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TECHNOLOGY DIFFUSION, PRODUCTIVITY AND INTERNATIONAL COMPETITIVENESS: AN EMPIRICAL ANALYSIS

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EXECUTIVE SUMMARY

Technology plays a major role in productivity growth and in shaping international competitiveness. Its potential economic gains are realised, however, as much from the widespread diffusion of new products and processes as from their initial development. Economy-wide productivity gains from the development of the computer, for example, came not so much from the higher productivity of the computer industry itself as from productivity gains in the manufacturing and services industries that bought computers.

It is thus essential to understand the patterns of technology generation and diffusion when measuring the importance of technology for productivity, employment, and competitiveness. This report presents some results on patterns of technology diffusion in OECD countries and develops a number of measures of equipment-embodied technology diffusion. These measures are then used to analyse the determinants of productivity growth and competitiveness at the industry level, with more specific focus on the role of technology development and diffusion.

The methodology used makes it possible to examine a number of analytical issues, and to draw implications for policy. The main analytical results are presented below.

Technology diffusion

Supply and demand of technology. Innovations are developed mainly in a cluster of high-technology manufacturing industries, and a cluster of services industries are the main acquirers of technologically sophisticated machinery and equipment. R&D performance is more concentrated (the top five industries account for between 60 and 80 per cent of the total) than technology use (the top five user industries account in most countries for 40 to 50 per cent of the total). The use of technology in many service industries is greater than what their (large) weight in the economy might suggest. The part of embodied technology acquired externally has increased over time, partly because of more extensive sourcing of high-technology goods.

Reinterpreting technology intensity. Simple indicators of R&D intensity are an imperfect measure of the technological sophistication of industries; more appropriate are indicators at sectoral level that combine both performed R&D and externally acquired technology. The spread between high-, medium- and low-technology (HT, MT, LT) industries diminishes when technologically sophisticated inputs are taken into account. When acquired technology is included, the technology intensity of small countries increases significantly; big increases also appear in the technology intensity of medium-technology industries in Japan, Germany, Canada, and the Netherlands; the overall total technology intensity for Japan overtakes that of the US.

The role of capital inputs in technology diffusion. For every country, the share of technology obtained through capital investment is less than 50 per cent of total acquired technology (but this is probably an underestimate); the United States leads in the diffusion of technology through capital investment. The industries most dependent on investment-based technology acquisition are in services (finance and insurance, social and personal, communication services); those least dependent are in high-technology manufacturing.

Technology acquisition through imports. Bigger countries source less technology from abroad than smaller ones, which depend on imports for more than 50 per cent of their acquired technology; the share of technology obtained through imports has increased over time for all countries except Japan. The United States is the most important source of technology for all countries (especially for computers and aerospace); for the United States, the DAEs and Japan are the most important source of technology acquired through imports.

Technology clusters. In most countries, the bulk of acquired technology comes from the information technology (IT) cluster of industries; the materials technology cluster (chemicals, basic metals, rubber, plastics) is important in Japan, Germany, Italy, and Denmark. The importance of IT has increased over time; it is the fastest-growing technology cluster. Certain types of technology tend to gravitate towards certain sectors: information technology to HT manufacturing, communication services, and finance, insurance and real estate; transportation technology to transportation services; consumer goods technology to wholesale and retail trade; materials technology to agriculture and MT and LT manufacturing; fabrication technology to mining, utilities, and construction.

Productivity

Productivity patterns. In most countries, and notably in the United States, productivity growth recovered somewhat in the 1980s, with total factor productivity (TFP) increasingly important for explaining GDP growth in the private business sector. Sectoral TFP growth showed different movements in manufacturing and services in the 1970s and 1980s, increasing in manufacturing but decreasing in services. At a detailed sectoral level and in every country, higher TFP growth occurred in most sectors classified in the ICT industry group (computers and communication services, etc.), but some traditional scale-intensive, low-technology manufacturing sectors also appeared in the top ten industries in TFP performance.

Diffusion and services productivity. Embodied R&D has a significant positive impact on TFP growth in the services sector. On average, across ten OECD countries, the estimated rate of return of embodied R&D on TFP growth in services was 130 per cent in the 1970s and 190 per cent in the 1980s. The principal sources of these diffusion-based productivity gains were investment in equipment for R&D-intensive products and foreign procurement through imports. The relation between capital investment and productivity growth in services gives one of the most robust results in the analysis: the rate of return of capital-embodied R&D exceeds 200 per cent in the 1980s.

Country-specific results. In the 1970s, the highest rate of return for direct R&D was registered by Japan (40 per cent), but in the 1980s, it shrank by almost half. It improved for the United States in the 1980s, and was at the same level for both countries over the last decade. For the 1980s, the highest rate of return was registered in Italy (50 per cent). Canada is also one of the few countries whose rate of return showed an increase in the 1980s to stand at 10 percentage points above that of Japan and the United States. The estimated rate of return of embodied R&D for the services sector also varied across countries and periods. For the 1980s, it was relatively high in the United Kingdom (430 per cent), Canada (320 per cent), and France (300 per cent).

Machinery and ICT services. Direct R&D was significantly positive for the machinery sector and embodied R&D for the ICT services sector, but no significant relationships between R&D and productivity were obtained for other industrial groups. The estimated rate of return of direct R&D for the machinery sector declined over time and stood at around 20 per cent in the 1980s. The social rate of return for embodied R&D for the ICT services sector was generally stable at around 150 per cent in the 1980s. Among the sources of embodied R&D, the rate of return of imported R&D is three times that of domestic R&D, and, for the ICT services sector, capital investment is an important source of productivity.

Contribution of technology to TFP growth. For each country, direct R&D's contribution to TFP growth was stable for the machinery sector over the two periods; in the 1980s, its impact was slightly greater in several countries. On average across all countries, the impact of R&D is estimated at around 0.7 percentage point in both periods. For the ICT services sector, the average impact of domestic R&D is lower than that of imported R&D in both periods (0.3 vs. 0.5 in the 1980s). However, domestic R&D was more important than imported R&D in the United States, Japan and Germany. Imported R&D dominated in Denmark, Australia, the Netherlands, and Canada. The impact of domestic R&D increased in the 1980s in every country except the United Kingdom and France, most notably in the United States and Japan, perhaps owing to more linkages with domestic ICT manufacturers. In contrast, the impact of imported R&D decreased in the 1980s in most countries except the United Kingdom and the United States, despite rapid growth in high-technology trade.

R&D potency over time. The results point to some decline in the coefficient of direct R&D in manufacturing in the 1980s. At the same time, however, the impact of R&D spillovers into services seems to be increasing. Considering the importance of services in the economy and the increasing impact of technology diffusion on the ICT services group, the growing economy-wide benefits of manufacturing R&D activities through domestic and international diffusion should be emphasised.

Competitiveness

Changing composition of world trade. There have been significant changes in the structure of international trade since the 1970s. The share of OECD countries in world merchandise trade has grown, and trade has increasingly involved manufactured goods, mainly for two-way trade in similar products (intra-industry trade). Non-OECD Asian countries have achieved gains of one- to two-fold in manufacturing classes, and Japan has gained about 3 percentage points in machinery and transport equipment. The recent period is characterised by increasing intra-industry and intra-firm components in total trade, a phenomenon that is at odds with the product specialisation hypothesis of traditional trade theory.

Rising importance of high-tech trade. In 1992, exports from high-technology industries constituted about a quarter of manufactured exports from OECD countries, a share that has increased by 10 percentage points since 1970, largely at the expense of low-technology products. The bulk of the changes took place during the 1980s. Individual high-technology products making the most notable gains were computers and semiconductors, two out of only four products whose market shares more than doubled since 1980. Other high-technology products with relatively important gains in market shares since 1980 were telecommunications equipment, pharmaceuticals, scientific instruments, and aircraft.

Increased exposure to international competition. Although there were large differences among countries, import penetration in the manufacturing sector increased in every country, most strongly by far in Spain and in the United States. In France, Germany, and the United Kingdom, high-technology and science-based industries are the most import-intensive groupings. In Italy, import penetration is the lowest of the four large European countries and has barely increased since 1980. There is a great deal of variance among industries, with import penetration tending to be relatively high in instruments, computers and communications equipment, and particularly low in wood products and non-metallic minerals.

Shifts in export specialisation. Of the larger OECD countries, the United States is relatively specialised in high-technology and science-based exports, even if that specialisation pattern has weakened somewhat since 1980. Japan's export specialisation has evolved the most, with a strong movement out of low-technology, labour-intensive exports and towards high- and medium-technology exports or exports of industries characterised by scale economies and the production of differentiated products. Between 1970 and 1992, the weak specialisation in high-technology, high-wage industries in the EU countries has weakened further, while an already strong specialisation in low-technology, low-wage, labour-intensive industries has strengthened.

Performance in export markets. Germany has consistently had the highest overall manufacturing export market share since 1980, largely owing to successful exports by its medium- and low-technology industries. As the weight of these industries in total OECD manufacturing exports is declining, however, it will have difficulty in sustaining this performance in the future. The United States' share fluctuated widely over the 1980s, but in 1992 stood at the same level as in 1980, just behind Germany. This stability can be traced to heavy losses in certain high-technology industries (computers, pharmaceuticals, aerospace) as well as in medium-technology exports, which were compensated by increases in exports of low-technology industries. The share of Japan, third on the list, has increased since 1980, even though it declined in the latter half of the 1980s, following appreciation of the yen.

R&D as a factor in competitiveness. R&D is an important aspect of competitiveness, especially in high-technology industries and for European countries. There is little evidence that investments in R&D and/or physical capital have a greater impact in large countries, but the data clearly support the so-called "home-market effect" (countries tend to develop a comparative advantage in industries for which there is a strong domestic demand). Direct R&D was found to be more important than spillovers for competitiveness. This does not mean that spillovers within and across borders may not have a sizeable economic impact, but simply that differences in the amount and composition of spillovers do not seem to matter much for the relative position of countries.

Policy implications

Nature of technology policy. Policies that neglect the environment for diffusion are too narrow and will not help economies realise the full economic potential of new technologies. Policy needs to recognise that innovation and diffusion are not two distinct activities, but two facets of the same process. As firms develop their ability to absorb and use new technology effectively, they also improve their capacity to develop innovations themselves.

Thinking about the whole economy. Technology policy must cease focusing exclusively on the strength of a few high-technology manufacturing industries, as these alone are unlikely to deliver economy-wide productivity gains. Various policy measures are needed in order to diffuse best practices, through "technology extension centres", for example, that cover services as well as manufacturing. Government can also play an important direct role by encouraging technology diffusion in the large, publicly owned or controlled services sector (education, health).

Competition in product markets matters. Competitive pressures on both technology-supplier and technology-user industries are important for realising the social returns to innovative activity. For the former, policies need to ensure both that firms have sufficient incentives to innovate (through intellectual property rights) and that they cannot capture all the benefits from their innovations. Reforms of the patent system that favour early disclosure go in this direction. For the latter, lack of competition and excessive regulation will blunt the incentives to modernise by adopting new technologies. In this respect, important productivity gains can be reaped by liberalising large parts of the services industries in Europe. This will encourage greater product innovation and variety, higher productivity, lower prices and increased demand.

Costs of protection. Imported technology is an important channel of technology diffusion, especially for smaller countries and for EU countries that trade heavily with each other. Attempts to favour domestic development of new products or processes in the manufacturing industry through discriminatory practices will increase costs to other domestic firms that need access to the best available component, machinery, or materials, whether produced domestically or abroad. In terms of technology diffusion, the costs of trade protection will include not only consumers' traditional welfare costs but also those incurred by producers in manufacturing and in services who obtain technologically advanced equipment and components from abroad.

The role of IT. Technology policy needs to pay particular attention to ensuring that the necessary social infrastructures are made available to take advantage of the network characteristics of IT clusters and the potential they offer for realising economy-wide gains. The ongoing "information highway" programme and related plans will help strengthen the links between IT clusters by promoting investment in the sectors involved. The policy issues here are many: encouraging the creation of networks of firms and public institutions that facilitate the generation of future IT applications; developing market-driven rules for standards setting; liberalising product markets, in manufacturing as well as in services, with a view to increasing incentives for adoption and diffusion.

CHAPTER 1

INTRODUCTION

Scope of the report

This report examines the process of technology diffusion and its importance for productivity and the international competitiveness of OECD economies. For a number of OECD countries, it makes use of internationally comparable data that span two decades and develops the analytical tools needed to observe patterns of technology diffusion across industrial sectors and national frontiers. It identifies national similarities and differences in the way technology is developed in some industries and used in others, looks at issues such as the technology content of investment, the importance of imported technology, and the role of technology clusters, and suggests policy implications.

On the basis of the analytical tools and the study of the process of technology diffusion, the report also examines the impact of technology generation and diffusion on medium-term productivity and international competitiveness in individual industries. It investigates, at a detailed sectoral level, productivity and performance in international markets and attempts to identify the respective roles of development and acquisition of technology and of domestic and foreign sourcing.

Questions addressed

Recent developments in theories of economic growth and international trade have shed new light on the role of technology as a fundamental source of growth, productivity, and competitiveness. At the same time, the promotion of advanced technology as well as its broader diffusion among economic sectors have increasingly become focal points of government policies: the recognition that the wide diffusion of new technologies throughout the economy makes it possible to realise their economic potential has led governments to design policies to promote technology diffusion alongside those meant to encourage innovative activity.

The capacity to innovate depends on a multitude of factors, such as the efforts firms themselves make through investments, the skill level of the work force, the "learning" ability of firms, and the general environment within which they operate. R&D expenditures are crucial, and their level and intensity help determine both productivity gains and success in international markets. In OECD economies, the bulk of new technologies are developed in the relatively small number of manufacturing industries that invest heavily in R&D.

Yet it is less the invention of new products and processes and their initial commercial exploitation than their widespread diffusion and use that generate major economic benefits. The economic performance of most manufacturing and service industries depends on putting technology to work by adopting and using ideas and products developed elsewhere. The ability of firms to translate innovations into new products and processes and the timely and widespread diffusion of technologies are thus of critical importance.

Many industries, particularly those outside manufacturing, acquire most technology by purchasing and assimilating advanced machinery. Capital-embodied technology, along with the relevant training, raises the technological level of an industry's capital stock and leads to improved productivity and competitiveness. At the aggregate level, especially for small open economies, this may outweigh productivity improvements due to own R&D or to other external sourcing mechanisms such as technology licensing.

Furthermore, as OECD economies become increasingly interdependent, as trade increases in the services industries (which adopt many technologies developed elsewhere), and as firms increasingly source technology abroad, technology diffusion takes on greater economic significance. Better understanding of how technologies generated in certain industries or countries are then adopted in others is therefore extremely important. To this end, this report develops certain analytical tools and in the process lays the groundwork for developing more balanced technology policies, policies that both encourage innovation and facilitate the adoption of new technologies. It addresses a number of questions:

- In which industries does new technology originate and which industries benefit most or least from the flows of technology embodied in new products?

- What is the technological content of a given industry's or country's investment?

- What role do imports play in the diffusion of technology? Which countries rely most on imported technology and where do they obtain it?

- What types of technology are diffusing across industries and countries? What is the importance of clusters of industries that share technology (such as IT)?

- How much impact do R&D and technology diffusion have on productivity growth?

- Does the impact of R&D and of technology diffusion on productivity differ in manufacturing, in services, or in specific industry clusters, such as ICT?

- Has the link between R&D variables and productivity changed during the 1970s and 1980s?

- What have been the main structural shifts and patterns in international trade over the last 20 years? What is the role of high-technology industries and products in this process?

- What role do R&D and technology diffusion, the size of a country's own market, and wage factors play in shaping international specialisation?

Policy issues

A number of policy concerns are directly related to these analytical issues. One is the balance between innovation and diffusion policies. While more and more countries emphasise policy measures that remove obstacles and facilitate the diffusion process, technology policy continues to focus overwhelmingly on encouraging the development of new processes and products in a limited number of "high-technology" industries. This often involves a cost: relying on the strength of a few high-technology manufacturing industries is not likely to deliver economy-wide productivity gains from new technologies.

Another policy issue concerns the importance, for realising the social returns to innovative activity, of competitive pressures both on industries that supply new technologies and on technology users (Griliches, 1979; Stoneman and Diederen, 1994). Monopoly structures in industries that develop new technologies allow them to charge prices that appropriate most of the benefits of innovation. As a result, productivity gains in user industries are lower than they would be if supplier markets were more competitive. Similarly, important productivity gains can be reaped by liberalising large parts of the services industries, the main users of new technologies. This will encourage greater product innovation and variety, as well as higher productivity, lower prices, and increased demand for these services.

Other policy issues concern the positive externalities arising from the "network" characteristics of the many new technologies whose benefits are proportional to the number of users (fax machines, for example). In this regard, governments can encourage learning and networks among firms and industries and support international collaborative agreements on technology and standards setting. In particular, it is important to ensure that the necessary social infrastructures are made available so that the IT cluster can realise its potential for economy-wide gains through widespread application.

Finally, to realise the economic potential of new technologies, there is the importance of an open trade regime. It is becoming increasingly clear that industrial globalisation and the international sourcing of technology increase the costs of trade protection, which include not only consumers' traditional welfare costs but also those incurred by producers who source technologically advanced equipment and components from abroad. To the extent that it is important to have access to and to be able to adopt and adapt technologies developed elsewhere in order to innovate, protection involves a more general cost for the economy as a whole in terms of a slower rate of technological development.

Part I

TECHNOLOGY DIFFUSION

CHAPTER 2

UNDERSTANDING THE PROCESS OF TECHNOLOGY DIFFUSION

This report argues that an economic environment that facilitates technology diffusion is central to a strategy for productivity growth and increased international competitiveness. It is therefore essential to understand the process of technology diffusion in order to formulate appropriate policies. In general, technology diffusion involves the application of an innovation following its initial development. In the traditional linear view of technological development, it was seen as a distinct phase. This report stresses instead how closely intertwined the processes of innovation and diffusion are. In effect, rather than thinking of innovation (the supply of technology) and diffusion (the demand for technology) as two separate activities, it is more accurate to think of the creation of new technology and of its adoption and management as two elements in a network of innovative activities (OECD, 1992).

As understood here, technology diffusion is the process whereby knowledge and technical expertise spread throughout the economy, and it encompasses all actions taken at the level of the firm or organisation to exploit the economic benefits of an innovation. In this perspective, it cannot be reduced to the introduction of new machinery onto the factory floor or into the office or the adoption by firms of new intermediate goods. It must also involve the other vital steps taken by firms in order to adapt technology developed elsewhere to their needs and thus increase the economic efficiency with which they use that technology. These steps include the reorganisation of factory work and materials flows (such as just-in-time production programming) and improved management practices on the shop floor, in production development, and in marketing.

The promotion of technology diffusion requires measures to increase intangible investments, such as investments in R&D, training, and human capital, as distinct from tangible investments in physical capital. Although many countries have not traditionally viewed intangible investments as an important aspect of science and technology policy, they are crucial to capturing the economic potential of new technology. There is increasing evidence that it is precisely these additional measures that determine the economic returns on investment in new equipment (OECD, 1992).

Theoretical work on technology diffusion has advanced hand in hand with changes in the way policy makers view the technology diffusion process and with renewed empirical interest in it. As a result, a number of useful notions are emerging. These include the distinction between the cost of adoption and the mere cost of purchasing and a view of the diffusion process as a selection process in which old and new technologies compete. Central to these notions is the recognition that any act of adoption involves certain transformations and is thus, in itself, an incremental act of innovation. Technology diffusion is about active adoption and change, not simply the passive adoption of new techniques or machinery.

Disembodied technology diffusion: research spillovers and the absorptive capacity of firms

There are two types of technology diffusion: "disembodied" diffusion and equipment-embodied diffusion. The former involves the transmission of knowledge, technical expertise, or technology in a way that does not necessarily imply the purchase of machinery and equipment incorporating new technology. This is sometimes an organised process: firms may, for example, sell the rights to a patent or license an innovation. More often, however, it is simply a consequence of innovative activity: the knowledge that the firm develops becomes available to other firms.[1]

Two central notions can help explain the pattern and the determinants of disembodied technology diffusion: research spillovers and absorptive capacity. Research spillovers are the means by which new knowledge or new technology developed by one firm potentially becomes available to other firms or industries, domestically or abroad.[2] They occur because knowledge has some of the properties of public goods, in that its economic benefits cannot be entirely appropriated by the firm that develops it.

While one may consider knowledge spillovers as "leaks" or as an unjust loss of profits for the innovator, they are, in fact, the *sine qua non* condition for the development of knowledge and of the economy. It is because innovations benefit more than just the originating firm and because they are widely diffused that knowledge can develop in a rapid and cumulative manner. Thus, the role of policy is to reconcile the extremes of a framework that must provide innovators with an environment that stimulates innovative activity (by restricting the use of the innovation and thereby guaranteeing some gains to the innovator) while making possible the maximum use of its product (by keeping the price low and thereby ensuring imitation, adoption, and diffusion).

The central role of research spillovers in the innovation process lies at the heart of the formation of formal or informal "networks". The "public good" aspects of innovation make it an activity with strong elements of "collective creation", whether codified in joint-venture arrangements between firms ("learning by interacting") or whether implicit in the use of knowledge as "barter" between otherwise competing firms. The existence of knowledge spillovers implies that the knowledge produced by a particular firm or industry depends not only on its own research efforts but also on efforts of others or, more generally, on the level of the knowledge pool available to it. Thus, innovation and diffusion are shown to be "two faces of the same coin": innovation is a prerequisite for and a determinant of diffusion, whose pattern in turn influences the level of innovative activity (Jacobs, 1990; OECD, 1992).

While spillovers determine the potential flows of disembodied diffusion, it is the efforts of the receiving firms and industries themselves -- their absorptive capacity -- that determine to what extent innovations developed elsewhere are actually incorporated into production processes. Thus, a firm's R&D expenditures and other intangible investments not only generate innovations, they also enhance its ability to assimilate and exploit information in the public domain (Cohen and Levinthal, 1989; OECD, 1992). Absorptive capacity is also important for embodied technology diffusion.

This line of argument recognises a dual role for R&D: in addition to developing a product -- new information -- and helping to maintain a market position for the innovating firm, R&D also improves a firm's ability to learn to anticipate and follow future developments, an aspect that has been referred to as "learning to learn" or "learning by learning", as opposed to "learning by doing". R&D helps firms identify, follow, and potentially take advantage of knowledge initially developed elsewhere: it enhances its learning or "absorptive" capacity. This suggests that firms need a substantial research capability in order to understand and assimilate knowledge developed elsewhere.

In the past, a number of authors have drawn attention to the role of learning. Tilton (1971) asserted that one of the main reasons for firms to invest in R&D in the semiconductor industry is to "facilitate the assimilation of new technology developed elsewhere". Lundvall (1992), Rosenberg (1990), and Nelson and Winter (1977) have all argued that in order for firms to be able to use freely available knowledge they may have to invest in R&D or in other intangible assets such as training. Rosenberg has likened performance of (basic) research to "a ticket of admission to an information network". All these authors argue that these expenditures are needed because knowledge is not simply "on the shelf"; a substantial research capability is often needed to understand and assimilate knowledge that is, in principle, in the public domain, particularly since assimilation usually involves transformation and adaptation as well.

While the role played by intangible investments in learning has been recognised for some time, their role in shaping the pattern of technology diffusion has only recently been explored. Imitation costs were previously interpreted as consisting primarily of the cost of transmitting information and considered small when compared to the cost of generating the innovation. Such costs may depend crucially, however, on the technological level of a firm (its stock of accumulated R&D, its training and organisational practices, etc.); in this case, these costs are only low when the firm has already invested in the development of its absorptive capacity in the relevant field. Thus, the ability to imitate and profit from technology developed elsewhere may in fact depend crucially on own R&D expenditures. Adoption of new technology presupposes absorptive capacity; the latter depends in large measure on the capacity to innovate. In effect, certain aspects of innovation weaken its public good characteristics and make substantive investments that favour absorption a prerequisite for diffusion.

Most technical advances today build on previous technology and incorporate many of the features of the displaced products and processes, so that the likelihood of successful innovation is a function of previously achieved results: what firms will do in the future is strongly conditioned by what they have done in the past (Stiglitz, 1987; Arthur, 1988). Because spillovers encourage high levels of intangible investment, and because the demand for new technology (the diffusion process) acts as a spur for supply (the innovation process), innovation and diffusion are in fact complements, not substitutes.

Equipment-embodied diffusion: buying technologically sophisticated inputs

Equipment-embodied diffusion is the introduction into production processes of machinery, equipment, and components that incorporate new technology. It recalls the more familiar pattern in which a cluster of industries supplies new technology. These industries are mainly (though not exclusively, as the services sector is increasingly undertaking R&D of its own) in the R&D-intensive manufacturing sector; they include computers, aerospace, electrical machinery, parts of electronic appliances and communications equipment, drugs and medicines, and the scientific and chemicals industries. They receive relatively little inflow of technology from other industries and can usually use primarily their own technology to improve productivity.

These industries sell their technologically intensive intermediate and capital goods to downstream industries (both manufacturing and non-manufacturing), to consumers, and to government, all of which represent user demand for technologically intensive machinery, equipment, and components. Services sectors such as finance and insurance and telecommunications acquire R&D indirectly in this way. Although their own R&D efforts are relatively small compared to high-technology manufacturing, they appear to obtain great technological gains by making large investments in new capital goods that embody extensive R&D performed by R&D-producing sectors like electronics and computers.

The mechanism through which equipment-embodied technology developed in one industry spreads and affects other industries involves a different kind of "spillover" (Griliches, 1979). While the knowledge spillover concerns externalities related to knowledge, this "spillover" concerns the prices that user industries pay for their R&D-intensive inputs or that consumers pay for R&D-intensive products. Because of competitive pressures in the supplier industries, prices do not accurately reflect changes in the user value, or marginal productivity, or quality, of the new commodities. As a result, the buyer industry can capture part of the fruits of another's R&D efforts, and its productivity can be increased thanks to the R&D expenditures of the industries that supply it with intermediate (and capital) inputs.

The impact of equipment-embodied diffusion on the productivity of user firms and industries is therefore determined by the market structure of the supplying industries. If the innovation-supplying industries are concentrated and exhibit strong monopolistic tendencies, they will be able to charge high prices for their technology and thus capture most of its social benefits. Competitive pressures will, on the other hand, force down prices, so that the purchase price of inputs will not fully reflect their increased downstream value; in this case, users will receive most of the benefit (Griliches, 1979; Mohnen, 1989).

Because competition and the nature of supply structures play an important role in the speed of technology diffusion, firms decide, on the basis of real or perceived pressures of competition, or the lack thereof, whether or not to scrap existing capital and to undertake material and intangible investments to replace or expand existing productive capacity. When firms become less technologically progressive, the explanation often given is conservative management in a framework of oligopolistic supply structures.

Other factors also affect equipment-embodied diffusion. Even when embodied technology is available in the form of machinery or components, it will only be absorbed by user firms and industries under certain conditions: *i)* the equipment in which it is embodied must be purchased, and this involves investment (mostly material but also intangible, involving training and reorganisation); *ii)* the equipment must be usable, it must in other words "fit in" with the firm's current technologies and its technological environment; and *iii)* the technology must fit easily into the firm's organisation, types of skills, and training possibilities (OECD, 1992).

Firms decide whether to adopt new technology on the basis of cost-benefit calculations of expected future costs and the likely profitability of alternative technologies. They are more likely to invest in new technology more quickly and earlier when capacity is expanding and investment relies less on replacement of existing capital. Net new investment (capacity expansion) is then determined by new demand, prices for the new product, and calculations of profitability. Decisions to replace (or modernise), on the other hand, are determined by the profitability of using new equipment compared with the profitability of running existing equipment. Important factors in this respect are relative operating costs and sunk costs associated with the existing capital equipment (non-recoverable costs, for example, if there is no market for the existing used capital good).

In addition to issues of investment (both traditional and intangible, in particular human capital requirements) and timing, other factors related to the systemic characteristics of technology are important to the process of equipment-embodied diffusion. In particular, as many technologies are interrelated, they have associated "network externalities" which involve two types of linkages. The first concerns production: technological networks or "clusters" are central to the production of many innovations. The second relates to use: for many technologies, the networks of users are a crucial factor in their development and pattern of adoption.

Generally speaking, innovations rarely work in isolation; their productivity depends on the availability of complementary technologies. One study of industrial performance identified intersectoral complementaries and interrelatedness as a key factor in ensuring efficient diffusion patterns (Amable and Mouhoud, 1990). It showed that Germany and Japan benefited greatly from complementarities between information technologies and medium-technology industries which use IT-related innovations as inputs in production (mainly mechanical and electrical engineering industries) and that Italy benefited from complementarities between lower-tech industries, such as textiles and industries that provide equipment for it. The existence of "islands" of high technology, on the other hand, cut off from the rest of the industrial base, retards diffusion and creates structural problems for other industries.

CHAPTER 3

THE MEASUREMENT OF TECHNOLOGY DIFFUSION

The distinction drawn above between disembodied and embodied technology diffusion is clear conceptually, but much less so in practice. Empirical work attempting to measure technology flows across industries and countries has used different methodologies. Depending on the methodology, the measurement captures either disembodied flows or embodied flows. Thus, work on interindustry flows through patents (see below) is closer to modelling disembodied diffusion flows; work using interindustry transactions flows based on input-output data is closer to embodied diffusion. Yet in practice, in both cases, the measure of total technology level or intensity of a particular industry will reflect both embodied and disembodied diffusion. This is because as noted above R&D investments have in effect a dual role: in addition to developing new products and processes, they are also aimed at helping firms absorb and assimilate technology developed elsewhere (Cohen and Levinthal, 1989).

Measuring the spillovers from research activities

The importance of technology diffusion and externalities (spillovers) in the innovation process has long been recognised. Early studies attempted to measure the difference between the economic returns from technology diffusion and those from technology development by quantifying the gap between private and social rates of return to innovation, but they did not explicitly identify the interindustry or intraindustry channels through which technology diffusion takes place. They concluded that the social returns from R&D (and especially from basic research) are significantly higher than private returns (Mansfield *et al.*, 1985; Bresnahan, 1986).

In addition, these studies examined how fast new knowledge developed by one firm comes into the public domain. In a 1985 study for example surveying 100 US firms in 13 manufacturing industries, Mansfield showed that information concerning the development decisions for a major new product or process were in the hands of at least some of the firms' rivals within about 12 to 18 months, on average, after the decision had been made. Other studies corroborating these results have also shown that the traditional means that firms dispose in order to protect themselves against this type of knowledge spillovers are not very successful: the effect of secrecy is weakened by the mobility of personnel and by "reverse engineering", while patents tend to operate more as a means of communication amongst firms (Levin et al., 1987).

Despite the emphasis on the central role of the spread of information in shaping diffusion patterns, the study by Mansfield points out that the fact that information leaks out relatively quickly does not also mean that imitation will occur equally fast. It often takes time to invent around a patent, to develop prototypes, to alter equipment, and to engage in the manufacturing activities required to introduce an imitative product or process. Thus, a more complete appreciation of the mechanisms involved has to take into account "learning by using" effects, the participation in other words of user firms in the process of development of an innovation and the costs that these firms incur in learning how to adapt innovations to their needs.

Subsequent empirical work explicitly modelled the channels of transmission of spillovers by constructing measures of technology flows or introducing an outside or borrowed stock of knowledge as an input into the production process alongside a firm's (or industry's) own accumulated R&D stock or expenditures. A number of different methodological approaches have been used: *i)* surveys of the diffusion of new plant and equipment; *ii)* use of patent data to estimate technology flows and measure their impact on productivity; and *iii)* construction of technology flows through the use of input-output transactions matrices.

The use of technology surveys

Surveys of the extent of use of specific new technologies, such as robots, numerically controlled machine tools, advanced materials, and microelectronics, have been undertaken in a number of countries. They measure actual adoption rates and provide a detailed snapshot of the use of specific technologies throughout industry. One of the best known studies, done in the United Kingdom (Robson *et al.*, 1988), reveals that five "core" manufacturing sectors -- chemicals, machinery, mechanical engineering, instruments, and electronics -- account for about 65 per cent of all innovations. Innovations produced in these sectors are particularly pervasive, and are used in a large number of other sectors.

Recent work on the diffusion of computer-based automation equipment in manufacturing in different OECD countries (OECD, 1989, 1990) reveals similar patterns and also underscores the importance of skills and firm organisation for the diffusion of advanced manufacturing technology (Grandstand and Sjölander, 1990). Essentially, firms must have management and technological competence and a broad range of skills of the appropriate kind and mix if applications are to be successful. Their relations with technology suppliers, the effects of links between large and small firms, and the strength or weakness of the technological infrastructure are all important factors in determining absorptive capacity.

Technology surveys have a number of limitations. They are by definition selective, focusing on the application of particular technologies in a given set of industries. Often, it is not possible to identify the source (industry and country) of the technology, so that while information on adoption rates is available, information on flows is not. Finally, most surveys have only dealt with the use of new technologies by manufacturing industries, yet the large share of services output and employment in GDP suggests that the technological sophistication of services is likely to be crucial to national productivity growth.

Technology flows based on patent data and innovation surveys

Technology flow matrices based on patent data emphasise the role of patents as "carriers" of underlying R&D expenditures. Schmookler (1966) was among the first to express the view that improvements in performance associated with technological progress can result either from intramural R&D or from R&D performed in other firms/industrial sectors and embodied in ideas or goods purchased by an industry. He proposed a method for measuring the transmission of R&D-generated knowledge from R&D-performing industries to industries purchasing their products.

Scherer (1982a, 1982b, 1982c) extended this work by constructing an "interindustry technology flows" matrix. Rather than relying exclusively on patents, he combined patent and R&D data in order to overcome the limitations of patents as cross-sectoral measures of industrial effort, which are due to the fact that the propensity to patent varies from one industry to another. In his scheme, patents are seen as carriers of underlying R&D expenditures, rather than as units of invention in their own right. Relying on Line of Business Data for US manufacturing firms, which make it possible to match industrial invention patents precisely with the R&D expenditures for the activities that led to the inventions, he coded each patent in his sample according to industry of origin and industries of anticipated use. At the conclusion of this procedure, he "tagged" each patent with the average R&D expenditures per patent in the appropriate line of business category. The result was a matrix of technology flows for which both patents and R&D expenditures are classified according to industries of origin and (anticipated) use.

In related work, Evenson and Putnam (1988) constructed a patent concordance matrix for Canada based on Canadian Patent Office data (the Yale-Canada Concordance). They constructed a matrix of technology flows by computing the proportion of patented inventions originating in one industry but used in other industries, with the help of a concordance between industry classes and patent classes.[3] They compared US data on interindustry flows of technology (based on patent data) for a single year with the results of the innovation survey carried out by SPRU for the United Kingdom and concluded that the two countries' sectoral patterns of technology production were broadly similar. More than 97 per cent originated in manufacturing, with about two-thirds from the core groups, one-fifth from the secondary groups, and one-tenth from other manufacturing. The pattern of use of innovations, however, was different, with non-manufacturing sectors being much greater users of such technology in the US than in the UK.

Patent concordance matrices reveal something about the potential relevance of one industry's R&D activity to other industries. Since industries' R&D expenditures are heterogeneous, patent classifications according to industry of origin and of use can help identify potentially significant R&D flows. However, they have disadvantages. They cannot reveal actual intersectoral spillovers if these spillovers are embodied in improved products that are traded across sectors. Furthermore, in practice, the construction of technology flow matrices like Scherer's, which are based on combined patent and R&D data, is very resource-intensive, while using the matrix constructed for Canada to analyse technology flows between industrial sectors in other countries is open to the criticism that the propensity to patent varies across countries.

