to improve the instructor's pedagogical effectiveness and the student's learning productivity by shifting the role of the instructor, the student, and the textbook to provide a more interactive, individualised environment (Gifford, 1997). It is particularly well suited to

Box 7.7. **Courseware for science education**

Computer software, designed for use by chemistry educators in lecture demonstrations or by individual students, uses interactive animation to demonstrate more than 50 key organic reactions in order to show changes in molecular geometry, solvation, and charge distributions.

SIRS, Simulations and Interactive Resources, III (*Journal of Chemical Education Software*) provides a collection of 23 programmes on CD-ROM designed to support interactive lectures in introductory chemistry. The programmes include animation, illustrations, and simulations of experiments in areas such as the periodic table, atomic structure, chemical thermodynamics, and acid-base equilibrium.

Interactive Physics (Knowledge Revolution) on CD-ROM is an interactive tool that allows teachers and students to explore concepts such as motion, time and distance, but also force equations, energy and mechanics. Using a mouse, students can draw a model on a computer screen, assign values, and run simulations. Measurements can be taken while a simulation runs.

A multimedia CD-ROM (*Atlas of the Oceans: Wind and Wave Climate* from Elsevier Science) integrates reference text, satellite data and digital video sequences of oceans. It focuses on wind and wave parameters from which contour maps and graphs can be produced interactively by the user. It also includes a searchable electronic book on global wind and wave behaviour.

University students may research the Earth system using Earth observation data and information over the Internet. The *Earth System Visualiser*, developed by the Earth System Science Community, enables the analysis and comparison of Earth system parameters using a variety of plot types. Students also learn how to evaluate and publish the results of their team research on the Internet.

A WWW site (Hewlett-Packard Co.) contains articles, newsletters, slide presentations, tutorials, and other classroom resources for people who teach engineering. The site also has tools for teaching the basics of electronics, with over than 60 interactive experiments at http://www.hp.com/info/college.lab

courses that are hierarchical, linear and stable in their structure and content, and therefore to a large percentage of lower-level courses in colleges and universities, notably entry-level mathematics.

A partnership of faculty, researchers, designers, multimedia developers, and computer scientists has resulted in the development of a first generation of such courses which can be used by campuses across the United States and which are supplemented by an infrastructure that provides support, maintenance, research and continuous improvement of the product. The system is built around a database that captures detailed information on student performance. On the basis of that information, it is claimed that pass rates have improved by 15 per cent on average and by 40 per cent on some campuses, and that retention rates have increased at 80 per cent of campuses using it. Subsequent course performance data, still being evaluated, suggest that users continue to achieve well in their studies.

In another example, Rensselaer Polytechnic Institute (RPI) replaced its traditional freshmen physics, chemistry and calculus courses, as well as some advanced courses, by ICT-based processes and achieved better outcomes for learners and somewhat lower costs (Table 7.6). The courseware used for these "studio" courses combines multimedia instructional materials, simulation building tools, calculation tools, and tools to gather and analyse data. The courses require almost no lectures and few contact hours. Learning takes place through guided inquiry supported by a modest amount of reading. Learning-by-doing experiments are carried out in pairs at students' pace at their convenience. Flexible physical arrangements support both group work and mini-lectures. The classes rely on commercial software and hardware developed for research purposes and on courseware developed specifically for the courses.

Distance education and virtual universities

Distance education has existed for a long time. However, educational institutions have only recently become engaged in ICT-based distance education. The WWW, for example, can now be used as

Table 7.6. **Cost of traditional and studio physics at Rensselaer Polytechnic Institute**

In US$

	Salaries	Space	Total
Traditional			
– Lecture	13 333	3 697	17 031
– Recitation	136 250	3 300	139 550
– Laboratory	77 340	6 600	83 944
– Total	226 927	13 597	240 524
Studio model	157 500	12 000	169 500
Difference (in %)	–31%	–12%	–30%

Source: OECD, 1996*q*.

an integrated interface for distance learning, often called the virtual classroom or the virtual campus. Virtual environments and simulations – which are likely to continue to transform scientific experimentation and industrial practice – are expected to play an increasingly important role in education and training and may help improve student achievement (National Science and Technology Council, 1995).

Broad cost comparisons of traditional and distance education indicate that the fixed costs of institutional buildings, purchase of equipment, and development of textbook material for traditional classes, on the one hand, and, on the other, those for the establishment/extension of telecommunications networks and the purchase/development of materials for distance learning, are not fundamentally different. However, the fixed costs account for a significant proportion of the total budget of distance education, whereas the variable costs that depend on student numbers are more important in traditional education (Danish Ministry of Education, 1993). Once the number of students which makes it worthwhile to establish distance learning has been reached, it is cheaper to provide the course to additional distance learners than it would be to traditional learners.

The principal advantages of the new technologies for distance education are that they effectively break down the distance barriers and that they are increasingly interactive. These technologies are now being used for distance education by a wide range of educational institutions, among them elite private universities for their graduate programmes. It is important to note that the educational significance of recent telecommunication developments lies in the possibilities they offer for guided self-instruction. The quality of the education provided depends ultimately on the quality of the courseware and the courses offered. These have to be conceived, devised and produced to support guided self-instruction.

OECD countries differ considerably in the use made of the opportunities offered by new technologies for distance education. Several European countries and Japan have used them for open universities in an attempt to remove the barriers raised by conventional institutions. Other European countries, such as France, Norway and Sweden, have added distance education to face-to-face education in dual-mode universities. This has also been the case with post-secondary education providers in Australia, Canada, New Zealand, and the United States, where part-time and off-campus students have traditionally been a significant part of enrolments (OECD, 1996*p*).

Elite private institutions, notably in the United States, have been more selective. While these institutions still make limited use of distance education, their presence may add legitimacy to the distance learning movement. They focus their efforts on specialised degree programmes and courses that can be exported internationally to companies and universities (*Chronicle of Higher Education,* 1997*a*). While some of these institutions are just beginning to examine how to expand these programmes, others, such as Stanford University, have been involved in distance education for years, broadcasting graduate courses in engineering to corporate sites throughout the country. Columbia University supplies graduate university courses to companies in Asia. It has already converted courses in art history, chemistry, Earth sciences, and international affairs to Internet-based formats.

Some pilot projects go beyond university-provided courses at a distance. Pilot projects using the UK SuperJanet network in medicine have permitted students at a remote site to view surgical operations via a video camera, to control the camera remotely, and to maintain audio contact with an instructor. In the United States, a high-speed multimedia network, which links five universities involved in the Science and Technology Center for Computer Graphics and Visualisation, is used for courses, seminars, workshops, and other interactions between students and faculty at the five sites. Each participating university contributes a different area of expertise, *e.g.* three-dimensional computer modelling, software-controlled machinery, VR, computer graphics, and rendering. This NSF-funded network provides graduate students and postdoctoral fellows with a training experience that is, according to the NSF, more than the sum of its parts and creates a model for distance learning at all educational levels. The high-performance network supports simultaneous audio and video conferencing, remote control of interactive software demonstrations, and data and graphics sharing (National Science Foundation, 1995).

The role of scientific instruments

In institutions of higher education, research, teaching, and learning are closely linked. Scientific instruments can be used to combine education and research. The influence of ICT on scientific instrumentation described above can also be observed in the education and training of scientists. Technology, notably new and affordable software and equipment, can contribute to training even in the undergraduate lab.

For instance, new computer technology may help to release students from aspects of laboratory experimentation, such as repeated data collection, which are of limited pedagogical value, and to focus their attention on the meaning of the data, thereby making better use of laboratory time. This is the goal of a US project to integrate computers into the laboratory. It provides computers equipped with interfaced probes and sensors for measuring temperature, pressure, pH, and conductivity that automatically record, plot and analyse data.

New and more affordable information technologies can also help to give the undergraduate, even the high-school student, access to more complex aspects of science. Educational modelling software can now bring molecular modelling, once the territory of theoretical chemists, into the classroom. ICT may sometimes also permit science students in universities to obtain remote access to and control of instruments in national laboratories. This is helpful because universities do not necessarily possess all the scientific instruments that would be useful for teaching science students.[8]

Results achieved with ICT in learning

The effectiveness of ICT for education and training has been examined in various contexts and compared to traditional teaching methods. The studies have consistently claimed that ICT-based instruction is equivalent or superior to conventional methods and may markedly improve achievement and attitude (OECD, 1997*d*). The specific contribution of Internet to higher education is currently being examined in France and the United Kingdom. New initiatives, which build on experience gained in the use of ICT, may further improve results; one is the French project to network universities specialising in engineering (VISIO-U), which builds on the experience of *École Nationale Supérieure de Cachan* in the use of ICT.

The conclusions of several of these studies, however, have been questioned. It is generally agreed that tests of student achievement are crude. Also, spending for ICT has frequently displaced spending for other areas, without due evaluation of their relative merits. Moreover, use of ICT has frequently been accompanied by changes in the classroom approach which may themselves have improved learning. Even when use of ICT is clearly successful, there are important caveats: a few recent applications can substantially expand children's understanding of maths and science, but only if they are properly used; also, because the best educational software is usually complex, it is better suited to older students and more sophisticated teachers. The use of ICT requires close examination of specific situations, rather than across-the-board implementation.

In any case, ICT is not equally relevant to all subjects. An emphasis on outcomes, which derives from a focus on individual assessment, has allowed ICT to make significant inroads into foreign languages, mathematics and writing, where outcomes can be easily evaluated. ICT has a strong potential to increase learning in areas of codified knowledge and algorithmic skills. Fields concerned with questions of meaning and value, or of culture and philosophy, may be less suitable to extensive computer mediation.

Implementation issues

The classroom revolution foretold decades ago in many OECD countries has failed to take place (OECD, 1997*d;* Geoghegan, 1996). Technology has not diffused throughout education. While technological development, especially of courseware, and technology acquisition still pose many difficulties, human aspects appear also to be a significant constraint. Many educational institutions continue to deploy and use information technologies without due planning (Table 7.5). As of 1997, less than half (48.4 per cent) of American colleges and universities had a strategic plan for institutional goals and implementation priorities for ICT, and only slightly over a quarter (28.9 per cent) had a financial plan that addressed acquisition, amortization and replacement issues. Funding is frequently based on one-off budget allocations or special appropriations and competes with other needs, such as more teachers, smaller classes, new books, maps, videos, and microscopes for the science lab (*Chronicle of Higher Education*, 1997*b*).

In many countries, scarce funding inhibits the large front-end investments needed to exploit fully the potential advantages of ICT (Massy and Zemsky, 1995). The courseware market may also be constrained by the (small) market for certain languages, as in Finland and Norway. Producing quality courseware is very complex, and product development and improvement an ongoing process.[9] Although hardware and networks are generally available, costs remain an issue.

In trying to remedy the funding problem, a growing number of universities in the United States are charging students a special technology fee. More than half of all public colleges and universities did so in 1996, assessing fees ranging from US$20 to US$200 a year, and some institutions have attempted to charge students on a use basis. While this is intended to cut down on abuse of resources, it could discourage students from using the technology. Fees are used for new multimedia computers, improved software and more on-line library resources, data and video networks, and high-speed access of on-campus students to Internet, cable television and voice mail (*Chronicle of Higher Education*, 1997*c*). Students opposed the fees a few years ago, but are now willing to pay for services which they consider essential, although critics consider that the costs should be included in tuition.

The adoption of ICT-based strategies in traditional institutions may also be delayed because of conservative tendencies (Massy and Zemsky, 1995). The possibilities of ICT are not always well understood by administrators, and training and organisational change may also be needed (OECD, 1996*q*). The full impact of ICT in education and training may become clearer when it is more broadly used. It will be necessary to pay attention to the needs of a broad range of potential users, for instance by placing more emphasis on consultation, training, information and support (Geoghegan, 1996).[10]

Adequate user support has also been a major problem. As the number of computers on many campuses doubled or even tripled in recent years, support has lagged far behind, in part because of a lack of appreciation of its importance, but also, more recently, because of the difficulty of hiring and keeping capable support staff at university-level salaries. In 1996, providing adequate user support became the biggest concern among ICT administrators in public colleges in the United States (42 per cent) while only 10 per cent saw enhancing the campus network as a key issue (Green, 1996).

In their promotion and review processes, comparatively few US institutions (12.6 per cent) formally recognise and reward faculty efforts to integrate technology into instruction. This may make the faculty uncertain about the institution's commitment to the integration of technology in teaching (*Chronicle of Higher Education*, 1997*b*).

In terms of distance education courses, factors frequently reported in the United States as keeping institutions from starting or expanding their offerings were programme development costs (43 per cent), limited technological infrastructure to support distance education (31 per cent), and equipment failures and costs of maintaining equipment (23 per cent). Nevertheless, these were not considered major obstacles (US Department of Education, 1997).

In spite of everything, ICT is already transforming education. While ICT applications and their benefits will inevitably vary among disciplines, type of institution, and type of student, the potential for using technology to improve learning is too great to ignore. If colleges and universities fail to adapt effectively, other institutions will take up the challenge (Massy and Zemsky, 1995). In the United States, for example, competition for students who do not desire the expensive and labour-intensive education provided by traditional institutions has already increased. The competition takes place between universities in the form of distance learning programmes, but also comes from other organisations which can use ICT-based teaching and learning programmes with built-in assessment protocols.

So far, most ICT-based educational improvements in productivity have led to greater benefits only at greater unit cost, with ICT acting as a quality-enhancing addition. Funding limits the extent of such improvements. For ICT to lead to cost savings, technology would have to replace some activities now being performed by faculty, teaching assistants, and support personnel, given that labour accounts for 70 per cent or more of current operating costs. The RPI courses mentioned above are estimated to cost less than the traditional physics course, for example (OECD, 1996*r*, Table 7.6). However, such substitution requires great care so as not to undermine educational quality.

IMPLICATIONS FOR THE SCIENCE SYSTEM AND THE ROLE OF GOVERNMENTS

The main impacts

Science, particularly at the leading edge, requires funding, time, well-trained scientists and research assistants, access to data and information, access to sometimes expensive scientific instruments, ways to communicate and publish research results, and ways to join in collaborative structures. Recent developments in ICT, and the growth of Internet in particular, affect many of these requirements, although their impact differs across disciplines.

It is clear that ICT, particularly electronic mail, has enhanced ***communication among scientists.*** E-mail and other forms of electronic communication have enabled more frequent and faster communication, have considerably expanded the size of scientific networks, and have reduced geographical barriers, thereby allowing scientists to build more specialised networks. Scientific work has not been revolutionised, however, nor has the hierarchy of scientific institutions changed significantly. While electronic communication allows scientists at peripheral institutions or regions to maintain contact with leading scientific developments, communication is only one need. Access to funding, scientific instruments, and top scientists is important as well. Because better communication may allow scientists in peripheral institutions to keep abreast of leading-edge science, this may expand the science base.

ICT has also improved ***access of scientists to information*** in many forms. Data and information are among the main requirements for scientific research, and much of a researcher's work involves collecting, processing, and transmitting data. ICT has made it possible to store large databases in electronic form, either on the Internet or in other formats, such as CD-ROMs or digital libraries. The information can take many forms and involve data, text or software. ICT has enabled scientists to access, process and retrieve rapidly these sometimes enormous databases. Data availability and the concomitant increase in computing power have freed scientists from their dependency on central processing facilities, but have also increased the need to share data. Efforts under way in the United States may improve scientists' access to unpublished research, such as PhD theses and thereby reduce the amount of repeated research.

ICT has greatly affected scientific instruments and their use by scientists. The most important impact results from the tremendous increase in ***computing power*** and computer use by scientists. This has helped them deal with many complex phenomena and enabled them to use ever larger databases. In some areas, computers have enabled a rapid shift in the science frontier, as in genome research. Greater computing power has also allowed strong advances in modelling, simulation and visualisation.

Scientific instruments have been revolutionised in other ways as well. Several have been miniaturised and make it possible to place complete laboratories on one chip. This has significantly improved the speed of analysis, simplified the use of more accurate instruments and lowered instrument costs. In some areas, these developments have significantly undercut the position of central laboratories. Furthermore, software has increasingly replaced hardware in many instruments, resulting in increased use of virtual instruments. The diverse uses of some instruments can now increasingly be embedded in software, allowing the user to determine precisely what the instrument does.

From a global perspective, the main role of ICT has been to enable researchers to access and operate scientific instruments over great distances, thereby contributing to the emergence of virtual laboratories. This may allow scientists, and often graduate students as well, to engage in scientific research that they might not otherwise have been able to undertake. The enhanced capacity to acquire and process data may also have reduced dependency on central computing facilities. The position of central facilities may also be undercut by the expanding use of micro-instruments. However, in some areas, central computing facilities and laboratories remain essential. Access time is scarce at many of these facilities and at other expensive instruments and generally reserved for the top universities and research institutes. Where broader access is possible, however, ICT might facilitate cost-sharing for some expensive scientific instruments.

ICT has also had significant impacts on ***scientific publishing.*** It can significantly increase the speed of communicating results and possibly, but by no means surely, reduce the costs of communication and publication. It can make scientific literature more widely available and, through electronic links, point to easily accessed related material. In parts of the science system, electronic publishing has already been transformed by these developments, and the main scientific publishers are in the process of developing electronic journals.

The move to electronic publishing is not a smooth one, however, and differs substantially among disciplines. The main problems relate to guaranteeing appropriate peer review, protection of intellectual property rights (particularly a problem when commercial interests are at stake), archiving and the long-term maintenance of electronically published media, ease of access to electronically published documents, and ensuring cost recovery from electronic media.

The final impact of ICT on science discussed above involves ***education and training.*** Two impacts should be distinguished. First, ICT can improve the preparation of scientists for research. It increases access to educational resources, particularly those relevant to science, and can support the process of learning and skill development. It has a strong potential for improving learning in areas where knowledge is codified or algorithmic skills are involved. This use of ICT may better prepare scientists to solve increasingly complex scientific problems. Training is also essential to help scientists use ICT appropriately. Experience with private ICT investments suggests that this is often an important bottleneck, resulting in a long learning curve, so that return on investment is often slow. Scientists are among the best-trained workers in modern economies, so that the experience of private firms may not be entirely relevant to their practices. However, even they may need to adjust to new ICT applications, such as collaboratories.

Second, if ICT helps improve the teaching process, university researchers may be able to spend more time pursuing their scientific interests. So far, the available evidence suggests that ICT has not been able to make a significant difference. It has helped improve the quality of teaching but has not resulted in lower unit costs. It should be noted, however, that the measurement of educational output – and particularly its quality – is notoriously difficult, so that productivity estimates are subject to large measurement errors.

Collaboratories reflect many of the major impacts of ICT on the science system. They often share expensive scientific instruments, involve large groups of scientists in many countries and so depend on extensive electronic communication, require sharing data from large-scale experiments, and are often at the forefront of electronic publication of results. Collaboratories may also allow graduate students to participate in scientific experiments and to interact with experts in their field as well as enable small institutions to share sophisticated instruments.

Diversity of disciplines

The impacts of ICT may differ substantially among disciplines, as working practices of scientists differ considerably (Kling and McKim, 1997). The WWW was developed at CERN (European Organization for Nuclear Research – European Laboratory for Particle Physics), a high energy physics laboratory. This type of research is very capital-intensive and centralised, and instruments are few and shared by many researchers. It also involves collaborative research by scientists in many countries. Those involved are well-known, and the publishing culture makes extensive use of pre-prints. The Internet and other ICT developments improve communication among collaborators, may provide wider access to instruments, and are increasingly seen as a good medium for publishing scientific results. In this type of science, the appearance of an article in a journal serves more as a reminder than as new information (Peskin, 1994).

The impacts on other sciences may be quite different (Kling and McKim, 1997). Sub-disciplines of biology are much less capital-intensive and thus less bound by access to scarce scientific instruments. Collaboration is far less advanced, and research is fragmented among many individuals and research groups. Publishing is geared towards peer-reviewed journals and sharing of pre-prints or working papers is relatively limited. Unlike particle physics or astrophysics, sciences like biology, chemistry and computer science may have relatively straightforward commercial applications, and scientific results are often treated as confidential information.

In the humanities and social sciences, ICT, and the Internet in particular, may have yet other impacts. This type of research often does not involve costly scientific instruments, collaborative structures are fewer, and publishing emphasizes refereed journal articles and books. Part of this work may also have a local character. In these areas, access to data and information and easier communication among researchers may be the main impacts. The Internet may also be used for certain types of research based on survey evidence.

The productivity of the science system

Have all these developments lowered the costs of research or improved the productivity of the science system? This is a difficult question and the ongoing transformation of the science system suggests that it is too early for a definite answer. A number of observations can be made, however. First, the developments outlined above can significantly reduce the time needed for certain scientific tasks, primarily computing, communication, data collection, and the execution of certain experiments. This may help reduce costs, although the evidence remains limited. The impacts may also differ substantially among disciplines.

Second, ICT may lead to economies of scale and scope. ICT allows scientists to specialise and work with many researchers on similar problems, sharing data and instruments, thus potentially creating economies of scale. Electronic media may also break down some of the barriers between sciences, thus enabling multidisciplinary work and economies of scope. However, collaborative arrangements are often highly specialised, while an increasing number of scientific breakthroughs cross disciplinary boundaries or based on co-operation with private industry (OECD, 1997*r*). The growth of electronic communication and collaborative structures might lead to overspecialisation, which might affect science output in the long run. Moreover, electronic communication is more useful for transmitting codified knowledge, *i.e.* knowledge reflected in patents, publications and other published media, and less so for the diffusion of non-codified knowledge, *i.e.* know-how or skills embodied in people. The latter is considered to be increasingly relevant in OECD economies (OECD, 1997*r*). It remains to be seen how these developments will affect the science system in the long run.

Third, the use of ICT in science may involve learning costs and thus reduce the potential gains in science productivity. Scientists are among the most skilled workers in the OECD area, but may not necessarily know how to use ICT in the most efficient way. Collaborative work, in particular, requires a substantial investment in learning to use ICT. University education now gives increasing attention to ICT use, but while ICT use is spreading rapidly among established scientists, not all are sufficiently aware of its potential. Private sector experience with ICT suggests that training and organisational change are important to achieving a return on ICT investment. While some institutes and universities may be able to ensure appropriate support, this may not be the case for all. ICT and Internet use are greatest at those institutions with sufficient technical support.

Fourth, leading-edge scientific advances remain expensive and, in some cases, costs may still be increasing. Technological advances and the use of ICT may help to reduce costs in some areas but are unlikely to reverse the overall trend. Furthermore, increased science productivity, if it is occurring, may be required simply to maintain the volume and quality of scientific output in a time of tight budgets in most OECD economies. To some extent, ICT may simply be reinforcing patterns that were already emerging, such as joint research and the globalisation of research.

The role for governments

Predicting the impact of ICT on the science system is difficult. The technologies are changing rapidly and their potential and limitations are still poorly understood. Governments will need to be flexible in their policies towards the science system to deal with these changes and will have to continue to monitor and analyse developments. In terms of policy, governments are likely have three distinct roles:

- First, they need to support the technical infrastructure underlying the ICT used by scientists and ensure network compatibility (OECD, 1996*o*). They need to ensure that scientists have access to a high-speed, low-cost and seamless research network that connects public and private research institutions world-wide.[11] Since the development of ICT infrastructures will be increasingly driven by commercial needs, governments will need to play a role in ensuring that the requirements of the science system are sufficiently met.
- Second, they need to provide a regulatory framework that ensures and governs access, protects property rights, and allows the development of collaboratory structures. Increasingly, this will require international co-operation, for instance in safeguarding access of scientists to databases – often commercial – to which they have contributed.
- Third, in funding science they need to give sufficient attention to ICT needs. Among the areas that might require public support are the establishment of electronic databases and the technical support for and ICT training of scientists. Sufficient support for ICT needs will become an important factor in the competitiveness of science systems. Increasingly mobile researchers and students may use access to ICT resources as an important criterion in selecting universities.

The implications of information technology for the science system will go substantially beyond the OECD area and will increasingly involve developing countries. The challenge to policy makers is to achieve an open and productive science system, where scientists world-wide can exchange research results. Several developing countries may be sufficiently equipped to benefit from the emerging global research village and to contribute to a broadened science base. In these countries, access to the international science system may also help to reduce the "brain drain". For others, however, further efforts will be needed to improve telecommunication infrastructures and to strengthen the human resource base.

NOTES

1. Bandwidth measures the number of bits than can be transmitted across a particular channel per second.
2. In some countries, such as the United States, publicly supported scientific data must be made available to citizens, by law.
3. EMBASE (Elsevier) is Europe's largest and most important biomedical reference database. It contains more than 6 million records, most with author abstracts, and references published works in biomedicine from some 3 500 journals from 100 countries. INSPEC is the world's foremost database on physics, electronics, electrical engineering, computing and information technology. NTIS is an engineering database.
4. Modelling involves the development of mathematical models of natural phenomena. Software is one of the tools researchers use for modelling. In simulations, mathematical models of physical phenomena are translated into computer software that specifies how calculations are performed using observed data and estimates. Visualisation consists of the graphical representation of data.
5. CAVE was developed by the Electronic Visualization Laboratory at the University of Illinois in Chicago in 1991. Caterpillar used the CAVE system at the National Center for Supercomputing Applications.
6. These problems are not insurmountable, however, and a range of options are available to tackle the bandwidth problem (OECD, 1997*d*).
7. Multithreading is the ability to separate computer tasks so that they can be executed in parallel on separate threads. This capability has been built into every virtual instrument so that the user does not need to learn a new programming technique. Graphical differencing tools allow developers to compare the difference between versions of LABVIEW programmes.
8. Recently, a professor of materials science and engineering at Lehigh University demonstrated the feasibility of remote access to and control of an instrument at Oak Ridge National Laboratory (ORNL) via the Internet. Students could control almost 80 per cent of the operations using a computer, could adjust the magnification and other settings and even the movement and position of the specimen, a super-thin metal film. The microscopic image, an array of gold and palladium atoms, was displayed in the lab with an overhead projector. Technicians at ORNL only had to load the specimen and turn on the high-resolution transmission electron microscope. Communications were carried out via a video-teleconferencing system (*Chronicle of Higher Education,* 1997*d*).
9. To tackle these problems, there is an increasing number of partnerships between the public and private sector. Canada's TeleLearning Network of Centers of Excellence, for example, utilises links between universities, industries and government to develop educational tools through design, prototype testing, and evaluation of emerging technologies.
10. A step in the direction of integrating ICT into mainstream education has been taken by several governments and is reflected in their national plans for education. In the United Kingdom, the National Council for Educational Technology (NCET), a government-funded agency, evaluates, promotes and supports the effective use of ICT to raise educational standards. Recent NCET work emphasizes how ICT can help in the science classroom and provides case studies on measurement and control, modelling, handling, and communicating information. It also demonstrates how to get started, by including basic information on available technology. In France, a new network will link the majority of the 84 universities and the main *grandes écoles,* to combine resources dealing with network-based services and support the development of communications strategies in these institutions.
11. Policy issues related to ICT are discussed in more detail in other studies, *e.g.* OECD (1997*d;* 1997*v*).

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STATISTICAL ANNEX

MAIN OECD DATABASES USED IN THIS DOCUMENT

- **AFA** – The Activities of Foreign Affiliates database uses the results of a survey of (majority and/ or minority) foreign-controlled firms in OECD Member countries. It contains the following variables, broken down by partner country and geographical region: number of enterprises/establishments, number of employees, gross output, turnover, wages and salaries, R&D expenditure, number of researchers, gross fixed capital formation, total exports and imports, intra-firm exports and imports, gross operating surplus, technological payments and receipts, stock of foreign direct investment, and capital under foreign influence. It covers 34 manufacturing sectors and 17 OECD countries from 1980 to 1994. The availability of data varies according to country.

Publication: OECD (1997), *Activities of Foreign Affiliates.*

- **ANBERD** – The Analytical Business Enterprise Research and Development database is an estimated database constructed with the objective of creating a consistent data set that overcomes the problems of international comparability and time discontinuity associated with the official business enterprise R&D data provided to the OECD by its Member countries. ANBERD contains R&D expenditures for the period 1973-95, by industry, for 15 OECD countries.

Publication: OECD (1997), *Research and Development Expenditure in Industry: 1974-95.*

- **BTD** – The Bilateral Trade Database for industrial analysis includes detailed trade flows by manufacturing industry between a set of OECD declaring countries and a selection of 45 partner countries and geographical regions. Data are presented in US dollars and cover the period 1970-94. The database covers 22 manufacturing sectors, and follows the same classification as that used for the Input-Output and ANBERD databases, and is compatible with the STAN database.

Publication: OECD (1997), *Bilateral Trade Database 1997* (on diskette only).

- **IIA** – The Short-term Industrial Statistics database gives an overview of short-term economic trends in manufacturing. It contains monthly, quarterly and annual data on output, deliveries, orders, producer prices and employment, as well as quarterly qualitative data from business surveys on variables such as stocks, order books, and capacity utilisation rates. Time series are available from 1955. The availability of data and its industrial sector coverage differs among countries.

Quarterly publication: OECD (1997), *Indicators of Industrial Activity*, 1997/1/2/3/4.

- **I-O** – The Input-Output database contains flow matrices of intermediate and final goods (both domestic and imported) for selected years in the 1970-90 period. It covers ten countries and 36 industries, of which 22 are in the manufacturing sector.

Publication: OECD (1996), *The OECD Input-Output Database.*

- **ISDB** – The International Sectoral Database combines a range of data series related to sectoral output and primary factor inputs (labour and capital) in a manner compatible with the OECD National Accounts Statistics. It covers the period 1960-96 for 15 OECD countries. Major variables included are: gross domestic product, total employment (persons engaged) and employees, gross fixed capital formation and gross capital stock, compensation of employees, consumption of fixed capital, gross operating surplus, and net indirect taxes. Most data are available in both current and constant (1990) prices.

Publication: OECD (1997), *International Sectoral Database – 1997 edition.* Available on diskette only.

- **ISIS** – The Industrial Structure Statistics database provides official annual data derived from industrial surveys, foreign trade data and national accounts. It covers manufacturing and non-manufacturing industries at a detailed level of disaggregation (4 digits according to ISIC Revision 2), for variables such as production, value added, investment, investment in machinery and equipment, exports, imports, wages and salaries, employment, number of establishments and hours worked. As of the 1997 edition, ISIS also contains data in the new international industry classification, ISIC Revision 3.

Publication: OECD (1997), *Industrial Structure Statistics – 1997 Edition.*

- **MSTI** – The Main Science and Technology Indicators database provides a selection of the most frequently used annual data on the scientific and technological performance of OECD Member Countries as of 1981. Of the 89 indicators included, 70 deal with resources devoted to R&D, and 19 are experimental indicators of the output and impact of S&T activities (patents, technology balance of payments, and trade of high-technology industries).

Publication: OECD (1997), *Main Science and Technology Indicators*, 1997/1/2.

- **STAN** – The Structural Analysis database is an estimated database which has been developed to ensure international comparability of survey-based national industrial statistics and their comparability with national accounts. It contains eight variables: production, value added (in constant and current prices), gross fixed capital formation, number of persons engaged, labour compensation, exports, and imports. The database covers 22 OECD countries and 49 manufacturing sectors. Data are available for the period 1970-95.

Publication: OECD (1997), *The OECD STAN Database for Industrial Analysis: 1976-95.*

- **S&T Databases** – This set of databases includes the R&D database, which contains the full results of surveys on the resources devoted to R&D by OECD countries as of 1963. It provides a detailed breakdown of R&D expenditures by funding and performance and data on R&D personnel by occupation and level of qualification. It also includes information on intended government R&D financing,

Country coverage of main OECD databases used in this document

	AFA	ANBERD	BTD	IIA	I-O	ISDB	ISIS	MSTI	STAN	S&T
Australia		✓	✓	✓	✓	✓	✓	✓	✓	✓
Austria			✓	✓			✓	✓	✓	✓
Belgium			✓	✓		✓	✓	✓	✓	✓
Canada	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Czech Republic							✓	✓		✓
Denmark		✓	✓	✓	✓	✓	✓	✓	✓	✓
Finland	✓	✓	✓	✓		✓	✓	✓	✓	✓
France	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Germany	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Greece			✓	✓			✓	✓	✓	✓
Hungary	✓						✓	✓		✓
Iceland			✓				✓	✓	✓	✓
Ireland	✓	✓	✓	✓			✓	✓		✓
Italy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Japan	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Korea						✓	✓	✓	✓	✓
Luxembourg				✓			✓	✓		✓
Mexico	✓			✓			✓	✓	✓	✓
Netherlands	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
New Zealand			✓	✓			✓	✓	✓	✓
Norway	✓	✓	✓	✓		✓	✓	✓	✓	✓
Poland								✓		✓
Portugal			✓	✓			✓	✓	✓	✓
Spain	✓	✓	✓	✓			✓	✓	✓	✓
Sweden	✓	✓	✓	✓		✓	✓	✓	✓	✓
Switzerland	✓		✓		✓		✓	✓		✓
Turkey	✓		✓	✓			✓	✓		✓
United Kingdom	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
United States	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

which shows the government budget appropriations or outlays for R&D broken down by socio-economic objective. The S&T databases also include data on patents and the technology balance of payments and provides the primary data for the ANBERD and MSTI databases.

Publication: OECD (1997), *Basic Science and Technology Statistics – 1997 Edition.*

Further details on these and other databases managed by OECD's Directorate for Science, Technology and Industry (DSTI) can be found at the following Internet address: <**http://www.oecd.org/dsti.**

Details on other OECD databases, such as those relating to national accounts or financial affairs, can be found at OECD's Internet address: <**http://www.oecd.org.**

THE CLASSIFICATION OF MANUFACTURING SECTORS

- *High-technology industries*: aircraft (ISIC 3845), office and computing equipment (ISIC 3825), pharmaceuticals (ISIC 3522), radio, TV and communication equipment (ISIC 3832).
- *Medium-high-technology industries*: professional goods (ISIC 385), motor vehicles (ISIC 3843), electrical machinery excluding communication equipment (ISIC 383 – 3832), chemicals excluding pharmaceuticals (ISIC 351 + 352 – 3522), other transport equipment (ISIC 3842 + 3844 + 3849), non-electrical machinery (ISIC 382 – 3825).
- *Medium-low-technology industries*: rubber and plastic products (ISIC 355 + 356), shipbuilding (ISIC 3841), other manufacturing (ISIC 39), non-ferrous metals (ISIC 372), non-metallic mineral products (ISIC 36), metal products (ISIC 381), petroleum refining and products (ISIC 383 + 384), ferrous metals (ISIC 371).
- *Low-technology industries*: paper, paper products and printing (ISIC 34), textiles, apparel and leather (ISIC 32), food, beverages and tobacco (ISIC 31), wood products and furniture (ISIC 33).

ANNEX TABLES

Annex Table 1.1. **Gross domestic product in volume, 1985-97**

Level in current PPP$ and percentage change from previous year

	1995 level (billion current PPP$)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[2]	CAGR[1]	
															1985-91	1991-97
United States	7 265	3.6	3.1	2.9	3.8	3.4	1.2	–0.9	2.7	2.3	3.5	2.0	2.8	3.8	2.2	2.8
Canada	628	4.8	3.3	4.2	5.0	2.4	–0.2	–1.8	0.8	2.2	4.1	2.2	1.2	3.8	2.1	2.4
Mexico	698	2.8	–3.6	1.8	1.3	3.3	4.5	3.6	2.8	0.7	4.5	–6.2	5.2	7.0	1.8	2.2
Japan	2 732	4.4	2.9	4.2	6.2	4.8	5.1	3.8	1.0	0.3	0.6	1.5	3.9	0.9	4.5	1.4
Korea	568	6.5	11.6	11.5	11.3	6.4	9.5	9.1	5.1	5.8	8.6	8.9	7.1	5.5	9.9	6.8
Australia	351	4.2	2.0	4.5	3.8	4.2	1.2	–1.3	2.6	3.9	5.4	4.1	3.7	2.7	2.4	3.8
New Zealand	59	1.6	1.1	0.2	2.2	–0.4	0.3	–2.3	0.6	5.1	5.5	3.3	2.7	2.8	0.2	3.0
Austria	166	2.2	2.3	1.7	3.2	4.2	4.6	3.4	1.3	0.5	2.5	2.1	1.6	2.1	3.2	1.7
Belgium	214	0.7	1.6	2.1	4.7	3.6	3.0	1.6	1.5	–1.5	2.4	2.1	1.5	2.7	2.8	1.4
Czech Republic	96	..	..	..	..	..	..	..	–6.4	–0.9	2.6	6.4	3.9	1.0	..	1.0
Denmark	117	4.3	3.6	0.3	1.2	0.3	1.2	1.4	1.3	1.3	3.5	3.1	3.5	3.4	1.3	2.7
Finland	92	3.3	2.4	4.1	4.9	5.7	0.0	–7.1	–3.6	–1.2	4.5	5.1	3.6	5.9	1.6	2.3
France	1 157	1.9	2.5	2.3	4.5	4.3	2.5	0.8	1.2	–1.3	2.8	2.1	1.5	2.4	2.8	1.4
Germany	1 674	2.0	2.3	1.5	3.7	3.6	5.7	5.0	2.2	–1.2	2.7	1.8	1.4	2.2	3.6	1.5
Greece	128	3.1	1.6	–0.5	4.5	3.8	0.0	3.1	0.7	–1.6	2.0	2.1	2.7	3.5	2.1	1.6
Hungary	80	..	..	..	..	..	..	..	–3.1	–0.6	2.9	1.5	1.3	3.8	..	0.9
Iceland	6	3.3	6.3	8.5	–0.1	0.3	1.2	1.1	–3.4	1.0	3.7	1.1	5.5	5.0	2.8	2.1
Ireland	59	3.1	–0.4	4.7	5.2	5.8	8.5	1.9	3.9	3.1	7.0	10.4	7.7	10.5	4.2	7.1
Italy	1 114	2.8	2.8	3.1	3.9	2.9	2.2	1.1	0.6	–1.2	2.2	2.9	0.7	1.5	2.7	1.1
Luxembourg	13	2.9	7.8	2.3	10.4	9.8	2.2	6.1	4.5	8.7	4.2	3.8	3.0	3.7	6.4	4.6
Netherlands	307	3.1	2.8	1.4	2.6	4.7	4.1	2.3	2.0	0.8	3.2	2.3	3.3	3.3	3.0	2.5
Norway	99	5.2	3.6	2.0	–0.1	0.9	2.0	3.1	3.3	2.7	5.5	3.6	5.3	3.5	1.9	4.0
Poland	212	..	..	..	..	..	..	..	..	..	5.2	7.0	6.1	6.9	..	..
Portugal	123	2.8	4.1	6.4	4.9	4.9	4.6	2.3	1.8	0.3	0.7	1.9	3.0	3.5	4.5	1.8
Spain	557	2.6	3.2	5.6	5.2	4.7	3.7	2.3	0.7	–1.2	2.2	2.7	2.3	3.4	4.1	1.7
Sweden	165	1.9	2.3	3.1	2.3	2.4	1.4	–1.1	–1.4	–2.2	3.3	3.9	1.3	1.8	1.7	1.1
Switzerland	177	3.4	1.6	0.7	3.1	4.3	3.7	–0.8	–0.1	–0.5	0.5	0.8	–0.2	0.7	2.1	0.2
Turkey	349	4.2	7.0	9.5	2.1	0.3	9.3	0.9	6.0	8.0	–5.5	7.2	7.2	6.3	4.8	4.8
United Kingdom	1 050	3.8	4.3	4.8	5.0	2.2	0.4	–2.0	–0.5	2.1	4.3	2.7	2.2	3.3	2.4	2.3
European Union	6 558	2.6	2.9	2.9	4.2	3.5	3.0	1.6	1.0	–0.5	2.9	2.5	1.7	2.6	3.0	1.7
OECD total	18 604	3.4	3.0	3.4	4.4	3.6	2.8	1.0	1.9	1.2	2.9	2.2	2.8	3.1	3.0	2.3

1. Compound annual growth rate.
2. Data for 1997 are estimates.

Source: OECD, *Economic Outlook 62,* December 1997; OECD, *Economic Outlook 63, Preliminary Version,* April 1998.

Annex Table 1.2. **Total employment, 1985-97**

Level in thousand persons and percentage change from previous year

	1995 level (thousands of persons)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[2]	CAGR[1]	
															1985-91	1991-97
United States	124 903	2.0	2.3	2.6	2.3	2.0	1.3	–0.9	0.7	1.5	2.3	1.5	1.4	2.2	1.6	1.6
Canada	13 507	3.0	3.0	2.7	3.2	2.1	0.6	–1.9	–0.6	1.4	2.1	1.6	1.3	1.7	1.6	1.2
Mexico	14 752	..	..	..	4.7	3.6	1.9	5.5	4.7	4.1	0.9	1.9	5.0	13.3	..	4.9
Japan	64 570	0.7	0.8	1.0	1.7	2.0	2.0	1.9	1.1	0.2	0.0	0.1	0.5	1.1	1.6	0.5
Korea	20 378	3.7	3.6	5.5	3.2	4.1	3.0	2.9	1.9	1.5	3.0	2.7	1.9	1.5	3.7	2.1
Australia	8 276	3.5	3.6	2.2	3.7	4.7	1.5	–2.1	–0.7	0.4	3.1	4.1	1.3	0.8	2.2	1.5
New Zealand	1 633	3.5	–0.4	0.8	–3.2	–2.6	0.9	–1.4	0.4	2.0	4.3	4.7	3.4	0.5	–1.0	2.5
Austria	3 439	0.2	0.4	0.0	0.6	1.5	1.9	1.9	1.5	–0.3	0.2	–0.4	–0.7	0.3	1.0	0.1
Belgium	3 695	0.6	0.6	0.5	1.5	1.6	1.5	0.1	–0.4	–1.1	–1.0	0.5	0.4	0.3	1.0	–0.2
Czech Republic	5 090	..	..	..	..	..	..	..	..	..	1.2	0.8	0.4	–0.2	..	..
Denmark	2 566	2.5	3.2	1.2	–0.3	–0.7	–0.8	–0.6	–0.9	–1.4	–0.3	1.6	1.3	2.3	0.3	0.4
Finland	2 068	1.0	–0.3	–0.3	0.3	1.6	–0.1	–5.2	–7.1	–6.1	–0.8	2.2	1.4	3.2	–0.7	–1.3
France	22 450	–0.1	0.5	0.4	1.0	1.5	0.8	0.0	–0.6	–1.2	0.1	0.9	0.0	0.3	0.7	–0.1
Germany	34 871	0.7	1.4	0.7	0.8	1.5	3.0	2.5	–1.8	–1.7	–0.7	–0.3	–1.2	–1.3	1.6	–1.2
Greece	3 824	1.0	0.4	–0.1	1.6	0.4	1.3	–2.3	1.5	0.9	1.9	0.9	1.3	1.2	0.2	1.3
Hungary	3 623	..	..	..	..	..	..	..	–9.6	–6.4	–2.1	–1.9	–0.5	–0.1	..	–3.5
Iceland	125	3.6	3.1	5.8	–2.8	–1.5	–0.9	–0.1	–1.4	–0.8	0.5	1.5	2.1	2.1	0.5	0.7
Ireland	1 273	–2.5	–0.4	1.3	0.1	0.0	4.4	–0.3	0.6	1.4	3.0	4.8	3.4	4.2	0.8	2.9
Italy	20 009	0.3	0.4	–0.3	0.5	–0.1	1.2	0.7	–0.9	–2.5	–1.7	–0.6	0.4	0.0	0.4	–0.9
Luxembourg	213	0.9	2.6	2.6	3.0	3.5	4.1	4.1	2.5	1.7	2.6	2.5	2.6	3.6	3.3	2.6
Netherlands	6 063	1.3	2.5	1.6	2.3	1.8	3.0	2.6	1.6	0.7	–0.1	2.4	2.0	2.5	2.3	1.5
Norway	2 080	2.3	3.5	1.9	–0.6	–3.0	–0.9	–1.0	–0.3	0.0	1.5	2.2	2.8	2.9	0.0	1.5
Poland	14 791	..	..	..	..	..	..	–5.9	–3.7	–2.1	–1.6	0.9	1.2	1.4	..	–0.7
Portugal	4 195	–0.5	0.2	2.6	2.6	2.2	2.2	3.0	–6.4	–2.0	–0.1	–0.6	0.5	1.9	2.1	–1.1
Spain	12 230	–0.9	2.2	3.1	2.9	4.1	2.6	0.2	–1.9	–4.3	–0.9	1.8	1.5	2.9	2.5	–0.2
Sweden	3 991	0.0	0.7	1.0	1.1	1.8	1.0	–2.0	–4.5	–5.5	–1.0	1.6	–0.9	–1.0	0.6	–1.9
Switzerland	3 796	2.0	2.3	2.5	2.6	2.7	3.2	1.8	–1.7	–0.9	–0.2	0.3	0.3	–0.2	2.5	–0.4
Turkey	20 396	1.7	1.9	2.3	1.5	2.6	1.7	1.7	0.8	0.9	2.5	3.7	2.4	2.4	2.0	2.1
United Kingdom	26 165	1.1	0.3	2.5	4.0	2.7	0.4	–3.0	–2.1	–0.4	1.0	1.2	1.1	1.7	1.1	0.4
European Union	147 006	0.4	0.9	1.1	1.7	1.7	1.5	0.1	–1.5	–1.7	–0.3	0.6	0.3	0.6	2.0	–0.3
OECD total	444 924	1.3	1.6	5.0	2.1	2.1	1.6	2.2	0.0	5.9	0.9	1.2	1.1	1.7	2.4	1.8

1. Compound annual growth rate.
2. Data for 1997 are estimates.

Source: OECD, *Economic Outlook 62,* December 1997; OECD, *Economic Outlook 63, Preliminary Version,* April 1998.

Annex Table 1.3. **Gross fixed capital formation, volume, 1985-97**

Percentage change from previous year

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[2]	CAGR[1] 1985-91	CAGR[1] 1991-97
United States	6.0	2.1	0.4	1.5	2.0	–1.4	–6.6	5.2	5.1	6.5	4.4	7.5	6.6	–0.4	5.9
Canada	10.3	5.4	10.7	9.8	5.9	–3.6	–3.5	–1.3	–2.9	7.1	–2.8	4.8	11.4	4.0	2.6
Mexico	7.9	–11.8	–0.1	5.8	6.4	13.1	8.3	10.9	–1.2	8.4	–29.0	16.4	20.9	3.3	2.9
Japan	5.0	4.8	9.1	11.5	8.2	8.5	3.3	–1.5	–2.0	–0.8	1.7	9.5	–3.4	7.5	0.5
Korea	4.3	10.6	17.0	13.7	15.9	25.9	12.6	–0.8	5.2	11.8	11.7	7.1	–3.5	15.8	5.3
Australia	9.5	–2.5	3.6	7.5	9.5	–8.2	–9.4	2.0	3.4	11.4	3.7	5.7	10.0	–0.2	6.0
New Zealand	4.0	–1.8	0.1	–2.2	4.8	–1.2	–18.6	1.4	14.8	16.7	12.0	6.3	4.3	–3.4	9.1
Austria	6.9	2.4	4.4	6.8	6.3	6.6	6.3	0.1	–2.0	8.4	1.9	2.4	3.8	5.5	2.4
Belgium	0.7	4.5	5.6	16.4	11.4	9.6	–4.7	1.3	–3.6	–0.1	3.2	0.6	4.5	6.9	1.0
Czech Republic	..	..	..	..	..	..	..	..	..	17.3	21.0	8.7	–4.9	..	..
Denmark	12.6	17.1	–3.8	–6.6	0.2	–0.9	–2.7	–1.0	–0.2	0.8	11.5	7.2	7.2	0.3	4.6
Finland	2.9	–0.4	4.9	9.8	14.8	–4.1	–20.3	–16.9	–19.2	0.2	11.3	8.4	11.2	0.1	–1.7
France	3.2	4.5	4.8	9.6	7.9	2.8	0.0	–2.8	–6.7	1.3	2.5	–0.5	0.2	4.9	–1.1
Germany	–0.5	3.3	1.8	4.4	6.3	8.5	6.0	3.5	–5.6	3.5	0.8	–1.2	0.2	5.0	0.2
Greece	5.2	–6.2	–5.1	8.9	7.1	5.0	4.8	–3.2	–3.5	–2.8	7.3	9.4	10.9	2.2	2.8
Hungary	..	..	..	..	..	..	..	–2.6	2.0	12.5	–4.3	6.3	9.6	..	3.7
Iceland	1.0	–1.5	18.8	–0.2	–7.9	3.0	2.0	–11.3	–11.4	–1.1	–2.8	26.5	9.9	2.1	0.8
Ireland	–7.7	–2.8	–1.1	5.2	10.1	13.4	–7.4	–1.3	–3.4	10.2	9.6	15.9	13.2	2.6	7.1
Italy	0.5	2.0	4.4	6.9	4.4	3.6	0.8	–1.8	–12.8	0.5	7.1	0.4	0.6	3.7	–1.2
Luxembourg	–9.5	31.0	17.9	15.0	7.0	2.7	31.6	–9.0	28.4	–14.9	3.5	–1.7	8.0	17.0	1.5
Netherlands	7.0	6.9	0.9	4.5	4.9	1.6	0.2	0.6	–2.8	2.2	5.0	6.1	6.1	3.1	2.8
Norway	–4.0	7.6	0.3	–1.8	–6.9	–10.8	–0.4	–3.1	4.3	4.5	3.7	4.8	15.1	–2.2	4.8
Poland	..	..	..	..	..	..	..	..	..	9.2	16.9	20.6	21.9	..	..
Portugal	–3.5	10.9	18.0	10.5	4.8	7.1	2.9	4.6	–6.2	4.5	3.6	5.2	13.5	8.9	4.0
Spain	6.1	9.9	14.0	13.9	13.6	6.6	1.6	–4.4	–10.5	2.4	7.8	0.9	4.7	9.8	0.0
Sweden	5.2	0.3	8.2	6.6	11.3	1.3	–8.9	–10.8	–17.2	2.0	12.4	3.7	–4.8	2.9	–3.0
Switzerland	2.8	5.4	4.0	8.1	5.3	3.8	–2.9	–6.6	–2.7	6.5	1.9	–2.7	–1.5	3.9	–0.9
Turkey	11.5	8.4	45.1	–1.0	2.2	15.9	–0.6	6.6	26.1	–16.7	9.1	18.2	6.4	10.6	7.4
United Kingdom	4.2	2.6	10.3	13.9	6.0	–3.5	–9.5	–1.5	0.6	4.3	1.5	1.5	4.8	3.0	1.8
European Union	2.5	4.0	5.6	8.6	7.1	3.8	–0.3	–1.0	–6.4	2.4	3.9	1.0	2.4	4.8	0.3
OECD total	4.8	3.1	5.1	6.3	5.4	3.1	–1.8	1.6	–0.2	4.1	3.0	5.8	4.2	3.5	3.1

1. Compound annual growth rate.
2. Data for 1997 are estimates.

Source: OECD, *Economic Outlook 62,* December 1997; OECD, *Economic Outlook 63, Preliminary Version,* April 1998.

Annex Table 1.4. **Unemployment in total labour force, 1985-97**

Number of unemployed in thousand persons and unemployment rate in per cent

	1995 level (thousands of persons)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[1]
United States	7 405	7.2	7.0	6.2	5.5	5.3	5.6	6.8	7.5	6.9	6.1	5.6	5.4	4.9
Canada	1 419	10.5	9.6	8.8	7.8	7.5	8.2	10.4	11.3	11.2	10.4	9.5	9.7	9.2
Mexico	997	4.4	4.3	3.9	3.5	2.9	2.7	2.6	2.8	3.4	3.7	6.3	5.5	3.7
Japan	2 098	2.6	2.8	2.8	2.5	2.3	2.1	2.1	2.2	2.5	2.9	3.1	3.4	3.4
Korea	419	4.0	3.8	3.1	2.5	2.6	2.4	2.3	2.4	2.8	2.4	2.0	2.0	2.6
Australia	774	8.1	8.0	8.0	7.1	6.1	7.0	9.5	10.7	10.9	9.7	8.6	8.5	8.6
New Zealand	110	3.5	4.0	4.1	5.6	7.1	7.8	10.3	10.3	9.5	8.1	6.3	6.1	6.7
Austria	216	4.2	4.5	4.9	4.7	4.3	4.7	5.2	5.3	6.1	5.9	5.9	6.3	6.2
Belgium	555	12.4	11.8	11.5	10.4	9.4	8.8	9.4	10.4	12.1	13.1	13.1	12.8	12.7
Czech Republic	164	..	..	..	..	..	..	..	..	3.6	3.2	3.1	3.5	4.4
Denmark	288	9.0	7.8	7.8	8.6	9.3	9.6	10.5	11.3	12.3	12.2	10.1	8.6	7.6
Finland	430	5.0	5.4	5.1	4.5	3.5	3.5	7.6	13.1	17.9	18.4	17.2	16.3	14.5
France	2 930	10.2	10.4	10.5	10.0	9.3	8.9	9.4	10.4	11.7	12.2	11.5	12.3	12.4
Germany	3 612	8.0	7.7	7.6	7.6	6.9	6.2	6.7	7.7	8.8	9.6	9.4	10.3	11.4
Greece	425	7.8	7.4	7.4	7.7	7.5	7.0	7.7	8.7	9.7	9.6	10.0	10.3	10.4
Hungary	417	..	..	..	..	..	..	..	..	12.1	10.8	10.3	10.0	8.7
Iceland	7	0.9	0.6	0.5	0.6	1.7	1.8	1.5	3.0	4.4	4.8	5.0	4.4	3.9
Ireland	177	16.8	17.1	16.9	16.3	15.1	12.9	14.7	15.1	15.7	14.7	12.2	11.9	10.2
Italy	2 724	8.6	9.9	10.2	10.5	10.2	9.1	8.6	8.8	10.2	11.3	12.0	12.1	12.3
Luxembourg	5	1.7	1.5	1.7	1.6	1.4	1.3	1.4	1.6	2.1	2.7	3.0	3.3	3.6
Netherlands	464	9.2	8.4	8.0	7.8	6.9	6.0	5.5	5.4	6.5	7.6	7.1	6.7	5.6
Norway	107	2.6	2.0	2.1	3.2	4.9	5.2	5.5	5.9	6.0	5.4	4.9	4.9	4.1
Poland	2 277	..	..	..	..	..	..	..	..	14.0	14.4	13.3	12.3	11.2
Portugal	325	8.7	8.6	7.1	5.8	5.1	4.7	4.1	4.2	5.5	6.9	7.2	7.3	6.7
Spain	3 584	20.9	20.5	20.0	19.0	16.7	15.7	15.8	17.9	22.2	23.7	22.7	22.2	20.8
Sweden	332	2.8	2.5	2.1	1.7	1.5	1.6	3.0	5.3	8.2	7.9	7.7	8.1	8.0
Switzerland	153	0.8	0.7	0.7	0.6	0.5	0.5	1.1	2.5	4.5	4.7	4.2	4.7	5.2
Turkey	1 633	7.1	7.9	8.3	8.4	8.6	8.0	7.9	8.0	7.7	8.1	6.9	6.0	5.7
United Kingdom	2 466	11.6	11.8	10.2	7.8	6.1	5.9	8.2	10.2	10.3	9.4	8.6	8.0	6.9
European Union	18 533	10.3	10.4	10.1	9.4	8.5	7.9	8.4	9.6	11.1	11.5	11.2	11.4	11.2
OECD Total	36 511	7.6	7.6	7.1	6.5	6.0	5.9	6.6	7.3	8.0	7.9	7.6	7.5	7.2

1. Data for 1997 are estimates.

Source: OECD, *Economic Outlook 62,* December 1997; OECD, *Economic Outlook 63, Preliminary Version,* April 1998.

Annex Table 1.5. **Inflation[1] in OECD countries, 1985-97**

Percentage change from previous year

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[2]
United States	3.4	2.6	3.1	3.7	4.2	4.3	4.0	2.8	2.6	2.4	2.5	2.3	2.0
Canada	2.6	2.4	4.7	4.6	4.8	3.1	2.9	1.2	1.0	0.7	2.6	1.4	0.5
Mexico	56.4	74.1	138.5	99.9	26.5	28.0	23.4	14.4	9.5	8.3	38.0	29.4	18.8
Japan	2.1	1.8	0.1	0.7	2.0	2.3	2.7	1.7	0.6	0.2	–0.6	–0.5	0.6
Korea	4.6	4.6	5.0	6.7	5.3	9.9	10.1	6.1	5.1	5.5	5.6	3.4	2.3
Australia	6.1	7.0	7.8	8.6	7.5	4.5	2.3	1.3	1.3	1.1	2.5	2.1	2.0
New Zealand	15.4	14.2	14.4	8.1	6.8	3.4	1.0	1.7	2.6	1.3	2.6	1.9	1.3
Austria	3.1	2.7	2.1	1.6	2.7	3.4	3.7	4.3	2.8	2.8	2.1	2.1	1.4
Belgium	6.1	3.6	2.2	2.1	4.6	3.1	3.2	3.6	4.2	2.3	1.7	1.6	1.4
Czech Republic	..	..	..	..	..	..	..	..	..	11.1	10.6	9.4	8.5
Denmark	4.3	4.6	4.7	3.4	5.1	3.4	2.5	2.2	0.8	2.4	2.1	1.6	1.7
Finland	5.4	4.5	4.7	7.0	6.1	5.9	2.5	0.7	2.4	1.3	2.4	1.3	1.1
France	5.8	5.2	3.0	2.8	3.0	3.1	3.3	2.1	2.5	1.5	1.6	1.2	1.0
Germany	2.1	3.2	1.9	1.5	2.4	3.2	3.9	5.6	4.0	2.4	2.1	1.0	0.6
Greece	17.6	17.6	14.2	15.6	14.5	20.6	19.8	14.9	14.4	11.3	9.8	8.1	6.9
Hungary	..	..	..	..	..	..	..	..	..	19.5	26.7	20.4	18.6
Iceland	31.2	25.4	19.6	22.9	19.8	16.7	7.6	3.8	2.4	2.1	2.8	1.9	3.5
Ireland	5.2	6.5	2.2	3.2	5.5	–0.7	2.4	2.5	4.4	1.3	0.4	1.2	1.6
Italy	9.0	7.8	6.1	6.8	6.3	7.6	7.7	4.7	4.4	3.5	5.1	5.0	2.6
Luxembourg	3.0	2.8	0.9	0.7	3.5	3.4	1.5	4.3	0.7	5.3	1.0	1.0	1.8
Netherlands	1.8	0.1	–0.7	1.2	1.2	2.3	2.7	2.3	1.9	2.3	1.6	1.3	2.2
Norway	5.2	–0.9	6.9	5.0	5.7	3.9	2.4	–0.4	2.1	–0.2	3.4	4.1	3.1
Poland	..	..	..	..	..	..	..	..	..	28.4	27.1	19.4	14.6
Portugal	21.7	20.5	10.1	11.8	12.2	12.4	12.1	10.6	6.0	5.9	5.1	2.2	2.6
Spain	7.7	11.1	5.9	5.6	7.1	7.3	7.1	6.9	4.3	4.0	4.8	3.1	2.2
Sweden	6.6	6.9	4.8	6.5	8.0	8.9	7.6	1.1	2.6	2.4	3.7	1.0	1.2
Switzerland	2.4	3.1	2.7	2.8	3.1	4.3	6.0	2.7	2.7	1.7	1.3	0.0	0.1
Turkey	52.9	36.0	33.3	70.1	74.9	58.7	58.5	63.8	67.7	107.0	86.9	78.6	83.0
United Kingdom	5.7	3.3	5.0	6.0	7.1	6.4	6.5	4.6	3.2	1.6	2.5	3.1	2.6
OECD total	6.7	6.5	7.9	7.8	6.2	6.1	5.9	4.6	4.0	4.4	5.1	4.3	3.7
OECD less high-inflation countries[3]	4.0	3.5	3.0	3.5	4.1	4.2	4.2	3.1	2.5	2.1	2.2	1.9	1.6
European Union	5.9	5.6	4.0	4.4	5.0	5.3	5.5	4.5	3.7	2.6	3.0	2.4	1.8

1. Implicit price index of GDP.
2. Data for 1997 are estimates.
3. High-inflation countries are defined as those that have had 10 per cent or more inflation in terms of the GDP deflator on average during the 1990s on the basis of historical data. Consequently, the Czech Republic, Greece, Hungary, Mexico, Poland and Turkey are excluded from the aggregate.

Source: OECD, *Economic Outlook 62,* December 1997; OECD, *Economic Outlook 63, Preliminary Version,* April 1998.

Annex Table 1.6. **Real long-term interest rates,[1] 1985-97**

Percentage

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[2]
United States	7.6	5.8	6.4	6.6	5.6	5.3	4.6	4.5	4.2	5.4	5.1	5.0	5.0
Canada	7.6	6.9	6.8	6.3	5.2	6.6	6.3	6.3	6.2	7.6	7.3	6.3	5.2
Mexico	4.6	35.7	30.4	–26.4	–30.6	–9.7	–5.0	–4.9	0.4	3.4	23.3	9.1	–5.5
Japan	4.3	3.0	3.7	4.0	4.3	5.3	4.0	3.0	2.6	3.6	3.3	3.3	2.2
Korea[3]	10.1	10.1	9.1	7.4	8.8	5.5	7.5	9.3	7.3	6.0	7.6	5.2	6.9
Australia	7.2	7.1	6.3	4.5	5.5	6.4	6.0	6.6	5.7	7.8	7.6	6.2	4.6
New Zealand	9.4	4.9	1.5	1.0	3.4	6.4	6.3	6.4	5.1	5.8	5.7	5.9	5.1
Austria	3.9	3.9	4.3	4.6	5.1	6.1	5.2	4.3	3.0	3.8	4.6	4.0	3.8
Belgium	5.3	3.6	4.3	5.4	5.7	6.7	5.7	5.4	3.6	4.3	4.7	4.5	4.1
Czech Republic	..	..	..	..	..	..	..	..	–11.5	–5.5	–1.4	..	..
Denmark	5.9	5.4	6.9	5.4	5.5	6.5	5.6	6.2	5.3	6.2	6.5	5.0	4.3
Finland	3.2	2.9	3.1	5.0	6.1	7.0	7.0	9.1	6.5	6.8	6.0	4.3	3.3
France	4.4	3.1	5.6	5.7	6.2	7.4	6.4	6.1	4.5	5.4	5.8	5.1	4.5
Germany	4.8	3.9	3.9	4.4	5.3	6.4	5.3	3.7	2.0	2.9	4.1	4.4	4.4
Greece	0.1	0.9	3.1	4.2	4.7	7.0	5.6	3.9	5.6	5.7	4.2	3.4	2.1
Hungary	..	..	..	..	..	..	..	..	..	7.1	11.0	2.4	..
Iceland	–6.1	–6.6	3.9	12.0	9.5	–2.5	3.3	4.1	9.8	7.9	9.2	10.1	10.5
Ireland	5.4	5.2	6.5	5.7	5.4	7.1	7.1	7.6	4.7	5.3	6.2	6.4	5.5
Italy	2.2	2.2	3.1	4.2	6.5	6.8	6.2	6.6	5.8	6.2	7.7	4.7	2.5
Luxembourg	–4.7	–3.6	–2.3	–1.4	–1.6	–2.6	–2.8	–2.9	–2.4	–3.2	–2.7	–2.2	–1.2
Netherlands	5.6	5.2	6.0	6.3	6.6	7.4	6.6	5.7	4.1	4.8	4.9	4.4	3.9
Norway	6.5	9.6	10.1	9.0	5.1	5.8	6.0	7.6	5.7	6.8	5.8	4.3	2.3
Poland[3]	..	..	..	..	..	..	..	..	..	–3.7	–5.9	–1.2	4.4
Portugal	6.5	1.3	2.2	3.9	8.2	9.0	9.4	9.2	4.7	3.2	5.9	3.8	2.8
Spain	3.1	1.7	4.5	4.5	7.7	8.0	5.8	4.7	4.1	5.1	7.0	4.7	3.3
Sweden	5.3	3.6	5.6	5.5	4.9	5.5	2.6	4.1	5.1	7.4	7.4	5.5	4.6
Switzerland	1.8	1.3	1.3	1.2	2.3	3.1	1.9	1.9	0.9	2.6	2.7	3.0	3.0
Turkey	16.0	12.9	10.1	21.7	5.4	–7.8	16.2	22.1	30.6	68.6	52.5	47.5	46.4
United Kingdom	6.0	5.5	5.1	5.0	4.2	5.3	3.5	3.2	2.8	5.0	5.9	5.5	4.4

1. Based on lagged GDP deflator.
2. Data for 1997 are estimates.
3. Based on private consumption deflator.

Source: OECD, *Economic Outlook 62,* December 1997; ADB database, February 1998.