Patents are only one innovation "output" indicator which can be used for the construction of technology flows. The use of innovation counts from surveys of innovative activities is another. DeBresson *et al.* (1994) have constructed a 43 x 66 innovation supplier-user matrix for Italy based on an innovation survey of 30 000 manufacturing business units for the period 1981-85. They found that Italian innovative activity was clustered in certain areas of economic activity and that it was more oriented towards final consumer goods than capital goods or other producer goods (in the chemical, metal products, mechanical machinery, and automobile industries). Consumers were by far the main users of innovation developed elsewhere, followed by the construction and automobile industries.

Technology flows on the basis of input-output matrices

An alternative method of constructing interindustry technology flows is to use input-output matrices combined with R&D expenditures. Input-output matrices make it possible to describe the economy on the basis of transactions across sectors for intermediate and investment goods. The usefulness of this methodology for mapping technology flows was originally suggested by Terleckyj (1974), and it has subsequently been employed in various papers and reports. It is the methodology adopted here, and it is developed in the following sections as a means of measuring the flows of embodied R&D and of constructing new indicators of technological intensity in individual industrial sectors.[4]

The main advantage of input-output matrices is that they reflect actual interindustry transactions. The method used to calculate technology flows then consists of using the input-output coefficients (*i.e.* each industrial sector's purchases, per unit of output, of intermediate and investment goods from other sectors) as weights for the R&D flows from a given sector to the sectors that purchase its products. In this way, purchased inputs (both of intermediate and of investment goods, domestic as well as foreign) act as carriers of technology across industrial sectors and from one country to others. Another advantage is that this methodology simultaneously takes into account both supply and demand factors and thereby goes beyond the "technology-push" and "demand-pull" debate (DeBresson, 1990; DeBresson *et al.*, 1994).

Using this methodology, a study done for the US Department of Commerce (Davis, 1982, 1988), which focused on intersectoral and international technology flows between the United States, Canada, and Japan, reinforced the widespread perception of the central role of certain key technologies (mostly IT-related) but also showed substantial international differences in the adoption of technologically sophisticated machinery and equipment.

The study stressed the fact that indirect technology inputs embodied in intermediate and capital inputs account for a large share of all the technology embodied in total output (whether exported or for domestic use). Moreover, the relative importance of direct (innovation-based) to indirect (diffusion-based) technology inputs differs widely among countries. In 1984, for example, (domestic) indirect technology inputs averaged about three-fourths the direct inputs in Japan, but about 50 per cent in the United States. This suggests that Japanese industries are both more dependent on technology from key indirect technology sources and more able to diffuse technology across industrial sectors. Canada, was shown to be largely dependent on the domestic diffusion of technology embodied in imports of intermediate and capital goods.

A recent Finnish study (Virtaharju and Akerblom, 1993), employing a similar methodology, divided Finnish industries into two groups: technology producers, characterised by extensive R&D and a small share of indirect technology; and buyers of technology, whose principal sources of technology were intermediate and capital inputs. The most technologically self-sufficient industries were the pharmaceuticals and telecommunications equipment sectors. Processing industries, food, textiles and clothing, and metal products relied most on acquired technology. One-fifth of total technology was embodied in imports, a share which declined in the 1980s as imports of intermediate goods dropped.

While input-output matrices provide a powerful tool for tracing technology flows across industrial sectors, they do have a number of disadvantages. First, the output of each supplier industry is assumed to be homogeneous, although there may be significant differences in the amounts of underlying R&D in different products. Second, all of the supplier industry's own R&D is assumed to be embodied in its output. In practice, however, only product R&D is embodied in output; process R&D manifests itself only in lower purchase prices and/or improved supplier profits. Third, the technology developed in one industry may affect other industries in the absence of transactions in intermediate or investment goods.

The methodology used in this report

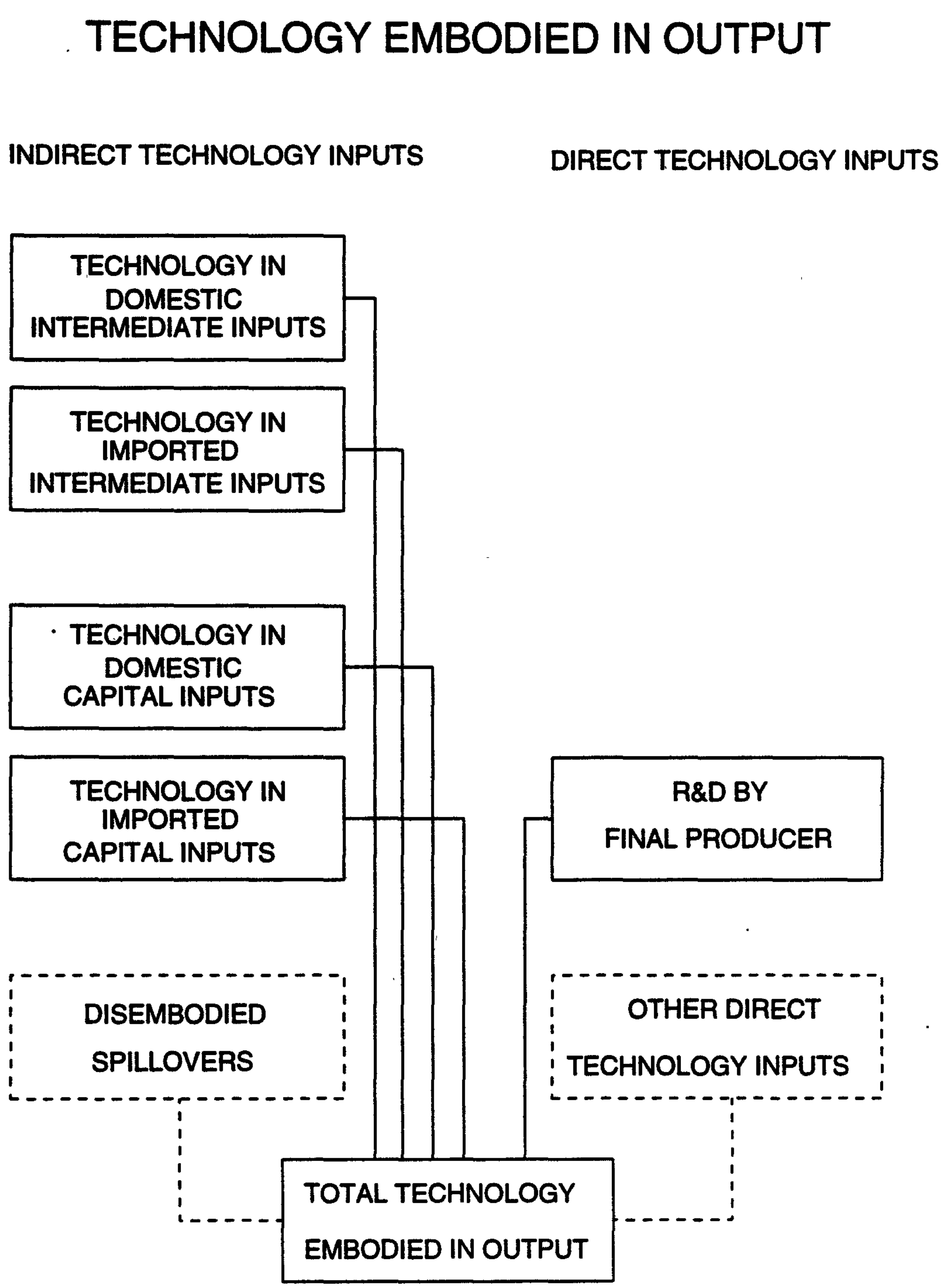
The methodology for analysing the impact of technology generation and diffusion on productivity and competitiveness at an industry-level consists of two steps: (i) the estimation of intersectoral and international technology flows; and (ii) the econometric estimation of the impact of such flows on productivity and competitiveness. Technology flows are estimated by using business enterprise R&D expenditures data with input-output and investment flows data to generate indicators of how industries use different types of inputs (intermediate inputs and investment goods) where "technology" is proxied by the R&D embodied in these inputs.

This approach allows the separation of the equipment-embodied technology used by a particular industry into that which is generated by the industry itself and that which is acquired through purchases of intermediate inputs and investment goods (see Figure 1). Acquired technology is separated further into that portion which was obtained from domestic as opposed to foreign suppliers. Similarly, these acquired technology flows can be grouped into broad categories such as information technology, transportation equipment, consumer goods, materials, and fabrication equipment.

The second step in the analysis consists of using these different stratifications of acquired technology as explanatory variables in an analysis examining the relative importance of own and embodied technology (investment vs. intermediate and foreign vs. domestic) on labour and/or total factor productivity. These indicators of the acquisition of technology can also be used to examine the relationship between the generation and use of technology by industry and sectoral performance in international markets.

The methodology used in this project for the estimation of technology flows between industries and across countries builds on a large body of literature.[5] It rests on two assumptions: R&D expenditures are used as a proxy for technology; and interindustry transactions are assumed to be the carriers of technology across industries and countries. Industries purchase intermediate and investment goods as inputs into their production processes. These intermediate and investment goods embody the technology (the R&D expenditures) of the industries where they originate. Thus technology is assumed to flow from one industry to another when the industry where R&D originates sells products which embody R&D to other industries to be used as inputs into their production processes. In other words, the output of a particular supplier industry is sold to various purchasing industries and these purchasing weights are used to allocate the producer's R&D across the user industries.

Box 1. Sources of technology embodied in output



Thus, the technology embodied in the output of a certain industry is the sum of its own R&D expenditures and of that which is embodied in its purchases from other industries (of intermediate and investment goods, domestically or from abroad).[6] [See the Appendix for a full mathematical derivation.] More specifically, the methodology used in this project models technology diffusion and acquisition through four separate channels of commodity transactions:

- purchases of domestic *intermediate* products;
- purchases of domestic *investment* inputs;
- purchases of *imported* intermediate products; and
- purchases of *imported investment* inputs.

The anaysis can be conducted by using technology *flows* or by normalising these to technology *intensities* (flows per unit of output). The *total technology intensity* of an industry j (defined as tti_j) is then the simple sum of five components: $tti_j = r_j + tint^d_j + tinv^d_j + tint^m_j + tinv^m_j$, where:

- r_j $(=R_j/X_j)$ is industry j's own R&D intensity;
- $tint^d_j$ $(=TINT^d_j/X_j)$ is the R&D embodied in domestic intermediate inputs per unit of output of j;
- $tinv^d_j$ $(=TINV^d_j/X_j)$ is the R&D embodied in domestic investment inputs per unit of output of j;
- $tint^m_j$ $(=TINT^m_j/X_j)$ is the R&D embodied in imported intermediate inputs per unit of output of j;
- $tinv^m_j$ $(=TINV^m_j/X_j)$ is the R&D embodied in imported investment inputs per unit of output of j.

Of the four embodied R&D components, the R&D embodied in domestic intermediate input purchases $tint^d_j$ is the weighted sum of the R&D intensities of the industries from which industry j is purchasing inputs, with as weights the total (ie direct and indirect) domestic intermediate input requirements from each industry per unit of output of industry j obtained from a modified version of the Leontief inverse matrix.[7] The R&D embodied in domestic investment input purchases $tinv^d_j$ is the weighted sum of the same R&D intensities, with as weights industry j's investment purchases from other industries multiplied by the total input requirements per unit of final demand of industry j.

Compared with domestic R&D flows, the formulation of imported R&D is rather simple, in the sense that it does not take into account the interindustrial propagation effects (which are captured through the Leontief inverse). Of the two embodied R&D components that relate to imported R&D, the R&D embodied in imported intermediate input purchases $tint^m_j$ is a weighted sum of foreign sectoral R&D intensities, with the weights being the intermediate demand of industry j from each other industry multiplied by the import share of that industry by trading partner country[8]. Similarly, the R&D embodied per unit of imported investment input purchases $tint^m_j$ is defined analogously as the weighted sum of foreign sectoral R&D intensities, with the weights being the investment demand of industry j from each other industry multiplied by the import share of that industry by trading partner country.

Strengths and weaknesses of the methodology

The main strength of the methodology is that it is rooted in comprehensive, economy-wide data and thus avoids the limitations associated with case studies. This is by virtue of the use of input-output relationships, which describe the economy as in interconnected system of industries. Unlike other studies of this type, the study will look at the variation which exists below the broad aggregate of manufacturing and include service sectors. The ability to look at service sectors is particularly important given the fact that technology is chiefly developed in manufacturing but is increasingly diffused in services, which account for two-thirds of total employment.

A second strength is that the methodology used is based on a well-established body of literature attempting to measure technology flows and link them to productivity growth and competitiveness. The value-added of this project is that it extends this methodology to distinguish between four different channels of technology diffusion and acquisition: (i) purchases of domestic *intermediate* products; (ii) purchases of domestic *investment* inputs; (iii) purchases of *imported* intermediate products and (iv) purchases of *imported investment* inputs.

Finally, another strength is the use of a data set which combines a high degree of international comparability across a wide cross-section of countries with the ability to match technology variables (R&D), industrial variables, inter-industry relationships (input-output matrices) and international trade flows. All other such studies are restricted to two or three country comparisons.

In terms of weaknesses, the methodology captures the flow of technology across sectors through the purchases of intermediate and capital inputs; yet in the presence of disembodied spillovers the R&D performed in one industry can benefit others even without any transactions taking place. This does not necessarily imply that only embodied technology diffusion is accounted for in the methodology; much recent theoretical and empirical work has argued that at least part of an industry's own R&D is aimed at assimilating the results of R&D done elsewhere. To the extent that in this methodology the measure of an industry's total technology level or intensity combines its own R&D with the technology acquired through input purchases from other sectors, it covers at least partly both embodied and disembodied technology diffusion, even if it cannot distinguish between the two.

The methodology also uses a number of limiting assumptions, common to much of the empirical work in this area. There are first the assumptions of static input-output analysis: constant returns to scale, capital investment exogenous to the model, and homogeneity of products within industries.[9] In particular the exogenous treatment of capital may underestimate the impact of R&D embodied in investment goods to the total R&D intensity of a sector and to its productivity growth.

In addition, an "import proportionality" assumption is used for the intermediate and investment flows matrices, namely that an imported input is proportionately distributed across all using industries (for example, if 10 per cent of total demand for steel is imported, and if both the motor vehicles and construction industries use steel, it is assumed that imported steel accounts for 10 per cent of their inputs). This assumption was also used in order to separate inputs by country of origin; thus, if 40 per cent of steel imports of country *a* come from country *b*, that share is assumed to hold for all industries in country *a* using imported steel. These assumptions are dictated by data availability; their impact is lessened to the extent that import matrices for many countries have been compiled on the basis of highly disaggregated data before being collapsed to the 36 industries used in this study.

There are finally a number of assumptions which relate to the specific methodology used for the estimation of technology flows. The first relates to the use of R&D intensities, as opposed to R&D stocks, as a measure of R&D activity and of the technology embodied in output. This involves the implicit assumption that the R&D performed by a particular industry in a particular year is completely embodied in the production of that industry. While calculation of R&D stocks may be preferable in principle, in practice lack of detailed information at the sectoral level on rates of obsolescence of R&D capital and on the lag structure that connects past R&D expenditures to current increases in technological knowledge make such calculations unreliable and render the alternative of using R&D intensity measures more attractive. Furthermore, in the productivity and technology estimations, an equivalence can be established between the use of intensities and using instead the rate of growth of R&D capital. Nevertheless, a number of sensitivity tests will be performed to assess the importance of this simplifying assumption.

Another issue in this respect is the differential treatment in the method employed of R&D of domestic vs. imported embodied R&D. In calculating the R&D embodied in (intermediate and capital) imports, no attempt is made to account for the interindustry propagation effects in acquired R&D through the Leontief inverse matrix. This may underestimate the importance of the contribution of imported R&D. A satisfactory treatment of these indirect effects, however, would necessitate a "linked" input-output model solved simultaneously for a number of OECD countries.

A final weakness relates to the data set used for R&D expenditures and for calculating R&D intensities and "total technology" intensities. In order to assure comparability of data across countries, it has been assumed that only manufacturing industries perform R&D. Services industries are assumed to be technology users exclusively (through their purchases of technologically sophisticated inputs), but not R&D performers. This assumption most likely leads to an underestimate of the technological sophistication of services industries.

CHAPTER 4

THE PATTERNS OF DIFFUSION: PRODUCERS AND USERS OF TECHNOLOGY

Chapters 4 to 8 of the report analyse the patterns of embodied technology diffusion in ten OECD countries on the basis of the methodology described above. This chapter addresses the question of who does R&D and who receives it -- identifying the industries that are the main R&D performers and those that use embodied technology as production inputs. The discussion then moves on to the implications of technology diffusion for defining the technology intensity of industries and for the economy (chapter 5). It is argued that a more appropriate definition of technology intensity should take into account not only how R&D-intensive the production of a particular sector is, but also the technological sophistication of its intermediate inputs.

The methodology employed here makes it possible to distinguish between different means of technology diffusion and patterns of technology propagation across sectors and countries. This makes it possible, first, to examine the role of capital inputs in technology diffusion (chapter 6). The next issue addressed (chapter 7) is international technology transfer; industries use imported inputs in their production processes, and these imports embody the R&D expenditures of the performing industry in the source country. The pattern of imported inputs thus provides information about the importance and sources of imported technology. Finally, chapter 8 investigates technology clusters, which are groups of industries sharing R&D, and examines how they differ in different countries.

R&D expenditures and acquired technology

OECD countries invest significant funds into research and development activities. The level and rates of growth of R&D expenditures are widely seen as indicators of innovative capacity and as important determinants of productivity gains. These R&D expenditures mainly originate in manufacturing and tend to be concentrated in a few "high-technology" manufacturing industries (see below) such as computers, semiconductors or aerospace. The products of these industries which are developed with the help of R&D are sold to other sectors and are used as inputs into their production process or are sold directly to final demand for domestic consumption or exports. In this process, the technology of the upstream industries becomes embodied in products.

The process whereby the R&D investment of one industry becomes embodied in its products which are sold to other industries implies that effectively at any given point in time the products of a certain industry embody its own technology and part of the technology of the upstream industries from which it is purchasing intermediate and capital inputs. This indirect source of technology -- in addition to own R&D expenditures -- can be estimated using input-output techniques. Thus at the level of the economy as a whole, the total technology embodied in output can be considered to consist of the total economy-wide R&D expenditures and the indirect technology which is embodied in products.

Figure 2 and Annex Table 1 shows these direct R&D expenditures in the manufacturing sector and the estimated indirect technology embodied in the gross output of the economy as a whole for 10 OECD countries. It suggests that these indirect technology inputs -- which can be labelled *acquired* or *embodied* technology, as opposed to *own* or *performed* R&D -- account for a large share of the total technology embodied in output. The relative importance of direct to indirect inputs differs between countries due to differences in the industry composition of output and the strength of R&D effort. Acquired technology ranges between 40 and 65 per cent for the 10 countries in question; it represents more than half of total technology in Australia, Canada and Italy.

These estimated technology levels also allow the calculation of technology multipliers as a measure of the total "technology" embodied in gross output that is obtained from a $1 expenditure in R&D (see Figure 3 and Box 1). These are obtained as the ratio of the estimated total technology embodied in output to the R&D directly performed. Most large countries have technology multipliers in the 1.7 to 1.9 range, implying that due to the fact that industries use the products of other industries as inputs, the total technology which is embodied in an economy's gross output (to be consumed either as intermediate or final demand) is typically 70 to 90 per cent higher than the value of the R&D expenditures of the manufacturing sector. These multipliers have increased slightly over time in most countries, both because industries source more technologically advanced machinery and equipment than in the past, and because the are subcontracting more to other industries.

Box 1. Interpreting the technology multipliers

The technology multipliers are calculated as the ratio of the estimated total (performed and acquired) technology embodied in gross output to the total intramural R&D expenditures (the performed technology) of the manufactuirng sector. They indicate the level of total "technology" embodied in gross output that is obtained from a $1 expenditure in R&D.

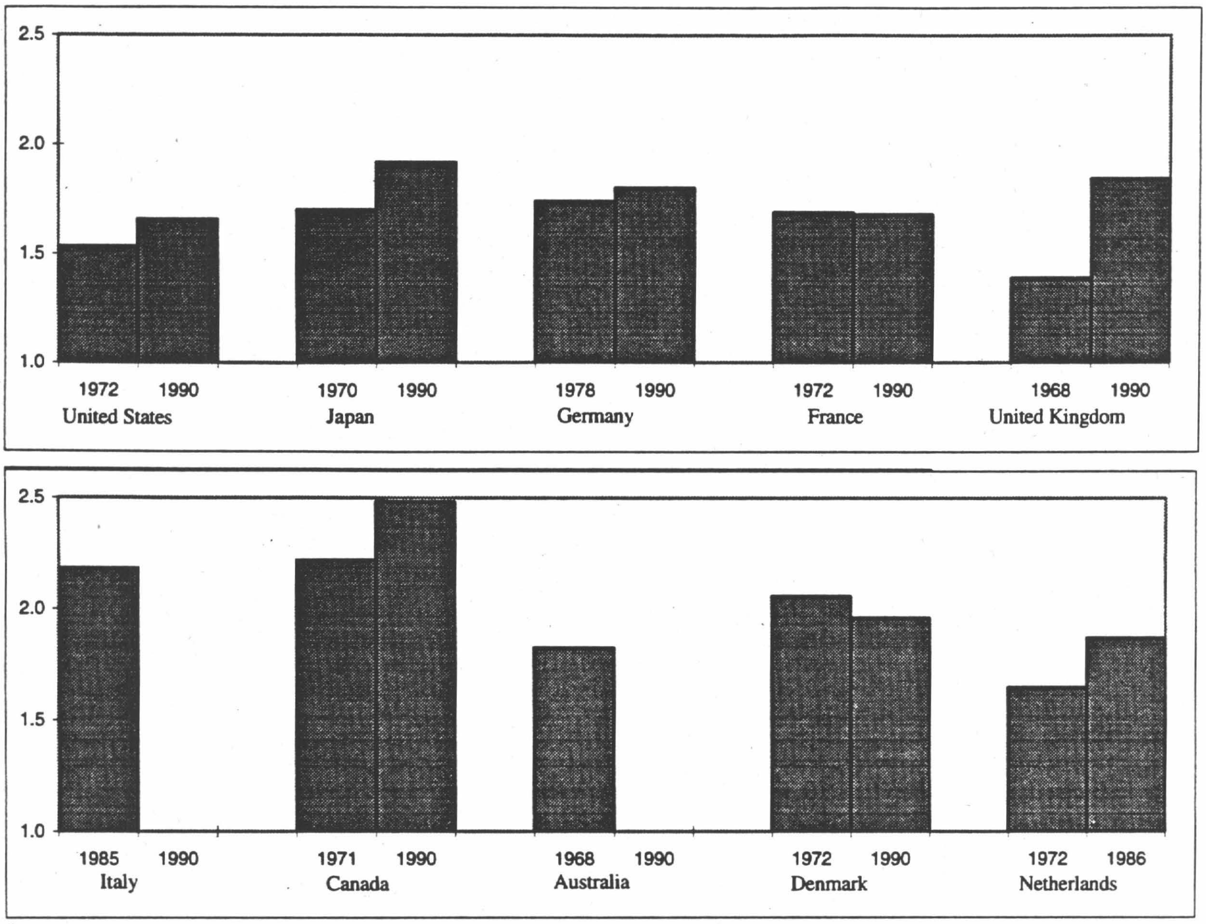
These technooogy multipliers are similar to the more traditional output multipliers in input-output analysis, whereby because the output of one industry is an input to others, in order to increase final demand by $1, it is necassary to increase gross output by more than $1. There is noe exact parallel, however, because technology multipliers refer to fross output only. In this context, technology multipliers refelect the public-private nature of technology.

It is well established that knowledge has certain characteristicstypical of public goods. It is first of all only *partially excludable*: it is difficult for firms which undertake R&D to fully appropriate the economic benefitsby excluding others from its use. It is also *non-rival:* new technology can be used many times and in many different processes without being exhausted.

Figure 2. Performed versus acquired technology

Source: OECD, STAN Input-Output database.

Figure 3. **Technology multipliers**[1]
Ratio of acquired technology to R&D expenditures



1 See text for definitions.
Source: OECD estimates (STI/EAS Division) from Input-Output and ANBERD databases.

R&D performers and technology users

This broad picture of performed and acquired technology is based on R&D expenditures and technology acquisition in different industries. At a more disaggregated level, the picture that emerges from this analysis is that of a cluster of high technology industries performing most of the R&D in manufacturing, and a different cluster of service industries acting as the main purchasers of technologically-sophisticated machinery and equipment (Figure 4).

Table 1 shows the five biggest R&D performing and technology using industries in the 10 OECD countries in the database. The R&D shares are expressed in terms of its share of total manufacturing R&D. The shares of technology use are expressed relative to the total acquired technology embodied in output, estimated using the methodology explained above. Looking first at the biggest R&D performers, two characteristics stand out. The first is that one industry, *communications equipment in semiconductors*, is the first or second R&D performer in 9 out of 10 countries. The second is that R&D performance tends to be quite concentrated in most countries: the top five industries account for 60 to 80 of total R&D expenditures, with the United States and the Netherlands exhibiting the most concentration, and Japan and Australia the least.

Table 1. R&D performance and technology use in 1990: five biggest industries in 10 OECD countries (1)

		United States				Japan	
Performers	**Share**	**Users**	**Share**	**Performers**	**Share**	**Users**	**Share**
Aerospace	26.7	Social & personal services	12.5	Communications equipment	16.3	Social & personal services	11.5
Communications equipment	16.8	Wholesale & retail trade	9.9	Motor vehicles	14.4	Construction	10.8
Chemicals	13.2	Real estate & bus. services	7.6	Electrical machinery	11.2	Real estate & bus. services	10.0
Computers	12.5	Transport & storage	7.1	Chemicals excl. pharm.	10.1	Transport & storage	8.6
Motor vehicles	10.6	Construction	6.4	Computers	10.1	Motor vehicles	6.0
		Germany				**France**	
Performers	**Share**	**Users**	**Share**	**Performers**	**Share**	**Users**	**Share**
Electrical machinery **	26.4	Motor vehicles	10.2	Communications equipment	23.8	Aerospace	10.4
Chemicals *	22.0	Real estate & business services	9.1	Aerospace	20.6	Transport & storage	10.2
Motor vehicles	17.6	Transport & storage	6.9	Motor Vehicles	12.4	Construction	7.1
Other non-electrical machinery	10.8	Other non-electrical machinery	6.8	Chemicals excl. pharm.	10.0	Motor vehicles	6.1
Aerospace	9.1	Construction	6.3	Pharmaceuticals	8.0	Social & personal services	5.8
		United Kingdom				**Italy**	
Performers	**Share**	**Users**	**Share**	**Performers**	**Share**	**Users, 1985**	**Share**
Communications equipment	22.9	Social & personal services	14.8	Motor Vehicles	18.4	Social & personal services	18.1
Pharmaceuticals	16.3	Aerospace	8.1	Communications equipment	14.3	Transport & storage	7.2
Aerospace	15.9	Real estate & business services	7.8	Pharmaceuticals	14.1	Construction	6.2
Chemicals excl. pharm.	11.4	Wholesale & retail trade	7.3	Aerospace	11.7	Chemicals excl. pharm.	5.3
Computers	8.6	Finance & insurance	6.7	Electrical machinery	8.4	Real estate & bus. services	5.0
		Canada				**Australia**	
Performers	**Share**	**Users**	**Share**	**Performers**	**Share**	**Users, 1986**	**Share**
Communications equipment	32.5	Motor vehicles	15.9	Communications equipment	15.0	Finance & insurance	15.3
Aerospace	13.2	Communications equipment	8.7	Motor vehicles	12.2	Construction	14.4
Computers	8.6	Communications services	8.7	Communications services	10.2	Wholesale & retail trade	9.7
Pharmaceuticals	7.4	Social & personal services	8.7	Iron & Steel	10.2	Social & personal services	9.8
Chemicals excl. pharm.	4.8	Transport & storage	8.5	Chemicals excl. pharm.	10.0	Fabricated metals	7.7
		Denmark				**Netherlands**	
Performers	**Share**	**Users**	**Share**	**Performers**	**Share**	**Users**	**Share**
Pharmaceuticals	23.8	Transport & storage	12.8	Chemicals excl. drugs	27.5	Electrical machinery **	13.2
Non-electrical machinery	15.6	Chemicals *	11.4	Electrical machinery	19.8	Chemicals excl. pharm.	8.9
Sc. instruments	11.5	Construction	10.0	Communications equipment	16.2	Social & personal services	6.8
Communications equipment	9.9	Agriculture	9.1	Pharmaceuticals	8.5	Construction	6.5
Other Manufacturing, nec	8.3	Non-electrical machinery	7.9	Food/beverages/tobacco	5.3	Transport & storage	6.3

1. The shares of R&D performers are in total manufacturing R&D (except for Australia, where they also cover services R&D); the share of technology use is in the total indirect technology embodied in output.

*: includes pharmaceuticals.

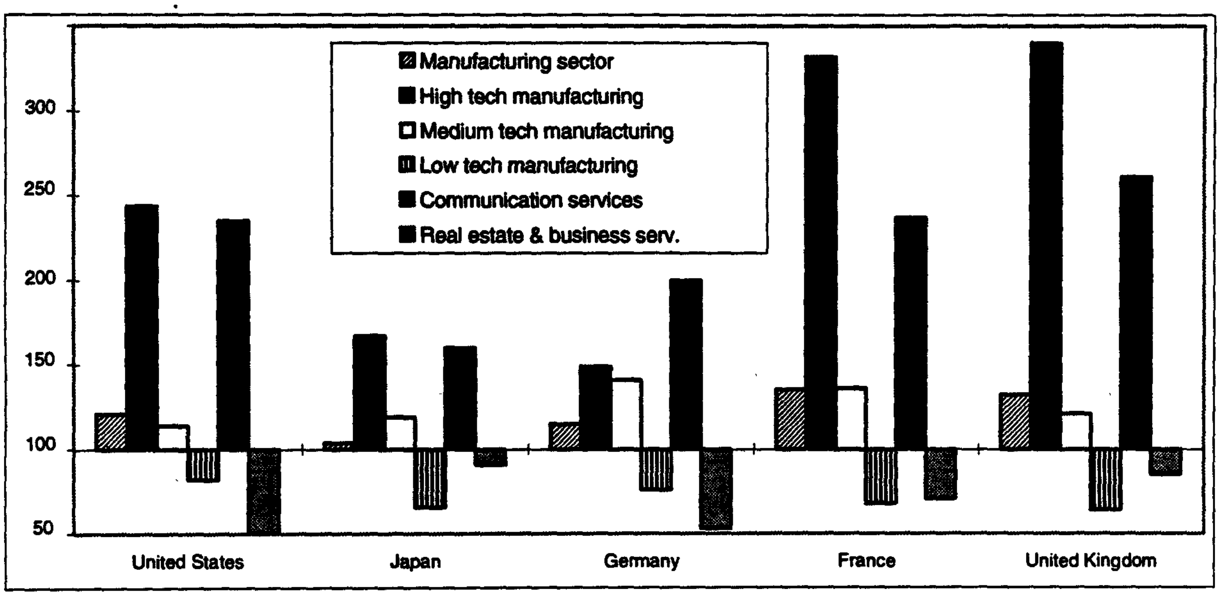
**: includes communications equipment

Source: OECD STAN Input-Output database.

The list of the industries making the greatest use of equipment-embodied technology in the 10 countries shows that technology diffuses mainly in the services sector. Service sector industries typically occupy four out of the five top spots in the list of most countries. *Social and personal services*, an industry category covering, among other, equipment purchases by the health industry is prominent and appears in the top 5 technology user industries in 8 out of 10 countries. The *construction* industry also appears as an important embodied technology acquirer in 8 out of 10 lists. The transport and storage service industry, real estate and business services, wholesale and retail trade, also show up as important users of technology.[11]

A few manufacturing industries also make the top-five technology users list in the 10 countries, notably *motor vehicles* in Germany, Canada and Japan, *aerospace* in France and the UK, chemicals in Denmark and the Netherlands, and *electrical machinery (including communications equipment)* in the Netherlands. A more general characteristic and difference of this list from the list of largest R&D performing industries is its lesser concentration. The top five technology users account for less than half (40 to 45 per cent) of total indirect equipment-embodied technology in every one of the 10 countries in the table. Thus the overall picture that emerges is one a few manufacturing industries performing most of R&D, with the products embodying technology being widely diffused in the economy, and particularly in the services sector (Figure 4).

Figure 5. **The technology content of production**

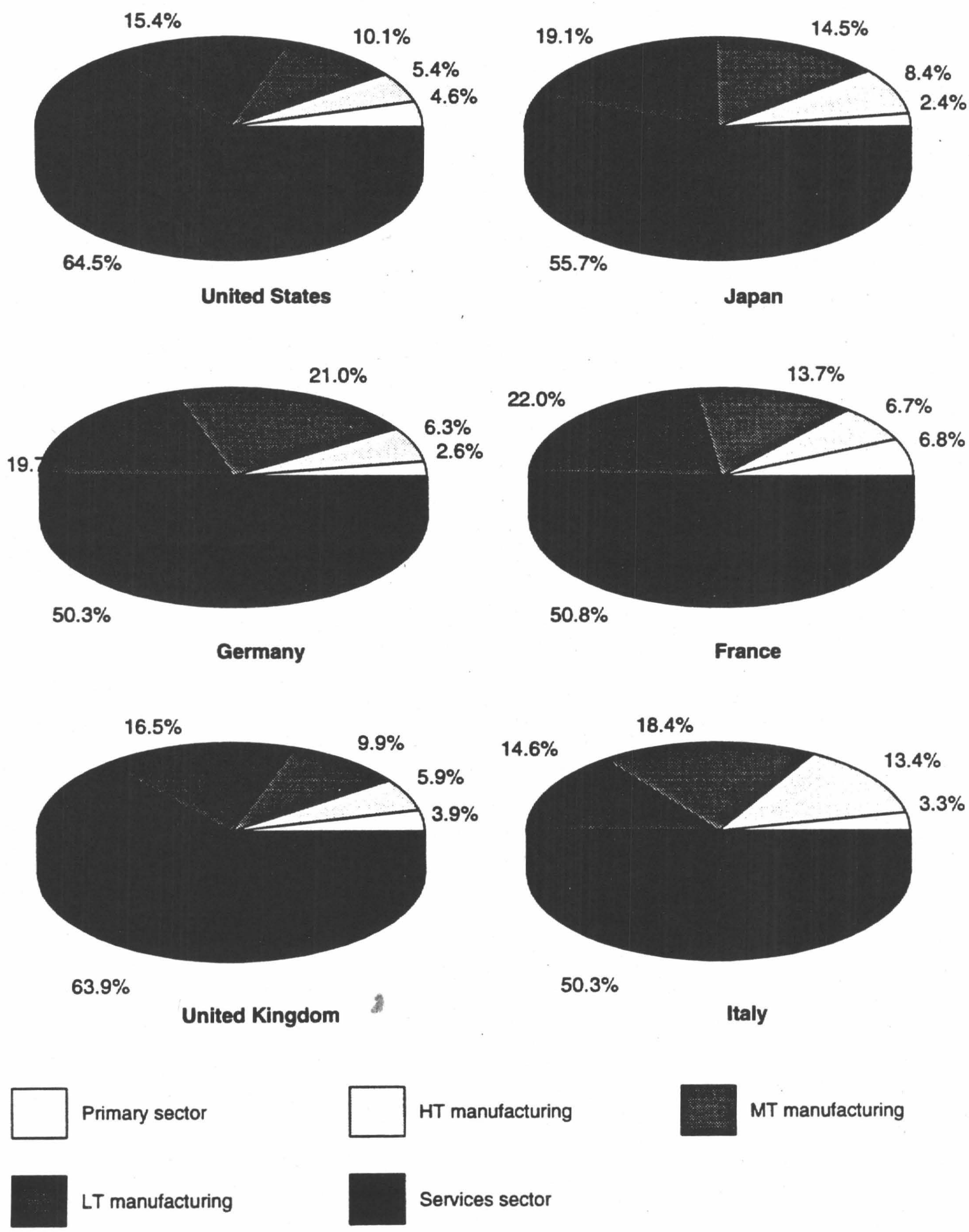


1. This index is calculated as the ratio of the share of technology acquired by each industry in the total embodied technology in the economy to the corresponding share in production.
A value of 100 means that an industry's weight in technology acquisitions is the same as its share in production.

Source: OECD (STI/EAS Division); calculations from input-output and ANBERD databases.

Figure 4. Technology use

Acquired technology by user sector



OECD STAN input-output database.

The presence of services industries in the list of the five largest acquirers of equipment-embodied technology could be explained by their sheer size in the economy. Large industries have more extensive interindustry transactions and should therefore be expected to purchase larger quantities of machinery and equipment incorporating new technology. Figure 5 and Annex Table 2 develop an indicator which attempts to correct for size by expressing an industry's share of embodied technology acquisitions in the total relative to its share in economy-wide production.

The indicator shows that size by itself does not explain technology use: a number of service industries use technology disproportionately to their weight in production. Communications services is the main industry in that respect, but technology use is intensive also in social and personal services in many countries. The technology content in production does however remain highest in the high technology segment of manufacturing; the indicators vary by country but industries such as computers typically use technology 3 to 7 times more than what their weight in economy-wide production would suggest. These industries are both technology performers and (relative to their weight in the economy) also large acquirers of embodied technology.

It should however be emphasised that the methodology used in this report restricts R&D expenditures to those undertaken in the manufacturing sector only. The services sectors are in effect increasingly active both as developers and as users of new technologies. While R&D is still overwhelmingly performed in the manufacturing sector, and especially in the high technology segment, the services account for an increasing part of total business R&D expenditures. This trend is particularly apparent in the United States, Canada and Australia, where up to 40 per cent of all R&D is now performed by services firms. It is less so in European countries and in Japan, but this may be due to the fact that these countries have not yet extended their R&D surveys to provide better coverage of services firms (OECD, 1995).

The increasing share of services in total business R&D can be traced to three different aspects of services. First, a core of research activities has always existed in the services sector (commercial R&D firms, design and engineering forms, etc.) and these activities may have increased in recent years. Second, there is research in completely new areas, such as the development of products in the crossroads of IT, entertainment and information exchange (e.g. multimedia, publishers developing products on CD-ROM rather than paper, etc.). Third, certain activities which used to be carried out by manufacturing are now carried out in service "spin-off" firms. A good example is the emergence of separate software firms, which are now ascribed to the services sector, whereas in the early days of the IT revolution, most software development took place in manufacturing industry.

CHAPTER 5

REINTERPRETING TECHNOLOGY INTENSITY

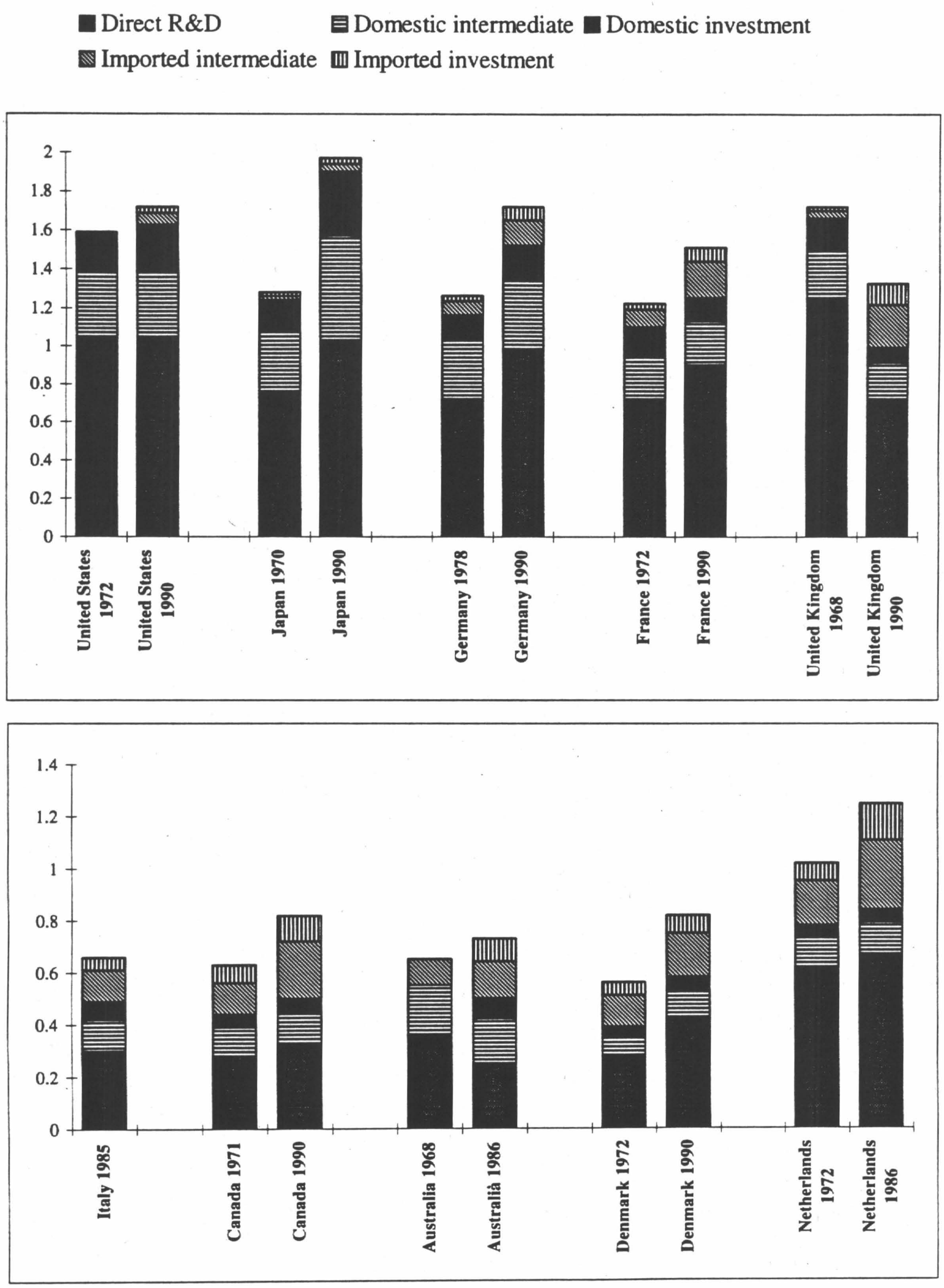
The concept of "technology intensity", usually measured as R&D per unit of output or value added, is widely used as a measure of the technological sophistication. Despite its broad use, the concept is generally not well defined and often does not have a clear correspondence with what it typically aims to measure: ie the adequacy of R&D expenditures or the level of technological sophistication of an industry. One of its main shortcomings is that by focusing exclusively on the R&D expenditures in a particular sector, R&D intensity indicators do not take into account the fact that industries often do little R&D themselves while simultaneously purchasing as inputs highly R&D-intensive intermediate and capital inputs from other sectors domestically and as imports. R&D intensity indicators for such industries will typically have a low value, while the industries themselves may be technologically sophisticated.

The input requirement coefficients derived from input-output matrices provide a tool for the construction of indicators of *total technology intensity.* These indicators measure the technology intensity in a particular industry by integrating embodied technology measures with measures of the internal R&D carried out by industries to obtain an indicator of combined technology intensity ie by combining direct and indirect (upstream) sources of technology. An approximation of the total technology intensity of a sector can be achieved by assuming that it is a weighted sum of the R&D intensity in all other sectors from which its is purchasing inputs, with the weights being the total input requirements coefficients from these sectors (thus taking into account both direct purchases and second-order effects).

Figure 6 shows the total technology intensities for the 10 OECD countries covered in this study. They are broken down into the part represented by the direct R&D intensity and the part due to indirect R&D inputs, in other words the technology that is acquired through purchases of intermediate and investment goods, domestically and from abroad. The figure suggests that an indicator of the technology intensity of an economy that is based exclusively on the ratio of R&D performed to production is misleading. Acquired technology plays an important role, accounting in some countries for more than the intensity of R&D expenditures.

The contribution of indirect technology inputs to the total technology intensity of economies varies significantly by country. It represents more than half in Canada and Australia, it has about the same weight as direct R&D intensity in Japan, Italy and the Netherlands, and it is a secondary source of technology in the remaining countries. The important role of acquired technology in Japan implies that while its R&D intensity is about the same as that of the US, accounting for indirect technology inputs through diffusion of technology across industries puts the technological sophistication of the country ahead of that of the US. The figure also shows that the increase in the technological sophistication of Japan which took place between 1970 and 1990 came primarily by a more intensive use of technologically advanced equipment and machinery in production, rather than from more intensive R&D expenditures.

Figure 6. Total technology intensities



Source: OECD, STAN Input-Output database.

This picture at the aggregate level is confirmed by examining the total technology intensity of different groups of industries. Table 2 examines the direct R&D intensity and the total (direct plus indirect/acquired) technology intensity of the high, medium and low technology industry groupings in the manufacturing sector. The high technology group has in effect been defined by its intensity of R&D expenditures in the OECD area, so that by definition its direct R&D intensity is higher than that of medium or low technology industries. The spread however between high and medium or low technology industry groups varies by country: it is much lower in Germany and in Japan than in the rest of the countries, pointing to a pattern of R&D effort which is more spread out in both high and medium technology manufacturing industries. Japan in particular has the lowest variance of R&D expenditures, with an R&D intensity in its low technology manufacturing industry group that is significantly higher than that of other countries (higher or almost at par with the R&D intensity of medium technology industries in Italy and Canada).

Table 2. **Direct and total technology intensities for high, medium and low technology manufacturing industries**

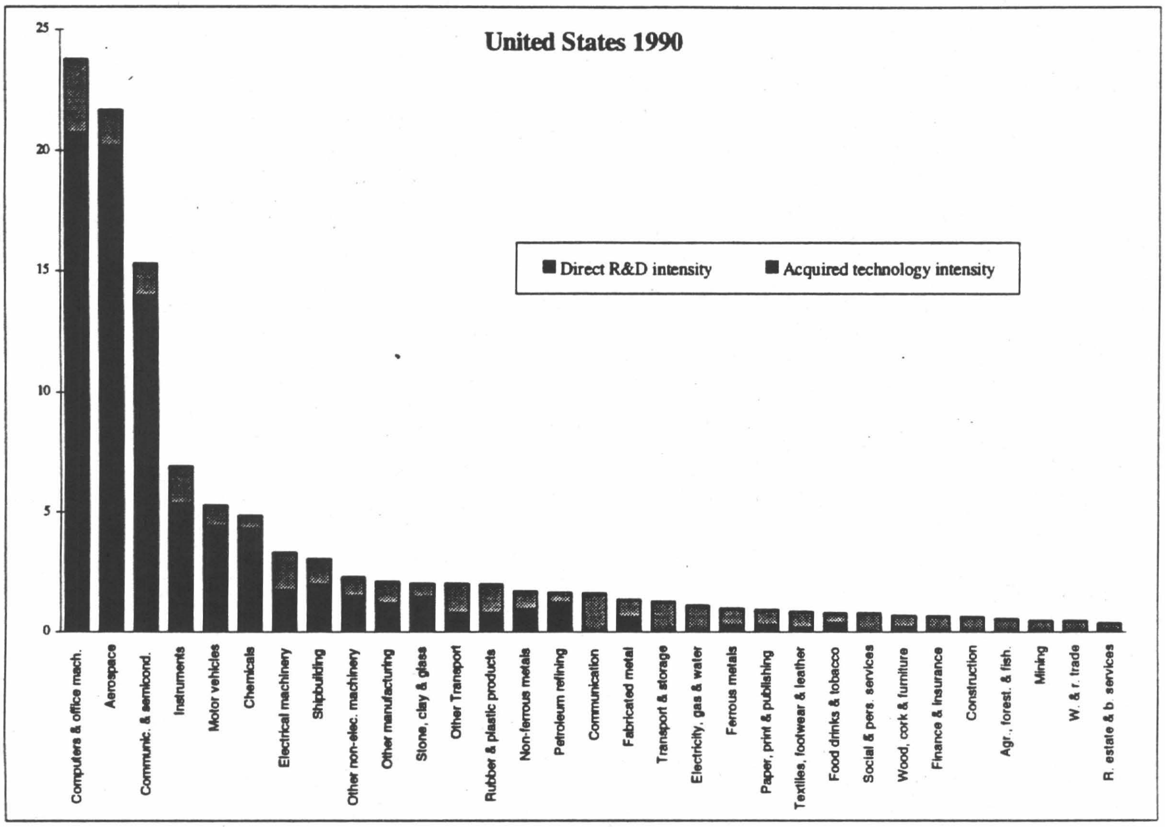
	Direct R&D intensities			Total technology intensities		
	High technology industries	Medium technology industries	Low technology industries	High technology industries	Medium technology industries	Low technology industries
United States 1990	12.3	3.0	0.5	13.9	3.7	1.0
Japan 1990	6.4	3.0	0.8	7.9	4.1	1.4
Germany 1990	7.3	2.8	0.4	8.4	3.8	0.9
France 1990	9.5	2.3	0.4	11.4	3.2	0.8
United Kingdom 1990	9.0	1.9	0.3	11.1	2.7	0.7
Italy 1985	4.2	0.9	0.1	5.4	1.5	0.3
Canada 1990	6.7	0.6	0.3	9.4	1.6	0.5
Australia 1986	5.0	1.2	0.2	6.1	1.8	0.5
Denmark 1990	8.0	2.2	0.3	9.2	3.0	0.7
Netherlands 1986	8.9	2.5	0.3	11.5	3.8	0.7

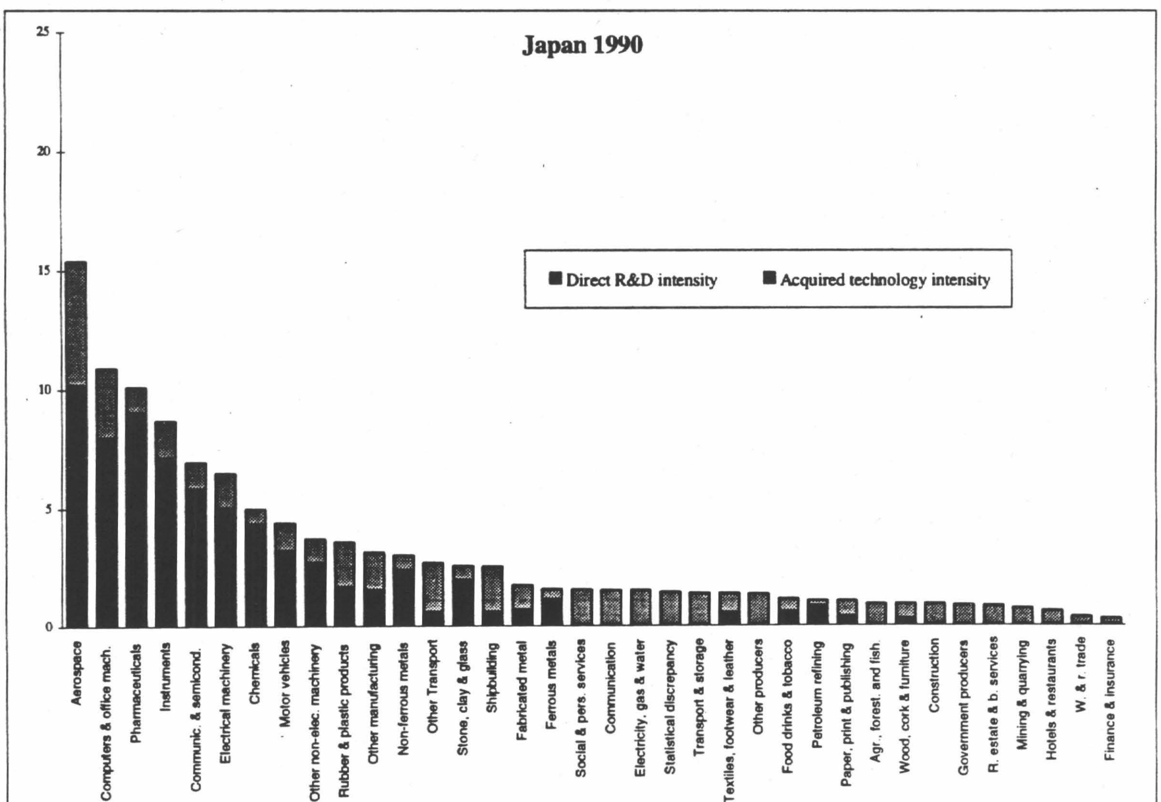
Source: OECD STAN Input-Output database; ANBERD database.

As one would expect, the inclusion of acquired R&D in the total technology intensity measure results in higher technology intensity measures in every industry group. This increase however is not uniform across the three groups or across countries. Medium and low technology industries gain more than high technology ones, bringing the three groups closer together than in the case where only direct R&D intensity is taken into account. Indirect technology acquisition increases substantially the technology intensity of the medium-tech group of industries in Japan, Germany, Canada and the Netherlands. In Japan and Germany in particular, taking account of acquired technology puts the technological intensity of medium technology industries much closer to that of high-technology ones. The technology intensity of the low-tech group of industries doubles in many countries (US, Japan, France, UK) and increases almost three fold in some (the Netherlands, Australia, Canada), but remains low overall.

Figure 7 looks closer at technology generation and acquisition at the level of individual industries by plotting the total technology intensity profiles for the US, Japan, Germany and France. It shows that when accounting both for R&D expenditures and for acquired technology, despite the large flows of technology from manufacturing to services, it is the industries in the high technology manufacturing group that remain the most technologically intensive. Nevertheless, the incorporation of the diffusion aspect makes the technology profile of countries less skewed towards the traditional high-tech industries, with some services industries in the top ten, as in the case of communications services in Germany and France. Furthermore, given that in these calculations the service industries were assumed to undertake no R&D of their own, their ranking is almost certainly underestimated.

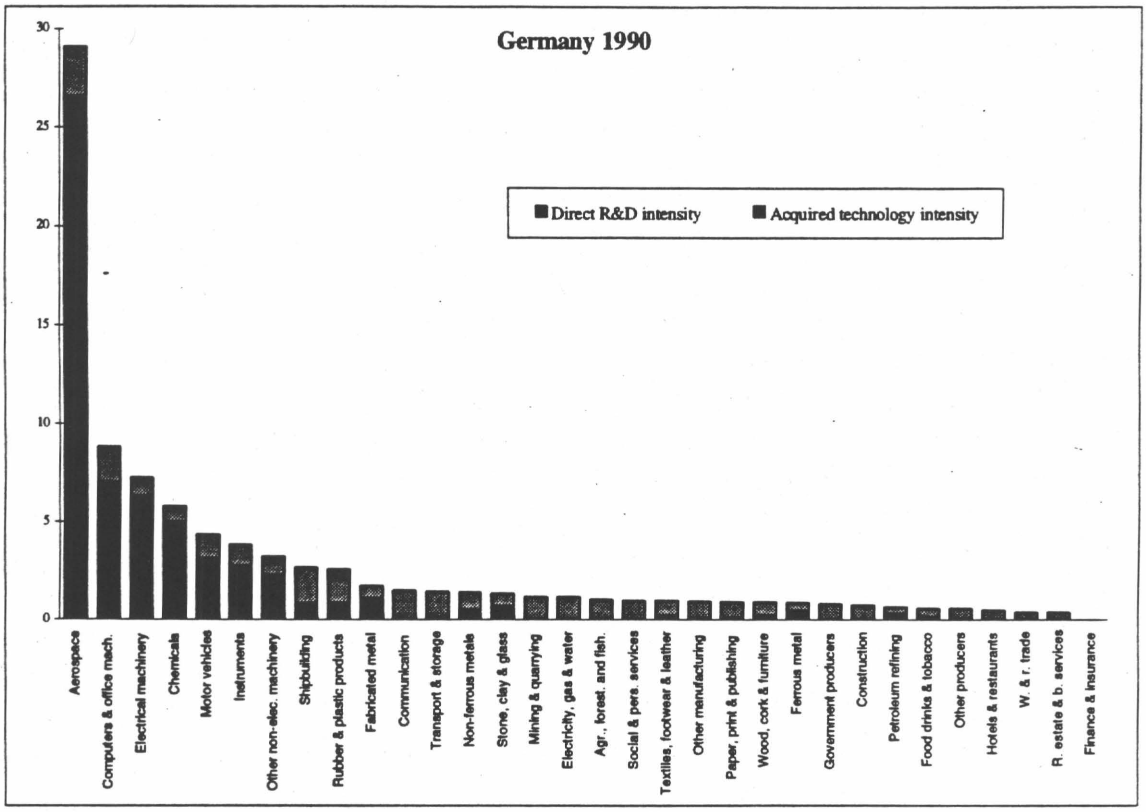
Figure 7. **Technology intensity profiles**

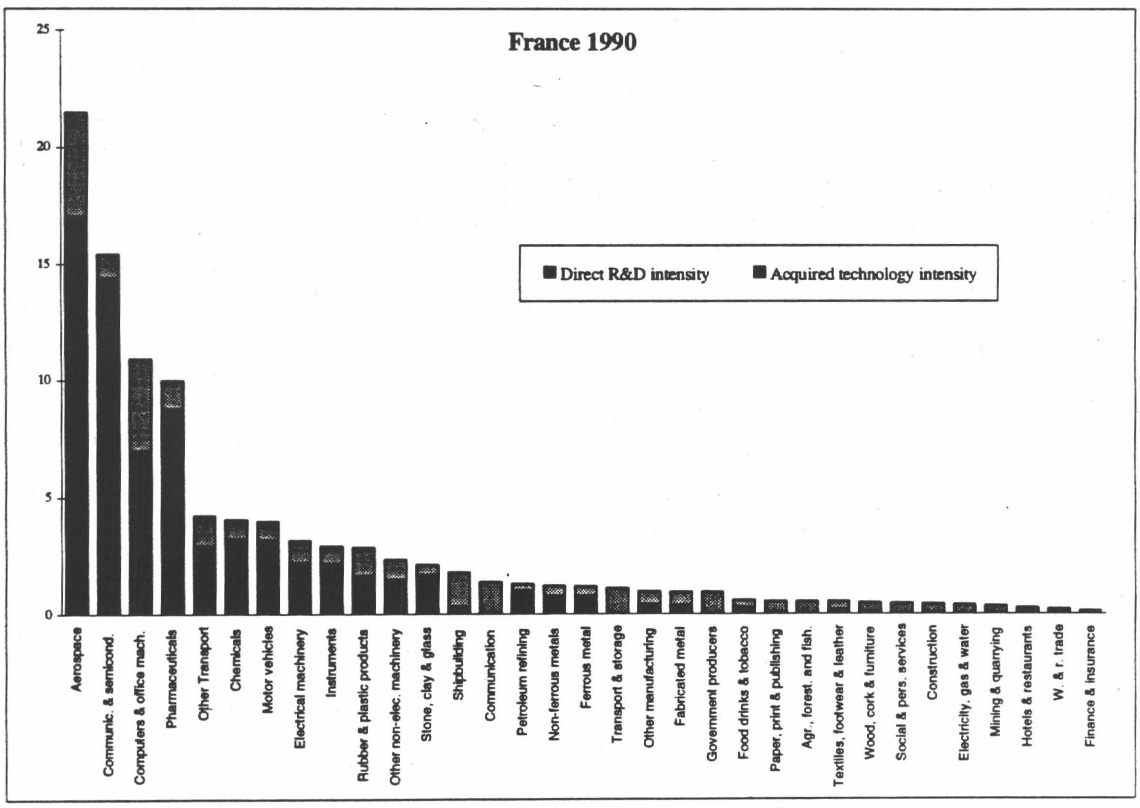




Source: OECD (STI/EAS Division) calculations from Input-Output and ANBERD databases.

Figure 7 (continued). **Technology intensity profiles**





Source: OECD (STI/EAS Division) calculations from Input-Output and ANBERD databases.

CHAPTER 6

TECHNOLOGY DIFFUSION THROUGH CAPITAL INVESTMENT

The importance of capital equipment in technical change

Economic theory has accorded great importance to the role of capital in technical change and economic growth. Much new technology is in fact embodied in the capital goods (machinery and structures) that industries purchase to expand and improve production. Capital investment also plays an important role in the diffusion of technology. As final products, machinery and equipment embody research performed by the manufacturing sector, and other sectors obtain access to most of that research through the purchase of capital equipment (computers, autos, airplanes, etc.) that embodies manufacturing R&D.

The capital embodiment of technology is also important from a policy perspective. When technology is embodied in capital, policies designed to increase capital spending will promote growth not only directly through increased investment but also indirectly through increased total factor productivity. In contrast, if technology is not significantly embodied in capital, then quite different policies related to the free flow of ideas are likely to be more relevant: these include policies related to basic research, the interaction between R&D labs and industry, and intellectual property rights.

International comparisons of long-term economic growth, as well as empirical work on the causes of widely declining productivity in the OECD Member countries, suggests that there is a close association between investment, productivity and growth. The uniting factor is technological change, which uses up capital: in order for technological change to result in greater overall productivity, it must be integrated into the production process through new equipment, which at the same time makes that process more capital-intensive.

Distinguishing whether technology is embodied in capital is thus important. In cases where it is, an increase in investment raises not only the level of output but also long run productivity. Including "quality adjustments" in capital outputs increases measured GNP growth and decreases inflation (part of the price rise in capital output is ascribed to quality improvements rather than inflation). It also increases constant price estimates of investment and of investment's income share. Estimates of the capital stock become sensitive to the rate of technical change and this will have an impact on estimates of capital productivity (Hulten, 1992). The embodiment of technology in capital also allows for non-diminishing returns to capital accumulation, in contrast to standard neoclassical theory but in accord with a substantial body of empirical evidence (Romer, 1990).

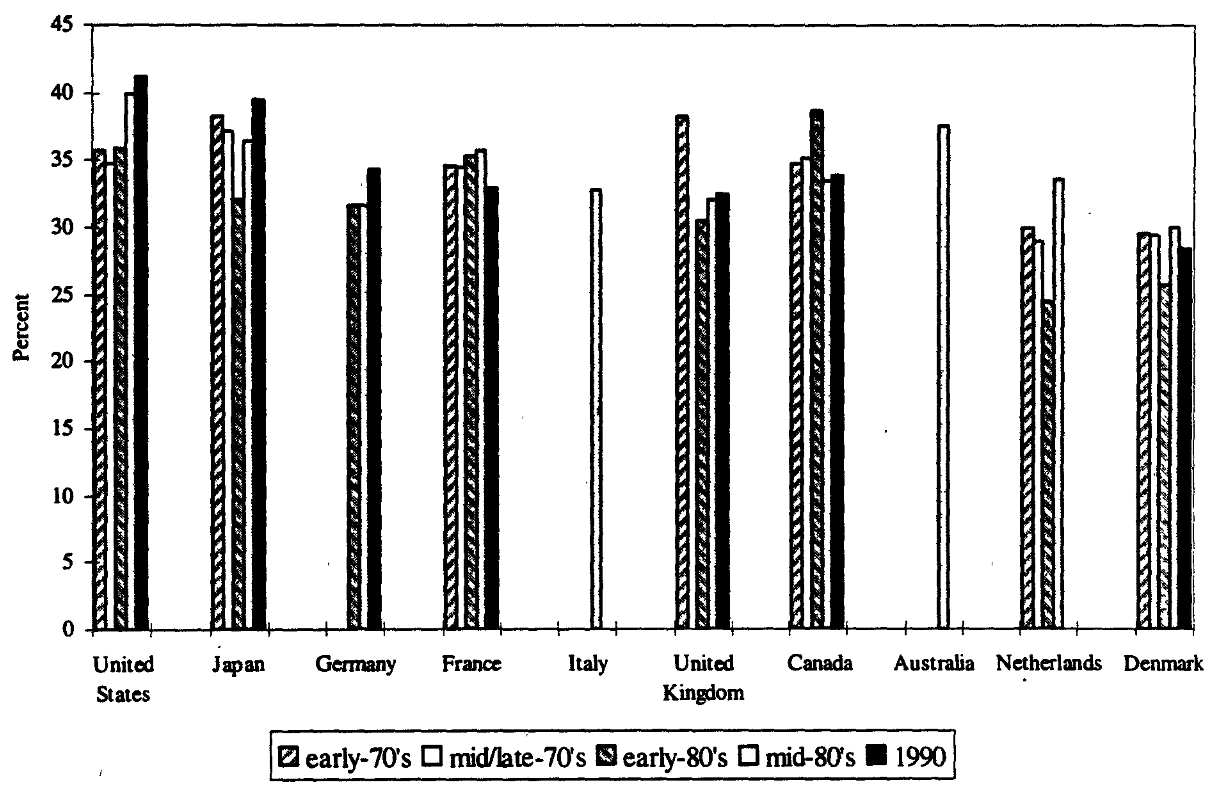
In order to evaluate satisfactorily the role of capital, however, it is necessary to consider the diffusion of technology through intermediate goods as well. Empirical studies of the relative impact of capital and intermediate inputs on productivity have provided very diverse results.[12]

Here, the indicators of acquired embodied R&D developed in this project are used to analyse this controversial issue by investigating the relative weight of technology embodied in purchased capital (investment) and technology obtained from purchased intermediate inputs.

Technology diffusion through investment purchases

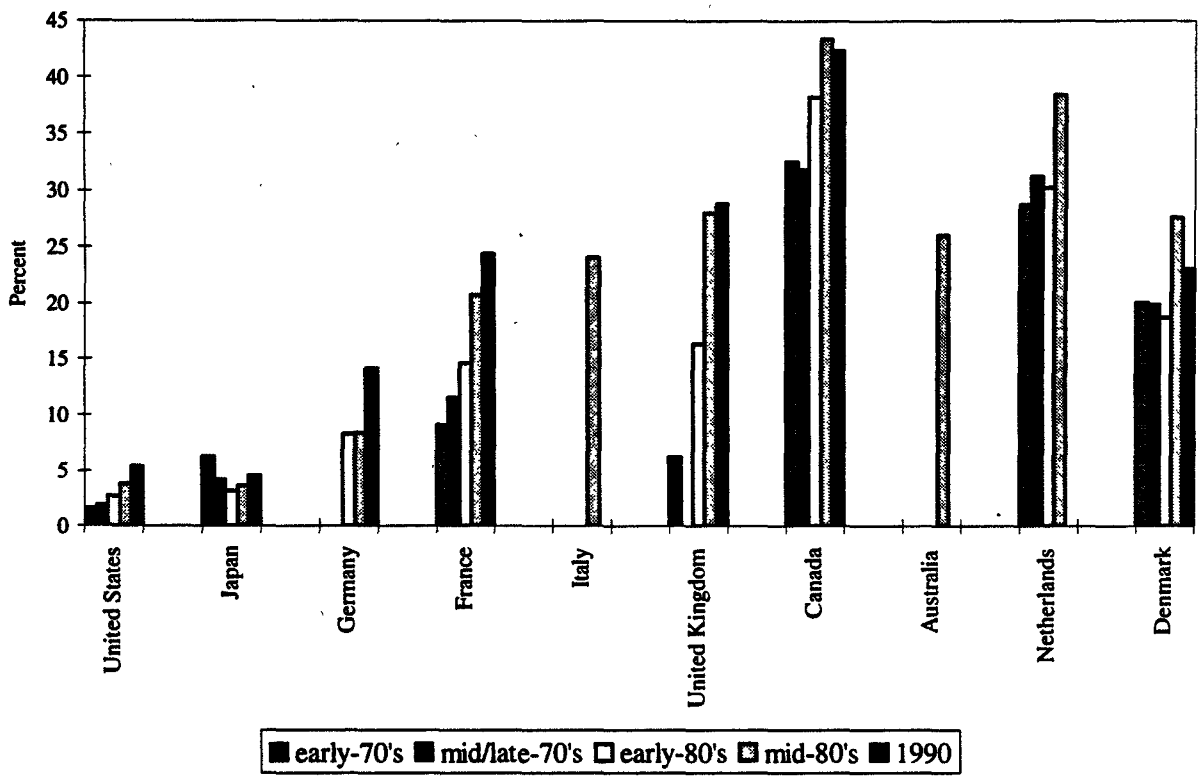
Figures 8 and 9 show R&D embodied in purchased capital goods as a percentage of all technology acquired by the private enterprise sector and by its services segment in the ten countries studied. Although the actual figures may be affected to some degree by cyclical fluctuations in capital formation expenditures, the estimated share of technology acquired through capital investment is well half of the total acquired technology for every country and ranges from 24 per cent in the Netherlands in 1981 to 41 per cent in the United States in 1990. In recent years, the US leads all countries in the diffusion of technology through capital investment.

Figure 8. Share of total acquired technology obtained through investment goods purchases (Total enterprise sector)



Source: OECD calculations (STI/EAS Division) from input-ouput and ANBERD databases.

Figure 9. Share of total acquired technology obtained through imported investment goods
Total private services



Source: OECD, STAN Input-Output database.

After the downturn of the 1970s, the share of technology embodied in capital investment appears to have increased during the 1980s for most of the countries for which periodical data are available. For the United States and Japan, which have a relatively high level of capital investment, the greatest increase occurred during the 1980s, with a particularly large jump in Japan, which saw a rise of 9 percentage points between 1980 and 1990, and an increase of over 5 points in the United States between 1982 and 1990. Growth was also quite high in the Netherlands, with an increase of over 9 percentage points over 1981-86. On the other hand, three countries (the United Kingdom, Canada, and Denmark) have failed to recover their level of the early 1970s.

It is likely that, by virtue of the methodology used, the measurements of technology embodied in capital in this report seriously underestimate the role of capital investment in the diffusion of R&D. Nevertheless, the results tend to confirm that, at the national level, capital investment is an important means of diffusing the R&D conducted by the manufacturing sector. For every country, its share is less than that of intermediate inputs, but if the measurements covered R&D embodied in the capital stock which is actually used in the production process, rather than only current flows of new capital goods (investment), capital would quite probably appear as an even more important factor in the diffusion of embodied technology.

There can be many reasons for differences in capital investment at different periods and in different countries. In addition to the impact of business-cycles and interest rates, in the context of this study they include: sectoral R&D expenditures, changes in the composition of industrial sectors, the mix of intermediate inputs in industries (in the Leontief inverse matrix), the relative weight of intermediate inputs and investment expenditures in each sector, the commodity profile of intermediate inputs and investment expenditures, and dependence on procurement of capital goods from abroad. The remainder of this chapter analyses, at a detailed sectoral level, the underlying factors specific to individual countries and to the different periods.

Annex Table 3 shows, for each of the countries studied, the industries that depend most heavily on capital investment for acquiring R&D. These typically include service sectors, such as communications, finance and insurance, real estate and business services, trade, utilities, and social and personal services. Petroleum refining, because of its capital-intensive nature, is the only manufacturing sector in the list. The table also shows that, by and large, these service sectors are among the industries that invest the most. In most countries, finance and insurance, real estate and business services, and wholesale and retail trade are the biggest investors and their R&D procurement is quite dependent on investment. For communications services, which ranked at or near the top of the list for all ten countries, however, the size of investment is less important than its composition, which is largely information machinery, particularly communications equipment and semiconductors.[13]

For most countries, the technology acquired in the services sector through purchases of investment goods showed a rising trend during the 1980s.[14] The fact that the economic weight of these sectors increased rapidly over this period due to deindustrialisation confirms that their share of capital-based R&D diffusion at the national level has risen over the 1980s. By way of contrast, the bottom panel of Annex Table 3 lists the five industries least dependent on R&D obtained through purchases of investment goods. The list typically includes manufacturing sectors classified as high-technology (aerospace, computers, communications equipment and semiconductors). They mostly obtained external R&D in the form of intermediate rather than investments goods, and their investment expenditures are also a smaller share of total private investment.