Annex Table 2.1. **Manufacturing production**

Volume

	Percentage change from previous year					Index (1990 = 100), seasonally adjusted					
	1981-90[1]	1994	1995	1996	1997[2]	96/Q2	96/Q3	96/Q4	97/Q1	97/Q2	97/Q3
United States	2.8	5.5	3.5	2.8	5.0	117.5	119.0	120.2	121.8	123.0	125.2
Canada	2.0	7.7	3.8	1.3	5.5	110.6	112.7	113.4	115.1	117.0	119.1
Mexico[3]	1.6	4.1	–4.6	11.2	10.2	117.2	124.0	121.6	123.1	129.2	136.6
Japan	4.7	0.8	3.5	2.7	5.8	96.1	98.1	100.2	102.7	102.6	102.3
Australia	1.5	7.2	–0.1	1.9	1.0	107.0	109.3	108.4	108.4	109.9	110.5
New Zealand[3]	0.2	6.0	4.1	0.8	1.3	117.4	119.3	120.8	119.5	118.9	120.9
Austria[3]	3.6	5.2	4.4	2.5	6.6	111.1	110.9	113.0	112.7	119.1	118.9
Belgium	3.0	1.7	6.6	1.5	4.0	107.5	111.8	111.9	105.9	109.6	118.4
Denmark	3.2	10.5	4.5	1.0	4.0	116.3	119.9	118.2	116.5	122.2	125.9
Finland[3]	2.7	11.9	8.7	3.3	9.2	119.9	122.2	125.7	127.3	129.7	135.2
France	1.2	4.5	1.9	0.0	3.6	97.6	98.3	98.0	99.4	101.3	103.1
Germany	2.6	3.3	1.0	–0.1	3.0	96.1	97.6	97.5	97.5	99.5	101.3
Greece	0.3	1.1	2.2	0.6	0.3	98.3	97.9	98.1	97.9	98.5	98.3
Ireland[3]	7.1	12.7	20.2	8.2	12.2	173.5	173.9	183.9	196.1	194.1	191.0
Italy	1.8	6.9	6.4	–3.5	1.8	104.2	103.7	102.6	105.1	106.5	107.2
Luxembourg[3]	4.9	6.7	–0.5	–0.3	6.2	97.7	99.1	101.1	102.7	102.5	110.7
Netherlands	2.6	6.1	3.2	1.5	4.0	109.1	109.2	110.3	112.0	113.2	113.2
Norway	1.6	5.6	2.8	2.6	1.7	111.9	117.0	114.7	114.5	117.0	118.6
Portugal	4.0	0.5	3.5	1.7	4.7	96.2	98.2	100.2	99.0	101.1	103.3
Spain	2.2	8.8	5.2	–0.6	6.7	101.1	105.3	104.9	104.0	110.9	114.1
Sweden	2.4	11.3	12.7	3.1	7.6	120.7	120.5	125.4	126.2	127.0	131.2
Switzerland	2.4	3.7	2.7	0.5	5.1	101.8	104.6	104.1	101.1	110.1	113.1
Turkey	7.5	–8.0	13.3	7.5	11.6	130.8	128.5	131.1	138.4	145.5	145.7
United Kingdom[3]	2.8	4.2	2.2	0.4	2.0	101.4	102.3	102.6	103.0	103.7	104.6
North America	2.7	5.5	2.9	3.3	5.5	117.1	119.0	119.9	121.5	123.1	125.7
Asia-Pacific (OECD)	4.5	1.3	3.2	2.6	5.4	97.0	99.0	100.8	103.2	103.2	103.0
European Union	2.3	5.2	3.6	–0.2	3.5	101.8	102.9	103.0	103.7	105.8	107.6
Total OECD	2.9	4.2	3.4	1.9	4.9	106.8	108.4	109.2	110.6	112.3	113.9

1. Compound annual growth rates between indicated years.
2. 1997 growth rate is based on the first three quarters of 1996 and 1997.
3. OECD Secretariat estimates for missing quarters of 1997.

Source: OECD, *Indicators of Industrial Activity,* February 1998.

Annex Table 2.2. **Manufacturing production by industrial sector**

Percentage change from previous year

	Food, beverages and tobacco ISIC 31		Textiles, apparel and leather ISIC 32		Wood products and furniture ISIC 33		Paper, paper products and printing ISIC 34		Chemicals ISIC 35		Non-metallic mineral products ISIC 36	
	1996	1997[1]	1996	1997[1]	1996	1997[1]	1996	1997[1]	1996	1997[1]	1996	1997[1]
United States	0.4	2.1	–4.2	–0.4	2.0	3.1	–1.5	3.2	1.9	4.1	1.7	2.3
Canada	2.0	3.4	–2.6	8.0	5.3	8.6	–1.4	4.1	3.0	7.3	3.5	3.6
Mexico[2]	3.4	2.7	18.6	10.1	4.5	6.6	0.3	14.7	5.8	5.3	11.4	8.6
Japan	–0.2	–0.2	–3.5	–2.2	–1.5	–3.3	1.4	3.2	1.6	3.4	0.4	2.6
Australia	3.6	1.1	–3.8	7.0	5.0	3.1	–4.8	–9.1	5.4	0.3	–5.8	–0.6
Austria[2]	9.3	2.6	–3.7	10.1	1.7	6.3	1.7	4.3	10.6	0.8	2.5	7.2
Belgium	0.4	5.0	–8.8	1.1	–0.6	5.4	–1.5	12.5	4.8	0.0	–3.6	3.0
Denmark	–1.2	1.2	2.7	–3.5	–2.2	4.9	2.7	3.7	2.7	8.2	0.3	5.0
Finland[2]	4.4	1.0	–1.6	0.8	2.9	14.5	–3.2	10.9	2.0	2.2	4.6	13.5
France	2.0	2.2	–8.1	–2.2	–3.2	2.5	–1.0	3.8	2.9	3.7	–6.3	–2.9
Germany	1.3	0.0	–8.4	–1.8	–4.2	–0.5	–1.5	0.4	–1.0	3.8	–5.6	–0.3
Greece	–1.7	–3.4	–6.3	–2.6	–1.9	–7.6	0.2	–6.5	5.3	–0.3	7.1	2.7
Ireland[2]	3.1	1.6	–3.6	2.2	8.1	13.6	0.5	5.7	16.8	13.7	9.9	16.6
Italy	–2.2	2.8	–4.3	2.0	–5.9	–0.9	–2.6	10.5	–1.1	4.2	–4.3	–0.2
Luxembourg[2]	–4.2	1.2	–16.8	8.9	178.9	59.9	–0.8	7.6	2.2	2.6	–4.5	2.9
Netherlands	1.4	2.1	0.4	6.0	1.2	4.1	1.5	3.2	0.3	5.6	–1.2	6.9
Norway	1.8	0.7	1.3	4.0	2.8	10.6	0.7	3.1	2.2	–0.7	5.2	3.2
Portugal	2.3	3.2	–3.8	–1.2	5.9	10.2	..	..	3.3	5.8	2.7	12.6
Spain	–3.0	8.8	–4.5	3.1	–6.1	1.1	–1.2	6.8	–0.5	5.7	–2.2	4.6
Sweden	4.9	–0.9	–1.9	–0.1	–2.3	9.1	–1.2	5.7	5.7	6.8	–6.9	–0.8
Switzerland	0.8	–0.7	–12.3	–12.3	–9.9	–9.4	–0.2	2.7	6.3	6.3	–5.2	1.1
Turkey	6.1	10.6	8.2	5.6	4.3	31.5	–4.0	5.8	3.0	5.4	5.3	0.1
United Kingdom[2]	0.6	–1.5	–0.3	0.0	1.5	–0.6	–1.4	0.0	–0.9	1.2	–4.0	3.0
North America	0.9	2.2	–2.8	1.0	2.4	3.8	–1.4	3.6	2.3	4.4	3.2	3.3
Asia-Pacific (OECD)	0.6	0.0	–3.5	–1.7	–0.7	–2.5	0.2	0.9	1.7	3.2	0.0	2.4
European Union	0.6	1.8	–4.6	1.0	–3.2	1.4	–1.3	4.2	0.8	3.7	–3.6	1.7
Total OECD	0.9	2.0	–3.2	0.7	–0.5	2.0	–1.2	3.6	1.7	4.0	–0.5	2.3

	Basic metals ISIC 37		Metal products, machinery and equipment ISIC 38		Metal products ISIC 381		Non-electrical machinery ISIC 382		Electrical machinery ISIC 383		Transport equipment ISIC 384	
	1996	1997[1]	1996	1997[1]	1996	1997[1]	1996	1997[1]	1996	1997[1]	1996	1997[1]
United States	1.3	4.8	6.6	8.6	2.5	2.1	10.7	11.5	10.2	11.0	1.1	7.6
Canada	3.7	3.0	0.3	6.2	2.2	6.1	–7.3	2.5	6.3	10.0	1.7	6.6
Mexico[2]	20.1	13.6	21.5	15.6	..	..	..	..	..	..	..	..
Japan	0.3	7.7	5.0	8.4	1.2	–1.5	5.7	7.4	7.3	8.6	2.3	10.8
Australia	4.1	–7.9[3]	3.3	2.8[4]	..	..	..	..	..	..	..	..
Austria[2]	–5.0	9.9	1.8	9.1	2.3	..	–1.0	..	5.1	..	–0.2	..
Belgium	–2.1	1.5	1.1	3.0	6.5	4.3	–1.6	1.8	..	..	–1.1	1.1
Denmark	..	..	2.0	3.3[5]	–0.1	1.6	–1.8	4.5	12.6	3.0	–4.8	2.8
Finland[2]	8.6	5.7	6.1	11.2	6.2	11.1	4.7	5.8	9.4	18.7	–5.7	–5.1
France	–1.7	8.3	0.2	4.7	–3.0	5.3	0.6	2.3	0.1	3.7	1.6	4.9
Germany	–5.2	9.3	2.4	5.2	–1.8	3.7	0.4	4.2	4.3	6.8	14.3	6.4
Greece	–2.7	11.4	0.5	6.6	–3.0	10.2	8.4	10.5	7.0	15.0	–5.6	–6.6
Ireland[2]	7.0	–5.5	8.4	17.5	–0.4	..	8.1	..	6.7	..	13.8	..
Italy	–8.7	4.5	–1.8	–1.3	–8.1	–5.1	0.2	–4.4	–0.3	–3.8	–1.7	9.1
Luxembourg[2]	–0.4	7.9	6.2	7.3	–3.2	..	12.7	..	–3.0	..	–3.2	..
Netherlands	–3.5	8.9	3.0	3.1	0.3	..	5.4	..	2.1	..	5.0	..
Norway	2.8	4.8	4.2	–0.4	8.2	4.6	..	..	..	..	2.5	–4.8
Portugal	–3.4	22.2	8.8	6.1	11.6	..	10.9	9.9	4.1	5.4	18.6	–0.7
Spain	–4.8	5.7	2.3	7.7	0.6	3.2	2.2	1.7	1.9	7.9	0.1	38.4
Sweden	1.6	1.7	4.6	11.3	–0.9	11.7	–4.0	0.3	27.3	24.5	–2.0	9.6
Switzerland	–6.3	–6.5	–4.9	–4.9[4]	..	..	..	..	..	..	..	..
Turkey	8.4	10.4	17.3	20.7	14.4	10.6	14.7	24.9	30.0	17.7	10.3	26.8
United Kingdom[2]	0.5	1.5	2.4	4.0	–0.7	..	0.7	..	1.7	..	5.7	..
North America	5.7	6.8	7.0	8.9	..	..	..	..	..	..	..	..
Asia-Pacific (OECD)	0.7	6.2	4.9	8.2	..	..	..	..	..	..	..	..
European Union	–4.1	6.3	1.7	4.6	..	..	..	..	..	..	..	..
Total OECD	0.7	6.3	4.8	7.4	..	..	..	..	..	..	..	..

1. 1997 growth rate is based on the first three quarters of 1996 and 1997.
2. OECD estimates for missing quarters of 1997.
3. ISIC 37 includes ISIC 381.
4. ISIC 38 excludes ISIC 381.
5. ISIC 38 includes ISIC 37.

Source: OECD, *Indicators of Industrial Activity,* February 1998.

Annex Table 2.3. **Structure of value added by industry**

Percentage

	Share of agriculture, forestry and fishing in total business sector		Share of mining and quarrying in total business sector		Share of manufacturing in total business sector		Share in manufacturing value added							
							High-technology		Medium-high-technology		Medium-low technology		Low-technology	
	1985	1995	1985	1995	1985	1995	1985	1995	1985	1995	1985	1995	1985	1995
United States[1]	2.3	2.0	3.6	1.5	22.0	20.1	14.6	15.8	32.6	32.6	21.8	21.4	30.9	30.1
Canada[2]	3.8	3.0	7.7	3.8	23.2	24.8	7.8	9.2	28.0	31.3	22.9	18.7	41.2	40.8
Mexico	9.6	5.5	4.9	1.7	21.5	21.0	4.4	7.8	26.3	28.0	25.7	23.0	43.6	41.2
Japan	3.4	2.1	0.3	0.2	31.4	26.3	14.3	14.5	32.3	32.7	27.6	27.8	25.8	25.0
Korea[3]	14.0	7.3	1.2	0.3	32.9	29.9	10.9	15.7	18.4	28.7	32.6	30.8	38.0	24.9
Australia	4.1	3.5	6.7	4.1	17.6	14.5	4.9	4.5	23.6	21.7	30.1	30.9	41.3	42.2
New Zealand[4]	8.9	9.9	1.4	1.7	24.4	21.5	3.0	2.3	18.0	15.7	22.9	22.0	56.1	58.9
Austria	4.1	1.9	1.3	0.4	29.4	24.9	..	..	..	..	26.0	27.2	35.5	31.3
Belgium	2.7	1.6	..	..	26.7	23.5	..	..	..	..	..	..	35.6	35.8
Denmark	7.2	5.3	1.4	1.1	25.1	25.1	5.8	7.8	26.8	27.0	23.9	24.9	43.5	40.3
Finland	9.9	5.2	0.5	0.5	30.8	33.0	4.7	8.4	23.8	24.5	23.7	23.4	47.8	43.7
France	5.0	3.0	1.1	0.5	28.1	24.5	12.1	11.9	27.6	28.2	28.9	29.1	31.4	30.8
Germany[5]	2.1	1.3	1.1	0.5	38.0	31.5	10.6	11.2	38.4	38.0	28.5	30.6	22.5	20.3
Greece	19.5	16.0	2.5	1.3	20.6	15.7	..	..	..	..	28.8	25.7	55.0	55.7
Italy	5.2	3.3	..	..	28.3	24.2	7.2	6.4	27.0	26.7	26.7	27.8	39.1	39.1
Netherlands	4.7	3.7	10.0	3.0	21.2	21.0	14.4	13.3	25.4	24.0	27.9	27.8	32.2	34.9
Norway	3.9	3.3	23.0	15.8	16.1	16.6	5.6	5.4	24.8	23.9	29.0	26.2	40.6	44.5
Portugal[6]	8.3	4.4	..	..	34.2	28.6	..	..	..	..	24.0	19.6	51.8	60.7
Spain[7]	6.5	4.1	1.1	0.6	29.2	27.0	5.5	7.6	26.7	31.1	29.5	28.4	38.3	33.0
Sweden[1]	4.7	2.8	0.6	0.4	31.2	30.9	9.7	9.8	33.6	34.0	23.9	21.8	32.8	34.5
United Kingdom[1]	2.3	2.2	8.4	2.5	28.4	23.2	13.0	13.9	32.0	31.2	22.6	19.8	32.5	35.2

	Share of electricity, gas and water in total business sector		Share of construction in total business sector		Share of services in total business sector		Share in services value added							
							Wholesale and retail trade, hotels and restaurants		Transport, storage and communications		Finance, insurance, real estate and business services		Community, social and personal services	
	1985	1995	1985	1995	1985	1995	1985	1995	1985	1995	1985	1995	1985	1995
United States[1]	3.4	3.2	5.1	4.5	62.0	67.4	30.7	27.1	11.1	10.1	42.0	44.3	16.2	18.5
Canada[2]	4.2	4.5	7.4	7.7	53.8	60.6	30.5	28.1	15.7	13.7	41.4	44.1	12.3	14.1
Mexico	1.0	1.3	4.6	4.1	55.0	66.4	54.2	33.3	12.9	15.9	14.9	32.8	18.0	18.0
Japan	3.4	3.0	8.4	11.0	53.0	57.4	26.8	23.5	13.2	12.1	30.9	32.9	29.1	31.5
Korea[3]	3.3	2.5	8.5	15.5	40.1	44.5	38.0	28.7	20.3	18.4	32.3	42.7	9.5	10.2
Australia	3.8	2.9	7.1	6.0	60.7	69.0	31.7	29.9	13.2	11.5	32.1	37.1	23.0	21.5
New Zealand[4]	3.5	3.3	6.3	3.4	55.4	60.2	37.7	31.2	15.7	15.8	38.8	43.8	7.8	9.1
Austria	3.7	3.4	7.6	9.0	53.9	60.3	40.9	35.6	13.9	13.4	37.5	41.3	7.6	9.7
Belgium	5.8	5.1	6.3	6.3	58.6	64.2	33.4	33.4	16.7	15.7	11.6	9.8	38.3	41.1
Denmark	1.6	2.4	7.4	6.9	57.2	59.2	33.8	28.4	18.1	19.3	37.6	40.4	10.6	11.9
Finland	3.4	3.4	9.5	7.2	45.9	50.8	34.8	26.6	20.9	21.1	38.5	45.6	5.8	6.7
France	3.2	3.0	6.6	5.8	56.1	63.2	33.1	30.4	14.0	11.4	41.7	45.7	11.2	12.5
Germany[5]	3.3	2.7	6.2	6.4	49.3	57.6	23.7	20.7	14.0	11.4	30.8	28.3	31.5	39.6
Greece	2.9	2.7	7.2	7.0	47.4	57.3	31.1	27.0	17.8	14.4	18.2	22.0	32.9	36.6
Italy	5.4	6.7	7.3	5.8	53.7	59.9	41.5	35.9	11.7	12.7	10.3	9.7	36.6	41.7
Netherlands	2.1	2.1	5.6	5.8	56.4	64.5	28.4	25.9	12.8	12.1	37.0	42.7	21.9	19.3
Norway	3.8	3.5	5.4	4.7	47.8	56.0	30.4	26.0	20.7	22.7	37.4	38.9	11.5	12.4
Portugal[6]	4.3	5.0	5.9	6.3	47.9	55.6	47.6	40.4	16.7	13.5	25.8	29.5	9.8	16.6
Spain[7]	3.2	3.1	7.3	9.4	52.8	59.4	41.8	43.7	11.6	10.8	36.7	35.1	10.0	10.3
Sweden[1]	3.8	3.9	8.5	6.9	51.1	58.2	30.3	24.0	15.4	14.3	45.3	52.0	9.0	9.7
United Kingdom[1]	3.0	2.9	6.8	5.9	51.1	63.4	29.4	25.0	17.5	14.7	43.7	46.3	9.5	14.0

1. 1994 instead of 1995 for non-manufacturing industries.
2. 1992 instead of 1995 for non-manufacturing industries.
3. 1994 instead of 1995 for technology groupings.
4. 1993 instead of 1995.
5. 1993 instead of 1995 for total manufacturing and non-manufacturing industries.
6. 1993 instead of 1995 for total manufacturing and non-manufacturing industries; 1994 for technology groupings; 1986 instead of 1985 for non-manufacturing industries.
7. 1993 instead of 1995 for non-manufacturing industries.

Source: OECD, ANA, ISDB and STAN databases, December 1997.

Annex Table 2.4. **Investment intensities in business sector, manufacturing and services**[1]

Percentage

	Business sector			Manufacturing			Services		
	1985	1990	1995	1985	1990	1995	1985	1990	1995
United States[2]	19.0	15.9	15.8	11.3	11.0	11.1	20.1	16.2	16.1
Canada[3]	24.1	26.9	24.8	14.1	18.9	14.4	26.4	30.1	28.0
Japan	22.0	26.4	21.0	20.3	23.1	19.0	..	..	..
Korea	27.0	36.4	35.3	25.0	36.2	36.5	32.5	45.0	41.7
Australia[2]	21.8	19.2	22.3	10.4	15.3	13.7	25.0	19.9	23.0
Austria[3]	22.7	25.2	26.0	14.7	17.4	13.6	26.7	30.5	33.2
Belgium	16.4	23.3	19.9	15.1	26.7	17.6	17.4	23.7	21.6
Denmark	24.2	22.5	20.0	17.2	15.6	12.4	25.6	24.2	22.5
Finland	27.6	32.2	17.3	17.5	20.7	13.6	37.8	44.8	20.2
France	21.0	22.7	19.0	14.1	17.1	12.4	25.3	26.7	22.4
Germany	20.7	22.5	23.3	11.6	14.3	13.2	28.0	29.3	29.3
Iceland[4]	26.8	23.7	16.8	23.3	16.2	16.5	31.8	30.2	20.7
Ireland[2]	21.3	21.5	18.2	11.0	10.7	7.3	30.2	28.0	25.8
Italy[2]	21.5	21.6	18.2	14.0	16.9	14.3	25.9	24.9	20.1
Netherlands	21.0	22.6	20.7	19.9	17.9	13.8	24.5	26.1	23.2
Norway	28.4	23.4	23.9	16.1	15.6	14.1	30.0	23.1	24.4
Portugal[4, 5]	24.7	28.3	24.2	15.9	25.1	19.0	33.5	33.2	28.5
Sweden[2]	24.2	27.2	17.1	16.8	17.7	13.2	28.8	34.7	18.9
United Kingdom[2]	20.5	22.5	17.5	13.2	12.8	11.2	27.3	28.1	20.7

1. Investment intensity is defined as gross fixed capital formation/sectoral value added.
2. 1994 instead of 1995.
3. 1992 instead of 1995.
4. 1993 instead of 1995.
5. 1986 instead of 1985.

Source: OECD, ANA, ISDB and STAN databases, December 1997.

Annex Table 2.5. **Physical investment in information and communication technologies (ICT)**

Percentage

	Investment in hardware and software Percentage of gross domestic product		**Investment in hardware** Percentage of gross fixed capital formation	
	1985	1995	1985	1995
United States	2.1	2.9	5.5	7.7
Canada	1.2	2.6	3.5	6.6
Mexico	0.2	0.7	0.7	2.4
Japan	1.1	1.6	2.2	3.0
Australia	2.0	2.6	5.3	7.5
New Zealand	1.7	2.9	4.1	7.7
Austria	0.9	1.4	2.3	2.7
Belgium	1.3	1.6	3.8	3.5
Denmark	0.9	1.6	2.2	4.0
Finland	1.0	1.5	2.9	4.8
France	1.3	1.5	3.1	3.3
Germany	1.1	1.5	2.7	2.9
Greece	0.6	0.5	2.0	1.4
Ireland	0.9	1.2	2.9	3.8
Italy	0.9	1.1	2.4	2.4
Netherlands	1.0	1.9	2.8	4.2
Norway	1.0	1.5	2.1	3.5
Portugal	1.1	0.9	3.4	2.2
Spain	1.0	1.0	3.2	2.3
Sweden	1.6	2.2	3.6	6.3
Switzerland	1.5	2.1	2.8	4.0
Turkey	0.1	0.3	0.4	1.0
United Kingdom	1.7	2.1	5.1	6.4

Source: OECD and estimates based on data from the International Data Corporation (IDC), December 1997.

Annex Table 2.6. **Employment in industry and services**

Compound annual growth rates between indicated years

	Industry			Services[1]			Industry and services		
	1985-96[2]	1985-90	1990-96[2]	1985-96[2]	1985-90	1990-96[2]	1985-96[2]	1985-90	1990-96[2]
United States	0.1	0.7	–0.5	2.1	2.7	1.6	1.6	2.1	1.1
Canada	0.4	1.7	–0.7	1.9	2.8	1.1	1.5	2.5	0.6
Mexico	2.4	3.7	1.3	3.9	–0.1	7.4	3.4	1.2	5.4
Japan	0.6	1.0	0.2	1.8	2.3	1.3	1.3	1.8	0.9
Korea	3.9	7.7	0.9	5.0	4.4	5.5	4.6	5.7	3.6
Australia	0.3	1.5	–0.7	2.9	4.3	1.6	2.2	3.5	1.0
New Zealand	–0.3	–3.3	2.3	3.6	5.0	2.5	2.4	2.3	2.4
Austria	–0.6	0.4	–1.5	2.6	2.0	3.0	1.3	1.3	1.4
Belgium	–0.3	–0.1	–0.4	0.9	1.8	0.2	0.6	1.2	0.0
Czech Republic	–1.7	–1.7	–1.6	1.8	0.1	3.2	0.1	–0.9	0.8
Denmark	–0.1	0.5	–0.6	0.8	1.4	0.2	0.5	1.1	0.0
Finland	–2.7	–0.4	–4.5	–0.1	1.7	–1.5	–0.9	0.9	–2.5
France	–1.6	–0.6	–2.4	1.5	2.1	1.1	0.6	1.2	0.1
Germany	–0.7	0.8	–2.0	1.6	2.3	1.0	0.6	1.7	–0.2
Greece	–0.9	1.0	–2.5	2.9	2.8	3.1	1.6	2.1	1.2
Hungary[3]	..	..	–4.5	..	..	–0.2	..	..	–1.9
Iceland	–1.3	–1.0	–1.6	3.1	2.2	3.8	1.7	1.1	2.2
Ireland	1.4	0.8	1.8	3.0	1.5	4.4	2.5	1.2	3.6
Italy	–0.6	–0.1	–1.0	0.7	2.0	–0.4	0.2	1.2	–0.6
Luxembourg	0.6	1.3	0.0	2.1	4.8	0.0	1.6	3.6	0.0
Netherlands	0.8	2.9	–0.9	3.8	5.0	2.9	3.0	4.4	1.9
Norway	3.5	–1.8	8.1	–0.3	1.1	–1.5	1.0	0.3	1.5
Poland[4]	..	..	0.4	..	..	2.7	..	..	1.8
Portugal	0.2	3.1	–2.2	3.6	5.3	2.2	2.2	4.4	0.5
Spain	0.8	4.5	–2.2	3.4	5.4	1.7	2.4	5.0	0.3
Sweden	–1.9	0.1	–3.6	0.0	1.4	–1.1	–0.6	1.0	–1.8
Switzerland	–1.1	0.5	–2.4	2.5	1.6	3.2	1.3	1.2	1.3
Turkey	2.2	1.5	2.8	3.4	4.1	2.8	2.9	3.0	2.8
United Kingdom	–1.5	0.6	–3.2	1.7	2.9	0.8	0.7	2.1	–0.4

1. Services include government services.
2. 1996 data are estimates.
3. 1992-96.
4. 1993-96.

Source: OECD *Labour Force Statistics,* December 1997.

Annex Table 2.7. **Employment in manufacturing industries**

Shares in total manufacturing and compound annual growth rates in percentage

	Total manufacturing	High-technology			Medium-high-technology			Medium-low-technology			Low-technology		
	Growth 1985-95	Shares		Growth 1985-95	Shares		Growth 1985-95	Shares		Growth 1985-95	Shares		Growth 1985-95
		1985	1995		1985	1995		1985	1995		1985	1995	
United States	–0.2	13.5	11.1	–2.2	27.5	27.4	–0.3	23.2	24.2	0.2	35.8	37.4	0.2
Canada	–0.2	7.0	8.0	1.2	24.4	26.7	0.8	23.2	22.6	–0.4	45.4	42.7	–0.8
Mexico	0.1	..	..	..	..	..	..	21.5	19.8	–0.8	49.1	46.8	–0.4
Japan	0.2	12.5	11.6	–0.6	27.5	28.6	0.6	24.1	24.3	0.3	36.0	35.5	0.1
Korea[1]	2.2	..	..	..	15.9	25.1	7.5	30.5	29.9	2.0	43.1	32.1	–1.1
Australia[2]	–0.2	4.7	4.7	–0.6	22.4	20.3	–2.0	28.0	28.5	–0.4	44.8	46.3	–0.2
New Zealand[1]	–2.5	3.3	2.7	–4.3	17.9	16.3	–3.3	22.2	21.1	–2.9	56.6	59.9	–1.7
Austria	–1.4	..	..	..	..	..	..	..	..	..	43.3	40.4	–2.1
Belgium[1]	–1.5	..	..	..	..	..	..	..	..	..	39.6	39.0	–1.7
Denmark[3]	–1.2	4.7	4.9	–0.7	27.5	28.4	–0.8	24.3	25.0	–0.9	43.4	41.6	–1.7
Finland	–2.7	4.1	8.1	4.1	22.8	25.4	–1.7	22.5	23.9	–2.1	50.7	42.7	–4.4
France	–1.6	10.2	10.6	–1.2	30.4	29.9	–1.7	24.0	24.9	–1.2	35.5	34.6	–1.9
Germany	–1.1	8.1	7.7	–1.6	36.9	38.4	–0.7	28.0	28.2	–1.0	26.9	25.8	–1.5
Greece[2, 4]	–1.4	..	..	..	..	..	..	26.4	25.0	–1.7	57.1	58.6	–1.3
Iceland[1]	–3.0	..	..	..	2.3	2.8	–1.0	23.5	23.8	–2.8	74.2	73.5	–3.1
Italy[3]	–1.1	4.4	5.1	0.9	24.6	23.2	–1.9	27.1	26.7	–1.4	44.0	44.9	–0.9
Netherlands	–0.4	14.8	13.1	–1.6	21.8	22.3	–0.1	25.1	25.0	–0.4	38.4	39.6	0.0
Norway	–2.1	5.7	5.7	–2.1	22.7	25.5	–1.0	28.3	27.2	–2.5	43.3	41.6	–2.5
Portugal	–1.5	..	..	..	..	..	..	26.1	24.7	–2.1	59.0	59.7	–1.4
Spain[2, 4]	1.0	3.9	3.7	0.6	23.4	24.2	1.8	26.2	26.5	1.4	46.4	45.6	1.1
Sweden	–1.8	8.7	9.0	–1.4	29.3	31.9	–0.9	28.6	26.6	–2.5	33.3	32.5	–2.0
United Kingdom	–0.6	11.3	12.2	0.2	30.5	30.9	–0.4	23.4	23.2	–0.7	34.8	33.7	–0.9

1. 1994 instead of 1995.
2. 1992 instead of 1995 for the four industry groups.
3. 1993 instead of 1995 for the four industry groups.
4. 1994 instead of 1995 for total manufacturing.

Source: OECD STAN database, December 1997.

Annex Table 2.8. **Employment in services industries**

Shares in total services and compound annual growth rates in percentage

	Total services	Wholesale and retail trade, restaurants and hotels			Transport, storage and communications services			Finance, insurance, real estate and business services			Community, social and personal services		
	Growth 1985-95	Shares		Growth 1985-95	Shares		Growth 1985-95	Shares		Growth 1985-95	Shares		Growth 1985-95
		1985	1995		1985	1995		1985	1995		1985	1995	
United States[1]	2.6	41.3	37.5	1.5	7.8	7.3	1.9	24.0	25.5	3.2	26.9	29.6	3.7
Canada	2.1	48.0	44.9	1.4	13.8	12.6	1.2	20.7	23.8	3.5	17.5	18.7	2.7
Mexico[2]	0.7	40.0	41.7	1.2	13.1	13.6	1.2	6.2	6.4	1.1	40.7	38.4	0.9
Japan	1.6	38.6	33.2	0.1	11.9	11.2	1.1	9.4	9.3	1.5	40.1	46.2	3.1
Australia	2.8	37.8	37.6	2.8	12.2	9.8	0.6	17.6	19.8	4.1	32.4	32.9	3.0
New Zealand	1.5	33.7	32.5	1.1	12.4	9.1	–1.6	13.5	16.4	3.5	40.4	42.0	1.9
Austria[1]	1.9	50.4	49.9	1.8	19.4	18.0	1.1	17.7	18.7	2.5	12.5	13.4	2.7
Belgium[1]	1.5	42.7	38.7	0.3	14.9	12.9	–0.1	8.6	7.6	0.1	33.8	40.9	3.6
Denmark	0.6	38.3	36.8	0.1	20.3	19.0	–0.1	25.7	27.9	1.4	15.7	16.3	1.0
Finland	–1.2	47.8	43.8	–2.1	21.3	21.4	–1.1	20.6	25.6	1.0	10.3	9.2	–2.2
France	1.3	47.9	42.0	0.4	15.5	13.7	0.5	22.2	27.0	2.6	14.4	17.3	2.6
Germany[1]	2.6	45.4	43.1	2.0	16.0	13.5	0.7	8.5	8.2	2.1	30.1	35.2	4.4
Greece	3.2	36.4	39.4	4.0	15.9	11.5	–0.1	8.5	11.2	6.1	39.3	38.0	2.9
Iceland[1]	0.8	42.2	38.8	–0.1	19.1	17.7	0.0	19.2	22.8	2.7	19.5	20.7	1.5
Italy	1.8	55.4	49.6	1.0	16.8	14.4	0.7	4.7	4.4	1.4	23.1	31.6	3.9
Luxembourg[3]	5.5	46.0	38.4	2.4	13.9	12.6	3.8	14.2	16.8	8.5	25.9	32.2	9.4
Netherlands	2.7	37.2	36.9	2.6	13.3	11.5	1.2	19.8	23.9	4.7	29.7	27.7	2.0
Norway	0.6	41.2	38.2	–0.2	21.2	21.4	0.7	17.0	17.6	1.0	20.6	22.9	1.7
Portugal	3.5	58.3	52.0	2.3	15.2	10.1	–0.7	12.5	20.1	8.5	14.0	17.9	6.0
Spain	2.8	56.3	56.2	2.8	17.0	14.1	0.9	11.9	13.1	3.8	14.7	16.6	4.0
Sweden[1]	0.5	42.1	38.4	–0.5	20.5	18.3	–0.7	19.7	24.2	2.9	17.7	19.1	1.4
Turkey[1]	2.3	35.6	37.3	2.8	14.1	13.0	1.3	7.6	7.5	2.2	42.8	42.2	2.1
United Kingdom	2.5	45.3	37.2	0.5	13.3	11.0	0.6	21.6	27.5	5.0	19.8	24.3	4.7

1. 1994 instead of 1995.
2. 1993 instead of 1995.
3. 1991 instead of 1995.

Source: OECD, ANA and ISDB databases, and *Labour Force Statistics,* December 1997.

Annex Table 2.9. **Shares and growth in occupations, total economy**

	Percentage shares in 1995 (or latest year available)						Average annual growth rates between indicated years						
	White-collar	Blue-collar	White-collar high-skilled	White-collar low-skilled	Blue-collar high-skilled	Blue-collar low-skilled	Period	White-collar	Blue-collar	White-collar high-skilled	White-collar low-skilled	Blue-collar high-skilled	Blue-collar low-skilled
United States (1993)[1]	71.9	28.1	26.3	45.6	11.0	17.1	1983-93	2.4	0.7	2.7	2.2	0.8	0.6
Canada (1991)[1]	67.6	32.4	31.3	36.4	13.0	19.3	1981-91	2.4	–0.4	3.2	1.7	–0.8	–0.1
Mexico[2]	..	..	..	..	..	..	1980-93	8.4	4.6	..	..	..	..
Japan (1990)[1]	60.8	39.2	22.9	38.0	26.0	13.2	1980-90	2.1	–0.8	2.7	1.8	–1.3	0.4
Korea[2]	50.6	49.4	16.4	34.2	27.5	21.9	..	..	..	..	..	..	..
Australia (1991)[1]	67.0	33.0	38.6	28.4	13.8	19.2	1986-91	2.5	0.4	2.9	2.0	0.2	0.5
New Zealand[2]	64.2	35.8	37.0	27.2	19.8	16.0	1981-95	3.7	–0.3	3.8	3.6	–1.1	0.8
Austria[3]	55.2	44.8	29.4	25.8	25.4	19.3	1984-92	2.3	–0.2	..	..	..	..
Belgium[3]	66.0	34.0	39.1	26.8	16.5	17.6	..	..	..	..	..	..	..
Czech Republic[2]	53.6	46.4	34.2	19.4	23.9	22.5	..	..	..	..	..	..	..
Denmark[3]	64.0	36.0	35.8	28.3	16.0	19.9	1981-93	0.8	–0.5	..	..	..	..
Finland (1990)[1]	58.5	41.5	30.5	28.0	24.1	17.4	1980-90	2.1	–1.6	3.3	1.0	–2.0	–1.0
France[3]	62.1	37.9	35.4	26.7	19.3	18.6	1982-95	1.3	–1.6	1.7	0.8	–1.7	–1.6
Germany[3]	60.7	39.3	36.5	24.1	21.1	18.2	1980-90	1.7	–0.9	2.0	1.3	0.0	–1.8
Greece[3]	49.4	50.6	27.3	22.1	37.0	13.6	1981-92	3.4	–0.4	..	..	..	.
Hungary[2]	52.7	47.3	29.9	22.8	26.8	20.4	..	..	..	..	..	..	..
Iceland[2]	61.0	39.0	34.0	27.0	24.8	14.2	1991-95	1.3	0.2	2.9	–0.5	0.4	–0.1
Ireland[2]	61.2	38.8	30.2	30.9	22.1	16.7	1987-95	2.4	0.7	2.8	2.0	0.6	1.0
Italy[3]	55.5	44.5	24.8	30.7	24.9	19.5	1981-95	1.5	–2.0	1.3	1.6	–1.8	–2.2
Netherlands[3]	72.3	27.7	45.3	27.0	12.7	15.1	1981-90	3.7	0.3	..	..	..	..
Norway[2]	..	..	..	..	..	..	1980-93	1.6	–1.8	..	..	..	..
Poland[2]	43.3	56.7	27.1	16.3	40.2	16.4	..	..	..	..	..	..	..
Portugal[3]	51.7	48.3	26.8	24.9	30.9	17.4	1981-90	4.9	–0.2	..	..	..	..
Spain[3]	49.8	50.2	25.8	24.1	24.5	25.7	1980-90	2.9	–0.8	..	..	..	..
Sweden[2]	..	..	..	..	..	..	1980-90	1.4	–0.8	..	..	..	..
United Kingdom[3]	69.1	30.9	38.3	30.8	13.8	17.1	1981-95	1.0	–0.9	2.8	–0.7	–2.3	0.5

Sources: 1. OECD estimates from national data.
2. International Labour Office.
3. Eurostat.

Annex Table 2.10. **Employment growth by skill level in manufacturing and in services**

Compound annual growth rates between indicated years

Manufacturing	United States 1983-93				Japan[1] 1980-90				Germany 1980-90				France 1982-90				United Kingdom 1981-91			
	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS
Total manufacturing	1.0	–0.5	–0.4	–0.3	2.5	2.9	–0.2	1.1	2.0	1.1	0.8	–1.9	1.8	–1.8	–1.0	–3.1	2.3	–2.9	–2.0	–2.1
High-technology	–0.4	–2.5	–2.5	–2.7	..	..	..	..	3.4	2.9	1.8	–1.5	2.8	–2.3	–0.1	–3.3	5.0	–1.4	–1.3	0.1
Medium-high-technology	0.8	–1.1	–0.8	–0.6	4.1	2.9	1.2	1.7	2.7	1.3	1.6	–0.6	1.2	–2.9	–1.0	–3.8	1.8	–3.2	–2.3	–3.0
Medium-low-technology	0.0	–0.3	–0.6	0.3	0.7	2.5	–1.2	2.5	0.5	1.0	0.3	–1.6	1.0	–2.2	–0.9	–2.8	–4.8	–3.5	–1.2	–3.5
Low-technology	2.0	0.1	0.7	–0.2	1.2	3.2	–1.3	0.0	0.9	0.3	0.0	–3.6	2.1	–0.9	–1.4	–2.6	5.5	–2.9	–2.4	–0.8

	Italy 1981-91				Canada 1981-91				Finland 1980-90				Australia 1986-91				New Zealand 1981-91			
	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS
Total manufacturing	1.6	–2.3	–2.0	–1.6	2.4	0.5	–1.0	–1.6	2.3	–1.0	–2.4	–2.7	1.8	0.0	–1.0	–1.9	0.3	–2.7	–3.5	–3.9
High-technology	3.9	–3.4	1.0	–1.5	..	..	..	..	5.1	1.0	1.0	0.9	0.5	–1.1	–0.1	–4.0	–0.3	–1.9	–6.0	–9.4
Medium-high-technology	2.2	–2.3	–2.0	–3.9	..	..	..	..	1.5	–1.5	–3.0	–1.8	0.4	–1.7	–4.0	–3.9	–0.6	–4.9	–4.6	–6.1
Medium-low-technology	1.3	–2.1	–0.5	–2.9	..	..	..	..	0.0	–2.4	–2.4	–2.5	2.3	0.5	–0.3	–1.1	0.1	–3.2	–3.1	–3.5
Low-technology	0.4	–2.2	–2.8	1.8	..	..	..	..	1.7	–1.7	–3.4	–4.4	2.0	0.6	0.2	–1.4	0.8	–1.6	–3.3	–2.7

Services	United States 1983-93				Japan 1980-90				Germany 1980-90				France 1982-90				United Kingdom 1981-91			
	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS
Total services	3.0	2.4	1.3	2.4	3.3	2.5	–1.6	1.7	2.8	2.6	2.2	–0.5	2.2	2.0	0.3	1.1	3.8	1.8	0.4	1.3
Wholesale and retail trade, hotels and restaurants	1.2	2.2	0.8	1.9	4.3	2.6	–4.4	2.1	1.4	1.9	2.5	–1.6	2.1	1.7	–2.1	–0.1	3.0	2.3	1.7	1.9
Transport, storage and communications	2.0	1.1	0.3	2.5	–0.5	0.9	–6.1	0.8	–0.2	2.9	–1.7	–0.8	0.8	–0.1	1.5	–3.7	5.0	0.7	–1.4	0.7
Finance, insurance, real estate and business services	4.3	3.4	4.4	6.5	4.9	4.2	1.7	4.2	2.7	2.6	0.9	–2.8	3.5	4.4	3.0	4.9	9.4	2.4	2.6	2.0
Community, social and personal services	3.0	2.3	1.3	1.3	2.1	0.9	–2.5	1.1	3.2	2.4	2.6	–0.2	1.9	2.3	0.8	1.2	2.0	0.2	–1.6	–1.2

	Italy 1981-91				Canada 1981-91				Finland 1980-90				Australia 1986-91				New Zealand 1981-91			
	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS	WCHS	WCLS	BCHS	BCLS
Total services	2.5	2.7	2.1	3.1	3.2	1.8	0.1	0.8	3.9	1.2	0.6	0.1	3.9	2.6	1.1	2.1	6.3	1.8	–1.3	1.4
Wholesale and retail trade, hotels and restaurants	–0.1	2.4	–9.7	10.1	2.5	1.9	0.3	1.0	3.8	0.4	–0.3	–1.4	2.8	3.5	2.3	3.4	5.2	2.3	4.0	2.7
Transport, storage and communications	0.6	2.3	0.8	0.2	1.7	–0.1	–1.9	–0.2	0.6	0.2	–3.3	–0.9	3.1	0.3	–6.6	–0.5	0.8	0.0	–6.0	–1.6
Finance, insurance, real estate and business services	9.3	4.0	7.3	10.1	4.8	1.8	3.1	4.6	6.7	3.4	6.2	3.7	6.7	0.6	1.4	5.3	7.1	1.6	2.0	6.4
Community, social and personal services	1.0	2.3	3.1	1.2	2.8	2.1	0.6	0.8	3.4	1.3	1.3	0.5	3.6	2.6	0.7	1.4	6.6	1.1	–4.0	2.3

1. For Japan, high-technology is included in medium-high-technology.

WCHS: White-collar high-skilled; WCLS: White-collar low-skilled; BCHS: Blue-collar high-skilled; BCLS: Blue-collar low-skilled.

Source: OECD estimates from national data, December 1997.

Annex Table 2.11. **Relative unit labour costs**

Index, 1991 = 100

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[1]
United States	125	130	142	147	152	157	134	114	104	105	102	100	97	97	94	94	98	104
Canada	82	86	94	96	89	86	81	86	94	98	97	100	90	83	76	76	80	82
Mexico	140	170	126	65	83	80	61	62	73	81	86	100	115	132	134	85	83	94
Japan	81	87	76	85	87	85	114	118	122	108	95	100	105	129	140	141	119	110
Korea	66	60	65	66	63	66	56	61	74	102	101	100	95	91	96	97	99	96
Australia	104	118	125	118	124	103	86	84	94	104	103	100	90	83	86	86	96	100
New Zealand	123	120	117	114	96	94	94	104	113	104	102	100	89	92	97	104	114	121
Austria	112	112	112	111	108	107	112	113	106	103	103	100	100	100	96	97	94	91
Belgium-Luxembourg	133	121	101	92	92	93	99	101	98	95	101	100	102	101	103	112	108	104
Denmark	88	82	81	82	83	86	94	104	101	97	105	100	101	98	99	103	102	103
Finland	91	95	99	96	99	99	95	93	95	100	104	100	77	62	68	77	74	72
France	110	108	104	104	105	108	110	108	102	98	101	100	101	103	100	100	99	94
Germany	91	83	87	88	86	85	94	104	103	101	103	100	107	115	116	125	121	111
Greece	90	96	111	106	111	110	91	87	96	102	107	100	97	93	96	104	108	112
Italy	87	87	89	94	92	90	91	91	90	94	98	100	95	79	75	67	76	80
Netherlands	123	111	115	112	101	99	106	111	108	101	102	100	103	105	101	104	101	97
Norway	92	97	99	100	98	98	97	98	103	104	100	100	97	96	99	104	104	106
Portugal	75	82	81	76	75	75	77	74	78	82	89	100	111	107	110	116	117	118
Spain	99	91	89	77	79	78	77	77	82	89	98	100	102	93	85	82	85	84
Sweden	100	102	88	80	82	86	86	86	90	94	96	100	98	72	68	68	77	73
Switzerland	72	72	78	87	86	84	91	95	96	91	99	100	98	99	108	116	114	107
United Kingdom	116	120	113	103	99	101	95	96	100	97	98	100	94	84	86	84	88	106

1. Data for 1997 are estimates.

Source: OECD, *Economic Outlook 62,* December 1997.

Annex Table 2.12. **Size distribution of enterprises: business sector**

Percentage

		Number of enterprises/establishments[1]					Employment					Value added				
		1-9	10-19	20-99	100-499	500+	1-9	10-19	20-99	100-499	500+	1-9	10-19	20-99	100-499	500+
United States	1993	75.9	12.4	9.9	1.6	0.3	12.2	7.9	18.4	14.6	46.9	2.0	2.3	10.0	13.6	72.1
Canada[2]	1994	93.2	3.7	2.3	0.5	0.2	15.7	7.2	19.6	16.3	41.1		..	..	..	..
New Zealand[2]	1996	89.3	6.0	3.9	0.6	0.1	29.9	10.4	19.3	15.0	25.5	..	..	..	..	..
Austria	1992	26.8	14.1	45.2	12.1	1.8	1.9	3.1	29.3	36.0	29.8	1.6	2.7	23.0	36.4	36.2
Belgium	1992	85.8	7.0	6.1	0.9	0.2	17.1	8.2	20.2	19.5	35.1	21.8	9.3	23.4	18.6	27.0
Czech Republic[3]	1996	..	97.7	1.7	0.6	0.1	..	38.6	13.5	19.2	28.8	..	32.4	14.0	18.8	34.9
Denmark	1992	80.5	10.2	7.8	1.3	0.2	26.8	11.4	22.5	18.0	21.4	19.4	10.3	24.7	20.4	25.2
Finland	1992	86.2	6.8	5.6	1.1	0.3	18.4	7.4	17.5	19.0	37.7	15.7	6.7	15.6	20.1	42.0
France	1992	84.6	6.9	7.1	1.1	0.2	19.1	7.2	21.3	17.3	35.1	15.4	5.7	18.5	17.2	43.2
Germany	1992	81.1	10.9	6.5	1.2	0.2	21.4	10.0	17.8	17.5	33.4	15.7	7.9	20.8	24.8	30.7
Greece[4]	1992	..	59.3	34.0	6.0	0.7	..	20.3	34.9	27.9	16.8	..	13.1	29.0	33.1	24.8
Hungary[5]	1995	87.9	..	10.6	1.3	0.3	..	..	..	..	..	11.1	..	20.9	23.4	44.6
Iceland[6]	1992	88.5	6.1	4.6	0.8	..	28.2	12.4	25.5	34.0	..	..	..	..	..	..
Italy	1992	94.2	3.7	1.9	0.2	0.0	45.8	11.2	15.5	9.9	17.6	..	..	..	..	..
Luxembourg	1992	76.0	11.5	10.3	2.0	0.3	15.5	10.0	26.3	25.3	22.9	..	..	..	..	..
Netherlands	1992	78.8	9.1	10.4	1.5	0.2	18.4	9.5	23.8	20.1	28.2	17.4	8.8	23.1	22.4	28.2
Norway	1992	89.9	5.4	3.9	0.7	0.1	32.7	11.1	23.6	10.2	22.4	24.2	10.5	14.3	10.1	40.9
Portugal	1992	87.0	6.7	5.3	0.8	0.1	26.3	10.7	25.1	19.3	18.5	14.5	7.1	21.8	20.0	36.6
Spain[4]	1992	..	57.8	34.0	7.2	1.0	..	17.8	32.9	20.8	28.6	..	13.1	29.0	33.1	24.8
Sweden[5]	1992	..	94.6	4.4	0.8	0.2	..	30.1	18.5	17.5	33.9	..	27.5	17.8	18.4	36.2
Switzerland	1992	86.3	7.1	5.4	1.0	0.2	22.8	9.6	21.7	20.0	25.9	..	..	..	..	..
United Kingdom[2]	1991	92.2	3.7	3.3	0.6	0.1	26.6	6.4	16.1	17.2	33.8	9.6	3.8	16.4	14.9	55.3
European Union	1992	85.5	8.1	5.3	0.9	0.2	25.5	9.6	18.1	16.2	30.5	19.7	8.9	21.4	21.4	28.6

1. The statistical unit for Austria and Greece is the establishment. Belgium and the United Kingdom are based on VAT units, Denmark on legal units, and the Netherlands on kind of activity units.
2. 0-9; 10-19; 20-99; 100-499; 500+.
3. 0-24; 25-99; 100-499; 500+.
4. 10-19; 20-99; 100-499; 500+.
5. 0-9; 10-99; 100-499; 500+.
6. 1-9; 10-19; 20-99; 100+.

Source: OECD, database on SME statistics; Commission of the European Communities, *Enterprises in Europe.*

Annex Table 2.13. **Size distribution of enterprises: manufacturing industry**

Percentage

		Number of enterprises/establishments[1]					Employment					Value added				
		1-9	10-19	20-99	100-499	500+	1-9	10-19	20-99	100-499	500+	1-9	10-19	20-99	100-499	500+
United States	1993	53.8	17.4	21.6	5.5	1.6	3.5	3.9	14.6	16.5	61.5	2.0	2.3	10.0	13.6	72.1
Canada[2]	1994	67.2	11.4	14.8	5.7	0.9	5.9	5.4	20.8	24.9	43.1	..	..	..	..	..
Mexico[3]	1994	..	80.3	15.1	2.7	2.0	..	12.2	21.2	15.6	51.0	..	..	..	..	..
Japan[4]	1995	55.0	19.8	21.2	3.5	0.5	12.3	10.3	30.9	25.3	21.2	5.7	6.2	23.0	29.7	35.5
Korea[4]	1995	44.3	27.5	24.1	3.6	0.5	9.4	12.0	30.7	22.2	25.7	4.2	6.0	20.1	23.3	46.4
Australia	1994	67.1	15.0	14.1	3.4	0.4	12.8	9.5	27.5	32.7	17.5	6.5	5.7	24.0	38.8	25.1
New Zealand[2]	1996	80.3	10.4	7.8	1.3	0.2	20.8	11.9	25.7	21.5	20.1	..	..	..	..	..
Austria	1992	25.0	13.1	45.1	14.7	2.1	1.8	2.9	29.6	42.4	23.4	1.4	2.6	24.6	44.5	26.9
Belgium	1992	71.3	10.7	14.2	3.2	0.7	8.0	6.2	23.8	26.0	36.1	5.1	3.7	16.2	46.5	28.4
Czech Republic[5]	1996	..	94.8	3.2	1.5	0.5	..	19.7	12.4	24.2	43.8	..	14.3	11.7	23.8	50.2
Denmark	1992	62.7	16.1	16.6	4.0	0.6	13.2	9.9	23.0	29.4	24.5	8.8	8.5	21.3	31.4	29.9
Finland	1992	73.5	10.3	11.9	3.4	0.9	7.6	4.8	16.3	23.8	47.5	4.3	2.8	11.3	18.9	62.7
France	1992	69.4	11.0	15.5	3.4	0.7	8.5	5.3	22.2	24.4	39.6	7.2	4.4	19.1	23.5	45.8
Germany	1992	64.0	16.8	14.5	3.9	0.9	7.8	6.2	16.3	21.6	48.2	5.7	4.6	11.6	24.1	54.0
Greece[6]	1992	..	59.0	34.2	6.1	0.7	..	20.5	35.3	27.8	16.4	..	15.0	33.1	33.5	18.3
Hungary[7]	1995	75.6	..	20.2	3.4	0.9	..	..	..	..	..	3.9	..	16.3	26.8	52.9
Iceland[8]	1992	76.0	11.9	10.2	2.0	..	19.2	13.8	33.6	33.4	..	..	..	..	..	..
Italy	1992	82.1	10.5	6.4	0.9	0.1	24.2	14.8	24.3	17.0	19.8	..	..	..	..	..
Luxembourg	1992	55.5	16.8	19.4	6.8	1.4	4.4	4.6	16.2	30.4	44.3	..	..	..	..	..
Netherlands	1992	63.1	13.9	18.1	4.3	0.6	10.3	7.0	26.3	27.9	28.5	8.2	5.7	22.2	28.9	35.0
Norway	1992	74.0	10.6	12.0	2.8	0.6	11.3	8.1	28.6	16.7	35.3	7.9	6.6	13.0	15.1	57.4
Portugal	1992	74.0	10.9	12.5	2.4	0.3	12.9	9.5	32.9	29.4	15.3	6.8	6.4	26.7	31.5	28.6
Spain[6]	1992	..	57.8	34.0	7.2	1.0	..	15.6	33.5	24.6	26.3	..	13.1	30.2	40.1	16.7
Sweden[7]	1992	86.3	..	10.2	2.7	0.9	14.3	..	17.7	22.6	45.5	12.0	..	16.4	22.8	48.7
Switzerland	1992	76.2	10.0	10.5	2.8	0.4	11.3	7.1	23.3	29.0	29.4	..	..	..	..	..
Turkey	1994	94.9	1.6	2.5	0.8	0.2	35.2	3.0	14.7	21.9	25.2	5.7	1.5	12.3	32.9	47.7
United Kingdom[2]	1991	86.4	5.8	6.0	1.4	0.4	13.3	4.7	14.3	17.0	50.8	5.5	3.7	18.5	16.6	55.8
European Union	1992	69.7	15.0	12.1	2.6	0.5	11.5	8.1	19.2	21.1	40.2	7.3	5.9	15.8	23.0	48.1

1. The statistical unit for Mexico, Japan, Korea, Australia, Austria, Greece and Turkey is the establishment. Belgium and the United Kingdom are based on VAT units, Denmark on legal units, and the Netherlands on kind of activity units.
2. 0-9; 10-19; 20-99; 100-499; 500+.
3. 1-15; 16-100; 101-250; 250+.
4. 4-9; 10-19; 20-99; 100-499; 500+.
5. 0-24; 25-99; 100-499; 500+.
6. 10-19; 20-99; 100-499; 500+.
7. 0-9; 10-99; 100-499; 500+.
8. 1-9; 10-19; 20-99; 100+.

Source: OECD, database on SME statistics; Commission of the European Communities, *Enterprises in Europe*.

Annex Table 3.1. **Export volumes**

Total goods, customs basis, level in millions of US$, and percentage change from previous period

	1995 level (millions of US$)	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[1]
United States[2]	576 513	11.9	–1.0	–9.1	–2.9	7.9	3.6	5.1	11.0	18.8	12.5	8.3	7.0	7.0	3.4	9.9	12.6	9.5	15.8
Canada	198 028	–0.3	3.4	–0.5	7.4	18.6	6.4	3.8	3.6	9.3	1.2	9.3	0.2	8.4	12.7	14.3	11.9	4.5	8.0
Mexico	67 145	35.7	22.2	12.7	25.8	9.1	–5.8	4.0	–12.9	–10.4	2.2	1.5	3.4	–2.9	9.5	12.1	34.9	18.3	15.3
Japan	329 005	19.2	10.7	–2.3	8.1	15.8	5.0	–0.5	0.4	4.2	4.6	4.9	2.4	1.7	–1.9	1.6	3.3	0.5	11.9
Korea	117 123	3.1	15.6	10.0	16.7	16.5	7.3	11.9	20.9	16.4	–4.2	6.1	9.8	8.7	6.8	14.5	24.1	19.8	20.7
Australia	53 520	–0.2	–5.8	9.6	–5.9	16.4	11.4	3.7	10.8	–0.4	4.3	7.7	15.2	4.8	5.7	8.4	5.0	11.9	5.0
New Zealand	11 277	5.1	1.3	3.1	5.3	4.7	10.7	–1.7	2.7	4.2	–3.1	6.0	10.5	2.2	4.4	10.1	2.5	5.0	5.2
Austria	50 884	4.5	5.0	1.6	4.3	9.4	9.7	1.0	2.2	7.6	15.3	11.2	7.1	3.5	–2.7	11.4	10.7	4.8	7.5
Belgium-Luxembourg	149 433	1.9	0.3	1.6	4.1	5.0	4.1	7.9	6.9	4.6	8.1	3.1	4.0	0.0	6.7	10.1	8.5	2.9	6.2
Czech Republic	14 058	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3.0	33.2	–1.2	3.5
Denmark	38 197	9.0	7.0	2.0	7.6	5.1	4.7	1.3	2.5	5.4	7.5	5.9	7.5	4.9	–3.4	8.9	4.3	2.8	3.5
Finland	35 052	9.7	2.5	–2.9	4.0	9.7	0.9	0.4	1.6	3.3	–0.1	2.9	–9.1	9.0	18.6	14.0	5.9	4.2	9.1
France	253 212	3.3	3.9	–2.8	3.6	7.0	2.4	–1.1	3.7	9.0	9.1	5.3	3.9	4.7	–1.0	6.5	7.9	5.0	10.4
Germany	440 263	1.7	6.5	3.3	–0.3	9.1	6.0	1.4	2.9	6.7	8.2	1.4	1.4	0.8	–6.4	9.1	6.7	4.7	12.0
Greece	11 425	12.9	–15.9	0.4	16.5	18.1	–0.2	17.9	11.1	–32.3	39.3	–5.8	11.4	18.2	6.1	2.5	3.5	2.6	1.7
Hungary	12 932	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16.7	8.7	14.4	18.7
Iceland[3]	1 744	6.3	5.2	–17.0	15.2	–0.5	13.3	15.2	14.4	–2.0	0.3	4.1	–0.7	–4.9	3.7	15.6	–1.6	9.8	4.6
Ireland	41 938	7.8	0.7	7.2	12.1	18.4	6.5	3.7	14.5	7.1	11.2	8.5	5.6	14.7	10.2	14.8	20.1	9.0	12.0
Italy	233 834	–3.4	4.4	0.9	4.5	5.1	6.3	1.8	3.1	8.6	5.5	2.6	0.8	3.6	11.6	10.5	8.8	5.2	4.3
Netherlands	144 039	1.1	0.6	–0.6	4.5	7.4	5.9	2.1	4.5	9.2	6.4	5.2	4.8	2.6	1.1	6.5	6.6	4.1	6.0
Norway	45 705	5.5	–1.7	–0.8	12.5	9.1	3.5	1.8	13.9	4.6	15.0	6.7	6.6	8.1	5.2	12.4	5.5	12.9	5.6
Poland	21 301	..	..	..	..	..	..	..	..	..	..	..	..	..	..	18.3	16.7	9.8	10.1
Portugal	21 722	6.9	–2.5	11.8	19.1	14.5	10.6	7.8	11.7	9.3	20.5	12.6	0.7	7.7	–4.3	14.5	14.1	9.7	10.1
Spain	91 234	0.3	9.4	6.0	8.4	17.6	2.6	–3.7	7.9	6.1	4.5	12.1	11.2	5.0	11.8	21.2	9.7	9.6	13.2
Sweden	79 085	1.3	1.2	3.7	11.5	8.1	3.4	3.0	2.6	3.6	2.3	0.1	–2.3	1.2	9.8	16.3	11.4	6.0	10.2
Switzerland	79 085	4.5	2.6	–5.0	–0.5	7.9	7.8	0.0	1.7	7.4	7.8	3.4	–2.8	3.3	0.9	3.7	1.8	2.4	6.6
Turkey[3]	17 366	14.4	80.9	29.8	5.2	29.2	14.8	–20.8	21.9	8.9	0.6	0.9	6.7	5.4	14.2	16.6	7.6	9.0	20.2
United Kingdom	230 376	1.2	–1.3	3.2	1.8	8.5	5.8	4.0	5.5	2.5	5.4	6.5	0.6	2.2	0.1	12.9	8.6	6.5	6.1
OECD total	3 365 495	5.5	4.0	–0.2	3.9	10.0	4.9	2.2	4.6	7.6	7.0	5.1	3.4	3.8	2.3	9.6	9.5	6.4	10.7
European Union	1 800 477	1.7	3.4	1.6	3.3	8.2	5.0	2.0	4.2	6.2	7.4	4.0	2.5	2.8	1.3	10.3	8.3	5.2	8.6

1. Data for 1997 are estimates.
2. Derived from values and unit values on a national accounts basis.
3. OECD estimates.

Source: OECD, *Economic Outlook 62,* December 1997.

Annex Table 3.2. **Import volumes**

Total goods, customs basis, level in millions of US$, percentage change from previous year

	1995 level (millions of US$)	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[1]
United States[2]	747 318	–7.4	2.0	–2.5	13.6	24.2	6.3	10.3	4.6	4.0	4.2	3.0	0.0	9.6	10.5	13.6	9.5	9.9	15.3
Canada	181 223	–4.4	1.4	–16.4	11.0	19.7	10.4	7.6	6.3	14.2	5.4	3.4	1.7	8.5	11.6	13.2	9.6	5.6	16.4
Mexico	55 687	39.7	27.7	–37.9	–26.5	36.8	13.8	–18.0	–22.3	40.1	14.9	21.7	31.4	22.8	0.7	11.2	–12.5	22.1	23.9
Japan	281 561	–4.9	–2.4	–0.7	1.3	10.6	0.7	9.7	9.0	16.9	7.7	5.0	3.8	–0.6	3.8	13.6	12.5	3.4	4.8
Korea	128 591	–5.5	15.5	–1.9	9.2	19.0	3.9	–2.2	9.3	13.1	17.8	12.0	16.7	2.1	6.4	21.4	21.2	11.7	7.9
Australia	53 730	7.1	10.6	4.9	–12.5	22.0	7.1	–4.3	1.0	16.4	20.3	–4.8	–1.5	9.0	6.4	12.8	11.0	8.6	8.9
New Zealand	10 595	–2.3	2.9	6.3	–6.7	19.9	0.0	–1.6	10.3	–7.7	21.4	7.8	–9.4	10.5	4.1	16.3	6.9	3.0	5.0
Austria	60 470	7.5	–3.9	–0.8	8.0	8.4	5.4	5.2	5.4	7.7	10.6	11.2	3.0	3.1	–1.1	12.9	6.2	3.3	6.3
Belgium-Luxembourg	139 807	1.5	–3.9	0.8	–1.4	4.9	3.8	10.6	8.3	4.9	6.8	5.2	4.1	1.0	0.6	4.6	4.6	3.5	5.4
Czech Republic	19 644	..	..	..	..	..	..	..	..	..	..	..	..	..	..	15.6	43.4	9.3	2.4
Denmark	35 856	–6.9	–2.4	2.3	3.0	3.6	7.8	7.2	–1.9	–1.6	2.3	2.9	5.2	4.1	–6.7	12.3	5.1	–0.1	5.3
Finland	24 335	12.4	–6.3	1.3	3.3	–0.1	5.8	5.5	9.0	9.0	10.6	–4.0	–16.9	–2.1	–3.6	20.0	8.2	8.9	7.9
France	250 337	2.4	–3.7	2.9	–2.7	2.6	4.7	7.4	7.7	9.0	8.0	5.7	2.9	0.9	–4.1	7.3	5.8	2.4	5.0
Germany	378 898	0.0	–5.0	1.3	4.0	5.1	4.9	5.4	5.3	6.4	7.3	12.7	12.0	1.3	–9.8	7.9	6.9	2.2	8.0
Greece	27 636	–12.0	1.1	12.8	3.7	2.1	13.1	5.9	13.0	–13.5	31.1	14.4	9.9	7.7	13.2	4.0	6.5	7.1	6.7
Hungary	13 046	..	..	..	..	..	..	..	..	..	..	..	..	..	..	15.4	–3.0	5.0	15.6
Iceland[3]	1 494	6.4	8.7	–2.4	–9.3	4.5	10.9	10.0	26.9	–4.7	–12.2	6.8	6.6	–5.1	–8.0	8.8	8.0	15.8	11.8
Ireland	29 139	–4.9	2.2	–3.5	3.3	10.2	3.3	2.9	6.3	4.7	13.0	6.8	0.8	4.8	7.0	13.2	14.4	9.8	13.0
Italy	182 613	10.2	–8.3	–0.1	1.2	7.5	8.6	2.8	10.2	3.7	9.6	4.1	2.9	3.3	–9.2	10.5	6.6	0.0	6.1
Netherlands	169 874	–1.2	–6.2	0.9	4.5	5.5	7.2	3.7	4.7	8.0	6.8	4.7	4.3	1.3	–2.7	7.1	8.9	6.1	7.0
Norway	31 113	11.2	–3.8	3.5	–3.4	13.5	11.6	14.6	–2.2	–9.3	–5.8	10.3	2.5	3.4	0.6	16.3	8.1	10.3	6.5
Poland	29 095	..	..	..	..	..	..	..	..	..	..	..	..	..	..	13.2	20.5	28.4	21.1
Portugal	31 140	11.9	6.9	5.9	–10.4	–5.5	6.7	19.3	27.9	22.2	8.3	15.9	6.0	13.4	–9.9	12.3	9.5	5.2	9.2
Spain	114 834	4.7	–4.4	4.4	–1.6	–0.9	8.2	20.3	28.1	19.3	16.8	9.8	11.4	6.9	–5.8	15.2	11.3	5.3	9.2
Sweden	57 625	1.6	–5.1	5.3	2.0	6.3	9.6	3.5	8.5	5.4	7.3	0.4	–6.5	–0.7	2.1	14.6	9.2	2.5	9.5
Switzerland	75 004	8.3	–4.9	–2.2	5.9	8.5	3.8	8.5	6.0	4.5	7.0	1.9	–1.3	–5.1	–0.9	8.5	3.9	2.4	5.9
Turkey[3]	25 675	19.0	24.7	3.5	11.8	24.2	7.8	–5.0	14.1	–1.1	8.1	26.6	–3.1	7.2	38.9	–20.7	31.8	25.0	18.4
United Kingdom	227 682	–6.0	–4.8	5.1	6.4	10.7	3.9	7.1	7.1	13.6	8.1	0.4	–5.4	6.4	0.4	6.3	4.8	8.6	6.1
OECD total	3 384 021	–0.3	–1.8	–1.0	3.8	11.3	5.8	6.8	6.6	8.1	7.7	5.6	3.5	4.3	0.9	10.8	8.5	6.4	9.8
European Union	1 697 690	1.1	–4.8	2.1	2.1	5.5	5.7	6.5	7.9	7.9	8.5	6.3	4.0	2.7	–4.5	8.6	6.9	3.9	6.9

1. Data for 1997 are estimates.
2. Derived from values and unit values on a national accounts basis.
3. OECD estimates.

Source: OECD, *Economic Outlook 62,* December 1997.