For the services sector, the importance of investment as the principal source of technology acquisition from the manufacturing sector is clear. In addition, although in terms of international trade the services sector is usually classified as "sheltered", it may benefit substantially from foreign technology if its imported capital goods have a large amount of embodied R&D. Figure 9 shows the changing distribution of domestic and foreign sources of acquired technology obtained through capital investment between the first and latest year for which input-output data are available for each country.

Dependence on foreign technology through capital procurement has increased since the early 1970s for every country for which information is available except Japan. This increase has been strong, with a share of imported technology that more than doubled in the United States and France and increased by five times in the United Kingdom. This rapid growth indicates that expansion in the services sector's output and investment has played a major role in increased international trade in high-tech products.[15]

It is possible to distinguish between two groups of countries on the basis of their degree of dependence on R&D acquired through imported capital goods. One is composed of the four countries (United States, Japan, Germany and France) for which imports account for less than half of total R&D gains through investment goods purchases. The other consists of those countries for which they are more than half (Italy, United Kingdom, Canada, Australia, Netherlands and Denmark). Although there may be many reasons for such differences, the domestic production base of the first group is large, internationally competitive, and covers most of the range of capital goods purchased by the services sector. That is not the case for the second group.

The preceding discussion of the role of capital investment in the diffusion of manufacturing R&D has various policy implications. First, since investment is the only major source of more sophisticated production systems in the services sector, policies could be directed to facilitating access to equipment containing new technology by lowering the investment costs, promoting further technical change in the high-tech manufacturing sector, and encouraging the volume of investment. The information technology cluster (computer, communications equipment, communications services, finance and insurance, and business services), in particular, has played a increasing role in capital-based R&D diffusion; public policy could therefore ensure that the necessary social infrastructures are made available. The ongoing "information highway" programme and other related plans will help strengthen the links between IT clusters by promoting investment in the sectors involved.

A second policy implication concerns the role of international trade. As the services sector in most European countries has procured a large part of its technology from foreign capital goods, international trade is important, both to the manufacturing sector, which sells its products on the world market, and to the services sector, which buys these products in order to modernise its production activities. Accordingly, from the aspect of technology diffusion, protectionist policies directed against a specific manufacturing sector may have adverse consequences for the services sector which is a major purchaser of those products.

CHAPTER 7

THE ROLE OF IMPORTS IN THE DIFFUSION OF TECHNOLOGY

The policy issues around imported technology

In the technology and industrial policy debate in OECD countries trade issues loom large. Whether in the context of attempting to support "national champions" or when encouraging international collaboration in technology, the question of the importance and role of technology obtained through imports is central to policy discussions. The practice of policy varies widely: some countries are more open to international technology flows than others, but there are many cases where countries have preferred to restrict through the use of "grey-area" trade measures the imports of sophisticated machinery or equipment with the aim of helping domestic producers. US anti-dumping duties on flat-screens displays from Japan aimed at protecting US manufacturers of flat-screens or the EC anti-dumping duties on Japanese floppy disks are examples.

Imported technology is an important channel of technology diffusion, especially for smaller countries and for countries in the European Union that trade heavily with each other. Industrial globalisation has led to a situation where international sourcing of inputs and technology is the rule rather than the exception. In this environment, attempts to favour the development of certain new products or processes in the manufacturing industry by domestic firms through trade restrictions will have as a by-product the increased cost to other domestic firms which rely on having access to the best available component, machinery or materials technology.

In a more general sense, as international sourcing of inputs and technology becomes more widespread, it also becomes more difficult to protect domestic "strategic" firms or industries without adversely affecting other, potentially equally "strategic", firms or sectors. International links are becoming so pervasive that the impact of what has traditionally been identified as trade policy on what has until now been considered as being within the real of domestic policy and vive versa are increasingly complex and intertwined. Thus, from the aspect of technology diffusion, in addition to consumers' traditional welfare costs, the costs of trade protection will include those incurred by producers, in manufacturing and in services, who are sourcing technologically advanced equipment and components from abroad.

Has imported technology become more important?

In the past few years, the pace of international technology transfers has been increasing rapidly, particularly among the OECD countries, making the issue of international technology diffusion particularly important (Nadiri, 1992). Statistics on the technology balance of payments (TBP) among OECD countries relating to trade in licences and know-how are one measure of (disembodied) technology diffusion across borders. They indicate a rapid increase in technology trade, with a substantial increase in the total volume of transactions. (the sum the receipts from technology sales and payments for technology purchases).

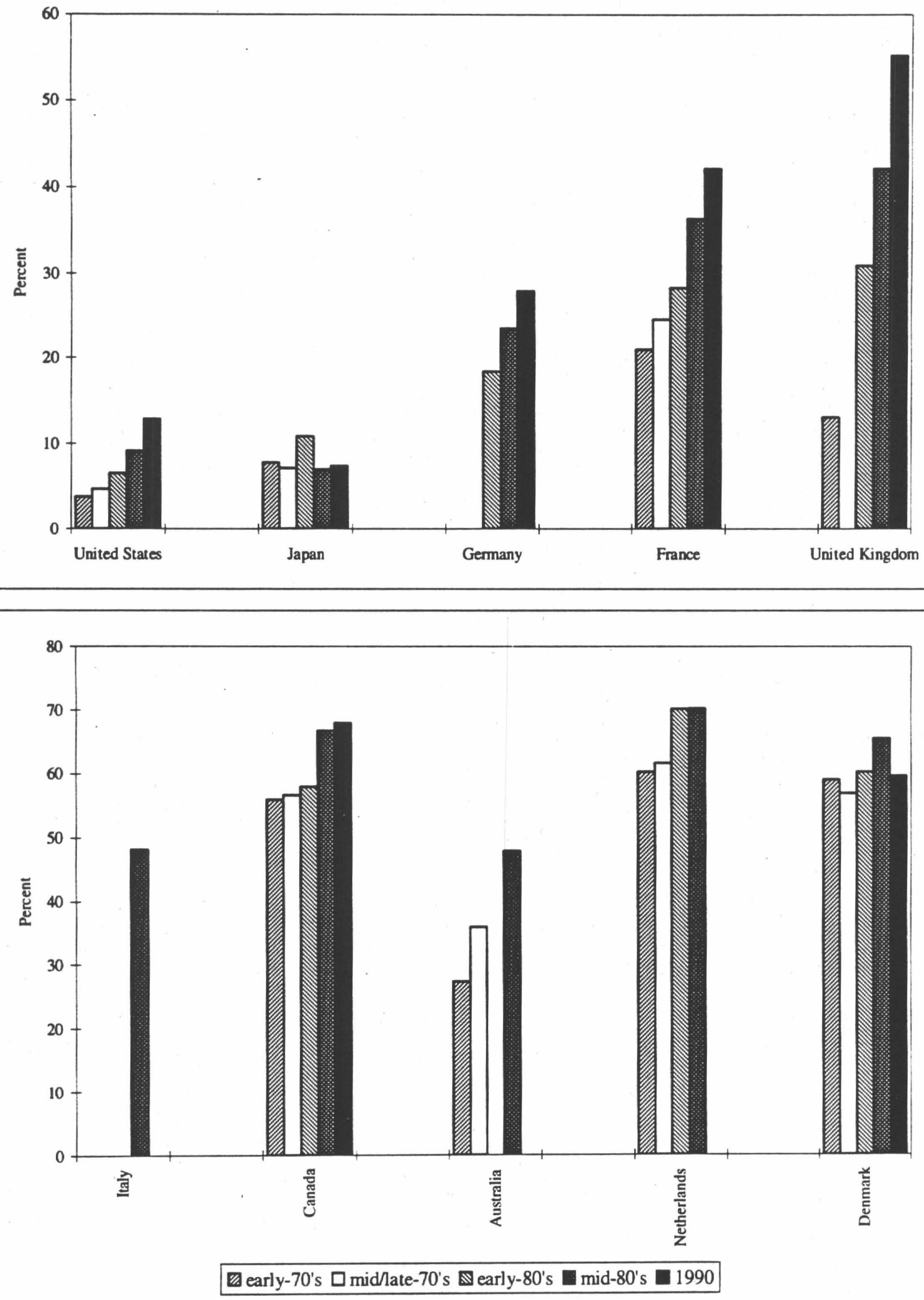
Another measure of interest is the international diffusion rate, calculated as the ratio of the number of external patent applications to the previous year's domestic patent applications. This is a simplistic measure of technological diffusion among countries and suffers from all the shortcomings of patent measures noted earlier. It can serve, nonetheless, as a general indicator of international technology diffusion It shows that, since 1981, the diffusion rate has increased for most OECD countries, and that research-intensive industries, such as electronics, communications, aerospace, and pharmaceuticals, where international expansion is rapid, command the major share of technology trade. Rather than through licensing, technology transfer usually occurs through joint ventures, sales of technology, supply of turn-key plants, etc.

The methodology developed in this report can also be used to examine more closely the international aspect of equipment-embodied technology diffusion. Just as technology can be diffused between industries *within* a country, increasingly it can also be diffused *between* countries embodied in imports of intermediate goods and capital equipment. Figure 10 shows that the share of acquired technology obtained from imports has increased over time for all the countries studied, except Japan. The level of acquired technology obtained from imports is inversely related to the size of the country's economy;[16] this reflects the fact that bigger countries do more R&D, tend to be more self-reliant, and benefit from more extensive linkages among domestic firms, which raises the level of domestically acquired technology. Smaller countries typically depend on imports for over half of their acquired technology. Yet even for the United States, the amount of technology acquired through imports has more than tripled over time.

The growing importance of imports is in keeping with the overall increase in international trade, which has outpaced growth of GDP throughout the OECD area. More specifically, the rising technological content of trade tends to be associated with three interrelated factors: the continued specialisation of technologically sophisticated production (Archiburgi and Pianta, 1992), OECD, 1994a); the need for businesses to recover R&D costs by expanding the market for their products through exports; and the increasing tendency for firms to engage in intrafirm trade with foreign affiliates, even though R&D is still typically performed in the home country (OTA, 1994; OECD 1994f). Although the specific role of these factors is not clear, they help explain why imports are more important for some sectors than for others and why patterns of technology flows between trading partners differ.

Of the countries covered in this report, the United Kingdom and the United States registered the fastest *growth* in technology acquired through imports, while Denmark, the Netherlands and Canada had low growth rates and Japan registered negative growth. In the countries registering a growth in technology acquired through imports, the growth tends to be sector-specific, with two or three sectors typically responsible for the bulk of the gain (Table 3). The most important sectors vary from country to country: the chemicals industry is chiefly responsible for the increase in imported technology in Denmark and the Netherlands, while it is the motor vehicles sector in Germany, and aerospace in the United Kingdom. Imported technology into the social and personal services industry shows up strongly in the case of the US, Canada and the Netherlands. However, for countries with an increase in the share of acquired technology due to imports, two industries frequently appear among the top three: computers and office machinery, and communication and semiconductor equipment.

Figure 10. Share of total acquired technology obtained from imports (Total enterprise sector)



Source: OECD, STAN Input-Output database.

Table 3. **Primary sectors responsible for the change in the import share of acquired technology**

Country	Total Share Change (points)	Primary Sectors Responsible (points)		Share of Acquired Technology via Imports from Key Country of Origin	
Canada (1971-1990)	11.0	5.4	Social & personal services	78	USA
		5.1	Communication & semiconductors	73	USA
		2.1	Computers & office machinery	77	USA
Denmark (1972-1990)	0.8	2.1	Non-electrical equipment	26	GER
		2.1	Chemicals	30	ROO
		0.8	Fabricated metal	29	ROO
France (1972-1990)	18.0	2.8	Computers & electrical machinery	31	USA
		2.7	Aerospace & shipbuilding	49	USA
		2.7	Transport & storage	49	USA
Germany (1978-1990)	8.8	1.3	Transport & storage	45	FRA
		1.2	Motor vehicles	32	ROO
		0.7	Electrical machinery	24	ROO
Japan (1970-1990)	-0.3	0.9	Electrical machinery	62	USA
		0.7	Real estate & business services	74	USA
		0.1	Communication	61	USA
Netherlands (1972-1986)	10.4	2.4	Chemicals	34	GER
		1.9	Electrical machinery	28	GER
		1.4	Social & personal services	26	GER
United Kingdom (1968-1990)	42.2	6.8	Aerospace	63	ROW
		4.9	Social & personal services	23	USA
		4.6	Real estate & business services	25	ROW
United States (1972-1990)	9.1	1.1	Social & personal services	30	JPN
		1.0	Communication & semiconductors	38	DAE
		0.9	Computers & office machinery	45	DAE

Source: OECD, STAN Input-Output database.

Three phenomena help explain why these sectors are important to the increasing role of imports as a mechanism for technology diffusion: 1) they are relatively new technologies; 2) their production structure is more globalised; 3) they originated in relatively few countries, so that international trade was a necessary diffusion mechanism. Each of these assertions are supported by the analysis.

The importance of the two information technology (IT) sectors, computers and communication and semiconductor equipment, as a source of acquired technology embodied in imports is typically most pronounced in the latest period for which data are available. In Canada, over 80 per cent of the total increase for these sectors occurred from 1986 to 1990, in France, more than 50 per cent from 1982 to 1985, in the UK more than 50 per cent from 1979 to 1984, and in the United States just under half from 1985 to 1990.

Recent case studies of these sectors indicate that in order to gain market access and enter into alliances so as to share the rising costs of R&D in this field, IT firms have "globalised" to a much larger degree than other sectors. This has meant a much higher level of exports and imports per unit of production. Two-thirds of this trade was intrafirm trade of semi-finished parts between corporate affiliates located in different countries (the average in manufacturing is one-third).

Aside from the US imports from the dynamic Asian economies (DAEs), the United States is the leading source of this technology for the other countries, with the second largest supplier never reaching 60 per cent of the US share. Given the concentration of this technology, trade is the primary mechanism for its diffusion.

Domestic vs. imported acquired technology

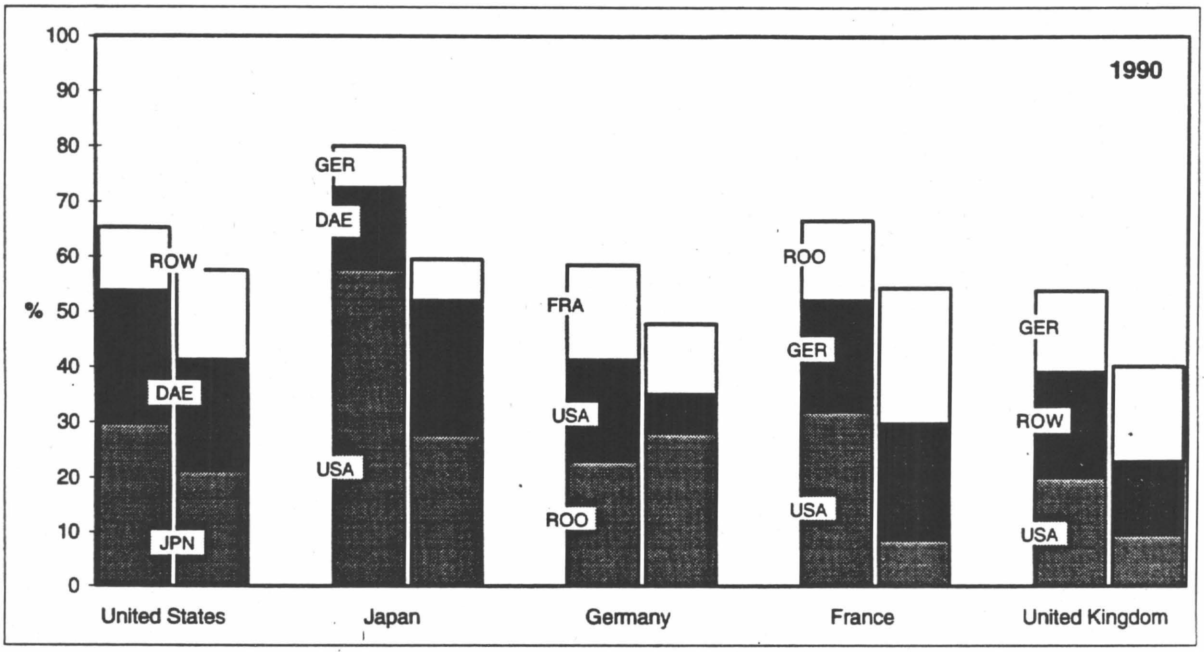
The importance of imports as a means of acquiring technology becomes apparent when their effect on technological intensity is compared to that of domestic sources. Imports were more important overall than domestic sources in Canada, the Netherlands and Denmark, while in Australia and Italy, the two sources were about equal (Annex Table 4). Only in the United States, Germany, and Japan were domestic sources more than twice as important as imports. Again, the influence of imports on the technological intensity of a sector is inversely related to the size of the economy. In small countries such as Australia, Denmark, and the Netherlands, imports are the major source of acquired technology in over 90 per cent of the top five sectors, while for the United States, Germany, and Japan they are in only 20 per cent. However, for aerospace and for computers and office equipment, the importance of imports exceeds or equals domestic sources of acquired technology in almost every case.[17]

When analysed over time, in five out of eight countries changes in the technological intensity of all industries were overwhelmingly due to imports; they were due about equally to domestic sources and to imports in two (Germany and the United States). Only in Japan were domestic sources of acquired technology significantly more important than imports. By and large, the impact of imports was most pronounced in the period extending from the mid-1980s to the late-1980s or 1990. Of the sectors where technological intensity fell over time, two-thirds of the drop was due to a decline in technology acquired from domestic sources, most often during the period from the early 1970s to the mid- or late-1970s.

Who sources imported technology and from whom?

The United States is responsible for almost half of the R&D performed by manufacturing industries in the OECD area, and is also the most important source of technology acquired through imports (OECD, 1994b). From a high of 75 per cent of all technology acquired through imports by Canada to a low of 28 per cent by the United Kingdom, the United States was the most important source of acquired technology for five of the other nine countries (Figure 11 and Annex Table 5). The share of technology acquired through imports from any one country varies widely. Canada and Japan are the most dependent upon a single country and Italy is the least.

Figure 11. **Share of imports by country of origin**



Note: The left column represents the share of imports based on technology content,
the right column represents the share of imports based on currency value.
ROO: Rest of OECD; ROW: rest of the world.
Source: OECD, STAN Input-Output database.

For the five industries that gained the most technological intensity from acquired technology, the United States was the most important supplier for 60 per cent of the sectors; for the aerospace and computers sectors, which figured among the top five in almost all countries, the US was the main source for eight of the nine other countries for aerospace technology and for all eight for computer technology. For the United States, the DAEs are the main source of technology acquired through imports for the five industries which benefit the most from acquired technology, but Japan is the largest overall source of acquired technology. This suggests that while Japan is not the principal source for the top five industries, it supplies large quantities of technology of a type which is commonly considered medium or low technology, such as motor vehicles, ferrous metals, and stone, clay, and glass.

While the United States is a large performer of R&D and a centre for particular types of technology, its predominance as a supplier of technology embodied in imports might simply reflect the fact that it is the largest economy in the OECD area and has the second largest export market share among the countries studied (OECD, 1994a). Is its role as a supplier of technology disproportionately large?

In order to answer this question, Annex Table 5 provides a list of the three largest suppliers of technology for each country and the share of this trade valued in US dollars. The United States was the primary source of technology acquired through imports and among the top three suppliers to each of the countries in the sample. Germany was in the top three for six countries. Surprisingly, Japan was among the top three for only three countries, all of which border on the Pacific: Australia, Canada, and the United States. By and large, these flows reflect general trading relationships between countries. Australian technology imports from Japan roughly match Australia's overall share of imports from Japan; based on the currency value of trade, the share of technology imports divided by the share of imports gives a ratio of one (col. 5 of Annex Table 5). This indicates that trade between these two countries is technologically neutral: it is not skewed towards products with a high technological content (technology-positive), nor is it composed mainly of items embodying little technology (technology-negative).

The US is the exception to this rule. Exports from the United States to the other nine countries consistently are technology-positive, with the share of technology usually twice the share of value. The only other cases of technology-positive trade are German imports from France, UK imports from the "Rest of the World" (RoW) group of countries and two of the three major trading partners of the US: Japan and the DAEs. Paradoxically, the United States not only provides a disproportionate share of technology in its trade with other countries, but it also receives a disproportionate share.

CHAPTER 8

TECHNOLOGY CLUSTERS: THE TYPES OF TECHNOLOGY ACQUIRED

While it is important to know whether technology is acquired from intermediate goods or capital goods or from imports or domestic sources, the most fundamental distinction concerns the type of technology being diffused. Identifying which technologies are being acquired and which are not and how trends change over time and differ among countries can give insight into the diffusion process which has implications for diffusion policies. As previous chapters have shown, industries do not all have the same propensity to acquire technology: some are self-sufficient, some rely on technology developed by others. What is the relation between these differences and the types of technology being acquired?

The evidence presented in this chapter suggests that of all the technologies currently diffusing in OECD countries, the information technology cluster is by far the most rapidly growing and most pervasive. This has several implications for diffusion policies, the first of which is the need for such policies to address all sectors, especially services. Typically, government programmes for diffusing technology concentrate on transferring technology to the manufacturing sector. Services however -- such as finance, insurance, and real estate, wholesale and retail trade, and communication services -- are also important acquirers of technology.

The second broad implication is that not all technologies should be given the same priority when it comes to diffusion; some have a wider application than others. Given limited resources, the first priority of diffusion programmes should be to diffuse the technologies which answer the needs of many sectors. Technology policy thus needs to pay particular attention to the network characteristics of IT, and to the potential of realising economy-wide gains from its widespread application. This implies encouraging the creation of networks of firms and encouraging public institutions to facilitate the generation of future IT applications. It also implies the development of market-driven rules for standard-setting, and liberalising telecommunication markets with the aim of increasing incentives for technology adoption and diffusion.

What types of technology are being diffused?

In order to describe the relative importance of different types of technology and to examine which sectors acquire which technologies and how trends differ over time and across countries in a comparable manner, five "clusters" of similar technologies have been defined in this report: information, transportation, consumer goods, materials, and fabrication. (Box 2 shows the various sectors included in each of these clusters.) The industries in each of these clusters share a number of common characteristics. As has been noted before, technology is represented here by the R&D embodied in intermediate inputs and capital equipment produced by the manufacturing sector exclusively; the *source* for all acquired technology and of all technology clusters are defined here is therefore, by definition, the manufacturing sector.

Box 2. Cluster Classifications

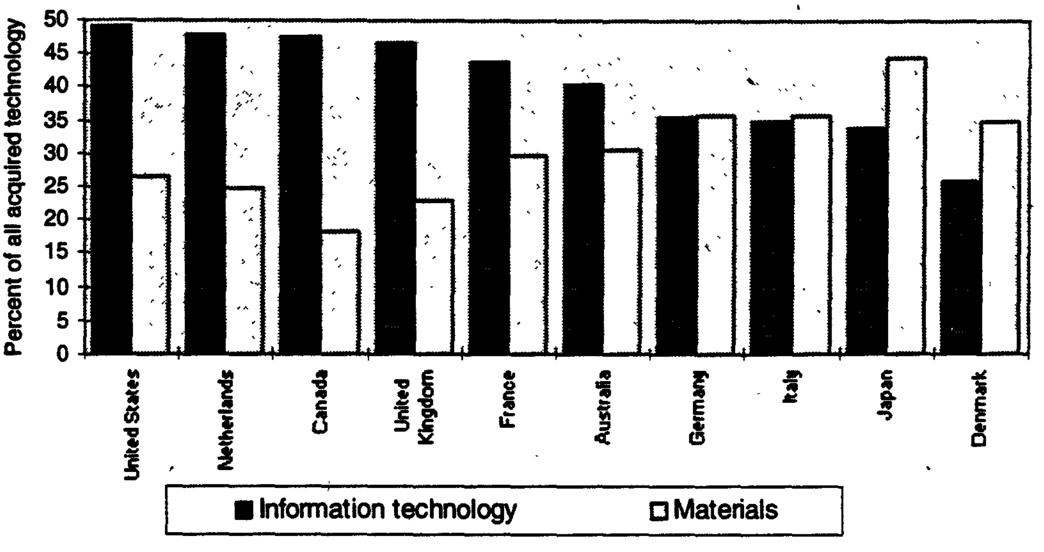
Cluster	Industry
INFORMATION	Computers, Communication & Semiconductor Equipment, Electrical Machinery, Instruments
TRANSPORTATION	Shipbuilding, Aircraft, Motor Vehicles, Other Transportation
CONSUMER GOODS	Food, Bev. & Tobacco, Textiles, Apparel & Footwear
MATERIALS	Agriculture, Construction, Mining, Paper & printing, Wood products, Stone, clay & glass, Ferrous metals, Non-errous metals, Chemicals, Pharmaceuticals, Petrol. Refining, Rubber & Plastics
FABRICATION	Fabricated Metal Products, Other non-electrical machinery, Other manufacturing

Previous chapters have showed how technology is acquired not only by manufacturing industries, but also by firms in other sectors, and especially in services. For ease of presentation and to improve comparability across sectors, the *acquiring* sectors have been aggregated into 13 broad groups: 1) agriculture; 2) mining; 3) low-technology manufacturing; 4) medium-technology manufacturing; 5) high-technology manufacturing; 6) electricity, gas and water (EGW); 7) construction; 8) wholesale and retail trade and hotels and restaurants; 9) transportation services; 10) communication services; 12) finance, insurance, and real estate (FIRE); and 13) social and personal services. This allows a mapping of the different sources of technology (clusters) to the different parts of the economy where they are used.

Figure 12 shows that for six of the ten countries, information technology (IT) made up the bulk of the technology being acquired, with over 40 per cent of all acquired technology for these countries in the most recent period. For the United States, the Netherlands, and Canada, IT has historically been the most important technology acquired, while this has only recently been the case for France and the United Kingdom. The importance of IT has increased for seven of the eight countries for which there is more than one data point. It is by far the fastest-growing acquired technology, averaging over a percentage point gain in share per year for the countries for which historical data are available.

With one or two exceptions, the shares of the other clusters either held steady or declined over the period. Nevertheless, they are important shares of total diffused technology. Material technologies -- chemicals, basic metals, and rubber and plastics -- were the most important acquired technologies for Japan and Denmark. This cluster was also important in Germany and Italy, where it shared first place with IT. It was the second most important cluster for six of the remaining countries, averaging about a quarter of total acquired technology. However, it is the technology whose share has fallen the most, averaging over a percentage point loss in share annually.

Figure 12. Share of acquired technology from information technology and materials industries



Source: OECD (STI/EAS Division) calculations from input-output and ANBERD databases.

The third most important technology cluster was the transportation group (aerospace, motor vehicles, and shipbuilding), which typically provided about a fifth of total acquired technology; it has remained quite stable over time. The fabrication technology cluster, consisting of fabricated goods such as stamped sheet metal and non-electrical machinery such as machine tools, represented about a tenth of all acquired technology. The consumer goods technology cluster, which includes technologies associated with textiles and apparel and food processing, played a small role, contributing only 1 or 2 per cent of the total.

Flows of technology from different technology clusters to various acquiring sectors

As Figure 12 shows, information technology makes up over 40 per cent of acquired technology in most countries and is the only technology with a consistently increasing share over time. Where does this technology go? Which sectors of the economy are the main users of IT, and which of other types of technology?

In the mid-1980s and in 1990, there is a clear pattern of flows of technology from different clusters to various acquiring sectors. To show the differences in these flows, an index of disproportionality of use was created by dividing the share of a particular technology acquired by each sector by the average for all sectors. Thus, if the high-technology sector obtained 75 per cent of all its acquired technology from IT and the average across all sectors was 47 per cent, the index would be 1.6 (75/47). Sectors with an index above 1.0 would be disproportionately high acquirers of that technology cluster, while those under 1.0 would be disproportionately low acquirers. Using this filter, Annex Table 6 aggregates each sector's principal acquired cluster technology with their corresponding index of use. The table shows that certain types of technology tend to gravitate towards certain sectors:

- IT towards high-technology manufacturing, communication services, and FIRE;
- transportation towards transportation services;
- consumer goods towards wholesale and retail trade;
- materials towards agriculture, low- and medium-technology manufacturing;
- fabrication towards mining, EGW, and construction.

In addition, the table shows two other trends. First, these links exist, by and large, in all countries. For the IT cluster, all of the countries had an index above 1.0 for the three sectors, and the same was true for most of the clusters. Only in a few instances, such as the acquisition of consumer goods technology by wholesale and retail trade in Australia and Denmark, did the index fall below 1.0. Thus, the linkage between the type of technology being diffused and the sector acquiring the technology holds regardless of country.

The second trend is reflected in the average index. Some technologies, such as IT and materials, are more evenly distributed than others, such as transportation and consumer goods, and therefore have a lower average disproportionality index. This reflects the fact that these technologies are more commonly used over a wider cross-section of industries. Transportation technologies, such as aerospace, are less general and are typically used only by the transportation services sector (airlines) and therefore have a much higher disproportionality index.

A final point relates to the importance of imports as a means of diffusing different technology clusters. For each country and cluster, Annex Table 7 compares the share of total acquired technology to the share of imported acquired technology. If the technology is trade-neutral, the cluster's share of imports should match its share of the total, resulting in a ratio of import share to total share of 1.0. If a disproportionate amount of acquired technology comes from imports, the ratio would exceed 1.0. The table shows that, for most countries, information and transportation technology clusters tended to be imported. This was especially true for transportation technologies, as all ten countries obtained a disproportionate amount of this technology from imports. On the other hand, the materials and consumer goods technology clusters were disproportionately domestic, with only one or two countries obtaining a greater share of acquired technology from imports. Finally, the fabrication technology cluster was very mixed, with about half of the countries favouring imports as a source of this technology.

NOTES TO PART 1

1. Levin *et al.* (1987) provide information based on evidence from surveys on the importance of various channels of knowledge transmission.
2. Research spillovers have been defined to include "any original, valuable knowledge generated in the research process which becomes publicly accessible, whether it be knowledge fully characterising an innovation, or knowledge of a more intermediate sort" (Cohen and Levinthal, 1989). Griliches (1993) and Nadiri (1993) provide surveys of the impact of research spillovers.
3. The aim was to link data on patents, which are function-oriented (*i.e.* they group inventions that employ similar engineering concepts or ideas), with data on economic variables, which are industry-oriented. To do so, they used the industry-of-origin (IIO) and industry-of-use (IOU) codes assigned to all Canadian patents in order to generate two concordances: one between the International Patent Classification (IPC) code and the industry of origin code and one between the IPC code and the industries of use codes. This makes it possible to obtain an estimate of the total number of patents (*i.e.* of technology flows) by origin and use in each industry.
4. DeBresson *et al.* (1994) found that their innovation matrix exhibits a pattern similar to that of intermediate flow (domestic and import requirements) input-output matrices. They concluded that input-output analysis is useful for identifying the location of economic activities in economic space and that the location of innovative activity is structured in a way that is statistically related to economic activity.
5. See for example Terleckyj, N. (1974), "Effects of R&D on the Productivity Growth of Industries: An Exploratory Study", (Washington D.C: National Planning Association); Scherer, F.M. (1982a), "Interindustry Technology Flows in the United States", *Research Policy*, 11, pp. 227-245, March; Davis, A.L., (1988), "Technology Intensity of U.S., Canadian and Japanese Manufactures Output and Exports", U.S. Department of Commerce, International Trade Administration, June.
6. To illiustrate the simplest version of the input-output scheme, assume that industry *i* undertakes $100 of R&D and sells $400 of output; $300 to industry *j* and $100 to industry *k*. As a first approximation, industry *j* is assumed to acquire $75 (ie $300/$400) of external technology from industry *i* and *k* to acquire $25. The assumption is that the "amount" of technology acquired is *proportional* to the quantity of goods purchased. Industry *i* itself however purchases some of the output of industries *j* and *k*, and this feedback loop, characteristic of input-output schemes, implies that industry *i*'s output embodies not only its own R&D but also some part of the R&D undertaken by industries *j* and *k*. Inversion of the input-output matrices captures the effects of this feedback loop and yields a consistent solution for the inter-industry flows of embodied technology. A fundamental conclusion is that the aggregate technological level of an economy, reflecting the total amount of technology in use by all industries, increases with increasing inter-industry linkages. With increasing technology diffusion industries benefit more from the R&D undertaken in other industries.
   Alternatively, it is possible to use R&D intensities rather than raw R&D expenditures (ie to normalise the technology flows by an industry's output. To illustrate the R&D intensity input-output scheme, assume that *j* is a second supplier industry which undertakes $150 of R&D and sells $300 of output; $100 to *i* and $200 to *k*. Each unit (dollar) of output of supplier industry *j* "embodies" $0.5 of its own R&D while that for *i* embodies $0.25 (ie $100/$400). These represent the own-R&D intensities of the supplier industries. Now assume that purchasing industry *k* in producing a unit of its own output uses $0.3 of the output of *i* and $0.1 of the output of *j*: these are the direct requirements coefficients for *k*. If *k* also itself undertakes $0.2 of R&D per unit of its own output, then a first approximation of its total own-plus-embodied R&D per unit of output will be $0.2+($0.25 x $0.3)+($0.5 x $0.1)=$0.325. As in the case where R&D expenditures are used directly, there is an embodied R&D feedback loop and inversion of the input-output matrices yields a consistent and higher figure for the embodied R&D per unit of output of industry *k*. The total R&D intensity of industry *k* is thus a weighted sum of its own R&D intensity and the R&D intensities of the industries from which it purchases inputs.
7. The Leontief inverse matrix gives the total (direct and indirect) input requirements per unit of final demand. It is defined as $B=[b_{ij}]=(I-A)^{-1}$ in the solution to the system $X=(I-A)^{-1}Y$, where X is the vector of gross output by

industry, I is the identity matrix, Y is the vector of final demands by industry, and A is the direct requirement matrix whose element a_{ij} is the quantity of output of sector i absorbed by sector j per unit of its output X_j, ie $a_{ij}=X_{ij}/X_j$. Thus the element b_{ij} of the Leontief inverse matrix B (also called a final demand-to-output multiplier) indicates by how much the output of industry i would need to increase in order to satisfy a one-unit increase of the *final demand* of industry j (Y_j). Since the output of industry j increases by more than one-unit in this propagation process, this matrix is applicable for the calculation of investment-based R&D indicators, but not suitable for defining the R&D contained in the output of industry j. In order to avoid overestimation of the R&D content of industry j as well as to clearly separate the direct and indirect R&D content, a modified version of the Leontief inverse matrix is calculated for this project, whose element b^*_{ij} indicates by how much the output of industry i would need to increase in order to satisfy a one-unit increase of the *gross output* of industry j (X_j) -- an output-to-output multiplier. See Leontief, W. (1986), *Input-Output Economics*, Oxford University Press, Ch.2, and Miller, R. and Blair, P. (1985), *Input-Output Analysis: Foundations and Extensions*, Prentice-Hall, p.328.