Annex Table 3.3. **Trade and current balances, 1995-97**[1]

Billions of US$ and percentage

	Trade balances			Current balances					
	Billions of US$			Billions of US$			Percentage of GDP		
	1995	1996	1997	1995	1996	1997	1995	1996	1997
United States	–173.6	–191.2	–201.3	–129.1	–148.2	–170.8	–1.8	–1.9	–2.1
Canada	24.6	30.1	19.4	–5.4	2.8	–6.0	–1.0	0.5	–1.0
Mexico	7.1	6.5	1.6	–1.6	–1.9	–6.5	–0.5	–0.6	–1.6
Japan	131.2	83.6	98.9	110.4	65.8	91.8	2.1	1.4	2.2
Korea	–4.7	–15.3	–5.7	–8.2	–23.0	–12.1	–1.8	–4.8	–2.6
Australia	–4.2	–0.9	2.0	–19.1	–15.8	–11.7	–5.5	–4.0	–3.0
New Zealand	0.9	0.5	0.2	–2.2	–2.6	–4.5	–3.7	–4.1	–7.0
Austria	–5.1	–4.7	–4.2	–4.7	–4.3	–4.2	–2.1	–1.9	–2.0
Belgium/Luxembourg	10.0	9.1	9.7	14.7	14.4	14.3	5.4	5.4	5.9
Czech Republic	–3.7	–6.0	–5.4	–1.4	–4.5	–3.8	–3.0	–8.8	–7.9
Denmark	6.8	7.6	6.3	1.7	2.9	1.6	0.9	1.6	0.9
Finland	12.3	11.1	9.9	5.2	4.8	4.7	4.1	3.8	4.0
France	11.0	15.0	29.8	10.9	20.5	32.1	0.7	1.3	2.3
Germany	65.0	71.3	78.0	–23.6	–13.1	–5.5	–1.0	–0.6	–0.3
Greece	–14.6	–15.6	–15.7	–2.8	–4.5	–4.8	–2.5	–3.7	–4.0
Hungary	–2.4	–2.7	–2.7	–2.5	–1.7	–1.7	–5.6	–3.9	–3.8
Iceland	0.2	0.0	–0.1	0.1	–0.1	–0.2	0.8	–1.6	–3.3
Ireland	13.5	15.2	16.0	1.7	1.4	1.2	2.8	2.0	1.7
Italy	44.7	60.7	54.6	25.2	40.9	40.9	2.3	3.4	3.6
Netherlands	21.1	20.0	17.8	23.6	24.8	22.5	5.9	6.3	6.2
Norway	7.8	13.0	13.6	4.7	11.2	11.1	3.2	7.1	7.1
Poland	–1.6	–7.9	–11.7	–2.1	–8.4	–12.5	–1.7	–6.3	–9.5
Portugal	–9.0	–9.6	–9.3	–0.8	–2.6	–2.4	–0.7	–2.5	–2.4
Spain	–17.6	–14.9	–12.5	1.1	1.8	4.2	0.2	0.3	0.8
Sweden	16.0	18.6	18.1	4.9	5.9	6.4	2.1	2.3	2.8
Switzerland	5.1	4.9	4.5	21.5	20.3	16.8	7.0	6.9	6.6
Turkey	–13.2	–9.6	–9.5	–2.3	–1.4	–2.5	–1.5	–0.7	–1.3
United Kingdom	–18.3	–19.7	–20.6	–5.8	–0.7	3.9	–0.5	–0.1	0.3
European Union	136.0	164.0	178.1	51.3	92.2	114.9	0.6	1.1	1.4
OECD	109.5	69.0	81.9	14.1	14.1	14.1	0.1	–0.1	0.0

1. Figures for 1997 are estimates.

Source: OECD, *Economic Outlook 62,* December 1997.

Annex Table 3.4. **Growth in value of exports and imports by type of manufacturing industry, 1985-95**

Average annual growth rates in percentage

Growth in value of exports

	Total manufacturing			High-technology			Medium-high-technology			Medium-low-technology			Low-technology		
	1985-90	1990-95	1985-95	1985-90	1990-95	1985-95	1985-90	1990-95	1985-95	1985-90	1990-95	1985-95	1985-90	1990-95	1985-95
United States	13.3	7.4	10.3	15.2	6.9	10.9	11.4	9.4	10.4	15.5	7.8	11.6	15.7	8.9	12.2
Canada	8.7	5.1	6.9	15.7	8.8	12.2	5.5	9.7	7.6	10.2	8.3	9.3	9.8	9.5	9.6
Japan	4.1	5.1	4.6	13.3	9.8	11.5	11.4	8.8	10.1	3.8	9.5	6.6	4.6	3.6	4.1
Australia	10.9	5.3	8.0	31.6	30.8	31.2	18.5	17.2	17.9	4.1	7.3	5.7	10.8	8.2	9.5
New Zealand	8.1	6.4	7.3	12.0	22.8	17.2	13.6	17.0	15.3	14.5	3.9	9.1	8.2	7.2	7.7
Austria	15.1	12.3	13.7	26.4	0.6	12.8	22.7	8.2	15.3	14.9	6.2	10.5	18.4	6.1	12.1
Belgium	15.4	9.6	12.5	19.0	12.4	15.6	20.6	8.8	14.6	14.5	4.4	9.4	17.5	7.0	12.1
Denmark	13.4	5.2	9.2	23.3	8.5	15.6	16.4	6.3	11.2	13.7	5.1	9.3	14.0	6.0	9.9
Finland	9.6	8.4	9.0	29.9	23.3	26.6	20.3	6.9	13.4	9.2	8.4	8.8	13.3	5.9	9.6
France	17.6	6.8	12.1	20.6	11.5	16.0	17.3	6.0	11.5	13.0	4.5	8.7	17.7	6.1	11.8
Germany[1]	14.1	5.8	9.9	17.5	7.3	12.3	17.7	4.8	11.1	14.5	3.9	9.1	17.1	4.0	10.4
Greece	14.0	7.7	10.8	16.9	22.4	19.6	14.3	14.3	14.3	7.8	6.0	6.9	14.5	5.4	9.9
Iceland	13.8	4.0	8.8	54.9	26.9	40.2	24.5	21.8	23.2	14.8	5.0	9.8	12.9	3.8	8.3
Ireland	15.7	10.9	13.3	23.5	18.0	20.7	18.0	12.6	15.3	14.9	2.8	8.7	15.8	9.2	12.4
Italy	14.2	7.2	10.6	17.0	5.6	11.1	18.2	7.6	12.8	12.5	6.7	9.6	15.9	6.2	10.9
Netherlands	14.8	5.8	10.2	23.5	14.4	18.8	17.2	4.6	10.7	8.0	2.3	5.1	17.0	4.6	10.6
Norway	12.0	8.4	10.2	22.2	4.4	12.9	14.1	–0.6	6.5	13.7	0.1	6.7	13.9	4.1	8.9
Portugal	15.5	8.3	11.8	16.7	13.2	15.0	27.5	13.0	20.0	19.9	2.1	10.6	23.1	4.7	13.5
Spain	16.7	10.2	13.4	26.1	11.3	18.5	24.4	11.9	18.0	10.3	6.3	8.3	15.3	9.8	12.5
Sweden	11.0	7.3	9.1	16.3	14.1	15.2	14.9	2.8	8.7	9.9	3.8	6.8	13.0	4.5	8.7
Switzerland	15.4	6.3	10.8	20.9	10.0	15.3	18.8	5.3	11.9	18.1	2.5	10.0	16.4	2.9	9.5
Turkey	4.5	14.0	9.1	44.1	1.9	21.2	6.7	17.4	12.0	7.9	8.9	8.4	11.0	12.6	11.8
United Kingdom	15.1	5.2	10.0	17.4	10.1	13.7	15.8	5.2	10.4	15.4	0.8	7.9	15.9	5.6	10.6
OECD total	13.9	6.7	10.3	16.8	9.2	12.9	15.0	6.8	10.9	11.9	4.8	8.3	15.2	5.9	10.4

Growth in value of imports

	Total manufacturing			High-technology			Medium-high-technology			Medium-low-technology			Low-technology		
	1985-90	1990-95	1985-95	1985-90	1990-95	1985-95	1985-90	1990-95	1985-95	1985-90	1990-95	1985-95	1985-90	1990-95	1985-95
United States	4.3	2.8	3.5	11.7	14.8	13.3	7.5	9.1	8.3	5.4	5.4	5.4	7.4	7.2	7.3
Canada	11.9	6.5	9.2	13.4	10.2	11.8	5.9	7.4	6.7	11.7	6.9	9.3	12.6	6.5	9.5
Japan	19.8	10.8	15.2	22.6	20.2	21.4	22.5	11.0	16.6	17.9	2.6	10.0	21.8	11.7	16.7
Australia	10.3	7.9	9.1	18.7	8.8	13.6	8.9	9.6	9.2	9.5	6.8	8.2	9.1	6.7	7.9
New Zealand	16.4	10.2	13.3	20.6	7.5	13.9	8.2	9.5	8.8	1.7	6.8	4.2	13.2	9.2	11.2
Austria	15.4	10.2	12.8	26.2	6.3	15.8	22.9	5.2	13.7	18.3	6.6	12.3	19.3	6.5	12.7
Belgium	15.0	9.6	12.3	21.3	8.3	14.6	18.2	6.7	12.3	14.9	3.9	9.2	17.8	6.0	11.8
Denmark	14.1	6.8	10.4	19.0	9.6	14.2	12.8	6.8	9.8	8.9	2.9	5.9	13.7	6.2	9.9
Finland	13.4	8.0	10.6	20.8	10.0	15.3	20.1	–0.6	9.3	14.4	0.2	7.0	17.7	0.6	8.9
France	15.6	5.5	10.4	25.0	6.3	15.3	21.7	4.1	12.6	16.0	1.8	8.6	18.5	3.3	10.6
Germany[1]	15.8	5.1	10.3	22.1	6.8	14.2	22.9	6.1	14.2	13.8	4.0	8.8	19.4	4.0	11.4
Greece	18.0	6.1	11.9	26.0	10.9	18.2	22.0	5.8	13.6	16.7	3.7	10.0	20.2	5.2	12.4
Iceland	10.2	6.4	8.3	27.3	–3.7	10.8	14.5	2.2	8.2	8.4	0.6	4.4	10.5	3.0	6.7
Ireland	15.0	57.7	34.7	17.8	40.0	28.4	18.7	61.5	38.4	11.6	58.4	32.9	16.1	55.1	34.2
Italy	12.8	1.7	7.1	21.6	2.8	11.8	21.7	3.3	12.1	13.9	3.1	8.3	16.0	3.9	9.8
Netherlands	11.8	7.7	9.7	23.1	10.9	16.8	18.8	4.6	11.5	11.3	2.6	6.9	15.8	3.7	9.6
Norway	14.8	6.1	10.4	14.7	5.7	10.1	8.9	7.4	8.1	16.0	–1.9	6.7	10.6	4.7	7.6
Portugal	32.1	10.4	20.8	35.2	10.5	22.2	35.7	3.7	18.6	27.3	4.5	15.3	34.9	8.4	20.9
Spain	30.9	10.2	20.1	33.9	1.3	16.5	36.1	5.5	19.8	26.8	6.6	16.2	35.8	8.3	21.3
Sweden	13.6	4.2	8.8	18.7	7.9	13.2	16.2	3.3	9.5	11.9	0.2	5.9	16.7	–0.2	7.9
Switzerland	15.7	3.4	9.4	21.5	10.8	16.0	20.8	2.9	11.5	16.2	–0.8	7.4	18.1	2.3	9.9
Turkey	25.2	8.7	16.7	17.8	14.9	16.3	17.5	9.9	13.6	14.8	10.7	12.7	30.2	17.7	23.8
United Kingdom	12.8	2.7	7.7	18.5	7.9	13.1	17.7	4.9	11.1	15.4	0.2	7.5	15.2	1.7	8.3
OECD total	13.8	7.4	10.5	18.4	11.0	14.7	15.9	7.5	11.6	12.6	4.5	8.5	15.7	6.7	11.1

1. Figures for Germany for 1995 refer to unified Germany.
Source: OECD, Bilateral Trade database, December 1997.

Annex Table 3.5. **Export market shares by manufacturing industry, 1980-94**

Percentage of total OECD exports in this industry

	Manufacturing ISIC 3		Food, beverages and tobacco ISIC 31		Textiles, apparel and leather ISIC 32		Wood products and furniture ISIC 33		Paper, paper products and printing ISIC 34		Chemicals ISIC 35		Pharmaceuticals ISIC 3522	
	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994
United States	15.7	16.4	14.8	16.1	11.5	10.3	10.8	12.8	14.4	16.1	14.8	15.7	15.4	11.6
Canada	4.2	4.9	3.3	3.1	0.8	1.2	16.0	22.4	18.2	14.4	3.1	3.4	0.7	0.9
Japan	11.7	14.9	1.7	1.0	7.8	4.5	1.0	0.9	2.6	2.7	6.0	9.0	2.3	3.0
Australia	1.1	0.9	5.8	3.7	0.9	1.5	1.1	0.8	0.3	0.4	0.5	0.7	0.5	1.0
New Zealand	0.4	0.4	3.1	2.6	1.0	0.7	0.6	0.9	0.7	0.7	0.1	0.2	0.1	0.1
Austria	1.5	1.7	0.7	0.7	2.9	2.3	5.7	4.2	2.7	3.3	1.1	1.4	1.6	2.0
Belgium	5.4	4.8	5.2	6.2	6.7	6.0	4.9	4.1	3.4	3.4	7.3	7.2	5.5	6.5
Denmark	1.4	1.3	5.5	4.9	1.3	1.3	3.0	4.1	0.7	0.9	1.0	1.2	2.5	3.3
Finland	1.3	1.1	0.5	0.4	1.6	0.4	8.9	4.8	10.2	8.3	0.8	0.7	0.4	0.3
France	9.4	8.3	13.3	13.5	10.0	9.0	5.3	5.2	6.0	7.0	10.7	10.0	11.8	11.2
Germany[1]	16.8	15.5	10.6	10.4	13.5	13.3	11.6	9.5	10.4	13.3	17.3	16.7	17.3	15.5
Greece	0.4	0.3	0.9	0.9	1.5	1.6	0.1	0.1	0.1	0.1	0.6	0.3	0.2	0.1
Iceland	0.1	0.1	0.7	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	0.7	1.2	3.0	3.4	1.0	0.7	0.2	0.3	0.3	0.3	0.7	1.8	1.3	3.4
Italy	7.0	7.0	4.2	5.1	18.1	22.0	10.8	12.3	3.2	4.2	6.4	5.4	5.6	5.4
Netherlands	5.6	4.7	12.8	12.8	4.2	4.0	2.5	2.6	4.0	4.4	11.8	7.6	4.9	5.4
Norway	0.9	0.7	1.3	1.2	0.3	0.2	0.9	1.0	2.2	1.5	0.9	0.9	0.2	0.2
Portugal	0.4	0.7	0.6	0.6	2.0	4.3	2.0	1.9	0.7	1.1	0.3	0.4	0.3	0.2
Spain	1.7	2.5	2.4	3.2	2.6	3.2	1.7	1.8	2.0	2.1	1.5	2.2	1.6	2.0
Sweden	2.7	2.3	0.6	0.7	1.2	0.7	8.9	7.0	11.1	7.7	1.7	1.9	2.5	4.8
Switzerland	2.7	2.6	1.1	1.1	2.7	1.9	0.9	1.2	1.6	1.8	3.2	4.3	12.8	11.8
Turkey	0.1	0.6	0.2	1.4	0.7	4.6	0.0	0.2	0.0	0.1	0.1	0.4	0.0	0.1
United Kingdom	8.8	7.1	7.5	6.6	7.8	6.3	2.9	2.1	5.3	6.2	10.1	8.7	12.7	11.2
Share in total OECD manufacturing exports	100.0	100.0	8.1	7.4	6.5	5.7	2.1	2.1	3.8	3.7	18.8	17.1	1.1	1.9

	Non-metallic mineral products ISIC 36		Basic metals ISIC 37		Metal products, machinery and equipment ISIC 38		Office and computing equipment ISIC 3825		Radio, TV and communication equipment ISIC 3832		Aircraft ISIC 3845		Motor vehicles ISIC 3843	
	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994
United States	8.3	8.9	8.6	7.1	19.0	18.9	34.9	25.3	15.7	22.8	51.5	44.9	12.9	13.4
Canada	1.5	2.7	5.7	7.0	3.6	4.7	3.3	3.1	2.2	2.7	2.9	3.8	7.3	10.9
Japan	9.5	10.6	17.2	13.3	16.7	21.4	9.7	24.7	33.9	32.3	0.3	1.2	21.3	22.8
Australia	0.3	0.5	3.2	3.0	0.3	0.5	0.2	0.9	0.1	0.4	0.4	0.6	0.2	0.3
New Zealand	0.1	0.1	0.2	0.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Austria	3.5	3.0	2.0	2.5	1.2	1.5	0.4	0.4	1.4	1.4	0.1	0.1	0.6	1.3
Belgium	7.1	7.4	9.5	8.1	3.2	3.0	1.3	1.2	3.7	1.9	1.3	0.6	5.2	5.8
Denmark	1.4	1.3	0.5	0.6	1.0	0.9	0.4	0.8	0.9	0.8	0.3	0.3	0.2	0.2
Finland	0.8	0.8	1.0	1.9	0.6	0.8	0.2	0.7	0.6	1.2	0.0	0.1	0.2	0.3
France	11.1	10.2	10.1	9.3	8.5	7.2	7.6	5.2	5.8	5.1	6.1	17.6	10.7	7.8
Germany[1]	16.9	14.4	16.3	15.6	19.3	16.6	13.2	7.8	14.0	10.1	9.7	12.7	23.0	19.7
Greece	1.4	1.0	0.6	0.6	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0
Iceland	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	0.7	0.6	0.1	0.3	0.4	1.0	2.3	5.1	0.5	2.0	0.1	0.2	0.1	0.0
Italy	17.2	17.4	4.6	6.3	6.2	5.7	7.3	3.5	3.1	2.6	2.1	3.0	4.9	3.8
Netherlands	3.6	3.4	3.7	4.1	3.1	3.1	3.0	6.8	6.2	3.8	2.7	2.2	1.3	1.3
Norway	0.4	0.4	2.4	2.8	0.5	0.4	0.4	0.3	0.4	0.3	0.0	0.1	0.1	0.1
Portugal	0.7	1.9	0.1	0.1	0.2	0.3	0.2	0.0	0.4	0.4	0.2	0.1	0.1	0.3
Spain	4.6	6.0	2.7	3.3	1.3	2.3	0.8	1.0	0.4	1.1	0.3	1.8	1.9	4.7
Sweden	1.8	1.2	2.9	3.5	2.9	2.2	3.0	0.7	3.0	2.7	0.1	0.8	3.0	2.4
Switzerland	1.0	1.4	1.7	1.7	2.8	2.4	1.0	0.7	1.3	0.9	0.9	0.4	0.2	0.2
Turkey	0.4	1.2	0.0	1.7	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1
United Kingdom	8.0	5.6	6.6	6.7	9.1	6.8	10.8	11.7	6.3	7.3	21.0	9.1	6.6	4.6
Share in total OECD manufacturing exports	1.9	1.6	9.2	5.1	47.3	55.2	2.2	4.6	4.0	7.3	2.7	3.0	11.6	14.1

1. Figures for Germany for 1994 refer to unified Germany.

Source: OECD, STAN database, April 1997.

Annex Table 3.6. **Import penetration by industry**[1]

Percentage

	Manufacturing ISIC 3		Food, beverages and tobacco ISIC 31		Textiles, apparel and leather ISIC 32		Wood products and furniture ISIC 33		Paper, paper products and printing ISIC 34		Chemicals ISIC 35		Pharmaceuticals ISIC 3522	
	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994
United States	12.2	17.0	5.1	4.8	19.6	29.7	9.2	10.7	4.2	4.5	9.4	11.6	5.5	5.8
Canada	35.8	49.4	9.3	15.5	28.4	41.3	9.5	32.9	13.5	23.3	20.9	39.1	16.2	31.9
Japan	5.2	6.3	6.2	8.1	9.8	18.2	7.1	13.9	2.4	2.1	8.4	6.7	6.7	5.9
Australia	26.4	27.2	8.0	8.4	30.8	44.3	13.1	11.9	15.5	12.5	33.8	27.1	22.7	47.0
New Zealand[2]	37.8	36.9	17.7	15.4	38.9	41.5	4.6	7.6	15.6	15.0	51.1	47.3	58.8	70.5
Austria	35.2	41.9	10.0	11.0	57.3	71.7	17.6	22.4	26.8	30.9	36.7	43.9	45.3	52.8
Belgium/Luxembourg	72.8	81.0	26.7	24.9	81.5	84.2	33.5	40.1	46.6	45.6	83.5	..	78.7	..
Denmark	50.3	50.7	23.8	27.8	66.8	77.5	44.7	38.8	25.2	23.3	65.0	62.9	64.3	63.1
Finland	28.2	37.5	6.5	9.8	44.8	65.3	8.1	12.1	4.6	9.9	37.9	50.3	44.3	60.4
France	25.8	30.7	15.0	18.0	31.6	46.7	20.4	19.8	16.4	15.5	28.3	31.4	14.7	21.0
Germany[3]	24.0	26.8	14.4	15.7	47.7	62.0	16.3	20.5	21.8	20.8	25.1	23.0	21.1	29.3
Greece	30.4	48.2	21.1	24.8	26.1	53.6	14.9	31.5	18.2	33.2	25.2	54.9	36.3	55.9
Iceland[4]	52.7	50.3	18.7	16.7	60.8	63.7	43.1	38.9	31.4	27.4	75.7	69.1	..	..
Italy	21.9	26.2	18.6	20.3	13.6	20.7	7.8	10.6	12.3	11.9	36.9	33.1	18.5	23.6
Netherlands[2]	64.8	77.2	32.0	42.1	..	..	54.6	54.9	30.0	29.7	84.2	93.5	54.7	69.8
Norway	42.6	44.2	9.4	10.3	76.5	81.2	25.9	32.9	17.0	19.9	47.6	60.4	50.6	46.6
Portugal[2]	24.5	36.9	9.2	16.4	21.0	34.8	4.6	11.9	15.0	23.8	25.7	38.0	40.9	47.3
Spain	15.2	29.8	5.7	12.5	8.2	30.2	9.1	17.4	11.2	21.9	17.8	29.4	12.2	18.9
Sweden	38.0	46.7	12.9	18.9	73.6	87.0	13.5	23.5	9.3	13.4	49.4	61.5	52.9	32.7
United Kingdom	28.4	34.8	15.4	16.5	36.7	50.8	24.8	24.8	17.8	17.2	28.0	28.9	17.5	23.6
Total OECD-21[4]	17.5	21.0	9.8	11.8	24.9	33.4	12.1	15.0	8.4	9.8	18.5	20.4	12.5	15.9

	Non-metallic mineral products ISIC 36		Basic metals ISIC 37		Office and computing equipment ISIC 3825		Radio, TV and communication equipment ISIC 3832		Motor vehicles ISIC 3843		Aircraft ISIC 3845		Scientic instruments ISIC 385	
	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994
United States	7.5	10.2	15.0	16.2	20.0	57.1	24.4	36.7	26.0	27.9	6.8	14.6	8.2	16.0
Canada	18.9	33.1	20.2	32.3	91.3	94.4	65.2	66.4	83.0	89.7	67.4	56.2	..	..
Japan	1.5	2.3	4.2	4.5	5.7	10.0	2.5	6.4	1.0	3.1	45.9	39.5	19.4	31.7
Australia	11.4	9.3	8.0	8.5	56.1	63.1	92.1	..	35.8	37.9	36.1	53.4	67.7	74.2
New Zealand[2]	15.5	16.8	57.9	56.0	92.9	90.6	59.8	74.2	49.2	55.4	53.0	74.0	86.0	97.7
Austria	17.6	19.3	35.0	45.1	..	..	74.5	91.4	76.9	83.0	..	..	..	..
Belgium/Luxembourg	60.6	51.5	..	..	..	..	..	..	..	..	..	..	..	..
Denmark	22.6	21.7	96.4	..	..	..	86.9	98.0	97.6	92.4	..	..	..	85.5
Finland	13.6	25.3	30.9	32.5	77.0	72.8	60.0	72.4	77.5	..	66.3	48.4	67.7	85.4
France	16.4	17.3	27.5	31.0	47.0	57.2	23.4	32.4	37.0	41.7	20.2	46.6	81.9	79.6
Germany[3]	12.1	12.7	23.7	22.1	72.3	63.5	24.7	33.5	20.6	28.2	..	99.9	86.3	94.8
Greece	10.9	23.3	39.5	54.5	97.7	104.4	64.3	79.7	73.5	84.0	..	..	98.1	..
Iceland[4]	21.2	22.3	94.6	96.5	..	..	..	..	..	..	..	..	..	..
Italy	5.6	7.8	20.7	22.9	..	78.6	36.5	63.4	27.2	45.1	34.3	54.7	37.5	37.0
Netherlands[2]	42.3	36.5	89.1	..	..	..	36.6	76.2	96.2	..	61.1	..	..	..
Norway	26.7	27.2	65.1	77.7	84.4	..	62.2	76.0	96.1	99.3	66.4	63.3	..	..
Portugal[2]	7.0	16.2	49.8	38.7	95.4	..	46.2	59.9	61.4	81.9	..	..	99.1	..
Spain	4.5	7.2	9.6	24.8	84.6	..	30.6	38.6	20.2	77.8	67.1	..	90.8	..
Sweden	25.8	33.1	40.5	53.5	98.6	81.1	58.6	..	58.7	64.0	34.1	33.6	90.3	69.8
United Kingdom	10.3	12.7	27.2	35.7	86.0	74.2	33.7	63.5	41.9	50.6	46.3	37.3	..	..
Total OECD-21[4]	9.0	11.1	16.2	17.1	..	..	..	..	..	..	..	..	23.2	36.3

1. Import penetration is defined as an industry's share of imports in domestic demand estimated as production plus imports minus exports.
2. 1993 instead of 1994.
3. Figures for Germany for 1994 refer to unified Germany.
4. 1992 instead of 1994.

Source: OCDE, STAN database, May 1997.

Annex Table 3.7. **Export specialisation by manufacturing industry, 1980-94**[1]

	Food, beverages and tobacco ISIC 31		Textiles, apparel and leather ISIC 32		Wood products and furniture ISIC 33		Paper, paper products and printing ISIC 34		Chemicals ISIC 35		Pharmaceuticals ISIC 3522	
	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994
United States	94	98	73	63	69	78	92	98	94	95	98	71
Canada	78	64	20	25	379	456	432	294	73	68	17	17
Japan	14	7	66	31	9	6	22	18	51	60	19	20
Australia	522	390	78	158	100	88	25	46	44	76	47	103
New Zealand	728	703	236	174	146	242	164	177	24	50	20	23
Austria	43	44	185	135	371	248	176	197	74	83	101	117
Belgium	97	129	124	125	91	84	63	71	136	149	102	136
Denmark	406	369	94	99	220	312	55	66	76	93	182	246
Finland	39	36	125	40	707	432	814	747	62	61	33	27
France	141	161	106	107	57	62	63	85	114	119	126	134
Germany[2]	63	67	80	86	69	62	62	86	103	108	103	100
Greece	232	287	376	531	28	46	35	29	152	111	45	48
Iceland	947	1 057	92	26	0	2	3	5	3	3	0	2
Ireland	447	287	144	58	28	21	46	28	99	148	193	287
Italy	60	72	259	314	154	175	46	60	92	77	80	78
Netherlands	228	270	75	85	44	55	71	93	209	161	87	114
Norway	150	169	37	30	105	141	245	213	102	133	19	29
Portugal	145	90	479	640	493	279	170	168	70	65	77	24
Spain	141	129	153	129	101	74	115	86	89	88	91	79
Sweden	22	29	45	31	328	304	406	338	63	84	90	211
Switzerland	42	43	101	74	35	46	60	69	119	163	482	451
Turkey	234	216	711	730	33	28	8	20	68	57	24	23
United Kingdom	85	93	89	89	32	29	60	87	114	123	145	158
Share in total OECD manufacturing exports	8.1	7.4	6.5	5.7	2.1	2.1	3.8	3.7	18.8	17.1	1.1	1.9

	Non-metallic mineral products ISIC 36		Basic metals ISIC 37		Metal products, machinery and equipment ISIC 38		Office and computing equipment ISIC 3825		Radio, TV and communication equipment ISIC 3832		Aircraft ISIC 3845		Motor vehicles ISIC 3843	
	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994	1980	1994
United States	53	54	55	43	121	115	222	154	100	139	328	273	82	82
Canada	35	56	136	143	85	97	78	63	52	56	70	78	173	221
Japan	81	71	147	90	142	144	83	166	290	217	3	8	182	153
Australia	25	53	291	317	28	50	20	96	12	41	35	61	15	28
New Zealand	31	24	54	123	12	19	1	4	6	12	2	6	6	4
Austria	228	178	132	146	79	89	24	24	90	85	4	9	38	78
Belgium	132	154	177	169	60	62	25	26	68	40	24	13	97	121
Denmark	102	96	36	42	72	68	27	57	66	57	21	24	18	15
Finland	60	76	79	168	47	68	15	66	46	110	3	5	16	24
France	118	122	107	111	91	87	81	62	62	61	65	211	114	93
Germany[2]	101	93	97	101	115	107	78	50	84	65	58	82	137	127
Greece	344	338	140	189	14	20	0	5	14	14	0	32	6	5
Iceland	1	7	166	265	3	10	0	14	0	0	14	62	0	0
Ireland	106	52	10	24	59	82	331	425	76	167	12	20	21	4
Italy	246	248	66	90	89	82	105	50	44	38	30	43	70	54
Netherlands	63	72	66	87	54	66	54	143	110	81	48	46	24	28
Norway	48	61	271	401	60	54	43	39	41	39	4	18	14	16
Portugal	165	281	27	21	40	48	42	5	97	56	38	20	24	43
Spain	264	243	155	133	74	93	47	39	25	42	19	75	109	190
Sweden	64	54	106	152	105	97	111	30	111	116	5	36	111	105
Switzerland	39	52	64	67	106	90	36	27	48	36	33	15	7	9
Turkey	378	195	45	277	20	23	0	2	10	20	0	10	42	19
United Kingdom	90	79	75	94	104	96	123	166	71	103	238	129	74	64
Share in total OECD manufacturing exports	1.9	1.6	9.2	5.1	47.3	55.2	2.2	4.6	4.0	7.3	2.7	3.0	11.6	14.1

1. The indicator is defined as the share of an industry's exports in the total country's manufacturing exports, divided by the industry's OECD-wide share in total manufacturing exports.
2. Figures for Germany for 1994 refer to unified Germany.

Source: OECD, STAN database, April 1997.