8. Thus, if the French car industry imports steel from Germany and the UK, the R&D intensity of the imported steel used for the construction of cars in France will be the sum of the German steel R&D intensity weighted by the share of steel imports from Germany in total steel imports of the French car industry and the corresponding figures for the UK.
9. These assumptions are discussed in more detail in OECD (1992), *Structural Change and Industrial Performance*, OECD Document Series.
10. The reader is alerted to the fact that despite substantial efforts to make input-output tables fully comparable across countries, some comparability problems remain and are likely to influence the results. Thus, the government producers sector is separately identified in most but not all countries (France, Japan, Germany, Canada, Australia, Denmark, the Netherlands). The same is true for some countries for an industry category called other producers.
11. According to the survey done by BLS (1989), Terleckyj (1974) reported separate significant effects for research contained in capital and research contained in materials for manufacturing industries; however, the capital effect was very much greater. In non-manufacturing, research embodied in materials had an effect but, surprisingly, research contained in capital did not. Subsequently, Sveikauskas (1981) and the regressions based on the largest sample in Scherer (1982b) report extremely high returns for purchased capital, but none for intermediate inputs (materials), yet other regressions in Scherer's work find significant positive effects for purchase of research through materials. Moreover, Griliches and Lichtenberg (1984) conclude that the influence of R&D embodied in purchases from other sectors is "weak and unstable over time". Finally, Terleckyj (1984) dropped out the research-through-capital variable once an industry's own research was introduced.
12. For example, 68% of investment done by the US communications sector in 1990 was the purchase of communication equipment and semiconductors, while the percentage was only 12.6% for industry as a whole. Although the level of this share is much lower than the United States, the purchase of information components in communication investment also constituted a large portion in other countries (43% in France, 40% in Italy, 38% in Japan).
13. The share of capital-embodied R&D in total acquired technology for the entire services sector (including utilities and construction) has increased by 9.1 percentage points for the United States (1982-90), 12.5 for Japan (1980-90), 2.7 for Germany (1978-86), 3 for France (1977-85), 2.7 for the United Kingdom (1979-84), 4.9 for Canada (1981-90), 4.4 for the Netherlands (1977-86) and 6.3 for Denmark (1977-90).
14. See for example papers in OECD (1993) *STI Review* No. 13.
15. The Spearman's rank correlation coefficient between the size of the economy and the share of acquired technology obtained from imports is 0.94. The 1991 ranking of the ten countries, on the basis of billions of US dollar purchasing power parities (PPPs) is: 1) United States (5 610); 2) Japan (2 349); 3) Germany (1 344); 4) France (1 036); 5) Italy (974); 6) the United Kingdom (900); 7) Canada (521); 8) Australia (285); 9) the Netherlands (248); and 10) Denmark (91).
16. Exceptions include computers and office equipment in Japan and aerospace in the United States.

Part II

PRODUCTIVITY

CHAPTER 8

TECHNOLOGY DIFFUSION AND PRODUCTIVITY TRANSFER

Introduction

The relationship between technological change and productivity has attracted a great deal of attention among economists and policy makers reflecting an increasingly widespread view that technological change is a major driving force behind long-term economic growth. It is by now well recognised that the productivity benefits from successful innovations are not fully appropriated by innovating firms but instead diffuse through the rest of the economy, ultimately contributing to rising levels of productivity and standards of living in the economy as a whole.

Part I of this report broadly demostrated that technology acquisition through the purchase of R&D-intensive intermediate inputs and capital goods are often as important as their own research and development, in particular for the services sector whose major source of technology is through the purchase of R&D-intensive investment goods from domestic or foreign suppliers. The next step in the analysis is to examine the role of technology diffusion alongside R&D expenditures in explaining medium-term productivity growth.

A number of papers have already addressed the technology and productivity nexus in various ways. Many studies have used embodied R&D in order to examine the possibility that a slowdown in the generation or diffusion of new technology has contributed to the post-1973 productivity slowdown or to disentangle the effect on an industry's productivity of direct R&D expenditures, as distinct from the effect of indirect R&D embodied in products domestically and from abroad, or for obtaining measures of the marginal productivity of R&D expenditures or of the rate of return to R&D investment.

The report examines empirically the relationship between performed and acquired R&D and productivity, and addresses two questions on the technology-productivity relationship:

- The potency of R&D and structural change in the technology and productivity nexus: has the link between R&D variables and productivity become continuously weakening during the 1970s and 1980s? If this is true, it may partly explain the so-called "productivity paradox", i.e., why productivity growth has slowed since the early 1970s against the public belief that OECD economies are in the midst of a major wave of technological change.

- The relative importance of performed R&D and equipment-embodied technology: have large technology flows from manufacturing to service sectors contributed to their productivity performance? have international R&D spillovers accelerated in terms of other countries' productivity gains from imports of R&D-intensive products over the last two decades?

The picture that emerges from the empirical work in the two chapters that follow lends some support to the idea that developments in technology and productivity growth have been unbalanced across sectors in OECD economies. Productivity gains from R&D and its diffusion were reaped at least until the last decade in very localised industrial groups: the machinery sector in manufacturing, and ICT services; in other words the ICT cluster. R&D investment and embodied R&D had a significantly positive impact on TFP growth in ICT industries.

R&D performed in these industries was diffused across sectors raising productivity in other industries who bought R&D intensive products as inputs into their production process. Because of the technological closeness among these sectors relative to other clusters of industries, new technologies developed by ICT manufacturers through their own R&D efforts were easily transferred into ICT services industries and enhanced their productivity growth. In contrast, positive impacts of diffusion of new technologies were not realised in other clusters because of technological distance, regulations and long lags to optimally organise new technologies in production systems.

Technology diffusion and productivity transfer

An examination of the link between technology and productivity growth has often provided the impetus for attempts to create measures of disembodied or equipment-embodied technology. Many studies have used embodied R&D in order to investigate whether a slowdown in the generation or diffusion of new technology has contributed to the slowdown in the growth of total factor productivity (TFP).[1] Other studies have focused on disentangling the effects of direct R&D expenditures and of indirect R&D embodied in products on an industry's productivity, or on obtaining measures of the marginal productivity of R&D expenditures or of the rate of return to R&D investment.[2]

Studies that focus on the effects of technology diffusion on productivity strongly support the argument that the productivity of industries often depends more on technology developed elsewhere than on own innovation. The results of early work on the United States by Terleckyj (1974) indicated that the rate of return to R&D embodied in goods purchased from other industries was almost twice the rate of return to own R&D; these results were confirmed by subsequent work on other countries, which also showed strong interindustry differences. Griliches and Lichtenberg (1984), for example, found that for a sample of 193 US manufacturing industries, R&D embodied in purchased inputs had a greater impact on TFP growth than a firm's own (process and product) R&D.

An OECD study based on data for 16 industries in six countries from about 1970 to 1983 found that in order to understand TFP growth at the industry level, it is important to look at both the industry using the new technology and the industry creating it. It also found wide discrepancies in the flow of new technology into industries, with non-manufacturing benefiting less than manufacturing (Englander *et al.*, 1988). The study showed that, within manufacturing, the chemicals and machinery industry groups, with a heavy concentration of R&D and most of the high-tech industries, show very strong TFP growth in response to R&D diffused from other industries (as well as to their own R&D expenditures).

As noted above, technology developed in one industry may affect productivity in others without transactions in intermediate and investment goods. Knowledge spillovers, for example, occur through ideas borrowed by research teams in one firm or industry from others, reverse engineering, professional journals, turnover of personnel, etc. Such non-embodied interindustry spillovers can affect the productivity of the user industry, even if the prices at which inputs are sold across industries fully reflect their quality improvements. Goto and Suzuki (1989) studied the electronics industries in Japan and were surprised to find that, despite the fact that the price of electronics products had fallen significantly and quality had increased dramatically, there was no evidence that the rate of growth of TFP of manufacturing industries was linked to the inflow of R&D embodied in intermediate and investment goods purchased from electronics-related industries. They concluded that the explanation of this apparent paradox was that their methodology could not capture the effects of disembodied diffusion through knowledge spillovers.

Goto and Suzuki then adopted a methodology based on the technological closeness of industries rather than on their purchases of inputs from each other, a methodology devised by Griliches and subsequently developed by Jaffe (1986). They were able to show that electronics technology mainly affected other industries' productivity growth through the diffusion of technological knowledge, rather than through transactions involving intermediate and investment goods embodying electronics technology. Industries whose technological positions were similar to that of electronics-related industries were able to exploit the technology developed through the latters' R&D activity in order to make their production processes more flexible and/or to manufacture the electronics-related products themselves.[3]

1. Other studies have used a methodology involving the empirical estimation of cost or production functions, where the firm's costs and productivity are affected by technology from outside the firm or industry. They have confirmed the cost-reducing and productivity-enhancing effect of both intrasectoral and intersectoral knowledge spillovers. Bernstein (1988) estimated the effects of intra-industry and interindustry spillovers on seven Canadian industries (food and beverages, pulp and paper, metal fabricating, non-electrical machinery, aircraft and parts, electrical products, and chemical products) and concluded that both types of spillover affect production costs. Levin and Reiss (1988) concluded that the extent of spillovers is higher for processes than for products and that it varies considerably among industries, with electronics industries appearing to have significantly higher spillovers than other industries.

The international dimension

Very few studies assess the effect of international technology diffusion on productivity growth. Early results reported by Mansfield (1984) for 15 US chemical and petroleum firms for the period 1960-76 suggest that R&D from abroad makes a substantial contribution, with an influence on productivity several times greater than that of domestic R&D. Excluding R&D from abroad when explaining productivity growth contributes to an upward bias in estimations of the rate of return to domestic R&D.

It is also possible to look at the potential effects of the R&D expenditures of an industry or economy on its counterpart in another country. Levy and Terleckyj (1985) have reported that the aggregate private R&D expenditures in the United States, Japan, and seven European countries are interrelated. Both European and Japanese R&D expenditures seem to have influenced US private R&D outlays. US R&D outlays also appear to have influenced R&D outlays in Europe and Japan. However, there was no evidence of positive cross-effects between the European and Japanese R&D investments. These results suggest a triangular relationship in investment in new technologies and in technology trade among these three regions.

Mohnen and Lepine (1988) have analysed the impact of imported technology on productivity growth in 12 technology-intensive Canadian manufacturing sectors. Their results indicate that industry demand for imported technology increases as own R&D investment increases. The strength of the effect varies, depending on the industries' own R&D intensity. Another study by Mohnen (1990c) reports a 30 per cent rate of return for foreign R&D and a 20 per cent rate of return for domestic R&D. The contribution of foreign R&D explains about 15 per cent of growth of output and about half of TFP growth in the Canadian manufacturing sector.

Coe and Helpman (1993) have recently used aggregate data to estimate the effects on total factor productivity of a country's own R&D capital and its imported R&D. In a sample of 22 OECD countries, they found that both domestic and foreign R&D capital stocks had large effects on TFP, with the impact of foreign R&D rising over time. The impact of foreign R&D capital is greater in smaller countries. Furthermore, they found that about one-quarter of the benefits of R&D investment in the seven largest economies are appropriated by their trading partners.

What emerges from the evidence is that technology diffusion among the advanced industrialised countries has increased substantially over the past several years. The transfer of technology is taking place much faster than before, and multinational firms are the main source of technology diffusion. The means by which technology is transferred and the dynamics of the interplay between domestic and foreign technology vary among industries and countries. In most cases, however, the R&D-intensive multinational corporations are the main actors in the technology transfer market.

Finally, the fragmentary econometric results that are available suggest that foreign R&D has a major impact on the TFP of domestic industries, with the rate of return on borrowed technology from abroad often exceeding that of domestic R&D. The mushrooming of cross-border trade in technology and the dynamic role played by multinational enterprises and the research-intensive industries in technology trade and foreign direct investment (FDI) are likely to be increasing sources of new spillovers, with the distribution of these benefits differing across firms, industries, and countries.

A number of empirical studies thus point to the importance of technology diffusion for productivity growth. TFP depends not only on the technology-related expenditures that industries themselves undertake, but also on technology that is developed elsewhere and becomes available to user industries. The diverse methodologies used indicate that diffusion affects productivity through a variety of channels: the purchase of technologically sophisticated machinery, equipment and components (equipment-embodied diffusion) or the simple "borrowing" of ideas, know-how, and expertise (disembodied diffusion).

CHAPTER 9

THE EVOLUTION OF PRODUCTIVITY OVER THE MEDIUM TERM

Before examining the results from the empirical analysis of the relationshp between R&D, technology diffusion and productivity in the next chapter, this chapter presents an overview of productivity performance in the 1970s and 1980s in OECD countries and more particularly in the ten OECD countries included in the model used in Chapter 10. Two measures of productivity are examined: labour productivity and total factor productivity. For the first, the following section gives an overview of medium-term trends in growth rates and briefly compares international productivity levels. For the second, since the methodology used to calculate TFP is rather new and is estimated from detailed input-output accounts, the results may differ somewhat from available OECD productivity data (for a mathematical presentation of the TFP measure, see Annex 2).

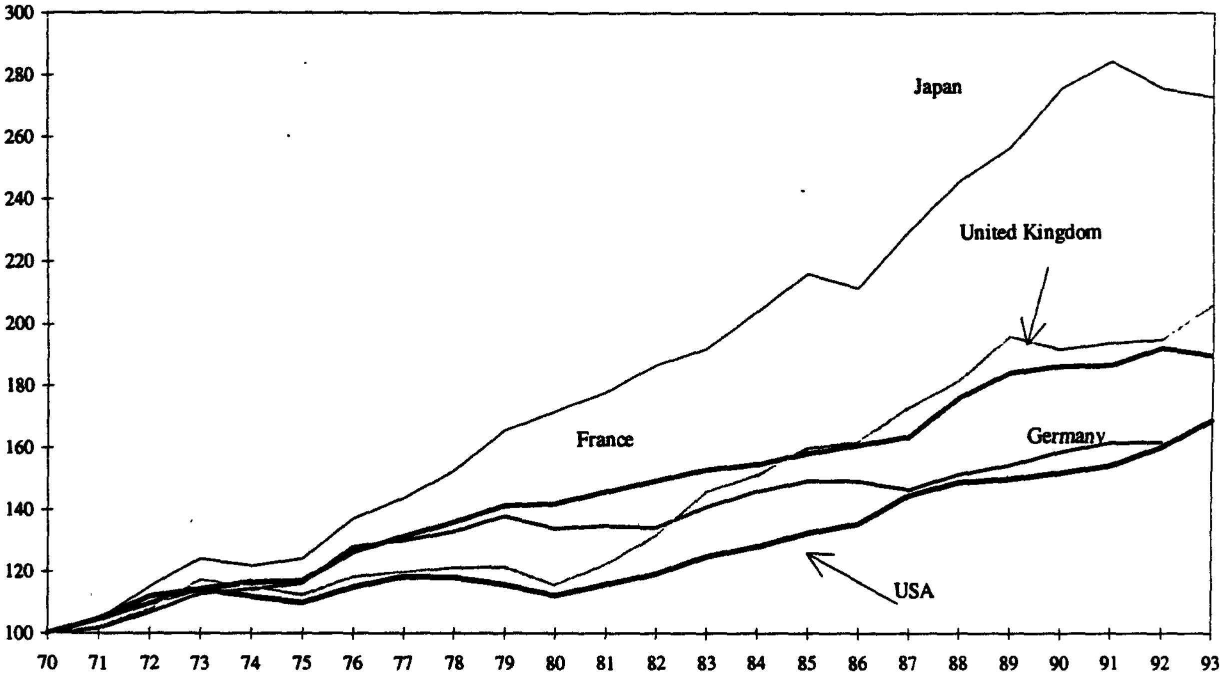
Labour productivity growth and levels

In a medium-term perspective, several trends are apparent. First, labour productivity growth in the 1980s and early 1990s is broadly in line with the trend in the 1970s but remains significantly below its value up to 1973. This observation holds for manufacturing industries as well as for the total business sector. Also, productivity growth in manufacturing industries exceeds productivity growth in the business sector in most OECD countries (Figure 13).

Second, among the countries for which information is available, the most impressive gains in labour productivity since 1980 were achieved by Finland, Italy, Japan, and the United Kingdom. Productivity growth was sluggish in Australia, Canada, Denmark, and Germany. With respect to individual industries, and for the OECD area as a whole, labour productivity growth rates have been highest in the basic metals industry, the textiles group, and the fabricated metal and machinery group. Paper, food and wood industries showed productivity growth below manufacturing averages. Not surprisingly, these trends differ significantly across countries.[4]

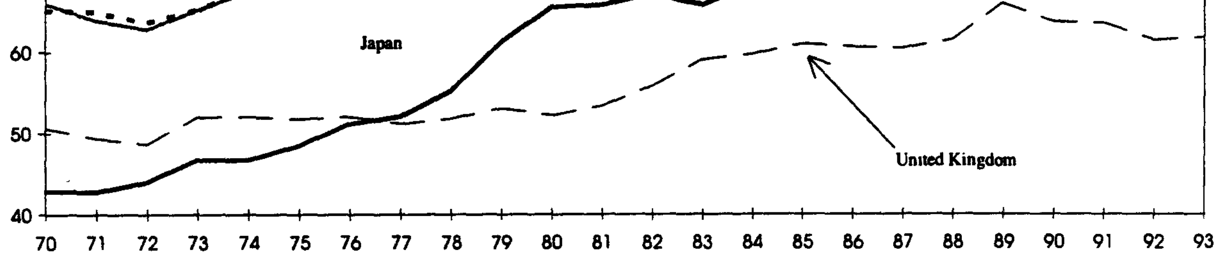
Productivity levels, measured as constant price value added in dollars per employee, provide an indication of orders of magnitude for the long-term trends in national and sectoral performance that are the main policy concerns for growth. Despite measurement problems (see Box 3), several observations can be made about the evolution of productivity levels. Among OECD countries and for total manufacturing, the United States has the highest level of labour productivity. However, over the past decades, labour productivity growth rates of other countries have been higher than those of the United States, and this has reduced the gap. Rapid diffusion of technology and the globalisation of economies tend to reinforce this catch-up effect (Figure 14). At the same time, the process of convergence seems to have slowed during the 1980s and reversed at the beginning of the 1990s. It is likely, however, that the recent widening of the productivity gap was the result of cyclical influences rather than the reversal of a general trend.

Figure 13. Manufacturing productivity growth (1)
1970 = 100



1. Manufacturing value added per employee.
Source: OECD, STAN database (DSTI, EAS Division), March 1995.

Graph 14. Manufacturing productivity levels (1) relative to the United States
1970=100



1. Manufacturing value added per employee; converted by means of PPPs.
Source: OECD, STAN database (DSTI, EAS Division), March 1995.

Box 3. Issues in labour productivity measurement

The measurement of productivity growth rates and, even more, productivity levels poses several methodological and interpretative difficulties. The main issues related to the measurement of output and of labour are described below.

Production vs. value added. While production (gross output) data are more readily available than data on value added, the former include the value of intermediate products. This can be misleading. For example, a rise in the share of intermediate inputs (through contracting out of certain activities) leads to a decline in employment but leaves gross output unchanged. This would result in a misleading indication of a steep rise of labour productivity.

Method of deflation. Value added, the preferred measure of output, has to be corrected for changes in prices if comparisons over time are made. Its accurate deflation relies on the existence of deflators for production and for intermediate inputs ("double deflation method"). Data to apply double deflation methods are, however, often unavailable for the services sector, and the construction of price indices relies solely on price changes in factor inputs, thus leading to an underestimation of productivity growth. Also, quality changes in products tend to be insufficiently reflected in price series. Studies using hedonic price indices (which capture quality changes) have shown that value added measured at constant prices can be dramatically different from matched price indices. The most impressive example comes from hedonic price series measured for the computer industry. It shows that downward price movements have been considerably underestimated and, as a consequence, so has real value added and productivity.

Currency conversion. For international comparisons of labour productivity levels, national figures have to be converted to a common currency. The use of current exchange rates prices output at the price at which it is traded internationally but makes results sensitive to exchange rate fluctuations. The alternative is to employ economy-wide purchasing power parities. The latter adjust for exchange rate swings but are based on bundles of consumer goods which only inadequately reflect relative values at the supply side of the economy. A third method uses unit values for manufactured goods to calculate industry-specific conversion factors for international comparisons; while theoretically preferable, these conversion factors require detailed industry analysis, and data are not available for a large number of countries.

Employees vs. hours worked. For reasons of data availability, the number of employees is frequently chosen as a proxy for labour input. Although the employee data have fewer methodological problems, the use of overtime and the expansion of part-time employment make productivity measurements based on employees less accurate than measures of employment that use hours worked or full-time equivalent. When adjustments for hours per worker are made, the productivity gap between European countries and the United States narrows, as average hours have fallen more rapidly in Europe. The opposite holds for Japan. Finally, restricting labour input to employees leaves out the self-employed and unpaid family members.

Cyclical effects. Different phases of the business cycle have a strong influence on productivity time series. For structural questions, therefore, comparisons should take place for similar phases of business cycles. Another possibility is to adjust underlying output and employment series for cyclical influences.

With respect to individual industries, labour productivity levels tend to be above the manufacturing average in the basic metals and chemicals industries. Both are highly capital-intensive, with a concentrated industry structure that permits productivity gains through economies of scale. Other factors influencing labour productivity levels are capital intensity, the quality of factor inputs, technology intensity, and the general structure of the manufacturing sector (Annex Table 8).

Total factor productivity measurement

Despite its limitations, total factor productivity (TFP) or multifactor productivity is a better indicator of improvement in production efficiency in a given period than traditional partial factor productivity (see Box 4). Industries usually use a spectrum of inputs in their production activities -- primary factors (labour, capital, and land) as well as various intermediate inputs (raw materials, energy, distribution, and other business services). Because labour productivity may increase while the productivity of other production factors decreases, partial productivity indicators do not, in themselves, correctly reflect actual changes in production efficiency. TFP makes it possible to evaluate an industry's overall efficiency of production by simultaneously relating output to use of several inputs.

TFP is expressed as production per unit of a composite index of inputs, appropriately aggregated. Broadly speaking, the literature distinguishes two methods for deriving TFP: the growth accounting approach and the production function approach. Both give the same results when the underlying production function is assumed to exhibit constant returns to scale and when both product and factor markets are competitive. TFP growth then corresponds to the neo-classical concept of technical change: shifts in the production function, as distinct from movements along the production function induced by factor substitution, owing to changes in relative factor prices and the bias of technological progress (Jorgenson and Griliches (1967).

The TFP growth estimates in this report are constructed using the growth accounting approach based on input-output data; the data are therefore only available in terms of rate of change and not in terms of level. Because of the lack of internationally comparable data from which to construct input-output based TFP series, however, the TFP growth indexes are available only at a rather aggregated sectoral level, and for at most 20 sectors for each country and for different input-output years across countries (see also Box 4).

Trends in TFP growth

Figure 15 and Annex Table 9 report growth accounting results for the aggregate private business sector in OECD countries for the 1970s and 1980s. The figure uses the growth accounting approach to break down growth in the aggregate business sector of G-7 countries during the 1970s and 1980s into what is attributable to growth of employment, to contribution of capital, and to the residual, total factor productivity, which is taken to represent disembodied technical progress. It shows that while average annual growth rates during this period were in the range of 2 to 3 per cent (Japan, with 4.5 per cent annual growth, is the exception), the size and contribution of the individual components differ significantly among countries.

Box 4. Total factor productivity: measurement issues

Researchers have not yet reached a consensus on TFP measurement, owing to different underlying economic theories, problems in the definition of both outputs and production factors, type of indexes used, etc. For this reason, several shortcomings of the TFP series calculated here should be mentioned.

First, the TFP series in this report are only available in the form of average growth rates for different input-output years in the various countries. Hence, the TFP data cannot avoid disturbances occasioned by cyclical movements in underlying variables, whereas most productivity studies have carefully avoided the periods of troughs by choosing peak years.

The second problem concerns sectoral data availability. Because of the lack of sufficiently disaggregated data on sectoral capital stock, TFP can only be calculated for broad industrial sectors, even if other data are available from the OECD STAN database at ISIC 3 or 4 digit level.

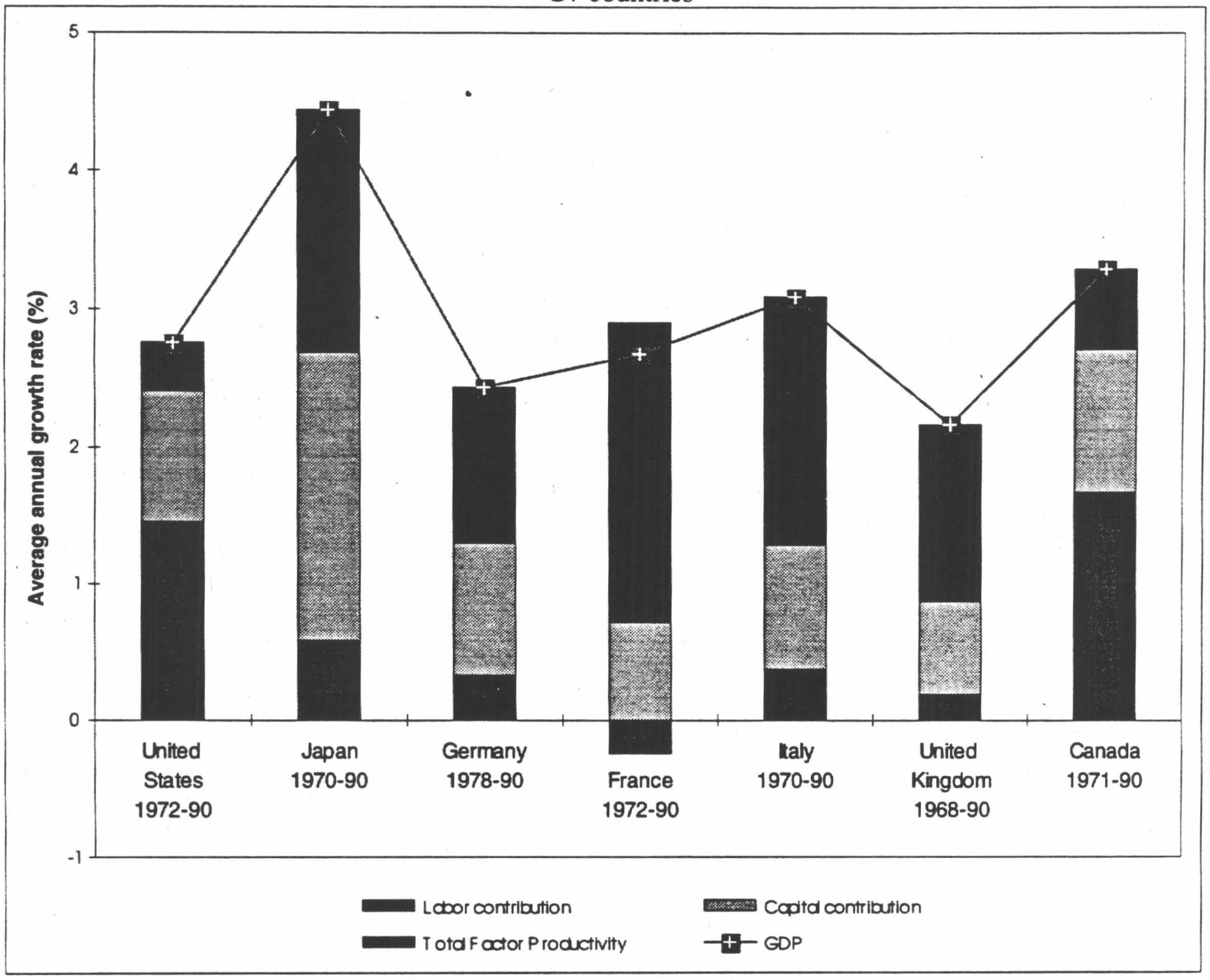
The third involves the errors that may arise owing to the lack of sufficient information on underlying variables in the model. Since technical change is accompanied by new products and quality changes in existing products, it is desirable to use a more appropriate measure of the volume of products and prices (e.g. hedonic price index). Similarly, given the increasing importance of the services sectors, an appropriate measure of services production is a serious statistical issue, as it is likely to change this sector's TFP index significantly. As Griliches (1994) notes, however, the current status of services statistics leaves this sector largely "unmeasurable".

Other problems arise from the accounting of primary inputs. For labour inputs, employment data should be adjusted by data on hours worked to reflect precisely the volume of flows of labour services into production. With more detailed data on services capital inputs, the proportionality assumed between the volume of capital stock and the flows of services capital can be relaxed. Moreover, because of the high degree of heterogeneity, these inputs should be disaggregated by type (for labour by sex, occupation, and educational attainment; for capital, by machinery, land, structures, etc.) in order to reflect the different marginal productivity of each category.

Besides the shortcomings of the data, the current TFP formulation also has some theoretical shortcomings. First, TFP indicators do not correspond to technical change if competition does not prevail in both product and factor markets. This is also true in a more realistic setting where various externalities and regulations affect production activities. Moreover, TFP indicators are likely to lump together other factors of technical change which might better be separated from pure technical change -- economies of scale, economies of scope, changes in work organisation, etc. In particular, the effect of economies of scale is likely to be a major part of productivity growth in the capital-intensive industries. In practice, it is difficult to distinguish between economies of scale and pure technical change, but it is theoretically possible to estimate empirically the contribution of economies of scale to productivity growth.

Finally, the growth accounting model is by nature static and fails to capture the dynamic features of capital accumulation. To incorporate dynamic elements into the basic model, some have used as a quasi-fixed factor the Marshallian distinction between short- and long-run and introduced capital. In such a context, productivity may be negative during medium-term adjustment, but may increase in a new long-run equilibrium, by establishing a more efficient long-run average cost curve. Such dynamics can be very important for periods of economic shock, and care must be taken in interpreting movements in TFP growth in the transition periods.

Figure 15. **Growth accounting results**
G7 countries



Source: OECD Secretariat estimations; STI/EAS Division.

In the G7 countries, the contribution of TFP "explains" more than 60 per cent of GDP growth in the United Kingdom, France and Italy, around 30 to 40 per cent in Japan and Germany, and only 10 per cent in Canada and the United States. These last two countries have the highest contribution from labour (more than 40 per cent), owing to the higher growth of their labour supply. In Japan and Germany, the most important factor behind economic growth is capital accumulation, which accounts for between 40 and 50 per cent of total growth.

In Annex Table 9, the first panel exhibits Divisia aggregates constructed in a consistent manner from sectoral production accounts; the second presents an aggregate production account based on GDP, labour, and capital at the macroeconomic level. While the former takes into account a sectoral production function whose parameters -- such as marginal productivities and the elasticity of substitution -- may differ from sector to sector, the latter is built on an aggregate production function that takes into account neither sectoral differences in production parameters nor changes in the profiles of sectoral production, employment, and capital over time.

The differences between the two aggregates can then be attributed to the distribution of value added, labour, and capital among sectors. The effects will be large when sectoral production functions differ and when the industrial structure is changing drastically. If data from the aggregate and sectoral production accounts are combined, the rate of aggregate productivity growth is the Divisia-weighted sum of rates of sectoral productivity growth and of the elements corresponding to the effects of the redistribution of value added, labour, and capital input among sectors with different production functions.[5] The following discussion focuses first on sectoral aggregates and then evaluates the impact of resource reallocation on aggregate TFP growth.

Despite the data limitations noted above, it appears that TFP growth rates play a significant role in medium-term economic performance in most countries. If growth in aggregate GDP (measured at factor cost price) is broken down into the contribution of labour, capital inputs, and TFP growth (the increased efficiency in production per unit of aggregate input), a simple average of ten OECD countries shows that 42 per cent of the average annual GDP growth of 2.9 per cent in the 1970s and 1980s is explained by TFP growth, 37 per cent by capital input, and 21 per cent by labour input.

The contribution of these components varies significantly across countries, as does growth in GDP, which ranges from 1.8 per cent in Denmark (1972-90) to 4.4 per cent in Japan (1970-90). The long-term average figures show that the contribution of TFP explains more than 60 per cent of GDP growth in the Netherlands, Denmark, the United Kingdom, France and Italy, 30 to 40 per cent in Germany and Japan, and only 10 to 30 per cent in Australia, Canada, and the United States. Labour's contribution is highest for this last group (more than 40 per cent), reflecting the higher growth of their labour supply. The labour contribution is negative for the Netherlands and Denmark and explains around 10 to 20 per cent of GDP growth in Italy, France, Germany, and Japan. The contribution of capital is highest in Japan and Germany (50 per cent and 43 per cent respectively); in the United States, Canada, and Australia it exceeds the contribution of TFP.

Although these growth accounting results are strongly influenced by cyclical fluctuations, it is interesting to see the differing importance of each source of growth over time. First, the labour contribution does not show any clear upward or downward tendency over time. Cyclical factors also affect capital input, but its importance for GDP growth is declining in every country. TFP growth, however, recovered in the 1980s in most countries.

Manufacturing vs. services

Annex Table 10 gives the sectoral growth accounting results for the 1970s and 1980s for the total business sector and for manufacturing and services (including public utilities and construction), as an average of sectoral results weighted by shares in gross output. Although growth of both gross output and TFP for the total private business sector recovered slightly between the 1970s and 1980s in five out of eight countries for which comparisons over time can be made, the trends are different in manufacturing and services.

During the 1970s, manufacturing grew more slowly than services in all countries except the Netherlands. The difference in growth between the two sectors was particularly pronounced in the United States, where output growth was four times higher in services than in manufacturing; however, the contribution of TFP growth was negative in both sectors. For other countries, TFP growth explains 25 per cent of manufacturing output growth in the Netherlands, 27 per cent in Japan, 20 per cent in France, 15 per cent in Canada, 20 per cent in the United Kingdom, and 8 per cent in Australia.

Intermediate inputs have contributed strongly to manufacturing output growth. While the impact of domestic sources is generally greater, imported intermediate inputs had a greater impact than domestic ones for the Netherlands and the United Kingdom and were also quite high in France and Canada. For primary inputs, the contribution of labour inputs was slightly negative in most countries except the United States and Canada. Capital input growth accounted for about 10 to20 per cent of manufacturing output growth across countries, except for the United States where it represented 50 per cent.

In the services sector, TFP declined in the United States during the 1970s but accounted for a large portion of output growth in Denmark and the Netherlands and a somewhat smaller portion for other countries. Compared to manufacturing, the contribution of intermediate inputs was smaller and accounted for 30 to 70 per cent of output growth, reflecting the lesser dependency of services on intermediate inputs; except in Denmark and the Netherlands, imported intermediate inputs were the least important factor. In general, primary inputs are the most important source of output growth in services. On average, primary and intermediate inputs accounted for around half of the production growth. Labour and capital inputs contributed almost equally in the United Kingdom; labour inputs contributed significantly more in the United States, Canada, and Australia, while capital inputs contributed significantly more in Japan, the Netherlands, and Denmark.

During the 1980s, the manufacturing output of three countries -- the United States, the United Kingdom and Japan -- grew more than in the 1970s. Nevertheless, average manufacturing TFP growth rose in six of the eight countries for which a comparison is possible (the exceptions are Japan and the Netherlands); and, in the 1980s, the cross-country unweighted average of manufacturing TFP growth was twice what it had been in the 1970s. TFP recovery was especially strong in the United States and the United Kingdom. As a result, the contribution of TFP has increased in most countries and, on average, explains around a third of manufacturing output growth.

For other sources of growth, the role of intermediate inputs (both domestic and imported) weakened for most countries. Although the two decades show no clear difference, the contribution of labour input rose in the United States and Japan, while it decreased in France and in the United Kingdom. The contribution of capital inputs has continuously decreased in all countries except Japan.

In short, output and TFP growth moved differently in manufacturing and services during the 1970s and 1980s. For manufacturing, average output growth slowed over the period, but TFP growth seems to have recovered in the 1980s. For services, instead, output growth accelerated in the 1980s but productivity growth declined: only in the United States and Japan did this sector's productivity growth rise. The importance of intermediate inputs declined slightly in manufacturing but increased in services. For labour inputs, the difference between manufacturing and services is more important: its contribution was almost negligible in manufacturing, but explained a large part of growth in services output. Capital input, however, played a slightly decreasing role in output growth across the two sectors in most countries. These observations suggest that it is important to disaggregate manufacturing and services for productivity analysis.

ICT cluster and TFP growth

Table 4 presents the ranking of the ten industries with the fastest TFP growth over the 1970s and 1980s for each of the nine countries covered. In terms of productivity performance, the sectoral ranking reveals the importance of information and communications technology (ICT) as well as other specific sectors in each country.[6] The definition of ICT industries varies in existing studies but usually covers both manufacturing and services industries, such as computer and office equipment, communications equipment and semiconductors, instruments, communications, finance and insurance, business services, etc. (Freeman and Soete, 1994).