Annex Table 3.8. **Exposure to foreign competition**[1]

Percentage

	Manufacturing ISIC 3		Food, beverages and tobacco ISIC 31		Textiles, apparel and leather ISIC 32		Wood products and furniture ISIC 33		Paper, paper products and printing ISIC 34		Chemicals ISIC 35		Pharmaceuticals ISIC 3522	
	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994
United States	18.8	27.7	8.9	11.1	22.9	36.5	11.1	14.7	6.6	9.1	15.5	21.7	13.3	12.5
Canada	58.5	73.8	19.8	28.4	33.5	51.2	47.8	80.1	47.2	60.2	37.8	60.4	21.7	39.8
Japan	18.5	17.4	7.1	8.6	18.0	22.7	7.8	14.4	4.2	3.3	14.9	14.2	8.6	8.2
Australia	37.2	39.4	28.5	29.8	42.0	63.6	17.3	17.5	16.9	15.0	45.1	36.6	28.5	62.6
New Zealand[2]	59.2	59.4	75.9	64.4	72.0	68.0	20.2	35.3	28.3	30.2	57.5	58.6	68.0	77.8
Austria	57.4	64.1	16.1	17.8	80.1	89.3	38.1	42.5	53.1	56.7	53.9	64.2	66.1	74.6
Belgium/Luxembourg	93.0	96.9	49.0	46.7	96.8	97.8	56.9	62.3	66.7	67.2	97.5	88.8	96.4	40.2
Denmark	74.7	77.0	59.9	64.8	86.4	93.4	75.3	72.3	35.1	34.1	83.4	85.6	92.6	92.5
Finland	52.7	66.9	11.6	17.0	69.7	81.6	45.8	63.5	49.9	63.6	54.9	70.8	58.1	73.6
France	46.0	53.0	29.7	36.7	49.9	67.6	29.8	31.5	26.1	26.4	49.2	54.3	36.1	42.7
Germany[3]	48.0	50.0	24.6	26.5	66.6	79.3	29.2	30.0	39.5	39.1	45.8	46.0	45.8	57.1
Greece	43.5	62.7	33.8	37.2	51.7	80.6	17.4	38.1	20.9	36.9	36.4	69.4	45.9	61.6
Iceland[4]	75.0	72.3	69.6	67.4	77.6	72.4	43.3	38.9	32.2	28.0	76.8	70.1	..	..
Italy	41.7	49.7	26.9	31.1	40.4	51.8	21.8	29.2	20.1	20.8	56.9	51.6	32.5	39.8
Netherlands[2]	88.8	95.4	64.2	77.2	99.9	84.0	68.1	70.1	47.0	47.6	98.5	99.7	80.2	90.3
Norway	61.4	64.2	23.6	25.9	83.0	88.4	31.8	48.3	37.6	40.1	69.1	84.2	57.6	55.2
Portugal[2]	44.4	55.5	18.4	23.6	57.4	69.5	52.6	38.4	45.7	45.6	36.8	49.8	52.3	54.7
Spain	30.6	48.5	13.3	21.4	28.3	50.2	20.8	29.5	23.9	34.9	33.0	44.3	22.9	28.4
Sweden	64.6	74.8	19.1	26.2	86.8	95.6	49.2	64.2	48.3	51.8	69.3	84.5	81.0	69.8
United Kingdom	46.6	55.8	23.3	26.6	51.8	69.1	29.2	30.2	24.9	26.9	49.8	52.1	44.9	49.6
Total OECD-21[4]	32.6	38.0	28.5	21.7	38.7	49.3	20.7	25.2	16.9	19.7	32.8	36.8	25.5	30.0

	Non-metallic mineral products ISIC 36		Basic metals ISIC 37		Office and computing equipment ISIC 3825		Radio, TV and communication equipment ISIC 3832		Motor vehicles ISIC 3843		Aircraft ISIC 3845		Scientic instruments ISIC 385	
	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994	1985	1994
United States	10.1	15.0	17.7	21.4	40.3	76.3	32.9	54.2	34.2	39.1	22.7	43.1	16.4	29.5
Canada	27.4	48.3	45.4	61.6	98.5	99.4	84.4	82.7	97.1	99.1	86.5	84.8	..	..
Japan	7.6	6.9	13.7	10.5	27.9	33.8	29.3	27.0	34.0	25.4	48.8	46.4	63.1	69.6
Australia	12.4	11.9	39.6	30.2	58.0	75.7	94.5	81.9	39.5	43.4	41.2	67.9	75.1	84.7
New Zealand[2]	20.5	21.3	78.7	82.4	93.9	92.9	64.2	80.4	50.8	57.7	53.6	76.8	91.1	99.8
Austria	40.0	36.2	66.7	71.6	..	..	94.1	99.2	92.4	96.3	..	..	99.1	100.0
Belgium/Luxembourg	88.9	82.8	98.8	91.7	..	..	..	..	..	..	..	..	93.3	90.4
Denmark	38.6	41.4	99.6	96.9	99.6	8.6	98.2	100.0	99.8	98.3	..	..	100.0	98.3
Finland	22.7	46.9	58.2	63.5	88.7	91.1	78.7	93.6	90.1	99.1	70.4	55.1	82.3	97.1
France	33.2	33.4	50.0	53.0	66.5	76.8	40.3	52.5	65.8	69.5	47.7	79.2	96.6	95.0
Germany[3]	27.0	23.6	45.5	40.1	91.8	81.6	45.4	54.3	59.9	60.1	99.9	100.0	98.8	99.8
Greece	29.5	43.0	62.3	75.4	98.2	84.9	69.9	85.1	76.1	86.6	..	..	99.5	96.3
Iceland[4]	21.3	23.4	99.8	99.9	..	..	..	..	..	..	..	..	..	..
Italy	21.7	28.9	36.2	37.7	98.9	94.8	54.4	82.3	44.5	69.0	57.2	80.0	54.4	55.4
Netherlands[2]	59.8	56.5	98.8	98.8	..	..	60.0	94.8	99.7	100.0	79.8	19.9	..	..
Norway	32.3	38.7	91.4	96.2	93.8	57.3	72.3	89.0	99.1	100.0	78.1	74.7	85.3	82.5
Portugal[2]	24.8	40.0	63.5	45.7	99.6	89.0	72.9	76.5	76.5	91.9	..	..	100.0	96.2
Spain	17.0	22.6	30.8	46.0	95.7	99.3	36.7	53.8	47.3	96.1	85.3	..	97.3	99.7
Sweden	42.2	50.3	70.7	82.2	100.0	92.2	84.9	100.0	89.3	92.3	54.8	58.1	98.9	89.9
United Kingdom	20.1	23.7	44.3	57.7	97.7	92.7	51.3	85.3	59.7	70.4	75.9	61.2	99.1	97.6
Total OECD-21[4]	18.2	21.8	31.0	31.6	..	..	..	..	..	..	..	..	43.5	60.2

1. The indicator is calculated as [EXP/PROD] + (1 – [EXP/PROD])(IMP/[PROD + IMP – EXP]), where EXP represents exports, IMP imports and PROD production.
2. 1993 instead of 1994.
3. Figures for Germany for 1994 refer to unified Germany.
4. 1992 instead of 1994.

Source: OECD, STAN database, May 1997.

Annex Table 3.9. **Outward and inward direct investment flows in OECD countries**

Millions of US$

	Inward direct investment flows						Outward direct investment flows					
	Cumulative flows		Annual investment flows				Cumulative flows		Annual investment flows			
	1981-90	1991-96	1993	1994	1995	1996[1]	1981-90	1991-96	1993	1994	1995	1996[1]
United States	365 084	279 843	43 534	49 760	60 236	84 629	175 985	388 921	78 164	54 465	95 509	85 440
Canada	33 699	36 878	4 981	7 259	10 739	6 696	41 847	35 868	5 805	7 414	5 747	7 561
Mexico	24 421	37 077	4 389	10 972	6 963	5 598	..	..	..	..	..	..
Japan	3 281	5 333	86	888	41	222	185 826	125 696	13 714	17 938	22 628	23 468
Korea	3 951	5 348	516	758	1 240	1 169	2 174	11 633	1 056	1 056	1 056	1 056
Australia	39 822	36 296	3 007	3 951	14 193	6 067	22 266	16 604	1 779	5 291	4 064	1 518
New Zealand[2]	3 945	13 640	2 380	2 792	2 922	2 772	4 563	3 810	–1 455	2 039	–167	1 530
Austria	3 274	7 950	982	1 314	636	3 719	4 132	7 934	1 467	1 201	1 043	1 064
Belgium-Luxembourg	33 699	60 367	10 458	8 345	10 638	11 048	20 862	40 654	3 843	747	11 503	7 248
Czech Republic[3]	..	6 060	654	869	2 562	972	..	304	101	120	37	26
Denmark	3 388	14 673	1 681	4 889	4 179	1 379	6 292	15 352	1 373	4 040	3 018	2 845
Finland	2 838	4 883	864	864	864	864	11 577	10 061	1 409	4 297	1 681	3 551
France[4]	54 681	109 148	16 449	16 449	16 449	16 449	101 346	143 728	19 744	24 381	15 761	28 274
Germany	17 653	19 021	1 915	1 548	12 050	–3 243	90 359	142 144	15 348	17 134	38 573	27 883
Greece[5]	6 145	5 290	977	981	1 053	..	..	..	..	..	..	..
Hungary	512	12 519	2 350	1 144	4 453	1 631	..	..	11	49	43	10
Iceland	74	22	–	–	14	1	26	93	11	23	24	5
Ireland[6]	1 373	6 031	854	419	626	1 722	..	..	..	..	..	..
Italy	24 888	19 944	3 746	2 236	4 817	3 454	28 707	36 812	7 221	5 109	5 732	5 476
Netherlands	37 846	42 233	6 599	7 345	10 766	3 317	65 755	78 073	10 714	17 088	12 412	9 991
Norway	5 634	8 913	2 244	1 359	1 644	3 437	8 995	12 881	791	2 145	2 844	5 341
Portugal	6 920	8 473	1 551	1 254	695	608	374	3 045	141	283	689	771
Spain	46 000	55 955	8 070	9 428	6 256	6 406	8 196	21 361	2 648	3 897	3 592	4 629
Sweden	8 619	36 327	3 843	6 347	14 375	5 461	48 081	31 262	1 358	1 358	1 358	1 358
Switzerland[5]	12 432	8 495	–83	3 368	2 187	..	31 858	43 951	8 763	10 798	12 176	..
Turkey	2 340	4 880	797	637	935	558	–7	867	175	175	175	175
United Kingdom	130 469	113 782	15 468	10 497	22 810	32 766	185 581	175 345	25 573	28 251	42 676	43 717
Total OECD	866 914	970 367	140 026	157 393	225 434	204 777	1 044 795	1 346 641	199 772	215 648	294 124	268 113

1. Most data for 1996 are provisional.
2. Data for 1995 and 1996 are based on fiscal years ending in March.
3. 1992-96.
4. Break in series. Data are based on new methodology.
5. 1991-95.
6. Break in series. The results shown are for net (inward and outward) direct investment capital flows.

Source: OECD, *Financial Market Trends,* June 1997.

Annex Table 3.10. **Manufacturing production[1] and employment trends in foreign affiliates and national firms, 1985-94**

	Employment						Production					
	Share of foreign affiliates		Compound annual growth rate	Share of national firms		Compound annual growth rate	Share of foreign affiliates		Compound annual growth rate	Share of national firms		Compound annual growth rate
	1985	1994	1985-94	1985	1994	1985-94	1985	1994	1985-94	1985	1994	1985-94
United States	8.1	15.7	5.0	91.9	84.3	–1.0	7.6	12.2	12.1	92.4	87.8	3.1
Canada[2]	..	..	..	..	..	..	..	..	..	..	..	..
Japan[2, 3]	2.6	2.8	4.3	97.4	97.2	1.0	0.7	0.9	2.8	99.3	99.1	2.5
Finland	2.4	8.8	7.1	97.6	91.2	–4.3	3.0	7.9	19.4	97.0	92.1	2.8
France[4, 3]	22.7	24.1	0.5	77.3	75.9	–1.9	16.0	18.1	1.0	84.0	81.9	3.2
Germany	16.3	12.4	–3.0	83.7	87.6	–0.5	7.7	6.2	–0.4	92.3	93.8	3.2
Ireland[5]	50.2	53.5	2.8	49.8	46.5	0.6	40.3	42.9	4.5	59.7	57.1	5.5
Italy[3]	15.1	19.3	1.0	84.9	80.7	–1.4	9.1	10.8	7.8	90.9	89.2	4.8
Netherlands	36.5	40.9	3.5	63.5	59.1	–1.2	16.7	23.3	2.6	83.3	76.7	0.5
Norway	9.2	11.6	–1.1	90.8	88.4	–3.2	7.3	8.6	6.3	92.7	91.4	3.7
Sweden	11.0	18.6	3.6	89.0	81.4	–3.2	7.9	13.6	11.0	92.1	86.4	3.7
Turkey[2, 3]	5.3	4.5	16.9	94.7	95.5	6.8	1.4	2.5	4.7	98.6	97.5	–0.1
United Kingdom[6]	18.4	25.4	2.1	81.6	74.6	–2.2	12.2	15.8	7.6	87.8	84.2	3.5

1. Turnover instead of production for the following countries: United States, Japan, France, Germany, Italy, Netherlands, Sweden.
2. 1986 instead of 1985.
3. 1993 instead of 1994.
4. 1987 instead of 1985.
5. 1990 instead of 1994.
6. 1992 instead of 1994.

Source: OECD, AFA database, December 1997.

Annex Table 4.1. **Trends in gross domestic expenditure on R&D (GERD)**

Millions of 1995 PPP$ and percentage change (based on constant prices)

	1995 level (millions of PPP$)	Compound annual growth rate			Annual growth rate					
		1981-85	1985-90	1991-96	1991	1992	1993	1994	1995	1996
United States	179 126	7.0	2.1	0.5	..[12]	0.0	–2.3	–0.3	4.0	1.1
Canada	10 240	6.7	3.1	3.9	1.8	3.5	6.3	4.7	2.9	2.2
Mexico	2 160	..	..	..	..	..	..	39.3	–1.1	..
Japan (adj.)	75 636	8.5	6.7	0.4	2.5	–1.1	–2.6	–1.0	6.5	..
Korea	15 132	..	..	..	..	..	..	..	..	..
Australia[1]	5 536	8.3	4.9	7.6	..	9.7	..	5.5	..	..
New Zealand	589	..	..	..	–2.6	3.7	7.5	..	..	..
Austria	2 553	4.3	5.7	1.8	9.0	0.4	1.7	6.1	1.4	–0.4
Belgium	3 391	..[12]	..[12]	..	1.6	..	–1.6	..[12]	3.7	..
Czech Republic	1 128	..	..	–10.3	..	–19.2	–26.9	–5.1	..[12]	7.2
Denmark	2 149	7.0	6.9	5.2	6.1	2.4	4.7	..	6.9	..
Finland	2 150	10.5	7.3	4.4	..[12]	1.4	0.4	10.4	5.8	..
France	27 044	4.9	4.5	0.4	0.5	1.6	0.1	–0.6	0.3	0.5
Germany[2, 3, 4]	38 412	4.3	3.6	–1.3	..[12]	..[12]	–3.2	–1.5	0.6	0.7
Greece	545[10]	..	..[12]	..	0.2	..	14.4	..	..	..
Hungary	504	..	..	..	..	..	..	..	..	..
Iceland	89	5.9	9.4	6.9	18.8	10.8	1.1	7.7	12.0	3.1
Ireland	867	5.6	6.3	17.1	15.0	15.6	18.5	18.9	15.6	..
Italy	12 693	8.3	5.9	–2.8	..[12]	–2.8	–6.0	..[12]	1.0	–0.4
Netherlands[5, 6, 7]	6 376	4.5	3.6	2.5	–2.6	–1.6	2.1	..[12]	4.6	..
Norway[7]	1 697	..[12]	2.5	..	1.1	..	3.9	..	..[12]	..
Poland	1 580	..	..	..	..	..	..	..	–2.5	
Portugal[8]	753	7.5	14.0	3.9	..	11.6	..	..	–1.0	..
Spain[4]	4 720	8.7	13.9	0.5	5.1	..[12]	–1.1	–5.4	2.7	1.0
Sweden[7]	5 939	8.2	3.0	..	–0.9	..	..[12]	..	..[12]	..
Switzerland	4 198[11]	..[12]	..[12]	..	..	–1.6	..	..	..	..
Turkey	1 332	..	..	–4.4	64.3	–1.7	–2.3	–22.8	12.7	..
United Kingdom	21 375	1.3	2.8	1.3	–5.1	0.0	3.5	1.8	–0.3	..
North America[9]	191 526	7.3	2.2	3.1	..[12]	0.1	–1.8	0.2	3.9	1.1
European Union[3]	127 634	4.4	4.3	–0.1	..[12]	–0.3	–0.5	0.1	1.1	..
Total OECD[3, 9]	409 120	6.5	3.7	0.5	..[12]	–0.1	–1.4	–0.1	3.5	..

1. 1981-86, 1986-90 and 1990-94.
2. 1987-90.
3. Figures for Germany from 1991 onwards refer to unified Germany.
4. 1992-95.
5. 1991-1994.
6. 1982-85.
7. 1985-89.
8. 1982-86, 1986-90 and 1990-95.
9. Including Mexico from 1993 onwards.
10. 1993.
11. 1992.
12. Break in series from previous year for which data are available.

Source: OECD, MSTI and S&T databases, February 1998.

Annex Table 4.2. **Gross domestic expenditure on R&D (GERD) as a percentage of GDP**

	1981	1985	1990	1991	1992	1993	1994	1995	1996
United States	2.4	2.9	2.8	2.8[9]	2.7	2.6	2.5	2.6	2.5
Canada	1.3	1.5	1.5	1.5	1.6	1.6	1.6	1.7	1.7
Mexico	..	..	..	..	..	0.2	0.3	0.3	..
Japan (adj.)	2.1	2.6	2.9	2.8	2.7	2.7	2.6	2.8	..
Korea	..	..	..	..	..	..	..	2.7	..
Australia[1]	1.0	1.3	1.4	..	1.6	..	1.6	..	..
New Zealand[2]	0.9	..	1.0[9]	1.0	1.0	1.0	..	1.0	..
Austria	1.2	1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.5
Belgium[2, 3]	1.4	1.7[9]	1.7[9]	1.7	..	1.6	1.6[9]	1.6	..
Czech Republic	..	..	..	2.1	1.8	1.4	1.3	1.2[9]	1.2
Denmark	1.1	1.3	1.6	1.7	1.7	1.8	..	1.8	..
Finland	1.2	1.6	1.9	2.1	2.2	2.2	2.3	2.3	..
France	2.0	2.3	2.4	2.4	2.4	2.5	2.4	2.3	2.3
Germany[4]	2.4	2.7	2.8[9]	2.6[9]	2.5[9]	2.4	2.3	2.3	2.3
Greece[5]	0.2	0.3	0.4[9]	0.4	..	0.5	..	..	..
Hungary	..	..	..	1.1	1.1	1.0	0.9	0.8	..
Iceland	0.6	0.7	1.0	1.2	1.3	1.3	1.4	1.5	1.5
Ireland	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.4	..
Italy	0.9	1.1	1.3	1.3	1.3	1.3	1.2[9]	1.1	1.1
Netherlands	1.9	2.1[9]	2.2[9]	2.1	2.0	2.0	2.0[9]	..	..
Norway[3]	1.2	1.5[9]	1.7	1.7	..	1.7	..	1.7[9]	..
Poland	..	..	..	..	..	..	0.8	0.7	..
Portugal[6]	0.3	0.4	0.5	..	0.7	..	..	0.6	..
Spain	0.4	0.6	0.9	0.9	0.9[9]	0.9	0.9	0.9	0.8
Sweden[3]	2.3	2.9	2.9	2.9	..	3.4[9]	..	3.6[9]	..
Switzerland[5]	2.3	2.9[9]	2.9[9]	..	2.7	..	..	..	..
Turkey	..	..	0.3	0.5	0.5	0.4	0.4	0.4	..
United Kingdom	2.4	2.2[9]	2.2	2.1	2.1	2.2	2.1	2.1	..
North America[7]	2.3	2.8	2.7	2.5[9]	2.4	2.3	2.2	2.3	2.3
Asia-Pacific (OECD)	2.0	2.4	2.7	2.6	2.6	2.5	2.5	2.6	..
European Union[4]	1.7	1.9	2.0	2.0[9]	1.9	1.9	1.9	1.9	..
Total OECD[4, 7, 8]	2.0	2.3	2.4	2.3	2.3	2.2	2.1	2.2	..

1. 1986 instead of 1985.
2. 1979 instead of 1981.
3. 1989 instead of 1990.
4. Figures for Germany from 1991 onwards refer to unified Germany.
5. 1986 instead of 1985 and 1989 instead of 1990.
6. 1982 instead of 1981 and 1986 instead of 1985.
7. Including Mexico from 1991 onwards.
8. Excluding the Czech Republic, Hungary, Korea and Poland.
9. Break in series from previous year for which data are available.

Source: OECD, MSTI and S&T databases, March 1997.

Annex Table 4.3. **Trends in total numbers of researchers**

	1995 level (full-time equivalent)	Compound annual growth rate			Percentage change from previous year(s)				
		1981-85	1985-89	1991-95	1991	1992	1993	1994	1995
United States[1]	962 700[12]	5.3	3.6	0.1[2]	1.9	..	0.1	..	..
Canada	77 807[12]	7.4	4.7	5.9[2]	8.6	6.1	5.8	..	..
Mexico	19 434	..	..	..	..	..	..	21.0	13.9
Japan (adj.)	551 990	5.2	4.7	3.0	2.8	4.1	3.0	2.8	2.0
Korea	100 456	..	..	..	..	..	..	..	..
Australia[2]	56 743[13]	5.4	7.6	7.1	..	9.9	..	4.3	..
New Zealand	6 104	..	..	..[15]	–2.9	..[15]	5.0	..	–0.8
Austria	12 821[12]	3.2	3.6	..	..	..	9.9	..	..
Belgium[3]	22 918	3.7	4.1	..	1.4	..	..	..[15]	1.6
Czech Republic[4]	11 936	..	..	..	..	..	–32.1	–2.2	..[15]
Denmark	15 954	6.0	6.4	7.3	4.7	6.7	6.3	..	8.0
Finland[4, 5]	16 863	3.0	7.3	4.7	7.3	..	4.2	..	5.2
France	151 249	4.6	4.2	3.9	4.7	9.2	3.0	2.3	1.4
Germany[6]	230 401[12]	3.6	..[15]	..[15]	..[15]	..[15]	–1.7	..	..
Greece	8 031[12]	..	..	13.5[2]	6.8	..	13.5	..	..
Hungary	10 499	..	..	–7.7	–17.5	–14.9	–4.0	–0.6	–10.7
Iceland	1 076	7.9	10.0	11.9	1.6	3.1	15.1	3.7	27.3
Ireland	8 514	7.4	9.9	13.3	11.8	8.7	14.0	15.8	14.9
Italy	75 722[13]	5.2	4.5	0.2	–3.4	–1.1	0.0	1.7	..
Netherlands[7]	34 038	..[15]	2.5	4.8	..	..	4.8	..[15]	–0.5
Norway	15 931	6.6	5.8	4.7[2]	5.2	..	4.7	..	..[15]
Poland	50 425	..	..	..	..	..	..	..	6.3
Portugal[8]	11 599	10.4	..[15]	7.1	..	..[15]	..	..	7.1
Spain	47 342	2.5	11.6	3.9	7.9	2.6	4.0	10.4	–1.1
Sweden	29 252	5.2	4.0	..[15]	1.8	..	..[15]	..	..
Switzerland[4, 9]	18 230[14]	..[15]	..[15]	..	..	..[15]	..	..	..
Turkey	15 854	..	..	7.3	6.4	5.2	8.2	6.3	9.6
United Kingdom	148 000	0.8	0.4	2.7[2]	..[15]	2.3	3.1	..[15]	4.2
North America[1]	1 054 610[12]	5.4	3.7	0.5[2]	..[15]	..	0.5	..	..
Asia-Pacific (OECD)	617 413	5.2	4.9	3.9	3.3	4.9	3.0	3.0	2.3
European Union[6]	778 080[12]	3.4	4.1	1.9	..[15]	1.9	1.9	..	..
Total OECD[6, 10, 11]	2 466 731[12]	4.6	4.1	1.8	..[15]	..	1.8	..	..

1. 1981-84.
2. 1985-90; 1990-94.
3. 1985-88.
4. University graduates rather than researchers.
5. 1983-87; 1987-91.
6. Figures for Germany from 1991 onwards refer to unified Germany.
7. 1989-93.
8. 1982-86; 1990-92.
9. 1992-95.
10. 1991-93.
11. Excluding Czech Republic, Hungary, Korea and Poland.
12. 1993.
13. 1994.
14. 1992.
15. Break in series from previous year for which data are available.

Source: OECD, MSTI and S&T databases, March 1997.

Annex Table 4.4. **Researchers per ten thousand labour force**

	1981	1985	1989	1991	1992	1993	1994	1995
United States	62	68[8]	74	75	..	74	..	..
Canada	33	41	45	45	51	53	..	..
Mexico	..	..	..	..	..	4	5	6
Japan (adj.)	54	64	73	75	78	80	81	83
Korea	..	..	..	..	..	..	..	48
Australia[1]	35	41	50	..	60	..	64	..
New Zealand	..	..	30	29	36[8]	37	..	35
Austria	21	23	25	..	..	34	..	..
Belgium	31	36	43[8]	43	..	..	53[8]	53
Czech Republic	..	..	..	..	40[2, 9]	27[2, 8, 9]	26[2, 9]	23[8]
Denmark	25	31	38	41	44	47	..	57
Finland[2]	..	..	..	55	..	61	..[6, 7]	..
France	36	43	50	52	56	58	59	60
Germany[3]	44	50	59[8]	61[8]	59[8]	58	..	..
Greece	..	..	14	16	..	20	..	..
Hungary	..	..	..	..	27	27	28	26
Iceland	31	38	54	49	50	57	58	72
Ireland	17	22	32	39	41	46	52	59
Italy	23	27	31	31	30	32[8]	33	..
Netherlands	34	42[8]	40	..	..	45[8]	48[8]	46
Norway	38	47	56	63	..	69	..	73[8]
Poland	..	..	..	..	..	..	27	29
Portugal[4]	7	10	12[8]	..	20[8]	..	..	24
Spain	14	15	22	26	27	28	30	30
Sweden	41	50	57	59	..	68[8]	..	..
Switzerland[5]	..	44[2, 8]	46[2, 8]	..	46[8]	..	..	..
Turkey	..	..	..	6	6	6	7	7
United Kingdom	47	47	47	45[8]	46	47	50[8]	52
North America[6]	59	66	71	60[8]	..	59	..	..
Asia-Pacific (OECD)	52	61	69	72	75	77	78	..
European Union[3]	33	37	42	44[8]	45	46[8]	..	..
Total OECD[3, 6, 7]	44	50	55	54[8]	..	55	..	..

1. 1990 instead of 1989.
2. University graduates rather than researchers.
3. Figures for Germany from 1991 onwards refer to unified Germany.
4. 1982 instead of 1981, 1986 instead of 1985, and 1990 instead of 1989.
5. 1986 instead of 1985.
6. Including Mexico from 1991 onwards.
7. Excluding Czech Republic, Hungary, Korea and Poland.
8. Break in series from previous year for which data are available.
9. Partly based on national estimates which do not correspond exactly to OECD methodology.

Source: OECD, MSTI and S&T databases, February 1998.

Annex Table 4.5. **Estimates of share of OECD gross domestic expenditure on R&D (GERD) and of total numbers of researchers by OECD country/zone**

Percentage

	Share of GERD[1]						Share of researchers[1]				
	1981	1985	1989	1991	1993	1995	1981	1985	1989	1991	1993
United States	46.8	48.2	45.3	44.2[6]	43.4	43.7	43.2	43.0[6]	42.2	40.4	39.1
Canada	2.2	2.2	2.1	2.2	2.4	2.4	2.6	2.9	2.9	2.9	3.1
Mexico	..	..	..	0.3[5]	0.4[6]	0.6	..	..	..	0.6	0.6
Japan (adj.)	14.7	15.8	17.5	18.4	18.1	18.6	19.7	20.4	20.9	20.6	21.4
Korea	..	..	..	..	..	3.7	..	..	..	..	..
Australia	1.0	1.0	1.1	1.1	1.3	1.4	1.5	1.7	1.9	2.0	2.2
New Zealand	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.2	0.2	0.3[6]
Austria	0.5	0.5	0.5	0.6	0.6	0.6	0.4	0.4	0.4	0.4	0.5
Belgium	0.9	0.8[6]	0.8[6]	0.8	0.8	0.8	0.8	0.8	0.8[6]	0.8	0.7
Czech Republic[2]	..	..	..	0.5[5]	0.3[5]	0.3[6]	..	..	..	..	0.6[5]
Denmark	0.3	0.3	0.4	0.4	0.5	0.5	0.4	0.5	0.5	0.5	0.6
Finland[2]	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.6
France	7.1	6.6	6.8	6.9	6.9	6.6	5.4	5.5	5.5	5.5	5.9
Germany[3]	10.0	9.2	9.6[6]	9.8[6]	9.6[6]	9.3	7.9	7.7	8.1[6]	10.2[6]	9.3[6]
Greece	0.1	0.1	0.1[6]	0.1	0.1	0.2	0.2	0.2	0.2[6]	0.3	0.3
Hungary	..	..	..	0.2[5]	0.2[5]	0.1	..	..	..	0.6	0.5
Iceland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.2	0.3
Italy	2.9	3.1	3.4	3.5	3.3	3.1	3.3	3.4	3.5	3.2	3.0
Netherlands	1.7	1.5[6]	1.5	1.4[6]	1.4	1.6	1.3	1.3[6]	1.2	1.3	1.3
Norway	0.3	0.4[6]	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6
Poland	..	..	..	..	..	0.4	..	..	..	..	..
Portugal	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2[6]	0.3	0.3
Spain	0.7	0.7	1.0	1.2	1.2[6]	1.1	1.2	1.1	1.5	1.7	1.8
Sweden	1.2	1.3	1.3	1.2	1.3[6]	1.2	1.1	1.2	1.2	1.1	1.2[6]
Switzerland[2]	1.2	1.2[6]	1.2[6]	1.1	1.1	1.1	0.8	0.8	0.8[6]	0.8	0.7
Turkey	0.3	0.3	0.2	0.4	0.4	0.3	0.6	0.5	0.5	0.5	0.6
United Kingdom	7.4	6.0	5.9	5.2	5.6	5.2	8.0	7.0	6.1	5.5[6]	5.7
North America[4]	49.0	50.4	47.4	46.7[6]	46.2	46.8	45.8	45.8[6]	45.1	43.8[6]	42.7
Asia-Pacific (OECD)	15.8	16.9	18.7	19.6	19.6	20.1	21.5	22.3	23.0	22.8	23.8[6]
European Union[3]	33.3	30.8	31.9[6]	31.7[6]	32.2[6]	31.1	30.9	30.0	30.0[6]	31.5[6]	31.5
Total OECD[3, 4, 5]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1. Based on OECD estimates for missing data.
2. University graduates rather than researchers.
3. Figures for Germany from 1991 onwards refer to unified Germany.
4. Including Mexico from 1991 onwards.
5. Excluding Czech Republic, Hungary, Korea and Poland.
6. Break in series from previous year for which data are available.
7. Partly based on national estimates which do not correspond exactly to OECD methodology.

Source: OECD, MSTI and S&T databases, February 1998.

Annex Table 4.6. **Trends in total government-financed gross domestic expenditure on R&D (GERD)**

Percentage, based on constant PPP$ prices

	1995 level (millions of current PPP$)	Compound annual growth rate			Percentage change from previous available year					
		1981-85	1985-90	1991-95	1991	1992	1993	1994	1995	1996
United States	64 676	6.5	–1.3	–1.2	..[13]	–2.7	–2.4	–2.3	1.7	–3.2
Canada	3 599	5.4	1.4	0.0	–0.3	..	0.5	..	–2.5	–2.1
Mexico	1 430	..	..	..[13]	17.2	–4.5	..[13]	20.8	2.9	..
Japan (adj.)	15 785	1.5	3.2	6.1	4.4	5.8	9.4	–1.8	13.8	..
Korea	2 881	..	..	..	..	..	..	..	..	..
Australia[1]	2 629[11]	3.9	3.0	3.8	..	4.9	..	2.7	..	..
New Zealand	308	..[13]	–0.9	–0.6	–0.1	–1.2	–0.1	..	–0.7	..
Austria	1 252	5.0	4.1	3.6	13.7	2.3	2.9	10.1	–0.1	–3.4
Belgium	895	..[13]	..[13]	..[13]	0.4	..	0.3	..[13]	1.8	..
Czech Republic[2]	364	..	..	–19.0	..	–40.3	–24.0	17.4	..[13]	18.0
Denmark	842	3.1	5.1	4.9	–0.5	–0.3	2.2	..	8.9	..
Finland	754	..	..	0.5	..[13]	..	–0.4	..	1.4	..
France	11 442	4.7	2.6	..[13]	1.5	..[13]	0.2	–4.9	2.0	..
Germany[3, 4]	14 377	1.6	2.0	–0.7	..[13]	..[13]	–1.5	–0.5	1.6	0.4
Greece[5]	256[12]	..[13]	..[13]	..	–8.3	..	3.1	..	..	..
Hungary	268	..	..	..	..	..	..	..	..	..
Iceland	51	–1.4	9.9	2.7	25.9	10.9	–8.8	7.7	2.0	13.2
Ireland	196	0.4	–2.3	11.2	6.2	4.9	35.0	–8.9	18.5	..
Italy	5 916	10.8	5.8	–2.5	..[13]	–4.9	–0.6	–6.7	2.7	–3.0
Netherlands[5, 6]	2 685	1.3	5.9	–1.0	–2.1	–0.8	1.2	–4.9	0.5	..
Norway[5]	739	3.5	5.4	0.3	–0.2	..	3.5	..	–2.8	..
Poland	1 023	..	..	..	..	..	..	..	..	..
Portugal[7]	490	8.1	13.2	5.0	..	9.5	..	..	2.1	..
Spain	2 056	4.4	12.7	..[13]	6.5	..[13]	1.7	–4.0	..[13]	..
Sweden[5]	1 644[12]	4.2	4.3	..[13]	–6.5	..	..[13]	..	..	..
Switzerland	..	..[13]	..[13]	..	..	5.3	..	..	..	..
Turkey	858	..	..	–6.4	61.2	–10.3	–0.6	–25.4	15.4	..
United Kingdom[8]	7 126	–1.2	–1.3	0.0	–6.5	–2.0	0.7	2.2	–0.8	..
North America[9]	69 704	6.7	0.3	–1.1	..[13]	–2.3	–1.5	–1.8	1.2	..
Asia-Pacific (OECD)	21 736	1.7	3.1	5.6	3.9	6.0	8.1	–1.1	9.9	..
European Union[4]	50 092	2.9	2.8	–1.7	..[13]	–3.2	0.4	–2.2	..	..
Total OECD[4, 9, 10]	141 345	4.9	1.4	–0.4	..[13]	–1.7	0.3	–2.0	2.0	..