As expected, most industries classified in the ICT cluster are ranked among the top ten in terms of TFP growth in every country. In particular, the communications sector is ranked in the top three in four countries, and when the transport sector is also included, it is listed among the top five in every country except the United Kingdom. Similarly, the electrical machinery sector, which includes communications equipment and semiconductors, is among the top three in five countries -- Japan, France, the United Kingdom, Canada, and the Netherlands -- and in fifth or sixth place for the United States, Germany, and Denmark (for Japan, this sector also includes computers and office equipment).

The general machinery sector, which includes computers and office equipment, is ranked as having the second highest TFP growth in the United States and Canada; it has a lower rank in France, the United Kingdom, and Japan. The instruments sector takes first place in the United States and second place in Japan; it stands fifth in Germany, where it includes computers and office equipment. Similarly, the real estate and business services sector is ranked first in Canada and fourth in the Netherlands, while the finance and insurance sector is ranked sixth for Germany and, as the finance, insurance, real estate and business services sector (FIRB), it is also listed for the United Kingdom. For every country, productivity performance for these ICT services is much lower than for both communications and ICT manufacturers.

Table 4. **Ten Highest TFP Growth Industries**

	US 1972-90	Japan 1970-90	Germany 1978-1990	France 1972-90	UK 1968-1990	Canada 1971-1990	Australia 1968-1989	Denmark 1972-1990	Netherlands 1972-1986
1	Instrument 2.68	Elec. mac. 2.70	Commu. 2.75	Commu. 4.76	Agriculture 2.85	Real estate 5.55	Trans & comm 3.31	Mining 7.58	Agrriculture 2.71
2	General mac. 2.06	Instrument 2.19	Agriculture 2.63	Agriculture 3.31	Elec. mac. 2.57	General mac. 2.04	EGW 2.12	Commu 2.79	Mining 2.36
3	Commu. 1.93	Trade 1.98	Transport 1.42	Elec. mac. 2.05	Mining 2.16	Elec. mac. 1.69	Paper 1.45	Agriculture 2.70	Elec. mac. 2.26
4	Textiles 1.28	Trans & comm 1.37	Instrument 1.29	Basic metal 1.51	Basic metal 1.87	Trans & comm 1.47	CSPS 1.38	Basic metal 1.48	Real estate 2.22
5	Transport 1.21	Basic metal 1.18	Elec. mac. 1.27	Textiles 1.14	Textiles 1.65	Textiles 0.94	Agriculture 1.29	Trade 1.40	Trans & comm 1.64
6	Elec. mac. 1.01	General mac. 1.08	Finance 1.06	Wood 1.11	Instrument 1.53	Basic metal 0.92	Textiles 1.12	Elec. mac. 1.11	Other man. 1.46
7	Agriculture 0.95	Textiles 1.07	Trade 0.78	CSPS 1.03	Ceramics 1.24	Wood 0.71	Basic metal 1.11	Textiles 0.73	Ceramics 1.40
8	Wood 0.81	Fab. metal 0.96	Basic metal 0.71	Fab. metal 0.97	Gen. mac. 1.13	CSPS 0.62	Other man. 0.30	Food 0.69	Rubber 1.38
9	Trade 0.62	Other man. 0.81	Other man. 0.60	General mac. 0.83	Trans & comm 0.99	Trans. equip. 0.52	Mining 0.25	Real estate 0.58	Wood 1.19
10	Ceramics 0.55	Chemicals 0.71	Ceramics 0.55	EGW 0.72	FIRB 0.96	Agriculture 0.43	Food 0.24	Transport 0.43	Chemicals 1.14

Notes: Major industry codes are follows: General mac. = general machinery, Commu.= communication services, Agriculture = agriculture, forestry & fishery, Elec.mac.= electrical machinery, Wood = wood product & furniture, Ceramics = stone, clay & glass, Trans & comm = transportation and communication services, Other man = other manufacturing, Finance = finance & insurance, FIRB = finance, insurance, real estate & business services, Real estate = real estate and business services, Fab. metal = fabricated metals, Rubber = rubber & plastic products, CSPS = community, social and personal services, Foods = food, beverage & tobacco, EGW = electricity, gas & water.

For other industry clusters, it may seem surprising that the primary sector (agriculture, forestry, and fishing and mining) appears among the top ten in every country except Japan and even stands among the top three in five countries. It is hard to know whether this is actually so or is simply a measurement error. Natural resource endowments may be part of the explanation, but productivity in these sectors can be extremely volatile, owing to drastic changes in exogenous factors, such as the discovery of new resources, weather, price changes, etc.

Another interesting result is that conventional scale-intensive or low-technology manufacturing industries -- basic metals, paper and pulp, ceramics, chemicals, fabricated metals, textiles, wood, rubber and plastics -- are also frequently found among the top ten. Since these TFP series do not exclude the effect of scale economies, some of the TFP performance of heavy industries may be attributable to this effect. The performance of light manufacturing industries such as textiles may be attributable to downsizing or competitive pressures from developing countries. Traditional services sectors such as the wholesale and retail trade (the United States, Japan, Germany, Denmark), the community, social and personal services (CSPS) sector (France, Canada, Australia), or utilities (Australia, France) are listed in the top ten. While it is difficult to explain this, changes in regulatory conditions or the introduction of efficient distribution systems or power plant may hold part of the answer.

CHAPTER 10

R&D, DIFFUSION AND PRODUCTIVITY GROWTH

Introduction

Productivity growth has many sources: product and process innovations, research and development, scale economies, demographic change, change in quality of capital and labour inputs, changes in the organisation of work, technological catch-up factors such as the introduction and imitation of advanced foreign technologies or know-how, etc. (Englander and Gurney (1994a) give a comprehensive survey of the importance of these factors for productivity). This report focuses on the role of R&D and of technology diffusion among industries in explaining productivity growth. Technology diffusion is captured by the R&D which is embodied in production inputs (intermediate and investment goods) that are purchased domestically or from abroad.

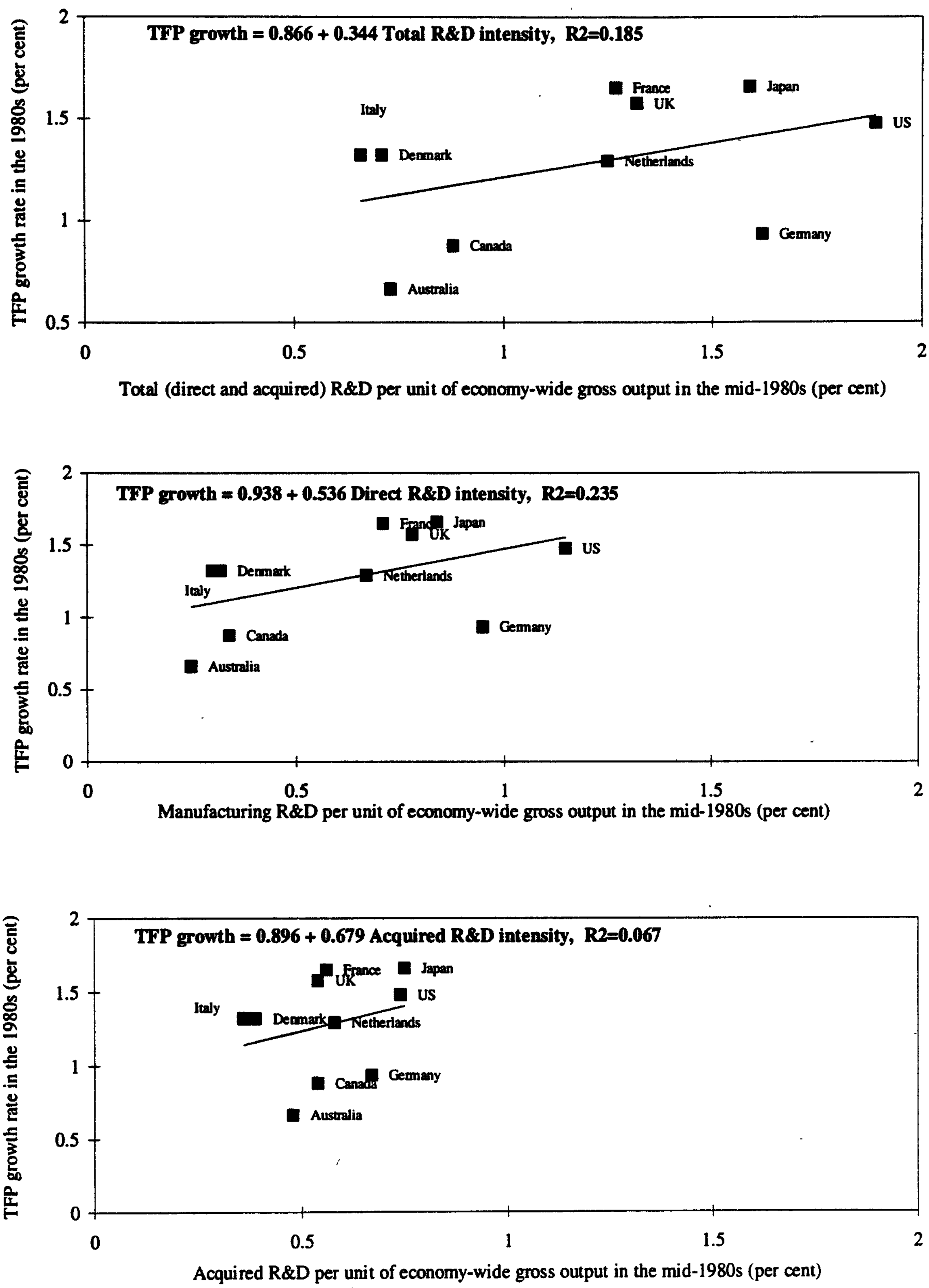
Firms carry out R&D in order to design new products which will provide more value per unit of resources used, or new processes which will reduce the resource requirements of existing products (Griliches and Lichtenberg (1984)). To the extent that TFP measures are appropriate indicators of growth in technological potential, R&D activities may contribute to expanding or shifting the production possibilities frontier in R&D-conducting firms. At the same time, some firms and industries are less R&D intensive but obtain large productivity benefits simply by purchasing technologically sophisticated inputs or capital goods into their production process (i.e., embodied R&D).

By combining TFP growth rates discussed in the previous chapter and R&D and embodied R&D variables, this chapter tries to infer the contribution of R&D expenditures and or embodied R&D for productivity growth at the industry level within the limits imposed by our data. The model used for the estimations is presented in detail in Annex 3; the remaining of this chapter discusses the regression results using various variants of the model and possible combinations of the data.

Regression results: manufacturing vs. services

As several authors have observed from cross-country and time-series data (Englander and Gurney, 1994a; Coe and Helpman, 1993), direct R&D and/or embodied R&D are likely to be positively correlated with aggregate productivity growth across countries (Figure 16). By applying the statistical models dscribed in the Annex, this section analyses the relationships more closely by distinguishing different industrial groupings and types of R&D variables for the 1970s and 1980s.

Figure 16. R&D and Productivity Performance in the 1980s



Source: OECD (STI/EAS Division) estimates.

The detailed estimates for manufacturing and for services are presented in Annex Tables 11 and 12. Since internationally comparable data on R&D expenditures in the services sector are not currently available, the regression for this sector only uses data on embodied R&D. The first panel in each table gives the unweighted OLS results, and the second the OLS results weighted by average sectoral shares of gross output during the period concerned.[7]

For manufacturing, both regressions indicate that direct R&D alone plays a role in explaining TFP growth. The statistical fit does not improve after inserting embodied R&D variables, and in regressions with the direct R&D variable, embodied R&D variables become insignificant. The estimated ten-country average for the rate of return of direct R&D is about 0.15 (15 per cent) and is about the same for the 1970s and 1980s. Although similar studies for the manufacturing sector (Terleckyj, 1982; Griliches and Lichtenberg, 1984; Scherer, 1982) have found that the coefficients of embodied R&D intensity are much larger than those of own R&D intensity, the present cross-country results do not support their findings.

Most similar studies tend to neglect services, but the present study gives quite striking results for this sector. In the unweighted regressions, embodied R&D variables are quite significant, and the rate of return of acquired R&D is very high for both periods and even increases in the 1980s (130 per cent in the 1970s and 190 per cent in the 1980s). R&D embodied in purchased capital equipment is found to be a major indirect source of productivity in the services sector. Moreover, equation (4) finds that foreign R&D has a higher rate of return than domestically acquired technology.

This means that international R&D spillovers have been particularly important for productivity gains in services and that international procurement of R&D-intensive products has led to larger productivity gains than domestic procurement. In the weighted regressions, no significant correlation was found except for the R&D embodied in purchased capital equipment (RTC) in the 1980s. The difference in results for the two regressions may be due to the fact that the weighted regression gives less importance to highly productive and R&D-intensive services sectors such as communications and real estate and business services with small output shares.

Although the above regressions assume that the same coefficients hold across countries, it is of considerable interest to see whether the rates of return of own or embodied R&D are significantly different. Therefore, a variant of the unweighted regression was run with different coefficients for the explanatory variables. Figure 17 shows the estimated rates of return of R&D and embodied R&D variables for manufacturing and services.

First, the rate of return for manufacturing R&D differs widely across countries and between periods. In the 1970s, the payoff to R&D investment was highest in Japan (40 per cent); Canada, the Netherlands and the United Kingdom also had a rate of return exceeding 20 per cent. In contrast, the rate of return was only 8 per cent in the United States and was almost trivial in Denmark and Italy (whose coefficients are statistically insignificant). In the 1980s, however, the return on R&D showed significant improvement in the US and Italy and some improvement in Canada. In contrast, it decreased in Japan, France, the UK and the Netherlands. As a result, Italy and Canada appear as the most R&D-productive countries in the 1980s, while R&D potency is almost the same for the United States and Japan, at around 20 per cent. For the European countries (except Italy), it falls to about half that of the United States and Japan.

Figure 17a. The Rate of Return of Direct R&D by Country
Manufacturing industries

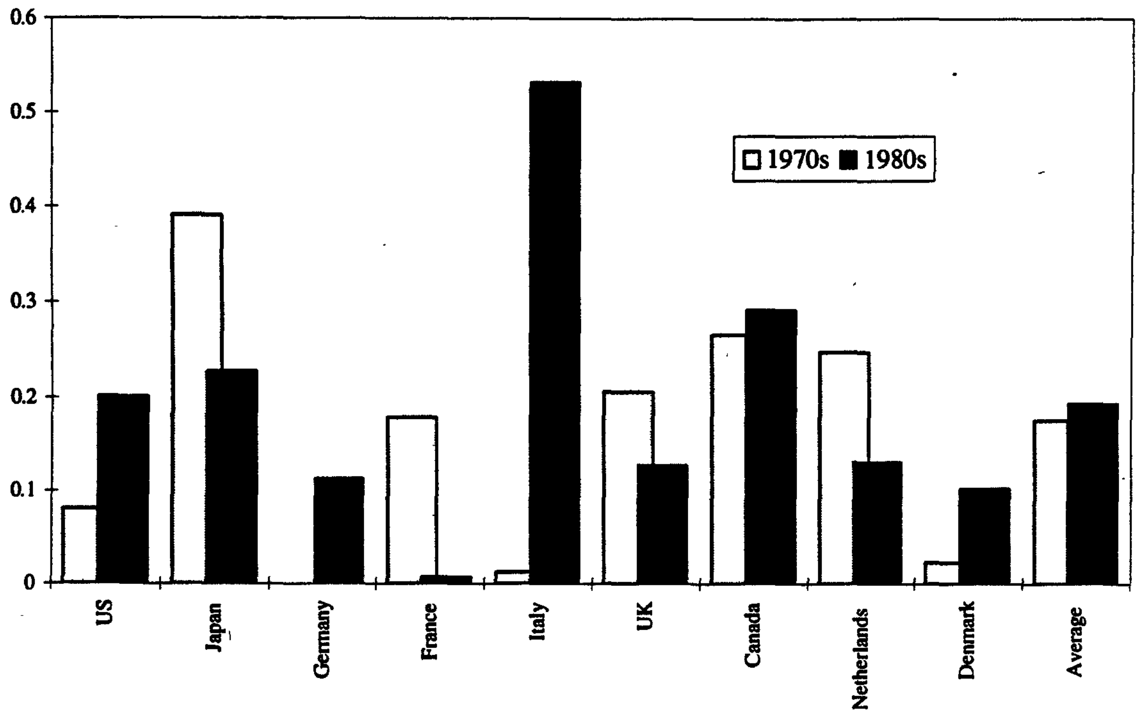
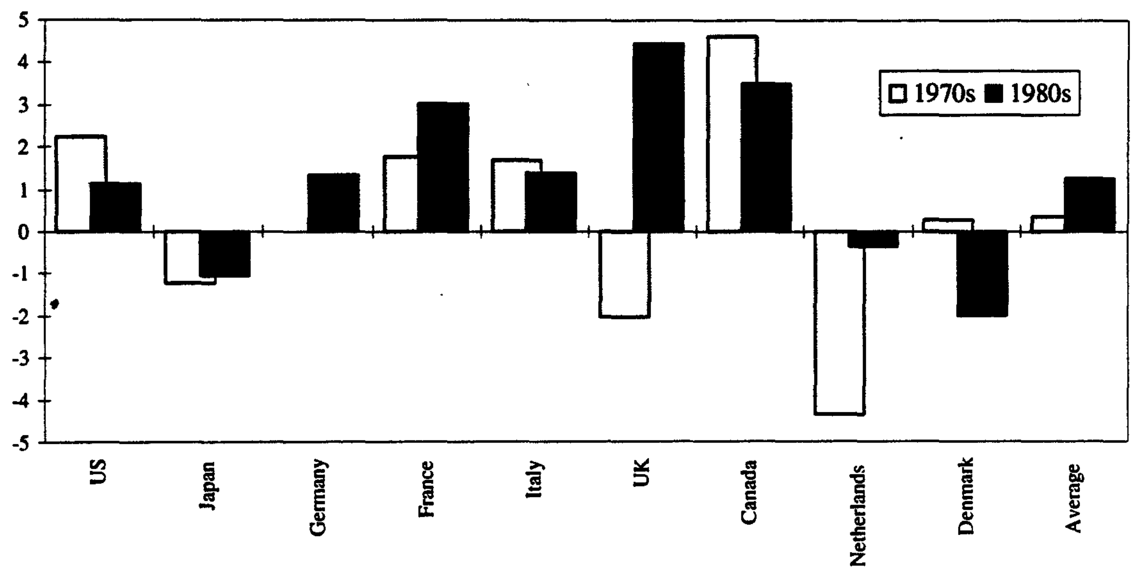


Figure 17b. The Rate of Return of Embodied R&D by Country
Service industries



Source: OECD (STI/EAS Division) estimations.

For services, estimated coefficients of embodied R&D are statistically insignificant except for France, Canada, the United States (1970s) and the United Kingdom (1980s). The results suggest that only France, the United Kingdom, and Canada realised productivity gains through the diffusion of technologies. For Japan and the Netherlands, the embodied R&D variable is in fact negatively correlated with TFP growth in this sector.

Moreover, countries with higher R&D potency in manufacturing are not always those with more potent embodied R&D; the potency of R&D in manufacturing in Japan and the Netherlands, for example, is high, but that of embodied R&D is almost irrelevant for productivity growth in services. In contrast, although the potency of manufacturing R&D is low and even decreased in the 1980s in France and the United Kingdom, that of embodied R&D in the services sector was relatively high and increased in the 1980s. The apparent contradiction between R&D potency in manufacturing and services may be attributable to some extent to the effects of international R&D spillovers -- increased dependency on R&D-intensive products from abroad.

Regressions across seven industrial groups

The regressions for the manufacturing and services sector can be further refined by breaking each broad sector down into sub-groups and pooling them across countries in order to obtain large samples for the regressions. Given that R&D intensities, TFP growth rates, and technology flows vary across industries, these industry groups are likely to show different rates of return for the different R&D variables. Annex Table 13 summarises the results of three types of cross-country regressions based on this model, each of which assumes different coefficients for the various industrial groups and the two periods. All the regressions include county-specific dummies for each period (not indicated in the table) and use the unweighted OLS method. The impact of direct and of embodied R&D variables are measured separately in every regression; in addition, one regression separates embodied R&D by source of origin (domestic or imported products), and another distinguishes it by types of products (intermediate and investment goods).

As might be expected, the regressions present a varied picture of the importance of R&D and its diffusion on productivity growth in the seven industrial groups concerned. In manufacturing, direct R&D coefficients are only significantly positive for machinery; for two groups, the sign is negative, but not significantly so. This suggests that the positive coefficient obtained in the regression for manufacturing as a whole is mainly due to the machinery group. The estimated rate of return of R&D for this group is around 0.19 to 0.27, slightly higher than the average rate of return for manufacturing as a whole, and every regression reveals a slight decrease in the potency of R&D over time.

Embodied R&D plays a significant role in productivity growth in the services sector, especially in the ICT segment, owing to high levels of investment in R&D-intensive products. Embodied R&D coefficients are significantly positive in the ICT services group for both domestic and imported R&D. The estimated rate of return for total embodied R&D is around 140 per cent and increases slightly in the 1980s. Moreover, the rate of return is higher for imported than for domestic R&D in both periods, although the return to imported R&D tends to decrease over the last decade.

The regression results confirm that the greatest share of the impact of embodied R&D is due to capital investment by the ICT group for R&D-intensive products such as computers and aeroplanes. For other services groups, the embodied R&D variable is not significant, despite apparent large flows of manufacturing R&D into these groups through input purchases. While there may be serious measurement errors in services sector TFP, regulations and inefficient use of high-technology products may be strong barriers to realising the productivity potential of new technologies.

Impacts on productivity growth in machinery and in ICT services

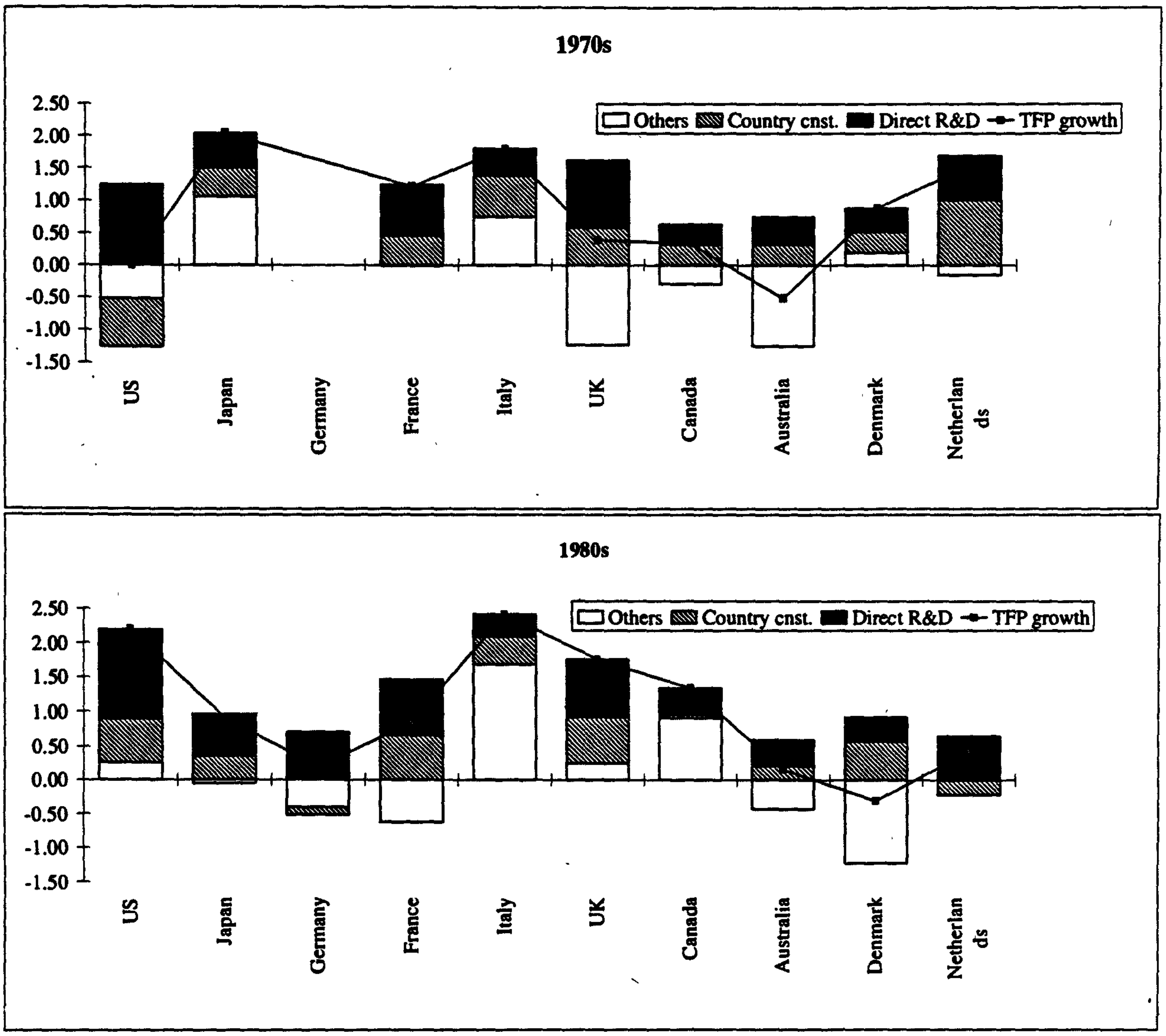
It is also interesting to see how much R&D or R&D diffusion have contributed to actual TFP growth in a specific sector. On the basis of the regression results described above, this can be roughly estimated by multiplying the estimated coefficients for individual groups by weighted averages of R&D intensities in each group, using gross output shares as weights. Since the level of R&D variables is different in different countries, the impact of R&D on TFP growth may differ even if common estimated parameters are used for each country. Given that the only significant results are obtained for the machinery sector and ICT services, the impact analysis was carried out for these sectors (Figures 18 and 19).

First, for the countries studied, unweighted average TFP growth in the machinery sector increased during the two periods from 0.8 per cent in the 1970s to 1 per cent in the 1980s, though performance differed considerably from country to country and for the two periods. Figure 18 suggests that the contribution of direct R&D was quite stable in each country in the two periods, with, if anything, a slightly increasing impact in the United States, Japan, France, and Canada. Since the estimated rate of return in the regression shows a small decrease in the 1980s, the rising or stable impact of direct R&D over time is explained by an increase in direct R&D intensities for the machinery sector in the 1980s.

Although the assumption of a common rate of return to R&D across countries may be open to question, Figure 18 generally confirms that R&D had a strong positive impact on TFP growth in the machinery group for every country, although actual TFP performance was poor. In particular, in the 1970s, R&D contributed more than 1 percentage point to productivity growth in the United States and the United Kingdom; for the United States, the contribution rose to 1.4 percentage points in the 1980s. The contribution of R&D was also high in France and the Netherlands for both periods and contributed to relatively higher growth in their TFP. However, for five other countries, the R&D impact was below the cross-country average of 0.7 percentage point in the 1970s, and except for Germany and Japan remained low in the 1980s.

While an explanation is beyond the scope of this report, estimated country-specific constants and other effects included in the residuals of regressions were also important for TFP growth in the machinery sector. Since the country-specific constant in the regression is assumed to be the same across a country's industries, the size of this effect is the same in Figures 18 and 19. For each country, this value corresponds to the intercept at which R&D intensities are zero, and it is interpreted as the average effects across industrial groups of disembodied technical change, scale economies, qualitative improvement of capital and labour, catch-up factors, uneliminated business cycle effects, measurement errors of TFP, etc., which are unrelated to R&D activities.

Figure 18. **R&D Contribution to TFP Growth in the Machinery Sector**

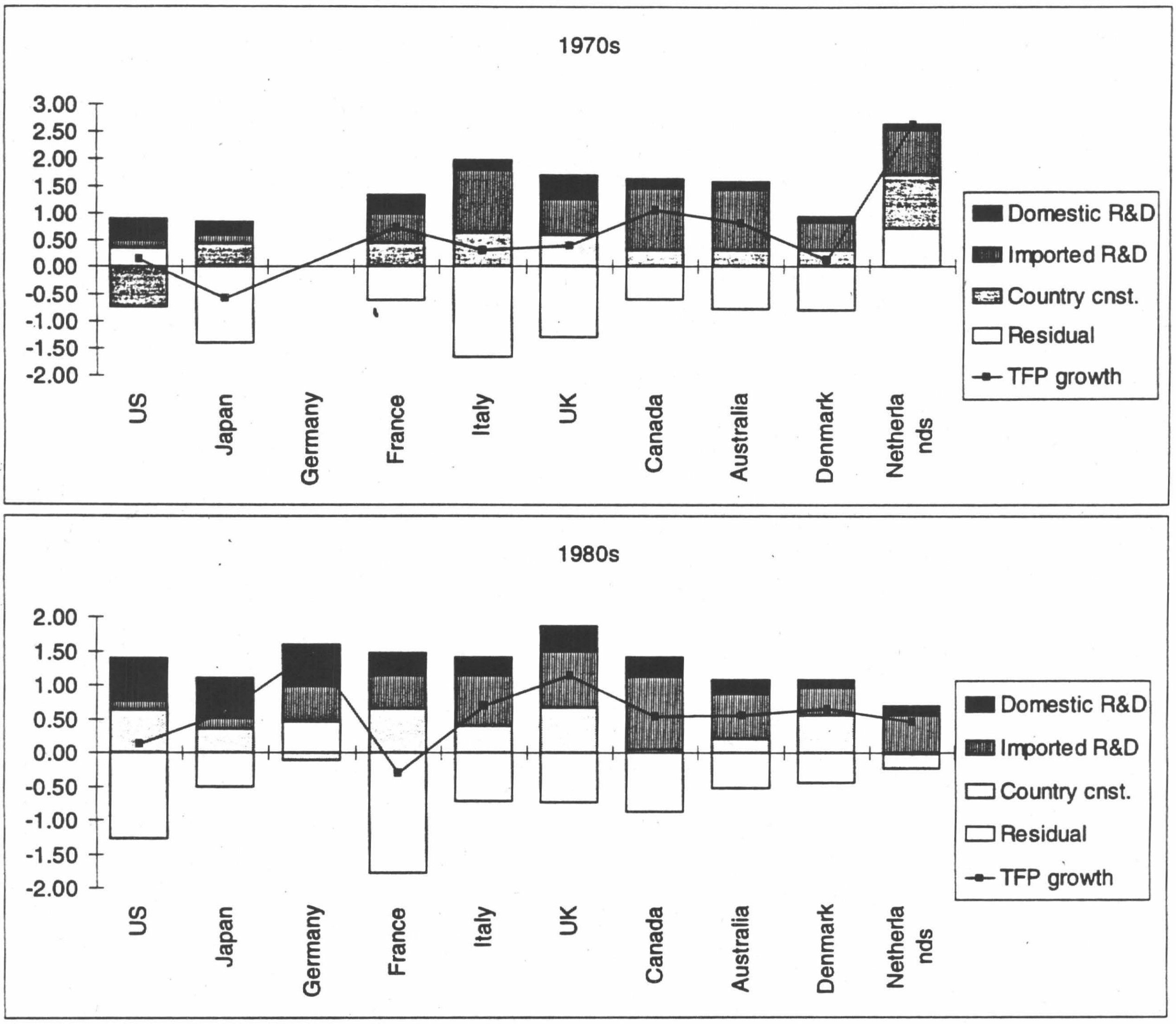


Note: The contributions of R&D and country specific dummies were calculated by using the estimated parameters of Regression 2 in Annex Table11. Averaging both hand-side variables over the industries in the machinery group was done by using gross output shares of each industry.

Source: OECD (STI/EAS Division) calculations.

For the ICT services sector, the impact of embodied R&D can be traced separately for domestic and imported R&D (Figure 19). Although actual TFP growth in this group as a whole was lower than it was in the machinery sector (an unweighted average across countries of 0.5 percentage point in the 1970s and 0.3 in the 1980s), embodied R&D contributed significantly to raising productivity potential. In particular, while R&D obtained through the purchase of domestically produced goods was more important than imported R&D in the United States and Japan, and to a lesser extent in Germany, imported R&D played a more significant role in other countries, particularly in smaller countries such as Denmark, Australia, and the Netherlands, as well as in Canada.

Figure 19. R&D contribution to TFP growth in the ICT services sector



Note: The contributions of R&D and country specific dummies were calculated by using the estimated parameters of Regression 2 in Table7. Averaging both hand-side variables over the industries in the machinery group was done by using gross output shares of each industry.

Source: OECD (STI/EAS Division) calculations.

2. The absolute impact of domestic R&D is, however, highest in the United Kingdom (0.4 percentage point) for the 1970s, 50 per cent higher than in the United States. In general, compared with the significant inter-country differences in the level of imported R&D, the average impact of domestic R&D for all the countries is greater (0.1 to 0.2 percentage point). Between the 1970s and 1980s, the impact of domestic R&D increased in every country except the United Kingdom and France and particularly in the United States, Japan, and Germany (roughly 0.5 percentage point), perhaps as a result of increasing domestic linkages with ICT manufacturers for the procurement of advanced products.

In sum, R&D investment and embodied R&D had a significantly positive impact on TFP growth in ICT industries. On average, R&D contributed 0.7 percentage point to machinery TFP growth; R&D performed in these industries was diffused across sectors, raising productivity in the industries that bought R&D-intensive products as inputs into their production processes. Because ICT services have strong linkages with ICT manufacturers, the estimated average impact of such indirect R&D for ICT services was 0.8 percentage point across the countries in both periods, of which 0.3 was from domestic producers and 0.5 from foreign producers. The improved productivity potential of the ICT services sector can certainly be attributed to the world-wide process of technology diffusion.

Comparisons with other studies

The literature on R&D, R&D spillovers, and productivity growth is large, rapidly expanding, and varied in terms of the approach followed or the questions addressed. A number of reviews of the literature cover various aspects (for example, Mohnen, 1990, 1994; Griliches 1992; Nadiri, 1993). Studies differ with respect to the data used and the methodology employed. Studies that take into account both R&D and some measure of R&D spillovers can be distinguished in a number of ways: whether they use firm-level, industry, or aggregate data; whether they examine intra-industry or interindustry spillovers; the kind of weighting scheme used in order to assess the importance of outside knowledge or R&D; the use of production functions or of dual-cost functions in estimations; whether they cover domestic effects only or international ones as well, etc.[8]

Compared with the many studies that already exist on the topic, the value added of this report is three-fold. First, the use of an internationally consistent data set of R&D expenditures, input-output matrices, and bilateral trade flows permits an analysis that covers ten OECD countries. Most other studies have concentrated on individual countries. Second, the level of disaggregation of the data makes it possible to examine the impact of R&D and technology diffusion on productivity growth separately for manufacturing and for services, as well as for different segments of each of these. Most other studies have either used aggregate data; or when they have used firm-level or sectoral data, they have usually focused on the manufacturing sector alone.

Finally, the methodology used allows for separating and contrasting two different channels of technology diffusion: R&D embodied in intermediate goods vs. R&D embodied in investment goods; and R&D embodied in domestic purchases vs. imported R&D. The international dimension is particularly important, given that most work on international spillovers has either used aggregate data or failed to distinguish between the effects on manufacturing and on services.

Despite the difficulties involved in comparing results from models with different data and methodologies, a number of stylised facts have emerged from the literature, and it is against these that this report's results can be judged. First, this study follows others in using a wide range of data sets, methodologies, and several time periods in order to find significant rates of return on embodied R&D (Table 5),[9] but does so only for the services sector, and in particular for the ICT segment of services. In many investigations, outside or user R&D is often more significant in explaining manufacturing productivity than the R&D of the sector of origin (e.g. Griliches and Lichtenberg, 1984; Englander *et al.*, 1988).

Table 5. Comparisons of results of various studies

Study	Data	Weighting Matrix	Rate of return on outside R&D
Terleckyj (1974)	20 manuf. ind. US	IO flows	45% (total), 78% (private)
		investment flows	50% (total)
	13 non manuf. ind. US	IO flows	187%
		investment flows	762%
Terleckyj (1980)	20 manuf. ind. US	IO flows	183%
Odagiri (1985)	15 manuf. ind. Japan	IO flows	0%
Wolff-Nadiri (1993)	50 manuf. ind. US	IO flows	0% (private or total)
		investment flows	11% (private)
Goto-Suzuki (1989)	50 industries Japan	IO & investment flows	80%
	45 industries Japan	position vector in R&D space	4.30%
Sveikauskas (1981)	102 industries US	investment flows	861%
Scherer (1982, 1984)	36 to 87 ind. US	patent flows	147%
Griliches-Lictenberg (1984b)	193 manuf. ind. US	patent flows	0% to 90%
Englander et. all (1988)	16 ind., 6 countries	Canadian patent flows	-11% to 50%
Doucharme-Mohnen (1989)	25 ind. Canada	patent flows	30% to 685%
Sterlacchini (1989)	15 manuf. ind. UK	IO flows	9% to 12%
		innovation flows	14% to 30%
Hanel (1994)	19 industries Canada	patent flows	0.60%
Van Meijl (1994)	30 industries France	IO flows	41% to 46%
		investment flows	415% to 569%
		patent flows	19% to 24%
Fecher (1992)	8 manuf. ind., 11 OECD count.	sum of sectoral R&D from 5 countries	0%
Soete-Verspagen (1993)	aggregate 23 countries	foreign technology payments	0%
		sectoral R&D from 9 sectors weighted by imports	0%
Coe-Helpman (1993)	aggregate 22 countries	Import weighted foreign R&D	0.03% to 0.18% (1)
Hanel (1994)	19 industries Canada	percentage sales from foreign affil.	0.20%
Sakurai et al. (1995)	15-24 ind., 10 countries	IO flows	0% (manufacturing)
		IO intermediate flows	0% (services)
		IO investment flows	167%-250% (services)
		IO domestic flows	69%-127% (services)
		IO imported flows	420%-360% (services)

(1) Output elasticity.
Note: Adapted from Mohnen (1994).

This report, instead, finds that embodied R&D is not significant for manufacturing while own R&D is; for the services sector, it is not possible to compare the rates of return of own R&D efforts and of embodied R&D owing to the lack of data on R&D expenditures by services industries. With respect to the lack of significant results for embodied R&D in manufacturing, it is worthwhile noting that, for the Japanese electronics industry, Goto and Suzuki (1989) find significant spillovers with an R&D position measure, but not with intermediate goods or investment flow matrices. This is consistent with the results of others (van Meijl, 1994) who suggest that disembodied ("knowledge") spillovers seem to dominate in high-technology sectors and embodied spillovers (through investment goods) in the services industries.

The actual estimates of the rates of return of both own and of "borrowed" R&D differ widely among studies, and the differences are greater for outside R&D. Rates of return to own R&D effort are typically in the zero to 30 per cent range and generally in the 10-20 per cent range. Here, estimated rates of return to own R&D in manufacturing are around 15 per cent on average for the whole sample of countries. In terms of outside or "borrowed" R&D, Mohnen (1994) finds an average estimate of the excess of the social rate over the private rate of approximately 50 to 100 per cent for the different studies that have included an outside R&D variable. There are also some extreme estimates of nearly zero as well as others exceeding 400 per cent (Van Meijl, 1994). In this report, the estimated rate of return on embodied R&D falls between 130 and 190 per cent, depending on whether one looks at the 1970s or the 1980s and whether the estimation covers the services sector as a whole or its ICT segment.

International R&D spillovers seem to be of increasing interest, with a number of recent studies exploring this issue. Results are mixed, and the balance tends to tilt towards recognition of their existence, if not of their actual magnitude. Coe and Helpman (1993) and Bernstein and Mohnen (1994) find strong and significant inter-country spillovers, while Soete and Verspagen (1992) find no evidence of embodied R&D spillovers, but some evidence for the disembodied kind. Where international spillovers are identified, they are larger in smaller countries than in large ones and are sometimes (but not always) larger than domestic spillovers. The high rates of return to R&D embodied in imports found here for the services industry as a whole and for the ICT segment (exceeding 400 per cent in the 1970s and 300 per cent in the 1980s) are on the high side of the various estimates. The contribution of imported R&D to TFP growth in each country in the sample is consistent with the results of other studies that show this effect to be inversely related to country size.

A final issue concerns the changing potency of R&D over time. Griliches and Lichtenberg (1984) and Sterlacchini (1989) find evidence of a decline in the externality effects of R&D, while Scherer (1982a) accepts the hypothesis for aggregate data but rejects it for disaggregated data. Englander *et al.* (1988) accept it for disaggregated data but do not accord it much significance. The evidence from the model used in this report suggests no significant decline in the potency of own R&D efforts in manufacturing over the 1970s and 1980s, and an increasing potency in embodied R&D in the services sector during the 1980s.

Notes for Part II

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1. More generally, the relationship between R&D investment and productivity growth has been a subject of considerable interest. Recent surveys include Mairesse (1991) and Griliches (1993).
2. In a survey of related work, Mohnen (1990) classifies work attempting to disentangle the effect of own and of "borrowed" R&D on productivity growth into a number of categories. The first approach measures the influence of R&D spillovers econometrically by treating spillovers as an unweighted sum of the R&D of all other firms or industries (Levin and Reiss, 1984, 1989; Levin, 1988; Bernstein, 1988; and Bernstein and Nadiri, 1989). The second approach measures the R&D spillover variable as a weighted sum of all external R&D. These studies can be further subdivided into four subgroups, according to the proximity measure used to construct the weights. One uses weights proportional to the flows of intermediate input purchases, as revealed by input-output transactions (Terleckyj, 1974; Griliches and Lichtenberg, 1984; Bresnahan, 1986; and Goto and Suzuki, 1989). The second subgroup uses flows of patents (the best-dknown example is Scherer, 1982a, 1982b, and 1984); others are Schankerman,1979; Pakes and Schankerman, 1984b; and Englander *et al.*,1988). The third focuses on the flows of innovations among firms and industries (e.g. Robson *et al.*, 1988), while the fourth uses patent data and the concept of technological distance (Jaffe, 1986, using an idea originally suggested by Griliches). A third approach adopts a framework in which all externally performed R&D is introduced separately (e.g. Bernstein, 1989).
3. They looked at the correlation of the position vectors of industries in a technology space, where each element in the technological position vector of each sector is the fraction of the sector's R&D expenditures in a particular technological area.
4. It should be noted that adjusting the labour input variable to reflect hours worked rather than numbers employed may change labour productivity growth rates significantly. In Germany, for example, labour productivity in the business sector -- when measured as output per worker -- grew at an annual rate of 1.7 per cent over the 1980s. Productivity growth per hour, on the other hand, was evaluated about similar in size in other European countries but much smaller in the United States.
5. Alternatively, the Divisia index of technical change can be understood as being equal to aggregate productivity growth plus the redistribution effects. ost of the productivity literature (for example, Jorgenson, 1980; Syrquin, 1984; Chenery *et al.*, 1986; Kuroda and Shimpo, 1991; Wolff, 1994) has paid careful attention to this issue, since redistribution effects can change aggregate productivity growth even if the sectoral rates of productivity growth remain unchanged for a given time period. This suggests that using aggregate data to measure productivity growth may result in a misleading indicator of technical change.
6. Growth rates of sectoral TFP are available only at a rather aggregated sectoral level, and because industry aggregations differ from country to country, they are not directly comparable. See Appendix 3 for the industrial aggregation scheme used in this study.
7. While the first estimates the average R&D impact irrespective of the volume of each sector's production, the second takes production volume into account and produces R&D coefficients that are close to those for aggregate manufacturing and services. Because the underlying sectoral classifications in the data differ somewhat among countries, the weighted regression can be expected to absorb the impact of this heterogeneity (for example, the
8. communications sector, which leads in terms of TFP growth, is separated out in some countries but not in others).
9. In one survey, Mohnen (1994) classifies work that attempts to disentangle the effect of own and of "borrowed" R&D on productivity growth into a number of categories. The first measures the influence of R&D spillovers econometrically by treating spillovers as an unweighted sum of the R&D of all other firms or industries (Levin and Reiss, 1984, 1989; Levin, 1988; Bernstein, 1988; and Bernstein and Nadiri, 1989). The second category measures the R&D spillover variable as a weighted sum of all external R&D and can be further subdivided into four subgroups, according to the proximity measure used to construct the weights. Papers in the first subgroup use weights proportional to the flows of intermediate input purchases, as revealed by input-output transactions (Terleckyj, 1974; Griliches and Lichtenberg, 1984; Bresnahan, 1986; Goto and Suzuki, 1989; Wolff-Nadiri,

1993), the methodology used in the present report is close to this approach. The second subgroup uses patent flows, and Scherer, (1982a, 1982b, and 1984) is the best-known example of this approach; others are Schankerman (1979); Pakes and Schankerman (1984b); and Englander *et al.* (1988). The third subgroup focuses on the flows of innovations among firms and industries and includes Robson *et al.* (1988), while the fourth uses patent data and the concept of technological distance (Jaffe, 1988). A third approach adopts a framework in which each element of external R&D is introduced separately (Bernstein, 1989).

10. The results from various studies presented in Table 5 are restricted to studies of domestic and international R&D spillovers using aggregate and sectoral data and employing the "primal" approach (i.e. using production functions in the econometric estimations). This leaves out all the studies that have relied on firm-level data and those that have used the "dual" (cost function) approach.

Part III

INTERNATIONAL COMPETITIVENESS

CHAPTER 11

TRENDS AND SHIFTS IN INTERNATIONAL TRADE AND COMPETITIVENESS

Introduction

This part of the report examines the role of technology in trade and in shaping international competitiveness. International trade has been the engine of growth in OECD countries since World War II. In recent years, it has been increasingly transformed: new patterns of international specialisation, increasing intra-indusrty and intra-firm trade, complex patterns of international sourcing are all characteristics of the globalisation of industrial activities and trade. Technology is central to this process; it is both what has allowed many of these developments to take place, and is a competitive tool in itself, as innovation and the succesful adoption of technology developed elsewhere are essential for success in international markets.

The combination of these changes is raising a host of policy questions. They include defining national interest and formulating domestic policies in an environment where firms and industries are increasingly inter-linked; the role of policies to support R&D and their impacts on the international distribution of tehnology and access to it by small firms and lagging countries; and the development of competition policy at international level. In a certain sense, the rising importance of technology-based trade implies that policy to support innovation and technology diffusion cannot be considered separately from trade policy.

As an introduction, this chapter reviews the changing composition of trade, with the growing importance of trade in manufactured goods and in particular in high technology products (Box 5 discusses different trade idicators). Increasing import penetration is shown to characterise all OECD countries but in different degrees, while the evolving export specialisation of economies presents a sharp contrast: while Japan is moving out of the low technology/low wage part of manufacturing trade and reinforcing its position in the growing high and medium technology and wage segments, the European Union countries are reinforcing their already strong specialisation in the declining low technology segments. At the same time, the US maintains with a slight erosion its strong specialisation in high technology, science-based exports. Finally, intra-industry and intra-firm trade are shown to be the dominant part of trade, with traditional inter-industry trade representing only a small part of the total.

Chapter 12 then develops a model to examine the determinants of international competitiveness, and in particular the role of R&D, diffusion and of scale economies in trade specialisation and performance. It finds clear support for the so-called "home market effect", ie that countries tend to develop a comparative advantage in industries for which there is a strong domestic demand, and some support for R&D as an important competitive factor, especially in high technology industries. At the same time, there is no strong support in the results that the wage level is by itself an import factor in shaping comparative advantage.

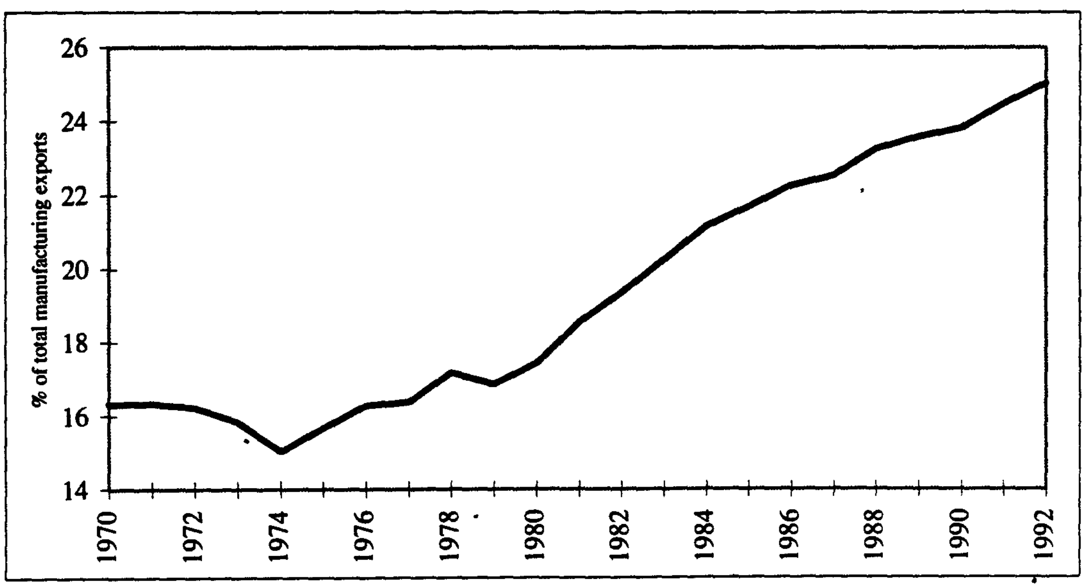
The changing composition of international trade

There have been significant changes in the structure of international trade since the 1970s. The share of OECD countries in world merchandise trade has grown, while trade has increasingly consisted of trade in manufactured goods, involving mainly two-way trade in similar products (intra-industry trade). Furthermore, the importance of high-technology products has increased.

OECD Member countries accounted for almost 70 per cent of world commodity exports in 1991, an increase of 10 percentage points since 1980. During that period, the importance of primary products, such as foods, beverages and tobacco, oils and fats, and minerals diminished to less than 20 per cent of the exports of most country groupings by 1991 (Table 6). In contrast, more than three-quarters of the exports of most OECD country groupings in 1991 were in manufactured goods, and more than a third in the machinery and transport class, compared to about a quarter in 1980.

Notable is the large and increasing share of machinery and transport in total exports from Japan, as well as the extent to which exports of several non-OECD countries in Asia shifted between 1980 and 1991 and now resemble OECD country patterns. The changing structure of the trade of individual countries or country groupings is underscored by the evolution of regional shares of manufactured commodity classes in total world exports. Non-OECD countries of Asia have achieved gains of one- to two-fold in manufacturing classes, and Japan has gained about three percentage points in machinery and transport equipment over the same period.

Figure 20. **Total OECD high-technology exports**
as a percentage of total manufacturing exports



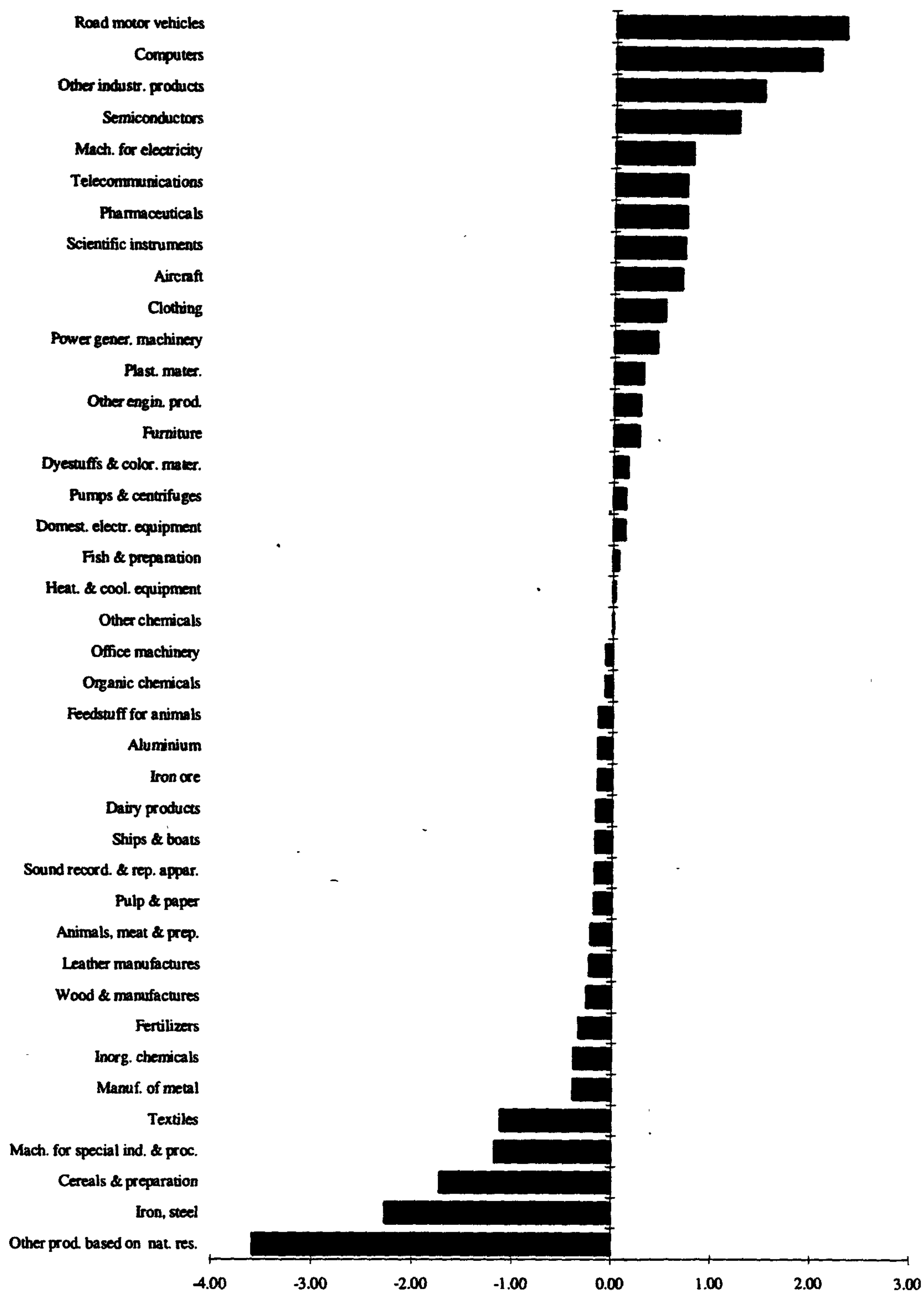
Source: OECD, July 1995.

Table 6. **Structure of world trade by commodity classes and regions**

		Commodity composition of total exports of selected regions						
		World	US	Japan	EU-12	EFTA	Aus-NZ	Asia
Total commodities	1980	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SITC 0-9	1991	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Food, bev., tobacco	1980	10.0	14.0	1.2	10.5	4.0	36.3	12.0
SITC 0&1	1991	8.9	9.1	0.6	10.3	3.9	22.2	7.4
Oils and fats	1980	6.9	11.9	1.2	3.5	8.6	28.9	13.1
SITC 2&4	1991	4.7	6.6	0.7	2.9	4.7	18.1	4.7
Minerals	1980	24.0	3.7	0.4	8.0	10.1	9.1	20.5
SITC 3	1991	9.5	3.1	0.5	3.7	9.1	15.3	7.4
Chemicals	1980	7.0	9.6	5.1	11.4	9.7	2.5	2.7
SITC 5	1991	8.7	10.5	5.4	11.8	11.6	3.0	4.7
Mach./transport	1980	25.6	39.0	58.4	32.7	28.1	5.0	12.9
SITC 7	1991	36.5	46.8	70.8	38.6	32.4	6.4	29.6
Other man. goods	1980	24.0	17.9	32.4	32.0	38.8	13.9	37.0
SITC 6&8	1991	28.9	19.2	20.5	30.9	37.7	14.4	44.8
			Origin of exports of major commodity classes					
		World	US	Japan	EU-12	EFTA	Aus-NZ	Asia
Total commodities	1980	100.0	10.8	6.5	34.5	5.6	1.3	8.1
SITC 0-9	1991	100.0	11.7	9.1	39.8	6.3	1.4	15.0
Food, bev., tobacco	1980	100.0	15.1	0.8	36.1	2.2	4.8	9.7
SITC 0&1	1991	100.0	11.9	0.6	46.1	2.8	3.6	12.6
Oils and fats	1980	100.0	18.6	1.1	17.6	6.9	5.6	15.3
SITC 2&4	1991	100.0	16.3	1.3	23.9	6.3	5.5	14.8
Minerals	1980	100.0	1.7	0.1	11.5	2.3	0.5	6.9
SITC 3	1991	100.0	3.8	0.4	15.5	6.0	2.3	11.7
Chemicals	1980	100.0	14.7	4.7	55.8	7.7	0.5	3.1
SITC 5	1991	100.0	14.0	5.6	53.6	8.4	0.5	8.0
Mach./transport	1980	100.0	16.5	14.8	43.9	6.1	0.3	4.1
SITC 7	1991	100.0	15.0	17.7	42.0	5.6	0.3	12.2
Other man. goods	1980	100.0	8.1	8.7	45.8	9.0	0.8	12.5
SITC 6&8	1991	100.0	7.7	6.5	42.4	8.2	0.7	23.2

Source: United Nations, *1992 International Trade Statistics Yearbook*, 1994.

Figure 21. Market share changes for different commodity groups, 1980-93 (1,2)



1. Change between 1980 and 1993 of OECD exports for each commodity group as a percentage of total OECD exports.
2. Exports for 1993 were calculated with 1992 data for Belgium-Luxembourg, Denmark, Germany, Greece, Ireland, Netherlands, Norway and the United Kingdom.
Source: OECD, NEXT database (STD, ESNA Division), March 1995.

Exports from high-technology industries constituted about a quarter of manufactured exports of OECD countries in 1992, a share that has increased by 10 percentage points since 1970, largely at the expense of low-technology products (Figure 20). The bulk of the changes took place during the 1980s. Individual high-technology products making the most notable gains were computers and semiconductors, two out of only four products whose market shares more than doubled since 1980 (Figure 21). Other high-technology products with relatively important gains in market shares since 1980 were telecommunications equipment, pharmaceuticals, scientific instruments and aircraft. Motor vehicles added the biggest gain to a market share already above 10 per cent in 1980, while iron and steel had an equivalent loss.

Changing patterns of import penetration

The weight of imported manufactured goods in the total domestic demand for goods in manufacturing varies significantly from country to country across the OECD area (Table 7). The highest import penetration can be found in Belgium, Denmark, and the Netherlands and the lowest in Japan and the United States. For most European countries, imports account for between 20 and 40 per cent of domestic demand. Despite these large cross-country differences, import penetration increased in the manufacturing sector in every one of the OECD countries listed in the table during the period from 1980 to 1992, with the strongest increases by far in Spain and in the United States. The only two countries where there was barely any change were Italy and Japan.

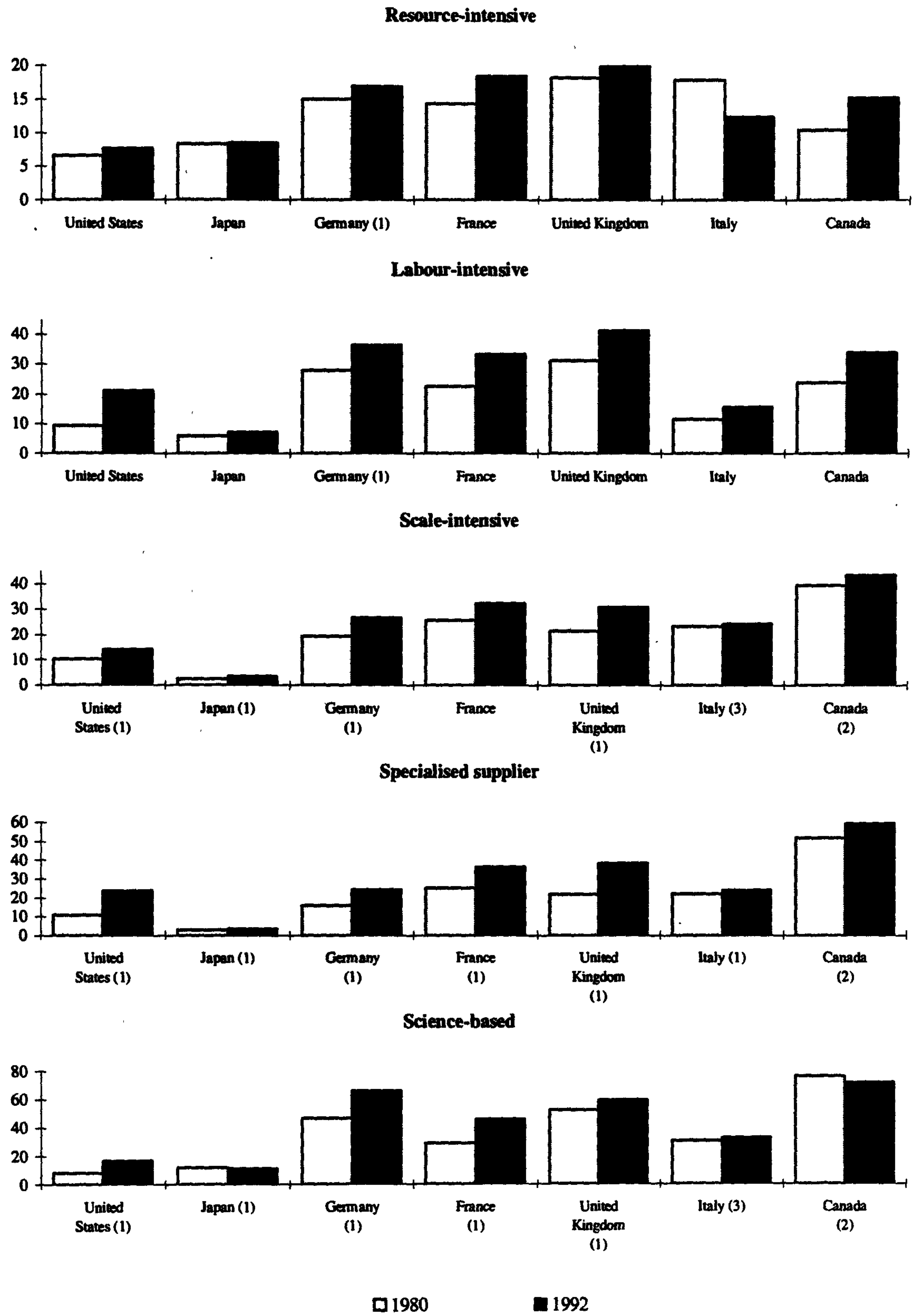
Table 7. **Import penetration by type of manufacturing industry: G7 countries**

	Total manufacturing			High technology		Medium technology		Low technology	
	1980	1992	Average annual growth rate 1980-92	1980	1992	1980	1992	1980	1992
United States	8.9	16.0	5.0	10.3	22.0 [1]	13.4	19.6 [1]	6.3	8.7 [1]
Canada	30.7	40.0	2.2 [4]	57.1	65.0 [2]	50.1	52.8 [2]	13.4	18.2 [2]
Japan	5.3	5.7	0.7	6.0	6.1 [1]	4.5	5.2 [1]	5.4	6.4 [1]
France	21.3	30.2	2.9	25.4	40.4 [1]	30.5	39.8 [1]	15.8	21.4
Germany	19.6	27.2	2.8	24.9	39.0 [1]	21.3	28.1 [1]	17.2	21.9 [1]
Italy	20.0	20.6	0.2	23.4	24.9 [3]	31.2	32.4 [3]	14.1	14.3 [1]
United Kingdom	23.4	33.5	3.0	34.0	50.0 [2]	31.9	41.1 [1]	16.6	21.8 [1]

1. 1991.
2. 1990.
3. 1987.
4. Average annual growth rate from 1980-90.

Source: OECD, STAN database (DSTI, EAS Division).

Figure 22. Import penetration by type of manufacturing industry: G-7 countries, 1980 and 1992



1. 1991 instead of 1992.
2. 1990 instead of 1992.
3. 1987 instead of 1992.

Source: OECD, STAN database (DSTI, EAS Division), March 1995.

The import penetration ratio in industry groupings are shown in Table 7 and Figure 22 (see Box 6 for industry grouping definitions). In the United States, imports are twice as important in high- and medium-technology as in low-technology industries. Specialised supplier and labour-intensive industries have the highest import penetration rates, while the lowest rates are in resource-intensive industries. Computers, communications equipment and textiles are the industries with the highest import penetration rates, with an increasing trend in the 1980s.

The profile of import penetration in Japan is strikingly different from that of other OECD countries. Imports accounted for less than 6 per cent of the total domestic demand for manufacturing in 1992, with little variation across the three technology groups. Imports tend to be particularly unimportant in the scale-intensive and the specialised supplier industries. They are more important in resource-intensive, labour-intensive and science-based sectors. Aerospace is the only industry for which imports represent a significant share of total domestic demand.

France, Germany, and the United Kingdom have broadly similar profiles both at the level of total manufacturing and at a more disaggregated level. For all three, high-technology and science-based industries are the most import-intensive groupings. Import penetration is very high for all three in computers, for France and Germany in scientific instruments, for Germany in textiles and aerospace, for the United Kingdom in fabricated metal products. Import penetration in Italy is the lowest of the four large European countries and has barely increased since 1980. There is a great deal of variance among industries, with import penetration tending to be relatively high in instruments, computers and communications equipment, and particularly low in wood products and non-metallic minerals. Italy is also the only large EU country where import penetration has declined significantly in a number of industrial sectors since 1980.

Table 8. **Export specialisation by type of industry (1)**

	United States			Japan			EU-12 (2)		
	1970	1980	1992	1970	1980	1992	1970	1980	1992
High-technology industries	159	153	150	124	141	144	84	83	80
Medium-technology industries	110	106	90	78	106	114	100	99	100
Low-technology industries	64	67	74	114	76	46	107	109	114
High-wage industries	136	119	118	64	92	108	97	100	95
Medium-wage industries	95	94	95	122	127	121	99	96	97
Low-wage industries	64	83	82	102	66	55	107	106	111
Resource-intensive industries	77	75	88	40	24	21	101	110	110
Labour-intensive industries	48	75	62	139	78	52	118	113	121
Scale-intensive industries	89	84	82	123	136	115	99	99	102
Specialised supplier industries	123	118	110	105	135	156	101	94	91
Science-based industries	206	205	178	66	80	102	75	78	81

1. The export specialisation (or revealed comparative advantage) index is calculated as the ratio of the share of the country's exports in that industry in its total manufacturing exports to the share of total exports by that industry (or industry grouping) in OECD manufacturing exports. A value of 100 indicates the same export specialisation as the OECD average (see Box 11.1).
2. Includes intra-EC trade.

Source : OECD, STAN database (DSTI, EAS Division), March 1995.

Export specialisation

Of the larger OECD countries, the United States is relatively specialised in high-technology and science-based exports, even if that specialisation pattern has weakened somewhat since 1980 (Table 8 and Annex Table 14). Japan is the country whose export specialisation has evolved the most, with a strong movement out of low-technology, labour-intensive exports and towards high- and medium-technology exports, or towards the exports of industries characterised by scale economies and producing differentiated products.

The export specialisation of France and Germany has remained relatively steady since 1980. In the case of France, it is relatively evenly spread over high-, medium- and low-technology industries, with some specialisation in the exports of resource-intensive industries. In Germany, exports are relatively concentrated in medium-technology industries and in sectors characterised by scale economies and producing differentiated products. Manufactured exports in the United Kingdom are concentrated in the high-technology and science-based industries, while Italy has reinforced its specialisation in low technology, labour-intensive exports since 1980.

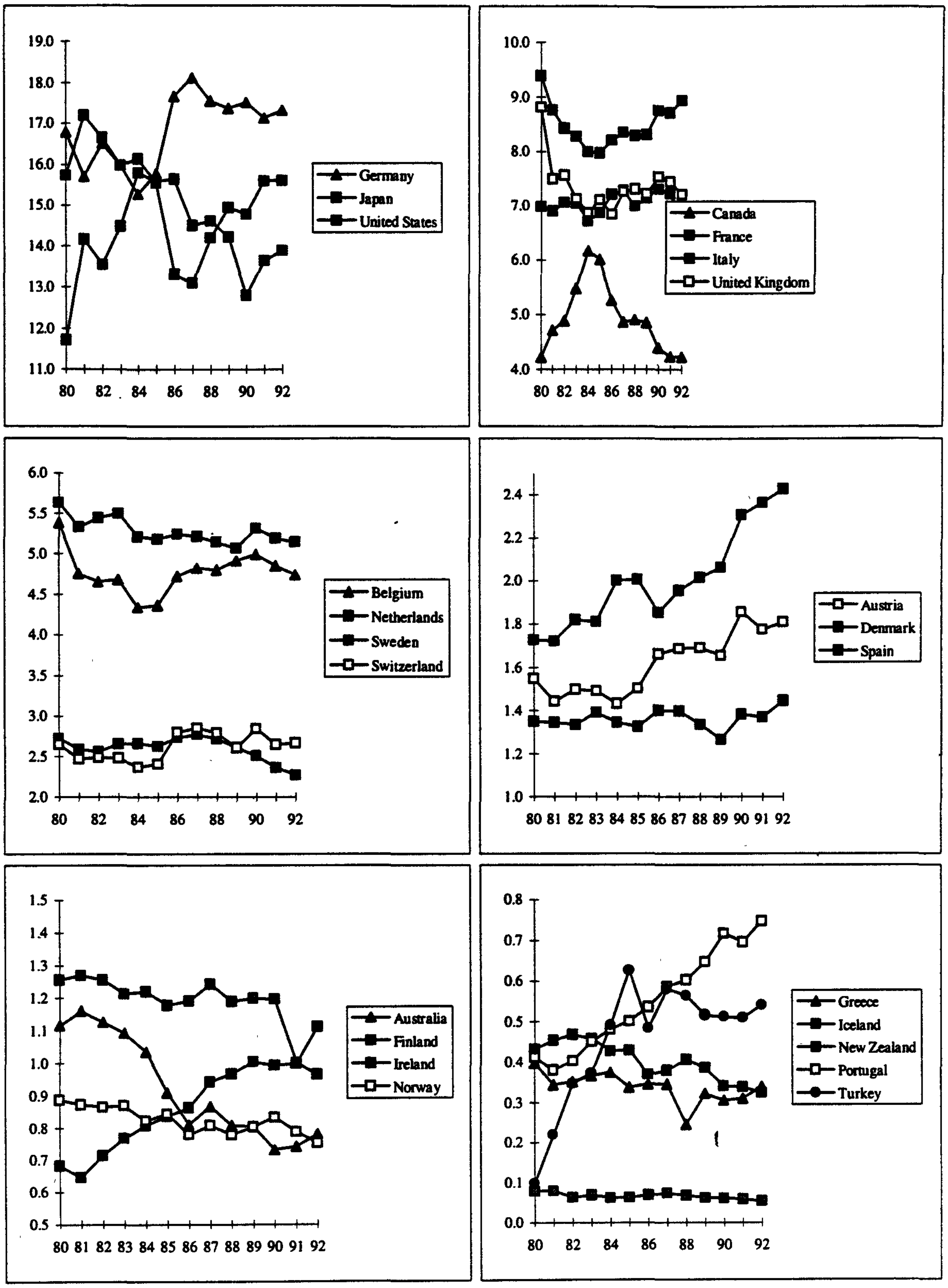
Most of the smaller OECD countries tend to be relatively specialised in exports of low-technology industries. This is particularly the case in resource-based economies such as Australia, Finland, New Zealand or Norway, or in the case of latecomers to industrialisation such as Greece, Portugal or Turkey which retain a strong specialisation in labour-intensive exports. Countries with a longer history of industrialisation, such as Austria, Belgium, Denmark, the Netherlands, Sweden or even Spain, have more diversified export profiles, sometimes (as in the case of the Netherlands) specialising in both resource-intensive and science-based exports. The case of Ireland is worth noting, since it is the only small country that has built a strong export specialisation in high-technology and science-based industries (notably computers), in part owing to exports from Ireland of a number of foreign-owned multinationals.