1. 1981-86, 1986-90 and 1990-94.
2. 1991-94.
3. 1987-90 and 1992-95.
4. Figures for Germany from 1991 onwards refer to unified Germany.
5. 1985-89.
6. 1982-85.
7. 1982-86, 1986-90 and 1990-95.
8. 1986-90.
9. Including Mexico from 1991 onwards.
10. Excluding the Czech Republic, Hungary, Korea and Poland.
11. 1994.
12. 1993.
13. Break in series from previous year for which data are available.

Source: OECD, S&T database, February 1998.

Annex Table 4.7. **Share of government-funded R&D performed in the higher education sector**

Percentage

	1980	1985	1990	1995
United States	26.2	23.0	25.1	31.9[5]
Canada	45.0	39.2	43.7	42.9[5]
Mexico	..	..	28.7	54.3
Japan	53.0	50.2	49.8	47.4
Korea	..	..	..	18.8
Australia	37.3[1]	40.5	42.5	47.5[6]
New Zealand	..	..	29.5	32.1
Austria	68.9[1]	70.7	72.6[3]	..
Belgium	51.7	51.4	63.9[4]	75.3
Czech Republic	..	..	..	21.7
Denmark	48.6	49.3	50.4	56.0
Finland	48.8[1]	..	49.3[4]	49.6
France	30.0[1]	27.4	28.1	35.8
Germany	37.4[1]	34.7	40.1	46.0[5]
Greece	18.4[1]	28.3[2]	46.8[4]	..
Hungary	..	..	38.4	41.9
Iceland	23.9[1]	35.1	27.0	34.0[5]
Ireland	23.4[1]	33.4	50.5	52.5
Italy	35.0	36.3	38.9	46.3[5]
Netherlands	49.5	50.1	55.9	58.5
Norway	49.2	44.4	48.6[4]	53.4
Poland	..	..	..	32.4
Portugal	28.5	45.5[2]	55.2	45.3
Spain	40.5	42.6	40.3	51.8
Sweden	65.6[1]	66.5	67.9[4]	..
Switzerland	72.2[1]	58.7[2]	74.0[3]	..
Turkey	..	..	86.3	89.5
United Kingdom	22.9[1]	27.8	32.3	38.2

1. 1981.
2. 1986.
3. 1989.
4. 1991.
5. 1996.
6. 1994.

Source: OECD, S&T database, February 1998.

Annex Table 4.8. **Government budget appropriations or outlays for R&D (GBAORD) by socio-economic objective**

	Defence as a percentage of total R&D budget		Percentages of civil[1] R&D budget									
			Economic development		Health and environment		Space		Non-oriented		General university funds	
	1991	1996	1991	1996	1991	1996	1991	1996	1991	1996	1991	1996
United States	59.7	54.7	22.1	20.5	43.5	45.1	24.5	25.2	9.9	9.2	..	..
Canada	5.6	4.3	39.9	33.9[4]	16.3	20.5[4]	8.5	6.9[4]	14.8	4.8[4]	20.5	19.6
Mexico	0.0	0.0	32.6	22.4	14.2	12.8	0.0	0.0	20.4	21.5	32.8	43.3
Japan (adj.)	5.7	5.9	33.5	34.4	5.7	6.9	7.2	7.0	8.5	10.2	45.1	41.4
Australia[2]	9.7	7.8	28.1	29.0	15.5	14.5	..	..	24.5	24.2	31.9	32.2
New Zealand[3]	1.5	1.2	47.5	..	25.7	25.7	..	0.0	1.2	1.8	24.5	21.6
Austria	0.0	0.0	14.6	12.9	8.6	8.3	0.4	0.0	12.4	13.4	64.0	65.3
Belgium	0.2	0.4	22.4	19.1	8.8	8.9	10.9	12.5	19.9	17.6	33.6	34.9
Denmark[4]	0.6	0.4	26.5	22.4	14.2	17.2	2.7	1.8	23.4	20.0	33.1	38.6
Finland[4]	1.4	2.0	41.0	43.2	16.5	14.8	3.1	3.0	10.7	10.9	28.7	28.1
France[4]	36.1	29.0	32.8	19.1	9.8	12.5	13.5	15.3	23.9	27.0	19.4	22.5
Germany	11.0	9.8	25.5	23.1	13.0	12.7	6.0	5.5	17.0	16.5	37.3	41.3
Greece[3]	1.4	1.6	30.1	24.2	17.8	15.8	0.3	0.3	3.5	11.5	46.8	48.1
Iceland	0.0	0.0	51.4	39.0	7.2	..	..	..	16.6	..	24.9	..
Ireland	0.0	0.0	48.5	46.9	12.7	12.1	3.8	2.9	5.1	3.5	29.9	34.7
Italy[3]	7.9	4.7	23.6	15.8	19.7	16.2	7.6	9.1	11.5	8.4	34.0	47.0
Netherlands	3.5	3.2	34.3	25.7	10.7	8.5	3.2	4.3	12.9	12.1	34.2	43.8
Norway	5.7	5.0	34.6	27.8	18.2	19.8	2.5	2.8	9.8	9.6	34.8	40.0
Portugal	0.8	1.3	39.4	21.7	17.6	17.0	0.3	1.2	9.4	..	28.6	..
Spain	16.8	10.8	33.1	31.0	18.2	13.6	8.4	8.2	13.0	10.4	24.0	34.9
Sweden[3, 4]	27.3	20.9	24.4	20.5	11.4	13.7	2.3	1.8	20.1	14.6	41.8	49.4
Switzerland	18.5	..	37.5	..	13.6	..	..	..	48.9	..	..	..
United Kingdom[4]	43.9	37.0	28.8	16.6	22.3	31.7	4.8	4.3	9.1	18.3	33.7	28.4
North America	56.3	51.5	24.2	21.8	39.8	41.9	22.1	22.7	10.8	9.2	..	..
Asia-Pacific (OECD)[3]	6.2	6.3	33.1	31.3	7.5	7.6	6.1	6.7	10.5	12.0	42.8	42.2
European Union[4]	21.0	16.8	30.3	23.1	14.3	15.5	7.2	7.4	15.7	16.4	30.8	34.4
Total OECD[3, 4]	37.6	35.4	28.6	22.8	22.3	26.3	12.1	13.4	13.4	13.5	..	..

1. For some countries, the categories do not add to 100 because of a residual category.
2. 1994.
3. 1995.
4. Change in methodology.

Source: OECD, MSTI database, February 1998.

Annex Table 4.9. **Higher education expenditure on R&D (HERD)**

Level in millions of current PPP$ and as a percentage of GDP

	1995 level (millions of current PPP$)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996[1]
United States	27 300	0.37	0.39	0.41	0.42	0.42	0.43[2, 8]	0.40[6, 9]	0.40[9]	0.40[9]	0.39[9]	0.39[9, 10]	0.38[9, 10]
Canada	2 327	0.35	0.35	0.34	0.33	0.34	0.37	0.40	0.40	0.40	0.39	0.37	0.36[10]
Mexico	990	..	..	..	..	..	..	..	..	0.12	0.14	0.14	..
Japan[2]	16 872	0.56	0.55	0.56	0.54	0.53	0.53	0.53	0.55	0.58	0.57	0.62	..
Korea	1 236	..	..	..	..	..	..	..	..	..	..	0.22	..
Australia	1 512	..	0.33	0.33	0.32	..	0.35	..	0.42	..	0.40	0.42	..
New Zealand[1]	181	..	..	..	..	0.17	0.28[6]	0.28	0.31	0.29	..	0.30	..
Austria	799[3]	0.44	..	..	..	0.44	..	..	..	0.52	..	..	..
Belgium	924	0.31	0.31	0.32[7]	0.30[7]	0.43[6]	..	0.43[5]	..	0.46[10]	0.44[6, 10]	0.44[10]	..
Czech Republic	96	..	..	..	..	..	..	0.03	0.02	0.04	0.06	0.10	0.10
Denmark	527	0.30	0.32	0.34	0.36	0.38	0.38	0.38	0.40	0.41	..	0.47	..
Finland	420	0.33[1]	0.35	0.36	0.37[5]	0.35	0.36[5]	0.46[6]	0.48[5]	0.45	0.44	0.46	..
France	4 518	0.34	0.34	0.34	0.34	0.35	0.35	0.36	0.37	0.39	0.38	0.39	0.39[10]
Germany	7 255	0.37	0.37[1]	0.42[6]	0.42[5]	0.41	0.41[5]	0.43[6]	0.43[5, 6]	0.44	0.43	0.43[5]	0.43
Greece	224	..	0.06[5]	0.07	0.13[6]	..	0.12	..	0.19	..	..	..	
Hungary	125	..	..	..	..	..	..	0.22	0.23	0.22	0.24	0.19	..
Iceland	25	0.22	..	0.20	..	0.26	0.25	0.34	0.41	0.32	0.33	0.42	0.36[10]
Ireland	166	0.16[5]	0.19	0.19	0.18	0.19[5]	0.20	0.22[5]	0.24	0.25[5]	0.26	0.27[10]	..
Italy	2 901	0.22	0.22	0.24	0.25	0.25	0.27	0.27	0.27	0.28	0.27	0.26[10]	0.25[10]
Netherlands	1 835	0.48	0.48	0.49	0.46	0.45	0.60[6]	0.61	0.60	0.60	0.59	0.60	..
Norway	442	0.33	..	0.36	..	0.41	..	0.44	..	0.47	..	0.45[1]	..
Poland	416	..	..	..	..	..	..	..	..	..	0.19	0.20	..
Portugal	254		0.12	..	0.15	..	0.19	..	0.28	..	..	0.21[1]	..
Spain	1 512	0.11	0.11	0.12	0.14	0.15	0.17	0.19	0.26[6]	0.29	0.27	0.27	0.27
Sweden	1 304	0.79	..	0.86	..	0.90	..	0.79	..	0.87	..	0.79[6, 9]	..
Switzerland	1 110[4]	..	0.37[5, 6]	..	0.56[1, 6]	0.56[1]	..	..	0.66	..	0.65	..	..
Turkey	919	..	..	..	..	..	0.23	0.38	0.33	0.30	0.24	0.26	..
United Kingdom	4 020	0.33[6]	0.34	0.35	0.34	0.33	0.34	0.35	0.36	0.37[6]	0.39	0.39	..
North America	30 617	0.36	0.39	0.40	0.41	0.42	0.42	0.38[1, 6, 9]	0.37[1, 9]	0.37[9]	0.37[9]	0.37[9, 10]	0.36[1, 9, 10]
European Union[1]	26 821	0.31[6]	0.32	0.34[6]	0.34	0.34	0.35	0.37[6]	0.38	0.39	0.39	0.39	..
Total OECD[1]	72 579	0.34	0.35	0.37	0.37	0.37	0.38	0.37[6, 9]	0.37[9]	0.38[9]	0.38[9]	0.38[9, 10]	..

1. OECD estimate or projection based on national sources.
2. Overestimated, or based on overestimated data.
3. 1993.
4. 1994.
5. National estimate or projection adjusted, if necessary, to meet OECD norms.
6. Break in series with previous year for which data are available.
7. Underestimated, or based on underestimated data.
8. National results adjusted to meet OECD norms.
9. Excludes most or all capital expenditure.
10. Provisional.

Source: OECD, MSTI database, January 1998.

Annex Table 4.10. **Share of R&D in the higher education sector funded by the business sector**

	1980	1985	1990	1995
United States	2.5	3.8	4.7	5.8[5]
Canada	3.9	4.3	6.3	10.4[5]
Mexico	..	..	..	1.4
Japan	1.0	1.5	2.3	2.4
Korea	..	..	..	22.4
Australia	1.4[1]	2.1[2]	2.2	4.7
New Zealand	..	..	4.6	9.4
Austria	1.0[1]	1.7	..	2.0[6]
Belgium	8.1	8.7	15.4[3]	10.6
Czech Republic	..	..	..	2.0
Denmark	0.6	1.0	1.6	1.8
Finland	2.1[1]	..	3.6[3]	5.7
France	1.3[1]	1.9	4.9	3.3
Germany	2.0[1]	5.9	7.8	7.9[5]
Greece	0.0[1]	..	6.1[3]	5.6
Hungary	..	..	22.7	2.9[5]
Iceland	1.2[1]	0.6	6.8	4.3[5]
Ireland	7.1[1]	6.9	10.2	6.9
Italy	1.3	1.5	2.4	4.7[5]
Netherlands	0.3	1.0	0.9	4.0
Norway	1.6	5.0	4.7[3]	5.3
Poland	..	..	..	11.4
Portugal	0.1	0.9[2]	0.7	0.8
Spain	0.0	1.1	8.9	8.3
Sweden	2.3[1]	5.5	5.2[3]	4.6
Switzerland	9.5[1]	3.3[2]	1.8[4]	1.7[7]
Turkey	..	..	10.3	13.1
United Kingdom	2.8[1]	5.2	7.6	6.2

1. 1981
2. 1986.
3. 1991.
4. 1992.
5. 1996.
6. 1993.
7. 1994.

Source: OECD, S&T database, February 1998.

Annex Table 4.11. **Business enterprise expenditure on R&D**

Level in millions of current PPP$ and as a percentage of business gross domestic product

	1995 level (millions of current PPP$)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
United States	128 700	2.36	2.35	2.31	2.24	2.21	2.26	2.34	2.27	2.13	2.03	2.08
Canada	6 195	1.04	1.10	1.09	1.05	1.03	1.10	1.15	1.23	1.33	1.37	1.40
Mexico	448	..	..	..	..	0.09	..	0.10	0.01	0.03	0.09	0.07
Japan	53 157	2.07	2.04	2.07	2.14	2.28	2.39	2.35	2.25	2.12	2.09	2.17
Korea	11 157	..	..	..	..	..	..	..	..	..	..	2.30
Australia	3 147	0.42	0.51	0.51	0.56	0.56	0.58	0.64	0.74	0.76	0.80	0.91
New Zealand	159	..	..	..	..	0.35	0.36	0.33	0.34	0.38	..	0.33
Austria	1 278[1]	0.92	..	..	..	1.06	..	..	..	1.11	..	..
Belgium	2 287	1.54	1.55	1.56	1.51	1.42	..	1.38	..	1.29	1.34	1.37
Czech Republic	734	..	..	..	..	..	..	..	1.55	1.06	0.91	0.90
Denmark	1 233	1.06	1.13	1.23	1.28	1.31	1.40	1.51	1.53	1.58	..	1.67
Finland	1 359	1.30	1.39	1.46	1.55	1.61	1.73	1.77	1.87	1.92	2.12	2.18
France	16 492	1.78	1.75	1.78	1.79	1.85	1.91	1.94	1.99	2.01	1.95	1.89
Germany	25 225	2.51	2.52	2.63	2.61	2.60	2.48	2.29	2.16	2.08	1.97	1.92
Greece	146[1]	..	0.12	..	0.13	0.13	..	0.16	..	0.21	..	..
Hungary	219	..	..	..	..	..	..	0.54	0.48	0.40	0.39	0.40
Iceland	28	0.18	..	0.19	..	0.31	0.31	0.40	0.45	0.66	0.68	0.77
Ireland	611	0.58	0.62	0.63	0.62	0.64	0.68	0.80	0.91	1.07	1.21	1.37
Italy	7 243	0.79	0.81	0.84	0.87	0.90	0.94	0.87	0.83	0.76	0.81	0.80
Netherlands	3 326	1.46	1.60	1.71	1.68	1.56	1.41	1.26	1.20	1.22	1.29	1.34
Norway	962	1.26	..	1.47	..	1.32	..	1.25	..	1.30	..	1.38
Poland	612	..	..	..	..	..	..	..	..	..	0.46	0.40
Portugal	149	..	0.13	..	0.13	..	0.18	..	0.19	..	..	0.17
Spain	2 277	0.36	0.42	0.43	0.50	0.53	0.61	0.61	0.58	0.55	0.49	0.51
Sweden	4 415	3.00	..	2.99	..	2.86	..	3.08	..	3.60	..	3.94
Switzerland	2 942[2]	..	2.66	..	..	2.53	..	..	2.23	..	..	..
Turkey	314	..	..	..	..	..	0.08	0.13	0.14	0.12	0.10	0.10
United Kingdom	13 992	1.99	2.17	2.11	2.06	2.07	2.08	1.98	1.99	1.97	1.85	1.79
European Union	79 193	1.58	1.63	1.66	1.66	1.67	1.67	1.61	1.59	1.56	1.51	1.49
OECD total	275 347	1.91	1.92	1.92	1.90	1.91	1.95	1.90	1.84	1.76	1.70	1.73

1. 1993.
2. 1992.

Source: OECD, MSTI database, February 1998.

Annex Table 4.12. **Percentage of business enterprise expenditure on R&D financed by government**

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
United States	32.3	31.8	33.4	31.3	28.0	25.6	22.5	20.8	19.4	18.8	18.4	17.3
Canada	12.2	11.8	11.6	11.1	10.0	9.2	9.7	..	9.6	..	7.1	7.0
Mexico	..	..	..	..	..	..	0.0	0.0	0.5	2.4	2.8	..
Japan	1.6	1.8	1.7	1.5	1.2	1.3	1.4	1.1	1.4	1.2	1.6	..
Korea	..	..	..	..	..	..	..	..	..	..	3.6	..
Australia	6.9	5.1	4.0	3.7	2.7	3.0	3.0	2.2	2.4	3.1	2.5	..
New Zealand	..	..	..	..	6.5	6.2	7.2	7.7	6.9	..	6.9	..
Austria	7.9	..	..	..	5.6	..	..	..	9.8	..	..	..
Belgium	8.4	5.8	4.8	4.7	8.9	..	7.8	..	7.2	4.5	4.4	..
Czech Republic	..	..	..	..	..	..	6.6	3.1	4.1	3.0	4.5	7.3
Denmark	9.9	11.0	11.8	11.7	11.7	9.6	7.9	6.8	5.8	..	5.4	..
Finland	3.2	..	3.2	..	3.1	..	5.4	..	6.1	..	5.6	..
France	23.4	22.8	22.2	20.8	19.3	19.8	22.3	16.4	15.3	13.0	12.7	..
Germany	15.3	13.7	11.9	11.4	11.0	10.7	10.0	9.8	9.0	9.0	9.0	8.9
Greece	..	14.7	..	11.3	8.6	..	5.5	..	4.6	..	..	..
Hungary	..	..	..	..	..	..	8.2	9.2	11.4	22.9	17.3	..
Iceland	15.8	..	27.7	..	10.9	10.9	9.6	9.4	14.4	14.4	3.3	14.4
Ireland	12.4	13.8	11.3	9.1	6.9	5.2	3.7	3.1	10.6	2.1	4.5	..
Italy	16.9	24.8	21.3	18.9	16.3	19.3	13.2	11.5	13.4	9.6	12.2	11.8
Netherlands	12.6	14.5	15.1	13.2	10.6	11.9	7.5	7.2	7.8	8.4	6.6	..
Norway	18.8	..	20.1	..	19.6	..	15.9	..	16.0	..	11.9	..
Poland	..	..	..	..	..	..	..	..	..	33.9	33.8	..
Portugal	..	3.6	..	2.5	..	6.5	..	9.1	..	..	5.2	..
Spain	7.7	11.0	13.8	15.2	11.8	11.8	11.3	11.4	10.6	10.6	9.2	..
Sweden	11.6	..	11.2	..	12.6	..	10.3	..	10.8	..	9.5	..
Switzerland	..	1.8	..	..	1.6	..	..	1.7	..	..	..	..
Turkey	..	..	..	..	..	..	0.0	0.1	0.1	1.6	1.7	..
United Kingdom	23.0	23.4	20.0	17.0	17.2	16.7	14.6	13.8	12.4	11.8	12.0	..
European Union	17.6	17.9	16.1	14.9	14.2	14.5	13.5	11.9	11.3	10.4	10.4	..
OECD total	22.1	21.8	21.9	20.1	17.9	16.7	15.0	13.6	12.9	12.3	12.2	..

Source: OECD, MSTI database, February 1998.

Annex Table 4.13. **R&D intensity by industry**

Business enterprise R&D expenditure as a percentage of value added

	OECD-14		Canada		United States		Australia		Japan		Denmark		Finland		France	
	1988	1994	1988	1995	1988	1994	1988	1994	1988	1994	1988	1995	1988	1995	1988	1994
Total manufacturing	6.6	6.6	3.0	3.3	8.9	8.0	2.5	3.6	6.6	7.3	3.8	4.2	4.2	5.8	5.8	6.8
Food, beverages and tobacco	1.1	1.1	0.5	0.5	1.3	1.2	0.9	1.1	1.7	1.7	1.4	1.5	1.8	1.9	0.8	0.9
Textiles, apparel and leather	0.5	0.7	0.7	0.9	0.5	0.6	0.2	0.6	1.4	1.6	0.2	0.1	0.8	1.2	0.5	0.9
Wood products and furniture	0.4	0.5	0.4	0.3	0.4	0.4	0.2	0.8	0.6	1.1	0.3	0.3	0.6	1.0	0.1	0.6
Paper, paper products and printing	0.6	0.9	0.9	0.5	0.7	1.3	0.5	0.9	0.9	0.8	0.1	0.2	1.3	1.4	0.3	0.3
Chemicals	8.1	8.8	3.5	4.2	8.7	10.0	3.7	4.6	10.7	11.4	7.7	10.4	9.4	8.5	6.9	8.0
Industrial chemicals	8.2	8.5	2.8	2.0	7.6	8.0	3.2	3.9	12.8	12.7	3.9	3.4	7.9	6.5	8.2	10.3
Pharmaceuticals	19.7	22.0	7.6	18.2	21.1	23.7	14.9	23.4	16.5	20.3	23.5	26.4	27.6	38.2	25.0	27.5
Petroleum refining	5.4	4.2	7.6	6.2	10.6	9.3	1.8	0.8	7.7	5.9	0.0	0.0	8.8	3.2	2.3	1.5
Rubber and plastics	2.6	2.9	0.7	0.8	2.1	3.1	1.2	2.0	4.7	5.1	1.3	2.1	5.8	6.8	4.0	3.7
Non-metallic mineral products	2.3	1.9	0.5	0.3	3.1	2.1	1.7	0.9	4.9	4.2	1.7	0.6	2.3	3.8	1.4	2.1
Basic metals	2.3	2.6	1.8	1.9	1.5	1.6	2.0	4.7	4.2	4.6	2.9	2.4	2.9	2.7	2.1	2.9
Ferrous metals	2.0	2.3	0.7	0.6	0.9	0.9	2.8	7.7	3.6	3.8	3.5	3.1	2.0	2.0	2.0	3.5
Non-ferrous metals	3.0	3.3	2.8	3.1	2.5	2.7	1.4	2.7	6.3	7.1	1.1	0.9	5.9	4.2	2.3	2.1
Metal products, machinery and equipment	11.6	11.1	6.3	6.4	16.2	13.4	5.1	6.4	9.8	10.9	5.3	5.6	7.8	11.1	10.3	12.1
Fabricated metals	1.3	1.3	0.7	1.3	1.3	1.3	1.1	2.4	1.6	1.6	0.9	0.3	1.8	2.1	0.7	1.2
Non-electrical machinery	4.3	5.5	1.4	1.6	3.1	4.0	5.4	4.9	6.1	8.3	3.6	6.7	7.0	6.8	2.9	6.9
Office and computing equipment	30.3	29.6	24.7	22.9	55.4	49.5	6.4	5.2	19.3	24.4	25.5	7.2	16.2	13.2	10.8	11.3
Electrical machinery	7.7	8.7	2.4	2.0	3.9	5.9	2.4	2.8	11.0	12.1	5.6	3.6	7.7	11.6	4.3	4.6
Radio, TV and communication equipment	19.8	17.1	30.2	32.2	24.6	15.0	. .	. .	13.8	15.4	14.1	17.6	28.0	35.9	29.3	34.2
Shipbuilding	2.1	2.8	0.0	0.0	0.0	0.0	1.1	7.7	1.8	1.5	3.1	4.5	4.5	1.0	1.2	4.5
Motor vehicles	11.3	12.2	0.8	0.7	17.5	16.5	5.5	5.9	9.9	10.0	0.0	0.0	2.7	4.6	8.6	12.6
Aircraft	44.8	34.1	26.3	19.4	50.6	36.1	1.7	1.4	16.4	16.9	0.0	0.0	3.1	0.5	40.1	37.6
Other transportation equipment	7.2	6.0	0.5	0.1	5.2	3.8	1.5	67.9	5.2	4.5	19.3	7.5	2.6	22.0	4.9	8.1
Scientific instruments	9.6	16.2	3.3	4.0	11.7	21.0	13.4	13.7	12.7	18.3	16.4	14.2	13.9	13.3	5.0	4.4
Other manufacturing	1.6	2.4	3.2	3.6	2.3	3.7	3.4	18.4	1.1	1.5	17.3	12.4	1.3	3.0	0.8	1.0
High-technology industries	26.6	22.5	23.8	25.2	36.9	25.1	18.4	20.5	15.4	18.1	19.9	21.9	22.5	30.2	27.4	29.8
Medium-high-technology industries	7.9	9.3	1.7	1.4	8.4	10.4	4.4	5.1	9.7	10.9	5.3	6.1	7.2	8.1	6.1	8.7
Medium-low-technology industries	2.2	2.3	1.6	1.6	2.6	2.7	1.6	3.4	3.4	3.4	3.1	2.3	3.1	2.8	1.9	2.0
Low-technology Industries	0.7	0.9	0.7	0.5	0.8	1.0	0.6	0.9	1.3	1.4	0.8	0.8	1.3	1.4	0.5	0.7

	Germany		Italy		Netherlands		Norway		Spain		Sweden		United Kingdom	
	1988	1995	1988	1995	1988	1994	1988	1995	1988	1994	1988	1994	1988	1995
Total manufacturing	6.4	6.2	2.7	2.7	6.5	4.9	4.9	4.8	1.3	1.4	8.0	10.4	5.3	5.4
Food, beverages and tobacco	0.5	0.4	0.3	0.4	2.6	2.2	1.1	1.7	0.3	0.3	2.0	1.5	0.9	0.9
Textiles, apparel and leather	0.6	1.4	0.0	0.1	0.6	0.9	0.9	2.0	0.1	0.5	1.4	1.3	0.3	0.3
Wood products and furniture	0.9	0.5	0.0	0.1	0.1	0.1	0.6	0.9	0.1	0.2	0.2	0.4	0.1	0.5
Paper, paper products and printing	0.4	0.3	0.0	0.1	0.2	0.3	0.8	1.2	0.1	0.2	1.9	1.9	0.3	0.2
Chemicals	8.3	6.6	5.2	4.4	7.9	6.8	7.6	9.5	1.6	1.4	10.5	15.6	9.4	11.1
Industrial chemicals	10.6	9.1	3.6	3.1	9.0	9.9	6.8	7.2	1.4	0.9	6.7	6.0	8.2	7.3
Pharmaceuticals	19.0	15.8	15.6	14.2	28.1	15.9	33.2	26.7	5.4	3.8	41.6	39.0	28.1	33.3
Petroleum refining	1.0	0.6	2.8	3.0	2.4	2.0	0.4	9.7	0.7	0.7	1.0	2.2	4.3	4.2
Rubber and plastics	2.8	1.9	1.5	1.1	2.7	1.7	2.8	1.7	0.8	0.7	2.5	5.1	0.8	0.9
Non-metallic mineral products	1.7	1.4	0.2	0.2	0.4	0.6	2.2	1.4	0.3	0.5	1.9	1.6	1.0	1.1
Basic metals	1.2	1.0	1.3	0.8	2.4	5.5	4.9	6.0	0.5	0.9	4.3	3.1	1.7	1.3
Ferrous metals	1.2	1.1	1.3	0.9	2.7	4.2	3.9	3.2	0.5	1.0	4.2	3.2	1.6	1.3
Non-ferrous metals	1.3	0.8	1.5	0.5	1.6	8.4	5.3	7.5	0.4	0.6	4.6	2.8	1.8	1.5
Metal products, machinery and equipment	9.5	9.8	5.3	5.6	11.5	8.0	9.8	8.0	3.1	3.4	13.1	17.7	8.7	8.0
Fabricated metals	1.7	1.4	0.6	0.6	1.1	1.0	2.9	1.1	0.7	0.7	1.6	1.9	1.0	1.6
Non-electrical machinery	7.5	6.8	2.2	2.0	2.6	2.3	5.0	5.3	1.7	2.3	11.4	9.0	3.8	4.5
Office and computing equipment	11.1	17.6	15.4	12.3	37.3	44.5	59.1	53.9	23.1	4.6	19.1	65.5	18.2	5.9
Electrical machinery	11.3	11.6	4.0	3.4	. .	. .	9.1	4.9	3.1	1.8	10.0	8.2	9.3	8.6
Radio, TV and communication equipment	18.4	14.8	16.6	25.3	12.0	7.6	31.2	48.8	10.6	13.0	34.9	67.4	15.9	13.9
Shipbuilding	3.1	3.4	3.3	13.0	0.5	0.5	4.2	3.5	1.6	13.5	5.4	3.6	1.4	2.3
Motor vehicles	10.0	13.6	8.6	10.9	11.3	17.0	6.4	5.3	1.6	2.1	15.9	19.1	9.0	9.7
Aircraft	53.4	43.4	36.2	39.1	19.8	12.5	1.2	3.6	23.3	39.8	28.3	52.0	21.4	22.1
Other transportation equipment	4.2	9.1	3.0	3.4	0.0	0.0	1.9	3.2	1.6	3.4	6.7	9.9	3.9	3.6
Scientific instruments	3.6	4.2	1.1	1.3	4.0	3.9	63.4	16.1	3.7	6.8	7.4	24.9	3.5	3.7
Other manufacturing	1.4	1.5	0.1	0.3	0.0	3.0	1.2	1.1	0.3	0.9	1.7	1.3	1.6	0.6
High-technology industries	19.9	17.9	18.8	20.3	15.6	11.0	31.3	34.1	10.5	8.2	32.7	53.4	20.3	20.4
Medium-high-technology industries	9.2	9.8	4.0	4.0	12.4	10.8	7.5	6.0	1.7	1.8	11.4	12.9	6.9	6.9
Medium-low-technology industries	1.7	1.3	0.9	0.8	1.7	1.8	3.6	3.5	0.6	0.8	2.4	2.5	1.4	1.4
Low-technology Industries	0.6	0.5	0.1	0.2	1.2	1.2	0.9	1.4	0.2	0.3	1.6	1.5	0.5	0.5

Source: OECD, STAN and ANBERD databases, April 1997.

Annex Table 4.14. **The structure of R&D efforts**

As a percentage of total business sector

	Total manufacturing industries		Share in total manufacturing								Total non-manufacturing industries	
			High-technology		Medium-high-technology		Medium-low-technology		Low-technology			
	1985	1995	1985	1995	1985	1995	1985	1995	1985	1995	1985	1995
United States[1]	92.0	80.5	62.8	48.0	27.2	41.0	7.3	7.0	2.7	4.0	8.0	19.5
Canada	71.1	60.7	58.2	70.5	17.9	13.6	16.0	9.4	7.9	6.5	28.9	39.3
Japan[1]	96.3	95.5	32.4	34.4	47.4	47.9	15.5	12.8	4.7	4.8	3.7	4.5
Australia[1]	77.1	65.5	29.7	27.4	45.3	32.3	16.7	29.8	7.9	10.6	22.9	34.5
Denmark	75.7	68.9	30.8	40.2	36.3	38.8	23.5	13.7	9.3	7.3	24.3	31.1
Finland	89.3	88.0	23.6	43.6	43.6	34.3	18.4	11.2	14.3	10.8	10.7	12.0
France[1]	92.7	88.7	56.1	51.4	31.1	36.6	10.3	8.6	2.5	3.4	7.3	11.3
Germany[2]	93.8	94.4	31.8	32.2	56.8	59.7	8.9	6.4	2.5	1.7	6.2	5.6
Ireland	93.6	90.2	48.0	45.9	21.4	22.0	9.0	10.2	21.6	21.9	6.4	9.8
Italy	90.5	85.6	48.6	49.5	39.5	39.5	10.7	8.4	1.1	2.6	9.5	14.4
Netherlands[1]	90.8	81.9	31.7	29.5	55.5	51.1	6.9	10.6	6.0	8.8	9.2	18.1
Norway	59.0	62.7	31.1	38.3	42.2	29.8	20.1	18.7	6.7	13.2	41.0	37.3
Spain[1]	83.5	78.8	39.3	41.8	37.2	35.9	17.9	15.0	5.6	7.3	16.5	21.2
Sweden[1]	88.1	87.0	38.9	48.7	46.2	40.7	8.8	5.5	6.2	5.1	11.9	13.0
United Kingdom	92.3	74.5	59.1	52.1	32.1	39.4	5.2	5.2	3.6	3.4	7.7	25.5
OECD total[1, 2, 3]	92.2	84.6	52.0	43.6	35.3	43.6	9.4	8.7	3.3	4.1	7.8	15.4

1. 1994 instead of 1995.
2. 1995 data refer to unified Germany.
3. The total only covers the countries listed in the table.

Source: OECD, ANBERD database, February 1997.

Annex Table 4.15. **Structure of services sector R&D**

As a percentage of total BERD

	Australia		Austria		Belgium		Canada		Czech Republic		Denmark		Finland		France		Germany		Greece		Hungary		Iceland		Ireland	
	1990	1995	1989	1993	1991	1995	1990	1996	1992	1996	1990	1995	1991	1995	1990	1995	1991	1993	1991	1993	1993	1996	1991	1996	1990	1995
Services sector	37.4	28.3	4.0	16.6	5.8	11.9	25.1	33.0	38.8	25.4	26.8	31.3	12.8	15.7	3.9	7.1	2.4	3.5	33.4	32.7	15.1	8.5	18.3	21.7	3.4	9.6
Wholesale and retail trade	8.9	5.5	..	1.8	1.3	0.1	3.6	6.4	..	0.3	4.9	5.0	..	0.9	..	..	..	..	1.5	0.7	0.6	0.2	..	..	..	0.0
Hotels and restaurants	..	0.0	..	0.0	0.0	..	..	..	..	0.0	..	..	..	..	..	..	..	..	..	..	0.0	0.0	..	..	..	0.0
Transport and storage	0.8	0.6	0.0	0.6	0.0	0.0	0.4	0.2	0.3	1.0	..	..	..	..	0.2	3.0	0.4	0.8	..	0.9	1.6	0.8	0.8	3.5	0.1	0.1
Communications	5.4	2.1	0.0	1.5	..	0.6	2.7	2.2	0.0	0.3	2.8	2.4	1.8	3.2	..	..	..	..	1.3	0.2	1.8	5.1	0.0	..	1.5	3.2
Post	..	..	..	0.0	..	..	..	..	0.0	0.1	..	..	..	..	..	..	..	..	..	..	0.0	0.0	..	..	..	0.0
Telecommunications	..	..	..	1.5	..	..	..	..	0.0	0.2	..	..	..	..	..	..	..	..	1.3	0.2	1.8	5.1	..	..	..	3.2
Financial intermediation	6.5	2.7	..	1.4	..	0.2	4.3	5.7	0.0	0.0	..	..	..	..	..	..	..	..	1.7	0.9	..	0.0	..	..	..	0.9
Real estate, renting, business services	15.3	17.1	4.0	8.6	..	10.9	14.1	18.6	38.5	23.9	19.2	23.8	..	10.7	3.7	4.1	1.9	..	28.6	29.8	11.0	2.3	17.5	18.1	..	5.4
Computer and related activities	5.9	8.1	..	2.4	..	6.5	4.4	6.4	0.2	0.3	3.8	7.6	..	2.9	..	2.5	..	..	23.0	22.7	0.5	1.0	..	17.7	..	4.5
Software consultancy	..	7.7	..	1.7	..	4.4	..	..	0.0	0.2	..	..	..	..	..	..	..	..	23.0	22.7	0.0	0.2	..	13.1	..	4.2
Other computer services	..	0.4	..	0.7	..	2.1	..	..	0.2	0.1	..	..	..	..	..	..	..	..	0.0	0.0	0.5	0.8	..	4.6	..	0.3
R&D	3.1	3.5	3.9	6.0	..	0.8	8.0	9.2	29.1	21.6	..	3.0	2.7	2.5	..	..	1.3	1.5	4.3	4.5	9.1	1.2	17.5	0.4	0.6	0.3
Other business activities	6.3	5.5	0.1	0.1	..	3.7	1.8	3.0	9.2	2.0	15.4	13.2	..	5.4	..	1.6	0.7	1.2	1.3	2.6	1.3	0.0	..	..	..	0.6
Community, social and personal services	0.6	0.4	0.0	2.8	..	0.0	..	..	0.0	0.0	..	..	..	0.8	..	..	..	..	0.3	0.2	0.0	0.2	..	0.2	..	0.0

	Italy		Japan		Korea	Mexico		Netherlands		New Zeland		Poland	Portugal		Spain		Sweden		Turkey		United Kingdom		United States	
	1990	1996	1990	1995	1995	1993	1995	1990	1995	1990	1995	1995	1990	1995	1990	1995	1991	1995	1990	1995	1990	1995	1990	1994
Services sector	7.4	12.7	2.8	3.0	6.3	7.8	32.5	6.3	12.3	32.6	25.2	15.4	27.2	22.9	14.5	12.9	3.7	15.5	1.3	3.4	17.3	21.9	18.7	23.8
Wholesale and retail trade	..	0.3	..	..	0.0	1.5	..	..	3.7	4.1	5.8	..	..	0.2	0.1	0.1	..	1.1	0.1	0.0	0.0	0.1	..	..
Hotels and restaurants	..	..	..	..	0.0	0.0	..	..	..	0.0	..	0.0	..	..	0.0	0.0	..	..	0.0	0.0	..	..	..	..
Transport and storage	0.0	0.2	0.2	0.2	..	0.0	0.1	..	2.7	0.7	0.1	..	0.7	1.3	0.1	..	..	0.2	0.6	0.0	0.1	0.2	..	..
Communications	0.2	3.3	2.6	2.8	..	0.0	0.3	..	..	1.2	..	3.0	11.0	13.4	2.6	3.9	..	2.4	0.5	1.0	4.1	4.4	..	..
Post	..	0.2	..	..	0.0	0.0	0.0	..	..	0.0	..	0.0	..	..	..	0.0	..	..	0.0	0.0	..	..	..	..
Telecommunications	..	3.0	..	..	..	0.0	0.3	..	..	..	..	..	..	..	..	3.9	..	..	0.5	1.0	..	..	..	..
Financial intermediation	..	..	..	..	0.0	0.0	0.0	..	0.3	2.8	0.1	0.0	..	1.1	0.0	..	..	..	0.0	..	..	..	..	..
Real estate, renting, business services	7.0	8.7	..	..	0.0	4.7	26.4	..	5.6	20.2	17.9	5.5	14.9	6.8	11.4	8.4	..	11.6	0.0	2.3	12.9	17.2	..	..
Computer and related activities	1.6	1.2	..	..	..	0.0	1.6	..	..	10.3	6.6	0.4	..	..	1.0	3.1	..	2.0	0.0	2.3	5.2	7.2	..	6.6
Software consultancy	..	1.0	..	..	..	0.0	1.6	..	..	9.1	6.3	0.0	..	..	..	2.7	..	..	0.0	2.3	..	..	..	..
Other computer services	..	0.2	..	..	..	0.0	..	..	..	1.2	0.3	..	..	..	..	0.4	..	..	0.0	..	..	..	..	..
R&D	5.4	6.6	..	..	..	4.7	24.8	..	0.8	4.2	5.3	5.1	..	2.9	4.4	0.2	..	7.5	..	..	7.5	10.0	..	3.1
Other business activities	..	0.9	..	..	1.3	0.0	..	..	4.7	5.6	5.9	0.0	..	3.9	5.9	5.1	..	2.0	0.0	0.0	0.1	..	..	..
Community, social and personal services	0.2	0.2	..	..	0.0	1.6	5.7	4.4	..	3.7	0.8	5.0	..	0.1	0.4	0.5	..	0.2	0.0	0.0	0.2	0.1	..	..

Source: OECD, S&T database, January 1998.

Annex Table 4.16. **Technology balance of payments in OECD countries, 1995**[1]

	Millions of US$[2]			Ratio	
	Receipts (x)	Payments (m)	Balance (x-m)	(x/m)	m/BERD[3]
United States	22 436	5 666	16 770	3.96	0.06
Canada	1 394	1 094	300	1.27	0.18
	289	1 189	–901	0.24	2.65
Japan	3 180	2 216	964	1.43	0.04
Australia	169	325	–157	0.52	0.10
New Zealand	20	8	12	2.48	0.05
Austria	96	381	–286	0.25	. .
Belgium	2 336	2 411	–75	0.97	1.09
Finland	43	307	–264	0.14	0.23
France	2 012	2 792	–779	0.72	0.17
Germany	7 290	9 207	–1 917	0.79	0.34
Italy	1 237	1 601	–364	0.77	0.22
Netherlands	6 208	6 139	69	1.01	1.85
Norway	121	183	–61	0.67	0.19
Spain	80	1 106	–1 026	0.07	0.49
Sweden	397	45	353	8.89	0.01
United Kingdom	3 990	3 339	651	1.19	0.24
European Union[4]	23 811	27 511	–3 699	0.87	0.26
Total OECD	51 298	38 009	13 289	1.35	0.15

1. Or nearest year.
2. At current exchange rates.
3. BERD = business enterprise R&D expenditure.
4. Including intra-zone flows.

Source: OECD, S&T database, December 1997.

Annex Table 4.17. **Resident and external patent applications in OECD countries**

Compound annual growth rates

	Resident patent applications			External patent applications		
	1980-85	1986-90	1991-95	1980-85	1986-90	1991-95
United States	0.5	8.6	9.0	5.2	16.1	27.2
Canada	3.2	4.2	2.6	7.0	28.4	27.0
Mexico	..	..	–8.1[1]	..	..	21.6[1]
Japan	10.6	3.5	–0.1	10.3	14.8	3.9
Korea	..	..	54.8[1]	..	..	32.8[1]
Australia	0.7	1.4	2.6	16.6	14.9	32.6
New Zealand	–2.6	–4.3	7.3	1.9	–4.2	129.7
Austria	0.1	–2.2	–4.4	6.3	8.3	19.7
Belgium	–1.2	–1.7	4.0	4.2	11.4	22.7
Czech Republic	..	..	–34.0[1]	..	..	–1.5[1]
Denmark	–2.3	7.7	3.6	9.3	20.2	28.0
Finland	5.0	4.1	–0.6	15.6	24.3	35.1
France	1.9	1.0	–0.3	2.2	13.4	11.8
Germany	1.4	–1.4	4.1	2.6	11.6	12.8
Greece	–3.0	–24.9	5.6[1]	4.4	57.5	10.7
Hungary	..	..	–9.5[1]	..	..	25.4[1]
Iceland	2.0	–12.5	–13.5	..	..	–7.3
Ireland	13.0	–0.3	2.1	3.3	23.2	43.4
Italy	..	..	2.5[2]	5.7	10.9	11.1
Luxembourg	–2.8	–18.9	–3.4[3]	–6.7	1.6	15.6
Netherlands	2.0	5.2	7.1	2.1	15.5	20.9
Norway	5.2	–0.1	4.1	12.0	31.0	30.5
Poland	..	..	–1.2[4]	..	..	28.5[4]
Portugal	–1.6	7.0	–5.3	56.2	–8.7	54.3
Spain	2.8	8.1	–1.3	2.3	21.2	15.6
Sweden	–1.2	–3.8	5.7	6.0	12.3	30.7
Switzerland	–3.3	–0.2	0.3	1.7	8.9	14.1
Turkey	–0.3	–5.6	8.6	..	..	–18.0
United Kingdom	0.1	–0.9	–0.8	8.0	17.1	24.0
North America	0.5	8.5	8.9	4.7	17.5	27.9
European Union	1.0	–0.4	1.9	4.6	13.6	27.6
Total OECD	5.8	3.6	2.0	5.5	14.7	21.1

1. 1992-95.
2. 1992-94.
3. 1991-94.
4. 1993-95.

Source: OECD, S&T database, February 1998.

Annex Table 4.18. **OECD countries' shares in patents delivered by the United States, by product group**

	Industrial chemicals		Pharmaceuticals		Non-electrical machinery		Office and computing equipment		Electrical machinery		Radio, TV and communication equip.		Motor vehicles		Aircraft		Professional goods	
	1985	1996	1985	1996	1985	1996	1985	1996	1985	1996	1985	1996	1985	1996	1985	1996	1985	1996
United States	54.9	52.8	49.9	61.1	53.0	56.4	48.8	57.5	54.9	56.5	54.8	49.8	42.4	54.4	43.9	50.6	54.9	58.2
Canada	1.1	1.7	1.3	2.6	2.2	2.8	0.8	0.9	1.8	1.7	1.6	1.4	1.7	1.9	1.2	1.7	1.6	1.8
Mexico	0.0	0.1	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
Japan	15.4	16.8	15.5	11.3	14.4	15.4	34.4	31.7	19.6	23.4	24.2	33.2	30.0	21.7	28.1	21.6	22.9	25.0
Korea	0.1	0.7	0.1	0.6	0.0	1.0	0.0	1.6	0.1	1.1	0.0	3.5	0.0	1.3	0.1	0.9	0.0	1.0
Australia	0.3	0.3	0.3	0.8	0.7	0.7	0.1	0.1	0.4	0.3	0.2	0.1	0.6	0.7	0.5	0.7	0.4	0.4
New Zealand	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Austria	0.3	0.3	0.2	0.5	0.8	0.7	0.1	0.1	0.5	0.2	0.1	0.1	0.5	0.3	0.3	0.4	0.3	0.2
Belgium	0.4	1.0	0.6	0.8	0.4	0.4	0.3	0.1	0.2	0.3	0.4	0.3	0.1	0.0	0.2	0.1	0.3	0.5
Czech Republic	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0
Denmark	0.3	0.4	0.4	0.9	0.4	0.4	0.1	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.3	0.2
Finland	0.1	0.4	0.3	0.5	0.6	0.8	0.1	0.1	0.3	0.4	0.1	0.5	0.3	0.1	0.1	0.2	0.2	0.3
France	4.0	4.4	5.3	4.3	3.3	2.5	2.5	1.8	3.6	2.8	3.9	2.4	3.5	1.9	5.7	5.0	2.7	1.9
Germany	11.9	11.6	9.6	5.8	12.5	10.4	6.0	2.3	9.3	6.9	6.7	3.2	13.1	12.9	11.0	11.9	8.3	4.6
Greece	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hungary	0.4	0.2	1.1	0.3	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.0
Iceland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Italy	1.7	2.0	3.1	2.1	2.0	1.9	1.0	0.3	1.1	1.1	0.7	0.8	1.2	0.7	1.3	0.6	0.8	0.6
Luxembourg	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	0.9	0.8	0.6	0.6	1.0	0.8	0.9	0.5	1.3	1.0	2.1	1.2	0.4	0.4	0.3	0.4	1.0	0.6
Norway	0.1	0.1	0.1	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.2
Poland	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Portugal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spain	0.1	0.3	0.3	0.3	0.2	0.2	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.3	0.1	0.1
Sweden	0.5	0.6	0.9	0.9	1.9	1.1	0.8	0.4	1.2	0.8	0.7	0.9	1.6	0.9	1.4	0.8	1.0	0.7
Switzerland	2.9	2.0	2.8	1.4	2.2	1.8	1.1	0.4	1.7	1.1	0.9	0.4	0.8	0.3	0.5	0.9	1.7	1.1
Turkey	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
United Kingdom	4.2	3.4	7.3	4.6	3.7	2.3	2.6	1.8	3.5	1.9	3.1	2.1	3.2	1.8	5.0	3.6	3.2	2.2
European Union	24.5	25.2	28.7	21.2	27.0	21.5	14.6	7.7	21.3	15.7	17.9	11.5	24.2	19.5	25.5	23.6	18.2	12.0
Total OECD	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: CHI Research and OECD, February 1998.

Annex Table 4.19. **Imported technology by source country**[1]

Technology embodied in goods imported from different countries, percentage, 1993

	United States	Japan	Germany	France	United Kingdom	Italy	Canada	Australia	Denmark	Netherlands
From:										
United States		50.6	13.9	26.3	15.1	9.5	71.4	33.5	10.2	11.0
Canada	9.9	0.9	0.5	0.7	1.0	0.5		1.0	0.2	0.8
Mexico	5.5	0.4	0.2	0.1	0.1	0.1	1.4	0.2	0.0	0.1
Japan	31.0		10.4	7.4	7.8	4.2	8.7	24.0	7.0	5.6
Korea	4.2	5.3	1.1	0.7	0.9	0.6	1.5	1.7	0.6	0.5
Australia	0.5	1.1	0.2	0.1	0.4	0.1	0.2		0.1	0.1
New Zealand	0.1	0.3	0.0	0.0	0.1	0.0	0.0	1.5	0.0	0.0
Austria	0.2	0.4	3.8	0.9	0.6	1.8	0.2	0.3	1.1	1.0
Belgium-Luxembourg	0.8	0.9	6.4	5.1	3.8	5.7	0.3	0.8	4.3	11.3
Denmark	0.4	0.7	1.4	0.5	1.1	0.5	0.2	0.6		1.0
Finland	0.2	0.1	0.5	0.4	0.6	0.3	0.1	0.3	2.4	0.5
France	5.2	3.2	18.7		9.0	17.4	2.5	2.4	6.5	7.8
Germany	8.2	9.5		21.9	17.0	25.6	2.7	7.1	24.0	25.1
Greece	0.0	0.0	0.1	0.1	0.2	0.3	0.0	0.0	0.1	0.1
Ireland	0.6	0.7	1.4	1.1	3.5	1.2	0.3	0.5	1.7	1.5
Italy	1.3	0.9	4.1	5.4	3.0		0.4	1.1	2.3	1.8
Netherlands	0.8	0.6	7.0	3.0	6.1	5.4	0.3	1.0	5.0	
Portugal	0.1	0.0	0.6	0.7	0.4	0.2	0.0	0.0	0.4	0.4
Spain	0.5	0.2	2.1	3.8	1.5	2.8	0.2	0.2	0.8	1.2
Sweden	1.3	1.1	1.7	1.3	2.2	1.5	0.7	2.1	9.0	2.1
United Kingdom	4.7	3.5	8.2	6.8		7.6	1.7	7.2	8.9	7.9
Norway	0.2	0.2	0.5	0.3	0.6	0.2	0.1	0.2	3.4	0.5
Switzerland	1.2	3.3	4.6	3.1	1.9	5.8	0.6	1.6	3.4	1.8
Turkey	0.1	0.1	0.3	0.1	0.2	0.4	0.0	0.0	0.1	0.1
China	2.0	2.3	1.0	0.7	0.3	0.6	0.5	1.1	0.7	0.3
Chinese Taipei	5.0	4.2	1.6	1.2	1.2	0.9	1.4	3.1	1.0	1.2
Hong Kong (China)	1.7	1.0	1.0	0.3	1.3	0.2	0.6	1.3	0.4	0.8
Malaysia	2.0	1.0	0.5	0.3	1.0	0.1	0.4	0.6	0.2	0.2
Singapore	4.3	2.1	1.2	1.0	1.4	0.8	0.8	1.9	0.5	1.1
Thailand	1.1	1.4	0.3	0.2	0.3	0.1	0.2	0.3	0.1	0.1
Rest of world	7.0	4.0	6.5	3.6	4.0	5.8	1.1	3.4	4.6	3.4
Secret/unspecified	0.0	0.0	0.0	3.4	12.9	0.2	1.6	0.0	0.8	10.3

1. Numbers may not add to 100.

Source: OECD, calculations from Input-Output and ANBERD databases, December 1997.

Annex Table 4.20. **Specialisation patterns in science by selected scientific fields, 1981-89 and 1991-93**

1981-89	USA	UK	GER	FRA	ITA	OSE	NDC	OWE	JPN	CAN	ECE	ANZ	CSA	NIE
Clinical medicine	106	116	88	89	108	62	153	115	77	84	48	48	89	97
Biomedical research	107	98	93	101	87	102	98	98	90	99	99	99	52	82
Biology	103	104	77	67	46	80	77	80	87	178	73	73	114	228
Chemistry	68	85	141	134	135	207	59	98	162	83	246	246	138	76
Physics	90	78	126	137	130	119	62	110	129	77	140	140	66	58
Earth and space sciences	121	101	70	93	85	82	71	76	42	148	51	51	114	152
Engineering and technology	110	96	105	68	67	87	52	66	137	110	81	81	222	72
Mathematics	108	82	110	126	95	132	61	87	60	116	137	137	150	83
1991-93	**USA**	**UK**	**GER**	**FRA**	**ITA**	**OSE**	**NDC**	**OWE**	**JPN**	**CAN**	**ECE**	**ANZ**	**CSA**	**NIE**
Clinical medicine	105	122	86	87	111	72	141	117	89	87	40	40	109	102
Biomedical research	110	97	88	103	85	90	98	102	91	99	95	95	38	86
Biology	101	92	72	70	51	113	99	82	85	184	62	62	118	247
Chemistry	73	86	143	131	116	174	63	97	136	75	248	248	122	70
Physics	89	74	134	123	120	109	66	100	133	76	154	154	65	54
Earth and space sciences	119	99	70	93	95	104	89	78	43	156	67	67	110	142
Engineering and technology	104	90	106	85	75	94	61	67	119	115	95	95	234	65
Mathematics	115	79	98	128	111	121	57	91	47	108	142	142	91	79
Differences between periods	**USA**	**UK**	**GER**	**FRA**	**ITA**	**OSE**	**NDC**	**OWE**	**JPN**	**CAN**	**ECE**	**ANZ**	**CSA**	**NIE**
Clinical medicine	–1.0	6.8	–2.2	–2.0	3.2	9.3	–12.3	1.5	11.4	2.6	–8.6	–8.6	19.8	4.9
Biomedical research	2.8	–0.1	–4.3	1.4	–2.0	–11.9	0.3	3.9	1.2	0.6	–4.8	–4.8	–13.5	4.1
Biology	–1.9	–11.7	–4.7	2.5	4.3	32.4	21.9	2.2	–2.0	6.9	–11.2	–11.2	4.1	19.1
Chemistry	5.4	0.6	2.5	–2.6	–18.9	–33.0	4.8	–1.2	–26.7	–7.8	2.0	2.0	–15.7	–5.8
Physics	–1.0	–4.3	8.3	–13.8	–10.0	–10.0	3.9	–10.0	3.4	–1.7	14.1	14.1	–1.3	–3.3
Earth and space sciences	–1.9	–1.7	–0.3	0.6	10.1	21.6	17.9	1.3	1.8	8.0	15.3	15.3	–4.1	–10.1
Engineering and technology	–5.9	–5.2	0.7	17.3	8.1	6.3	8.3	0.9	–18.2	5.2	14.8	14.8	11.1	–7.2
Mathematics	7.2	–3.0	–12.5	1.8	15.2	–10.3	–4.4	4.1	–13.4	–7.9	5.4	5.4	–59.2	–3.4
Correlation between periods	**USA**	**UK**	**GER**	**FRA**	**ITA**	**OSE**	**NDC**	**OWE**	**JPN**	**CAN**	**ECE**	**ANZ**	**CSA**	**NIE**
	0.965	0.939	0.978	0.963	0.937	0.924	0.945	0.966	0.956	0.992	0.987	0.987	0.908	0.993

OSE: Other South European countries.
NDC: Nordic countries.
OWE: Other West European countries.
ECE: Eastern and Central Europe.
ANZ: Australia and New Zealand.
CSA: Central and South America.
NIE: Newly Industrialising Asian countries.

For a given country (region) and field, this indicator is defined as the share of publications in that scientific field in relation to the total number of publications by that country (region), divided by the share of that field in total world publications X 100. Values greater than 100 indicate relative specialisation.

Source: National Science Foundation, *Science and Engineering Indicators 1996,* OECD calculations.

Annex Table 4.21. **Patterns of international collaboration in science and engineering research, 1981-87 and 1988-93**

Number of scientific articles and shares in percentage

Source country/region	Total	Share of multi-authored (%)	Internationally co-authored (%)	Internationally co-authored Total	Share of all articles	Share of total international co-authored	Degree of internationalisation[1]
				1981-87			
United States	987 214	46	9	88 849	34.7	23.3	0.67
United Kingdom	237 354	36	15	35 603	8.3	9.3	1.12
Germany	203 442	36	17	34 585	7.1	9.1	1.27
France	142 584	48	19	27 091	5.0	7.1	1.42
Italy	68 779	58	21	14 444	2.4	3.8	1.57
Other Southern Europe	44 016	42	20	8 803	1.5	2.3	1.49
Nordic countries	111 023	54	21	23 315	3.9	6.1	1.57
Other Western Europe	142 063	45	24	34 095	5.0	8.9	1.79
Japan	199 707	35	7	13 979	7.0	3.7	0.52
Canada	122 262	44	19	23 230	4.3	6.1	1.42
Former USSR	210 786	16	3	6 324	7.4	1.7	0.22
Other Eastern/Central Europe	78 696	37	19	14 952	2.8	3.9	1.42
Israel	32 054	56	25	8 014	1.1	2.1	1.87
Other Middle East	7 835	43	28	2 194	0.3	0.6	2.09
Africa	38 357	46	24	9 206	1.3	2.4	1.79
Australia, New Zealand	74 342	36	15	11 151	2.6	2.9	1.12
India	73 982	21	7	5 179	2.6	1.4	0.52
South and Central America	37 553	48	27	10 139	1.3	2.7	2.02
China	14 734	38	24	3 536	0.5	0.9	1.79
East Asian NIEs	10 109	43	25	2 527	0.4	0.7	1.87
Other Asia/Pacific	10 975	51	38	4 171	0.4	1.1	2.84
Total	2 847 867	42	19	381 387	100	100	1.00
				1988-93			
United States	908 125	53	14	127 138	33.1	22.6	0.69
United Kingdom	210 685	47	22	46 351	7.7	8.3	1.08
Germany	192 629	46	26	50 084	7.0	8.9	1.27
France	142 805	58	28	39 985	5.2	7.1	1.37
Italy	79 833	67	29	23 152	2.9	4.1	1.42
Other Southern Europe	66 741	52	29	19 355	2.4	3.4	1.42
Nordic countries	105 636	62	31	32 747	3.8	5.8	1.52
Other Western Europe	146 424	57	34	49 784	5.3	8.9	1.66
Japan	219 280	46	11	24 121	8.0	4.3	0.54
Canada	120 454	53	25	30 114	4.4	5.4	1.22
Former USSR	172 854	21	8	13 828	6.3	2.5	0.39
Other Eastern/Central Europe	66 296	50	33	21 878	2.4	3.9	1.61
Israel	28 957	64	33	9 556	1.1	1.7	1.61
Other Middle East	10 528	46	28	2 948	0.4	0.5	1.37
Africa	36 851	56	34	12 529	1.3	2.2	1.66
Australia, New Zealand	69 393	47	22	15 266	2.5	2.7	1.08
India	52 336	29	11	5 757	1.9	1.0	0.54
South and Central America	42 967	58	36	15 468	1.6	2.8	1.76
China	30 437	49	27	8 218	1.1	1.5	1.32
East Asian NIE[2]	29 846	50	23	6 865	1.1	1.2	1.13
Other Asia/Pacific	14 499	61	44	6 380	0.5	1.1	2.15
Total	2 747 576	51	26	561 522	100.0	100.0	1.00

1. Share of internationally co-authored/share of all articles.
2. NIE = newly industrialised economies.

Source: National Science Foundation, *Science and Engineering Indicators 1996,* OECD calculations.

Annex Table 4.22. **Technological performance indicators for US patents granted to inventors from other countries, 1985-95**

	Number granted[1]	Science linkage[2]	Technology cycle time[1]	Current impact index[2]	Technological strength[1]	Technological strength per 1 000 inhabitants, 1995	Technological intensity, 1995
United States	710 142	0.9	10.9	1.1	752 751	28.6	10.4
Canada	25 035	0.6	12.9	0.8	20 779	7.0	3.3
Mexico	644	0.6	15.1	0.5	335	0.0	0.0
Japan	250 079	0.3	6.9	1.2	290 092	23.1	10.6
Korea	4 568	0.2	6.9	0.8	3 837	0.9	0.7
Austria	5 149	0.3	11.1	0.6	3 193	3.1	1.5
Belgium	4 711	0.5	10.1	0.8	3 769	7.2	3.2
Denmark	2 791	0.9	12.0	0.7	1 870	3.7	2.0
Finland	3 773	0.4	11.5	0.7	2 453	0.3	0.1
France	41 073	0.4	10.2	0.8	31 215	30.5	38.9
Germany	109 086	0.3	10.0	0.8	82 905	103.0	50.0
Hungary	1 522	0.7	10.9	0.4	578	1.6	1.0
Ireland	630	0.8	10.8	1.0	599	0.1	0.1
Italy	16 638	0.3	11.0	0.7	11 314	273.9	88.2
Luxembourg	413	0.1	11.1	0.7	268	0.2	0.1
Netherlands	12 908	0.5	9.4	0.8	10 842	10.9	8.8
Portugal	72	0.3	14.6	0.8	60	0.0	0.0
Spain	1 723	0.5	13.0	0.6	999	0.2	0.1
Sweden	12 182	0.4	12.0	0.7	8 771	1.5	0.8
United Kingdom	39 738	0.6	10.2	0.9	33 777	38.2	20.4

1. 1980-95.
2. 1985-95.

Science linkage is calculated as the number of references to scientific literature indicated on the front pages of the patent.
Technology cycle time measures the median age of the patents cited as prior articles.
The current impact index is a measure of how frequently a country's recent patents are cited by all of a current year's patents. This normalised indicator has an expected value of 1.0.
Technological strength is determined by multiplying the number of patents by the current impact index.
Technological intensity = technological strength/1995 GDP (converted using PPP$) × 10 000.
Source: OECD calculations based on CHI Research TP-2 database; OECD, *Labour Force Statistics;* and *OECD Economic Outlook 62.*

Annex Table 4.23. **Venture capital in the United States and Europe by stage of investment and industry, 1992-96**

	United States (millions of US$)					Europe (millions of ECU)				
	1992	1993	1994	1995	1996	1992	1993	1994	1995	1996
Stage of investment										
Seed/start-up	496	657	751	1 111	1 135	278	200	310	321	441
Expansion	3 324	2 055	3 426	4 010	6 373	2 151	1 888	2 294	2 299	2 650
Acquisition/buy-out	1 108	1 319	979	1 821	1 906	1 870	1 680	2 401	2 572	3 007
Replacement	16	6	111	219	8	403	346	434	354	653
Industry										
Computer-related	1 008	1 543	1 072	1 951	3 004	181	246	236	391	337
Communications	1 069	614	832	1 322	1 325	184	51	130	263	298
Consumer-related	378	752	973	780	1 257	913	997	907	1 253	1 231
Medical/health	901	701	970	1 023	1 191	190	187	202	304	242
Biotechnology	473	543	489	412	645	62	58	73	118	181
Semiconductors and other electronics	268	176	260	413	476	136	148	203	248	272
Business services	74	114	90	326	392	517	366	549	422	806
Industrial products	305	125	149	279	373	847	790	1 256	866	1 372
Manufacturing	139	65	47	181	267	650	376	757	522	655
Finance, insurance and real estate	81	598	249	175	198	265	179	190	148	431
Energy	28	21	49	59	161	173	36	48	112	74
Construction	75	1	43	124	85	194	222	187	269	255
Agriculture and forestry	23	6	17	4	29	57	64	178	126	107
Transportation	116	36	26	94	18	140	211	325	353	197
Utilities	5	11	0	8	0	..	..	..	..	..
Others	0	5	1	12	0	191	186	198	151	293
Total	**4 943**	**4 036**	**5 267**	**7 161**	**9 421**	**4 701**	**4 115**	**5 440**	**5 546**	**6 752**

Note: Figures for the United States and Europe are not strictly comparable. In particular, the US definition of buy-outs is narrower than the European one.
Source: *EVCA Yearbook* (1997), *Venture Economics Yearbook* (1997).

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