Performance in export markets

Figure 23 shows the evolution of the shares of individual OECD countries in total OECD manufacturing exports. Germany has consistently had the highest overall export market share since 1980, largely owing to the success of exports of its medium- and low-technology industries. To the extent that the weight of these industries is declining in total OECD manufacturing exports, however, this is a performance that will be difficult to sustain in the future.

The share of the United States in total OECD manufacturing exports fluctuated widely during the 1980s, but was in 1992 was at the same level as in 1980, just behind Germany. A breakdown by industry shows that this stability can be traced to heavy losses in certain high-technology industries (computers, pharmaceuticals, aerospace) as well as in medium-technology exports, compensated by increases in exports of low-technology industries. The share of Japan, third on the list, has increased since 1980, even though it declined in the latter half of the 1980s, following appreciation of the yen. This overall increase was driven by market share gains in the high-technology and medium-technology industries, with losses in low-technology sectors, or alternatively by gains in exports of industries producing differentiated and science-based products, which were strong enough to compensate for market share losses in the exports of labour-intensive industries.

Figure 23. **Export market shares in total manufacturing (1)**



1. The export market share for each country is calculated as the share of its manufacturing exports in total OECD manufacturing exports, excluding Mexico.

Source: OECD, STAN database (DSTI, EAS Division), March 1995.

Box 5. Trade indicators

A number of indicators can be used to examine structural shifts and performance in international trade. In this report, trade indicators have been constructed in current prices using the OECD STAN database for individual industries, industry groupings, or for manufacturing as a whole.

Import penetration. Import penetration is calculated as the ratio of imports to total domestic demand (production plus imports minus exports). Expressed in percentage terms, the value of the indicator ranges between zero and 100. When it approaches zero, imports are a negligible part of total domestic demand, which is satisfied entirely by domestic production. As it approaches 100, imports account for almost all of the total domestic demand of a given sector or industry grouping. It is thus an indicator of import intensity and outward orientation of countries or industries.

$$MPEN_i = \frac{M_i}{PROD_i + M_i - X_i} \cdot 100$$

The import penetration indicator can reflect a number of different factors, such as the size of a country or its geographic position: larger countries with significant domestic markets and countries that are geographically removed from the centre of world trade will as a rule have a lower import penetration ratios. At the level of individual industries, import penetration rates reflect the nature of products being traded, with some products more tradable than others. Like any individual indicator, import penetration should be interpreted with caution and its limits understood. A low rate of import penetration does not for example necessarily imply barriers to entry. It may instead reflect superior productivity or lower prices of domestically produced products. Nor is a high import penetration rate necessarily a cause for concern, as economies gain through trade by specialising in certain products and importing others.

Export specialisation. The indicator of export specialisation (or revealed comparative advantage) shows the extent to which a country's exports are specialised in a particular industry relative to the OECD average. For a certain industry or industry grouping, it is defined as the share of the exports of the industry in the total manufacturing exports of the country divided by the share of total OECD-wide exports of the industry in total OECD manufacturing exports. By definition, the average value of the indicator for a particular industry in the OECD area is 100. Values greater than 100 indicate that a country's exports are relatively specialised in that industry. For an industry *i* in a country *k*, the formula is given by:

$$XSPEC_{ik} = \frac{X_{ik} \Big/ \sum_i X_{ik}}{\sum_k X_{ik} \Big/ \sum_i \sum_k X_{ik}} \cdot 100$$

The export structure of a particular country reflects its endowments, whether in natural resources, capital, labour or technology. The indicator of export specialisation helps to identify areas of strength and of weakness, as these are revealed by past export performance. The evolution of the indicator over time allows an analysis of the changing patterns of exports and thus of structural changes in the economy. Changes in its value reflect relative shifts in specialisation between industries, rather than outright increases or declines in export market share.

Box 5 (cont). Trade indicators

Intra-industry trade. Intra-industry trade (IIT) is a measure of two-way trade within the same industrial or product classification. IIT is defined as the value of total trade remaining after subtraction of the absolute value of net exports or imports. The index varies between zero and 100. If a country exports and imports roughly equal quantities of a certain product, the IIT index is high. If it is mainly one-way trade (whether exporting or importing), the IIT index is low. For aggregation purposes, the measure can be summed over many industries. The formulas for a particular product or industry i and for an industry grouping are given by:

$$IIT_i = \frac{(X_i + M_i) - |X_i - M_i|}{(X_i + M_i)} \cdot 100 \quad \text{and} \quad IIT = \frac{\sum_i (X_i + M_i) - \sum_i |X_i - M_i|}{\sum_i (X_i + M_i)} \cdot 100$$

IIT is the result of economies of scale and product differentiation. Countries simultaneously export and import similar products, leading to a situation of two-way trade in highly differentiated products even when the factors of production are similar. Generally, high IIT indices should be expected in countries with high per capita incomes, which are integrated into regional trading zones and geographically close to the bulk of world demand and trade.

The shares of France, Italy and the United Kingdom have declined slightly, while that of Canada has held steady. Of the four largest European countries, France is the only one which increased its export market share in high-technology and science-based industries during the 1980s, almost exclusively because of the success of aerospace exports. This increase has not, however, compensated for export market share declines in medium- and low-technology industries. In the UK, market shares declined across all industry groupings, and particularly in labour-intensive industries. Finally, in Italy, market shares increased in labour-intensive manufacturing, strengthening the country's specialisation in this direction.

Although their share remains very small in total OECD manufacturing exports, significant growth in export market shares can be seen in Ireland, Portugal, Spain and Turkey. In Portugal and Turkey the increase was largely due to the growth in textiles industry exports (and in food products also for Turkey). Export market shares were lower in 1992 than in 1980 in Australia, Belgium, Finland, Greece, the Netherlands, New Zealand, Norway and Sweden.

New forms of trade: intra-industry and intra-firm trade

Besides the shifts in the international orientation of economies and in their export performance, the recent period seems to be characterised by an increasing component of intra-industry and intra-firm trade in total trade, both types of trade that do not conform to the product specialisation hypothesis in traditional trade theory. Intra-industry trade (IIT) is trade between countries within the same broad industry or product group. This trade pattern reflects a number of factors: the oligopolistic structure of markets, with firms engaged in fierce competition at home seeking outlets overseas, often as a precursor to foreign direct investment; and the differentiation of products that follows more diverse tastes. economies.

Box 6. **Classifying manufacturing industries**

The text uses a number of different aggregation schemes for classifying manufacturing industries into groups: one based on technology, one on wages, and one on orientation.

Technology. Industries are grouped on the basis of their R&D intensity in the OECD area as a whole, defined as the ratio of business-enterprise R&D to production. The following high, medium and low technology groups emerge [1]:

High technology Aerospace (ISIC 3845), computers & office equipment (ISIC 3825), communications equipment and semiconductors (ISIC 3832), el. machinery (ISIC 383-3832), pharmaceuticals (ISIC 3522), scientific instruments (ISIC 385)
Medium technology Chemicals excluding drugs (ISIC 351+352-3522), rubber & plastic products (ISIC 355+356), non-ferrous metals (ISIC 372), non-electrical machinery (ISIC 382-3825), motor vehicles (ISIC 3843), other transport equipment (ISIC 3842+3844+3849), other manufacturing (ISIC 39)
Low technology Food, beverages, tobacco (ISIC 31), textiles, apparel and leather (ISIC 32), wood products (ISIC 33), paper and printing (ISIC 34), petroleum refining (ISIC 353+354), non-metallic mineral products (ISIC 36), iron & steel (ISIC 371), metal products (ISIC 381), shipbuilding (ISIC 3841)

Orientation. This classification is based on the primary factors believed to affect competitiveness. Industries are classified into resource-intensive (access to natural resources), labour-intensive (labour costs), scale-intensive (length of production runs), specialised-supplier (differentiated products), and science-based (rapid application of scientific advance)[2].

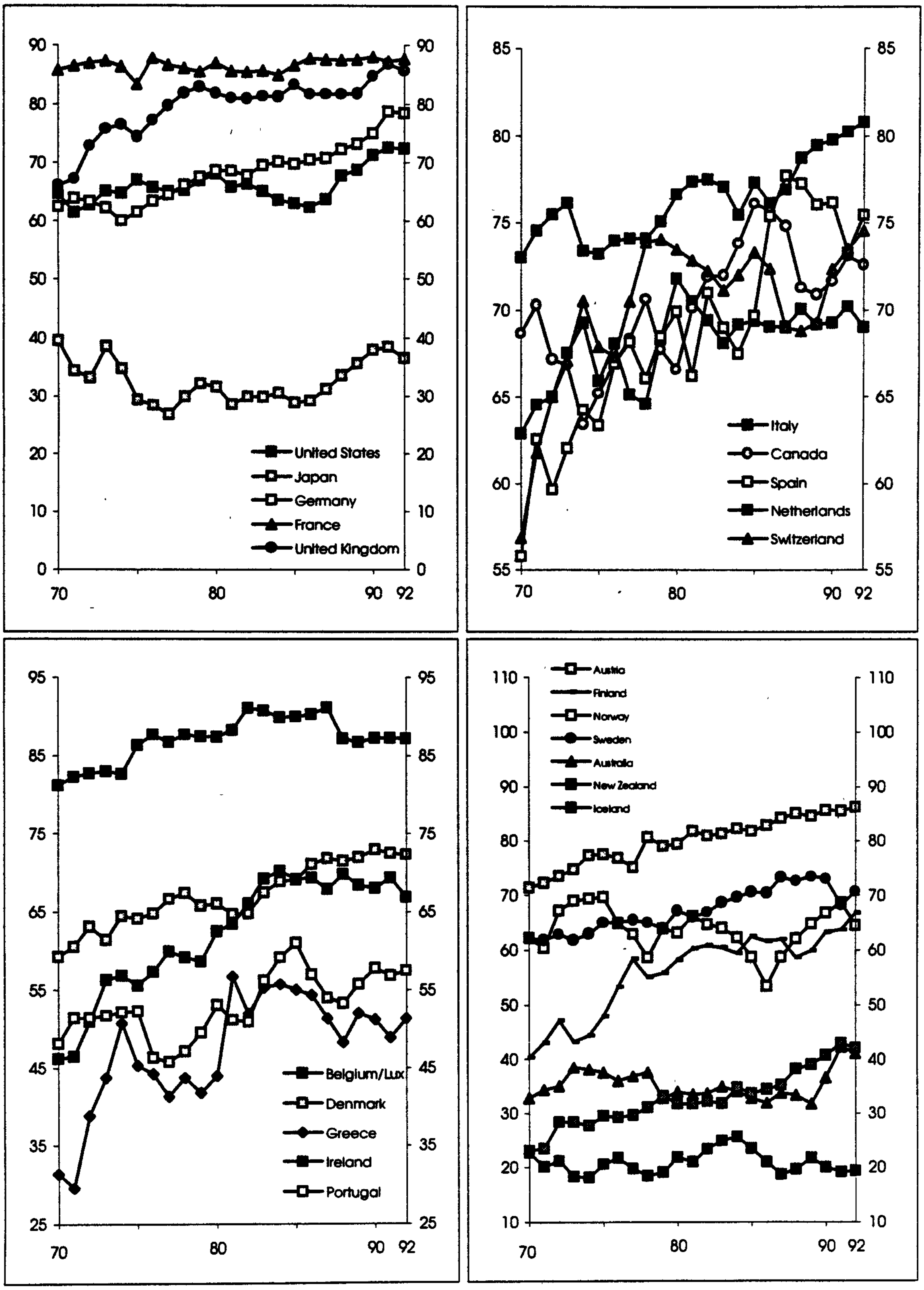
Resource intensive Food, beverages, tobacco (ISIC 31), wood products (ISIC 34), petroleum refining (ISIC 353+354), non-metallic mineral products (ISIC 36), non-ferrous metals (ISIC 372)
Labour intensive Textiles, apparel, leather (ISIC 32), metal products (ISIC 381), other manufacturing (ISIC 39)
Specialised supplier Non-electrical machinery (ISIC 382-3825), electrical machinery (ISIC 383-3832), communications equipment and semiconductors (ISIC 3832)
Scale intensive Paper & printing (ISIC 33), chemicals excl. drugs (351+352-3522), rubber & plastics (ISIC 355+356), iron & steel (ISIC 371), shipbuilding (ISIC 3841), motor vehicles (3843), other transport (ISIC 3842+3844+3849)
Science based Aerospace (ISIC 3845), computers (ISIC 3825), pharmaceuticals (ISIC 3522), scientfic instruments (ISIC 385).

Wages. The high, medium, and low wage grouping is based on the average labour compensation (calculated in US PPPs as labour compensation per number engaged) across nine countries (Australia, Canada, Finland, Germany, Japan, Norway, Sweden, US and UK) for 1985. The high wage grouping is then defined as industries in which the wage was more than 15 per cent above the median, the medium wage grouping as industries within 15 per cent of the median and the low wage grouping as industries with wages at least 15 per cent below the median. The groupings are quite stable over time (1975 and 1980) and for additional countries.

High wage Chemicals excl. drugs (351+352-3522), aerospace (3845), pharmaceuticals (3522), petroleum refining (ISIC 353+354), computers & office equipment (ISIC 3825), motor vehicles (ISIC 3843)
Medium wage Paper & printing (ISIC 33), rubber & plastics (ISIC 355+356), non-metallic mineral products (ISIC 36), iron & steel (ISIC 371), non-ferrous metals (ISIC 372), metal products (ISIC 381), shipbuilding (ISIC 3841), non-electrical machinery (ISIC 382-3825), scientific instruments (ISIC 385), communications equipment and semiconductors (ISIC 3832)
Low wage Food, beverages, tobacco (ISIC 31), textiles, apparel & leather (ISIC 32), wood products (ISIC 34), electrical machinery (ISIC 383-3832), other transport (ISIC 3842+3844+3849), other manufacturing (ISIC 39).

1. See OECD (1992), *Industrial Policy in OECD Countries: Annual Review 1992* for a further discussion on this classification.
2. See OECD (1987), *Structural Adjustment and Economic Performance*.

Figure 24. **Trends in intra-industry manufacturing trade (1)**



1. For definition see Box 11.1.

Source: OECD, STAN database (DSTI, EAS Division), March 1995.

Figure 24 shows the evolution of intra-industry trade since 1970 in the OECD area. For almost all countries, the proportion of total trade that is accounted by intra-industry transactions has increased significantly in the period 1970-92. At the same tine, important inter-country differences remain. The highest IIT indices in 1992 can be found in the United Kingdom, France and Italy (where over 80 per cent of total manufactures trade is accounted for by intra-industry transactions).

In general, country differences reflect the fact that high IIT indices should be expected in countries with high per capita incomes, which imply demand for variety and bring about trade in differentiated products, or for countries at a similar stage of development, belonging to regional trading zones (such as the EC member states). Low IIT indices should in contrast be expected in countries that are geographically far from the areas where the bulk of world demand and trade is concentrated and in countries that have a very high specialisation in one group of products (for example natural resource-based economies) or a high import dependence on others.

Annex Table 15 summarises intra-industry trade by product group for the G-7 countries. It confirms that intra-industry trade is more important in manufactured products than it is for primary commodities. IIT indices tend to be highest in the chemicals, manufactured goods, machinery & transport, and miscellaneous and other manufacturing products groups in most G-7 countries. In these groups products tend to be the most differentiated, and there are also high levels of foreign direct investment in the industries producing them. Nevertheless, despite this broad tendency for IIT trade to be highest in manufactured goods, country-specific factors remain very important. Of all the countries in the G-7 group, Japan is the one with the lowest overall IIT index and the most variance in the level of intra-industry trade between product groups. It is also unique among countries in having a comparatively low level of intra-industry trade, while being a highly developed economy specialising in manufacturing products.

Intra-firm trade (IFT) refers to trade in products which are sold internationally, but which stay within a multinational enterprise (MNE); it represents a significant portion of foreign trade for several OECD countries. Recent OECD work in this area for the United States and Japan shows that over a third of US trade is intra-firm but that, contrary to expectations, the overall share of intra-firm trade in total US trade has not shown a significant increase between 1977 and 1989 (OECD, 1993d). In Japan, intra-firm trade is -- as for the US -- relatively more important for the machinery industries, including transportation equipment. Moreover, wholesale and retail trade account for a significant share of total Japanese IFT, both on the import and the export side, reflecting the significance of corporate networks established by Japanese trading firms in foreign trade activities.

Intra-firm trade can be regarded as the replacement of market transactions by internal transactions within MNEs. Market imperfections and high transaction costs provide an incentive for MNEs to internalise international transactions of goods which are embodied with firm-specific knowledge and expertise. Results for the US and Japan support the "internalisation" theory of IFT by showing that this type of trade is more prevalent in manufacturing industries characterised by higher R&D and/or human capital intensity and greater international orientation.

CHAPTER 12

TECHNOLOGY AND EXPORT SPECIALISATION[1]

Introduction

The previous chapter examined the changing patterns of trade and international competitveness. This chapter develops a simple model in an attempt to help explain the factors that detemine international specialisation, and in particular the role of technology. The interest in the relation between technology and competitiveness dates back to the so-called neo-technological trade theories of the 1960s (product cycle, technology gap etc, for an overview see Dosi and Soete, 1988). These may be seen as attempts to overcome the rigidity of the standard neoclassical approach to international trade, which had become apparent for many observers, especially in the business school tradition and among economic practitioners. Most of these attempts were, explicitly or implicitly, based on Schumpeter's analysis of innovation and diffusion as the driving forces behind competitiveness and economic growth.

Since this issue was first introduced by Vernon and others in the 1960s, economic theory has changed considerably. Trade theorists started to apply the insights from models of imperfectly competitive markets to the analysis of international trade and worldwide competitiveness (so called "new trade theory", see Helpman 1984 for an overview). In this literature the existence of fixed costs, such as R&D, plays an important role (i.e., economies of scale). R&D investment is thus regarded as an important competitive factor. The size of the domestic market also plays an important role in models with imperfect competition and economies of scale. A common prediction of many models of this character is that, other factors left apart, countries will tend to specialise in areas where there is a relatively large domestic market (the so-called "home market effect").

More recently, growth theorists started to introduce the Schumpeterian insight of the importance of innovation and diffusion into formal growth models based on the assumption of imperfectly competitive markets (so called "new growth" theory, for an overview see Grossman and Helpman 1995). These models also point to the importance of R&D for growth of GDP and exports. However, while much of the earlier literature in this area has focused on the direct impact of the R&D effort of a firm, industry or country, the new growth literature focuses more sharply on the impact of diffusion (or "technological spillovers"). In fact, following this approach, it matters a lot what the actual boundaries of these spillovers are.[2] As with "new trade theory" "new growth theory" also emphasises the importance of a large domestic market. If technological spillovers are national in scope, a large country will benefit more from investments in new technology (R&D) than a small one. Hence, following this theory, a large country is more likely to gain a competitive advantage in R&D intensive activities.

Empirically, analysts in this tradition tried to highlight the relation between competitiveness and technology by regressing a measure of export performance on a technology variable, usually based on R&D or patent statistics, and - in some cases - other variables that were deemed relevant for the analysis. Generally, the relation is of the type X = f (T, O), where X is a measure of export performance, T is a technology proxy and O is a set of other variables. Perhaps the most elaborate of these analyses is the one by Soete (1987), which was carried out at the industry level. In addition to technology as reflected in patents, this test also included a host of other variables. More recent work include Magnier and Toujas-Bernate (1994) and Amable and Verspagen (1995). Generally, the results in this literature support the hypothesis of a positive relation between competitiveness and technological activity, though not equally so for all countries and industries. The role of scale factors is mostly ignored in these studies.

A model of technology and specialisation

The purpose of this chapter is to add to the existing literature in this area by exploring the relation between competitiveness, scale and R&D with the help of OECD databases and the work on embodied technology flows presented in Part I of this report. The data set includes 10 countries, 22 industries and (roughly) two decades (see the appendix for a complete listing). Two industries were excluded on the grounds that they are ill defined (two residual categories) and one industry because there appears to be problems with the data (petroleum refining). For some of the technology variables data are available for selected years only (in some cases only one year). This makes a regular time-series difficult. What is presented here is a cross-sectional analysis for 1985, the only year for which the technology variables are available for all 10 countries (even then about 10 % the observations are missing due to lack of data for certain variables, industries and countries).

The model applied is an eclectic one in which the international competitiveness of a country is explained by technological factors (direct R&D efforts and its the ability to profit from technological spillovers, whether of domestic or foreign origin), cost competitiveness (wage-level), its rate of investment and the size of the domestic market, or more formally of the type S = f(RD, DOM, FOR, WAGE, INV, Size), where:

- S is a normalized version of Balassa's revealed comparative advantage index,[3]
- RD (Direct R&D) is business enterprise R&D as a percentage of production,
- DOM (Domestic spillovers) is indirect R&D acquired through purchases of capital goods and intermediate goods from domestic suppliers as a percentage of production,
- FOR (Foreign spillovers) is indirect R&D acquired through purchases of capital goods and intermediate goods from foreign suppliers as a percentage of production,
- WAGE is labour costs per worker in common currency (ppp),
- INV is gross fixed capital formation as a percentage of production,
- Size is domestic demand (measured as production+imports-exports) in common currency (ppp).

The inclusion of the technology and scale variables have already been discussed. Part I of this report discusses the calculation of the spillover variables. The two remaining variables, WAGE and INV, have been included to take into account the possibility of differences across industries in the importance of cost-competition and capital requirements. They may also be thought of as representing "endowments" of capital and labour, respectively (the Hecksher-Ohlin theory). A variable reflecting human capital would have been a useful addition, but unfortunately no such variable was available at a sufficiently detailed level of aggregation (and a sufficient number of countries).

Results from the analysis

The small sample (8-10 observation per industry, 16-19 observations per country) does not allow for very extensive testing of differences across industries and countries on the impact of the variables included in our investigation. Three sets of regressions are presented. The first (Annex Table 16) tests for possible differences in the impact of the variables concerned across the three technology classes (high, medium and low technology). Also included is a test for the suggestion (new growth theory) that large countries enjoy higher rewards for investments in R&D and physical capital than do other countries. Annex Tables 17 and 18 then, present estimates for each industry and country, respectively. In each case a backward search for the model that displayed the least variance was conducted (best model).[4] The models were tested in log-form by the ordinary least squares (OLS) method. Since the dependent variable is normalized, a similar transformation was made for the independent variables (divided by the within industry - across country - mean).

When the coefficients are allowed to vary across technology classes (Annex Table 16 equation 3.1), the pattern which emerges is one where for the high-tech industries both direct R&D and market size turn out as important for the competitive outcome. Neither spillovers nor wage competition appear to have a significant impact. Investment has a significant but negative impact on comparative advantage, indicating that high capital requirements are not important in this case. For the medium-tech industries, in contrast, market size and investment (this time with the correct sign) were identified as the most important factors affecting competitiveness.

Finally, in the case of low-tech, only one competitive factor of some importance was identified, investment. To some extent these results resemble the "stylised" facts that led Vernon (1966) to formulate the product cycle theory. For instance capital requirements increase as the technological content of the industry decreases, as postulated by Vernon. The importance of R&D for high-tech industries, and market size for medium-tech industries, also fit this framework. What is lacking is that low wages do not seem to matter, not even in low-tech where it, following the perspective of Vernon, should be expected to have a sizeable impact.

A division of countries into large, medium-sized and small can be made along the same lines as for the technology-classes. If this methodology is adopted, two countries appear as large; USA and Japan. According to new growth theory, the rewards from investments in R&D and/or physical capital should be larger in large countries. This is tested by allowing the estimated impact for R&D and Investment in large countries to deviate from the rest of the sample (equation 3.2 in Annex Table 16). However, the results indicate that the impact of investment in R&D and physical capital on competitiveness do not differ substantially between the large countries and the rest.

Annex Table 17 reports estimates for the industry level. These results have to be interpreted with care, since the sample in each case is very small (normally 10).[5] Still, there are some interesting observations that can be made. First, with respect to the technology variables, there is strong evidence for a positive impact of direct R&D on competitiveness in the two most high-tech industries of the sample (aerospace and computers). The same holds for electrical machinery. There is some evidence, although weaker, for a positive impact in a number of other sectors, mostly low-tech. A high reliance of domestic spillovers affects competitiveness positively in two high-tech sectors (computers and instruments) only. Foreign spillovers, in contrast, appear to have a positive impact in a number of low-tech industries.

The most striking result, however, is that market size appear to influence competitiveness positively in a whole range of industries. Most of these are low-tech, but market size also appears to have an impact in some medium- and high-tech industries, such as cars, instruments and telecommunication and semiconductors. Investment turns out to influence competitiveness positively in five industries, four of which are low tech. Cost-competitiveness appear to be of lesser importance.

There are a number of cases where variables have a sign which is different from what one should expect. This holds in particular for the spillover-variables and for wages. A high reliance of domestic spillovers is shown to influence competitiveness negatively in four industries at the 10% level, extending to six if the 20 % level is adopted. Five of these are low-tech industries.[6] In the case of foreign spillovers, there are two examples of significant negative estimates at the 10% level, extending to four if the 20% significance level is adopted. The same holds for wages. For the latter it might be argued that a relatively high wage level reflects skills, and thus that a positive correlation should have been expected.[7]

When the same model is applied to each country (across industries), the strong impact of the market size variable is confirmed (Annex Table 18). It has the expected sign, significantly different form zero, for nine of ten countries (for the tenth country it also has the expected sign, but it is not significant). Direct R&D efforts turns up as significant with the expected sign for three countries only, all of them EU countries. As for spillovers, the domestic ones appear to have little impact at the country level. Foreign spillovers turn up significant and with a negative sign for three of the large countries of our sample, and significant and positive for the smallest one. Investment seems to matter for quite a few countries (two or four depending the significance level). The wage variable again performs badly, negative in two industries, positive in four, all significant at the 10 % level.

Notes for Part III

1. This chapter is based on . Fagerberg (1995), "Competitiveness, Scale and R&D: Evidence from 10 OECD Countries", mimeo, OECD.
2. This theme has also been emphasised, albeit from a different perspective, by the recent "national system of innovation" literature (Lundvall et al. 1992).
3. This index can be expressed as I=m(i)/m, where m(i) is the market share of the country on the world market for commodity i and m is the overall world market share of the country. It has a skew distribution (varies between 0 and indefinitely, with a weighted average identical to 1). Here we use a normalized version, S=I/(I+1), which varies between 0 and 1, with a weighted average of 0.5.
4. Roughly speaking this means that variables with t-values below one, e.g., variables that are not significant at a 20-30 % level of significance, are omitted,
5. It would clearly have been more satisfactory to have a cross-section that covered at least most of the OECD and - preferably - some of the fast-growing countries of Asia as well. This being said it might also be noted that among the countries included are all the large and medium-sized countries of the OECD area, so an important part of world trade is actually covered.
6. A possible explanation might be that the negative estimate reflect the impact of "technological closed-ness".
7. This appears less probable in the present case, since at least three of four cases with a perverse sign are distinctly low tech.

CONCLUSIONS AND POLICY IMPLICATIONS

These conclusions draw together the analytical results from the investigation of the process of technology diffusion (*Part I*), its relation with productivity (*Part II*), and issues of trade and competitiveness (*Part III*). There follows a synthesis of the policy implications of all parts of the report.

The patterns of technology diffusion

Part I of the report developed a methodology based on interindustry and international flows of intermediate and capital goods in order to undertake an internationally consistent examination of the flows of technology across industries and countries and the evolution of technology diffusion patterns over time. On the basis of this methodology, the report examined issues such as who performs and who uses R&D, questioned the traditional concept of R&D intensity as a proxy for technological sophistication, analysed the role of capital in diffusion, and focused on patterns of imported technology and on the importance of such technology clusters as information and communications. The main analytical results are described below.

Supply and demand of technology. Innovations are developed mainly in a cluster of high-technology manufacturing industries; a cluster of services industries are the main acquirers of technologically sophisticated machinery and equipment. R&D performance is more concentrated (the top five industries account for between 60 and 80 per cent of the total) than technology use (the top five user industries account in most countries for 40-50 per cent of total). The use of technology in many services industries is greater than what their (large) weight in the economy might suggest. The part of embodied technology acquired externally has increased over time, partly because of more extensive sourcing of high-technology goods.

Reinterpreting technology intensity. Simple R&D intensity indicators are an imperfect measure of the technological sophistication of industries; indicators at sectoral level which combine both performed R&D and externally acquired technology are more appropriate. The spread between high-, medium- and low-technology industries diminishes when the purchase of technologically sophisticated inputs is taken into account. The technology intensity of small countries increases significantly with acquired technology, which also accounts for big increases in the technology intensity of medium-technology industries in Japan, Germany, Canada, and the Netherlands; overall total technology intensity for Japan overtakes that of the United States.

The role of capital inputs in technology diffusion. The share of technology obtained through capital investment is less than 50 per cent of total acquired technology for every country (but this is probably an underestimate); the United States leads in the diffusion of technology through capital investment. The industries most dependent on investment-based technology acquisition are in services (finance and insurance, social and personal, communication services); those least dependent are the high-technology manufacturing industries.

Technology acquisition through imports. Bigger countries source less technology from abroad than smaller countries, which depend on imports for more than 50 per cent of their acquired technology; the share of technology obtained through imports has increased over time for all countries except Japan. The United States is the most important source of technology for all countries (especially for computers and aerospace); for the United States, the DAEs and Japan are the most important source of technology acquired through imports.

Technology clusters. The bulk of technology acquired in six out of ten countries comes from the information technology cluster of industries; the materials technology cluster (chemicals, basic metals, rubber, plastics) is important in Japan, Germany, Italy, and Denmark. The importance of IT has increased over time; it is the fastest growing technology cluster. Certain types of technology tend to gravitate to certain sectors: information technology to high-technology manufacturing, communications services, and finance, insurance and real estate; transportation technology to transportation services; consumers goods technology to wholesale and retail trade; materials technology to agriculture, and to medium-technology and low-technology manufacturing; and fabrication technology to mining, utilities, and construction.

Technology and productivity

The results presented in this report attempt to shed some light on the productivity impacts of both R&D expenditures and of embodied R&D diffusion among sectors and across countries. It develops new TFP growth indexes based on input-output accounts. The major findings are summarised below.

Recovery of productivity. The TFP growth estimates point to some recovery of productivity growth in the 1980s in most countries, notably in the United States, with TFP increasingly important for explaining GDP growth in the private business sector. While the contribution of labour inputs is stable over time, the contribution of capital inputs is declining overall. The resource reallocation effect on aggregate TFP growth is positive for Japan, Germany, France, Australia, and Denmark and accounts for 14 to 30 per cent of their aggregate TFP growth. However, it shows a negative contribution in the United States, the United Kingdom, and Canada where flexible factor markets function relatively well.

Different sectoral patterns. Sectoral TFP growth showed different movements in manufacturing and services in the 1970s and 1980s. While manufacturing TFP growth recovered in the 1980s, services TFP growth as a whole decreased. Although the contribution of intermediate inputs accounted for a major part of output growth in both sectors in every country, the contribution of labour inputs has increased in the services while capital inputs show a declining role in output growth in both sectors. In terms of TFP performance at the detailed sectoral level, higher TFP growth is observed in most sectors classified in the ICT industry group (computers and communication services, etc.) in every country. It is worthwhile noting that some traditional scale-intensive, low-technology manufacturing sectors were also listed among the top ten industries in terms of TFP performance in every country.

Rate of return to R&D. The pooled cross-country cross-industry regressions for the 1970s and 1980s indicate that the rate of return of R&D investment for the manufacturing sector stands around 15 per cent; no significant change is observed during the two decades in the unweighted regression. However, it shows a dramatic increase in the 1980s in the weighted regression, indicating the increasing importance of R&D investment for TFP growth in the aggregate manufacturing sector.

Diffusion and services productivity. The impact of embodied R&D on TFP growth in the services sector is significantly positive. On average, across ten OECD countries, the estimated rate of return of embodied R&D for services TFP growth was 130 per cent in the 1970s and 190 per cent in the 1980s in the unweighted regression. The principal sources of such diffusion-based productivity gains in this sector were, on the one hand, equipment investment for R&D-intensive products and, on the other, foreign procurement through imports. In particular, the increased role of capital investment in productivity growth in services is one of the most robust results in the present analysis, and shows an estimated rate of return of embodied R&D exceeding 200 per cent in the 1980s.

Country-specific results. When R&D coefficients are allowed to vary across countries, it is possible to obtain separate country-specific estimates of the rate of return of direct R&D for manufacturing and for total embodied R&D in the services for the 1970s and 1980s. Japan's rate of return of direct R&D was highest in the 1970s (40 per cent), but it shrank by almost half in the 1980s. For the United States, it increased in the 1980s, so that the two countries were at about the same level. For the 1980s, Italy registered the highest rate of return (50 per cent). Canada is also one of the few countries where the rate of return increased in the 1980s and stood 10 percentage points above that of Japan and the United States. Though robust results are not available, the estimated rate of return of embodied R&D for the services sector also varied across countries and between periods. For the 1980s, it was quite high in the United Kingdom (430 per cent), Canada (320 per cent) and France (300 per cent), but the correlation was negative for Japan, the Netherlands, and Denmark. For the United States, Germany, and Italy, the rate of return was similar, at around 100 per cent.

Machinery and ICT services. Another cross-country regression was run to investigate sectoral differences in the rates of return of direct and embodied R&D. To do so, industrial sectors were divided into seven groups and the groups from all the countries were pooled. The results showed that direct R&D was significantly positive for the machinery sector and embodied R&D for the ICT services sector, but no significant correlations for R&D and productivity were obtained for other industrial groups. The estimated rate of return of direct R&D for the machinery sector declined over time and stood at around 20 per cent in the 1980s. The social rate of return of embodied R&D for the ICT services sector was almost stable over time and around 150 per cent in the 1980s. Among the sources of embodied R&D, the rate of return of imported R&D was three times higher than domestic R&D, and capital investment appeared as an important source of productivity in the ICT services.

Contribution of technology to TFP growth. Lastly, for the machinery and ICT services sectors, the percentage contributions of R&D and of embodied technology to TFP growth were estimated. The contribution of direct R&D to machinery TFP growth was very stable between the two periods for each country, with a slightly increasing impact in several countries in the 1980s. The estimated average impact of R&D is about 0.7 percentage point in both periods across countries. For the ICT services sector, the average impact of domestic R&D is lower than that of imported R&D in both periods (0.3 vs. 0.5, respectively, in the 1980s). However, domestic R&D was more important than imported R&D in the United States and Japan, and to a lesser extent in Germany.

Imported R&D played a dominant role in Denmark, Australia, the Netherlands, and Canada. The impact of domestic R&D increased in the 1980s in every country except the United Kingdom and France and notably in the United States and Japan, perhaps owing to increasing linkages with domestic ICT manufacturers. In contrast, the impact of imported R&D decreased in the 1980s in most countries except the United Kingdom and the United States, despite the rapid growth of high-technology trade during the 1980s. The absolute level of imported R&D impact on TFP growth in the ICT services sector is significantly high in Canada (0.85 percentage point), Italy (0.76), the United Kingdom (0.75), and Australia (0.67 percentage point).

The productivity findings are thus consistent with the broad consensus reached through other studies in this area: R&D expenditures are an important source of productivity growth in R&D-performing industries, but the social rate of return of intersectoral and international R&D spillovers far exceeds direct productivity gains. In particular, the sectoral data show that the ICT cluster of industries has played a major and increasing role in the generation and diffusion of new technologies. The estimates confirm the strong importance of foreign R&D observed by Coe and Helpman (1993) at the macroeconomic level. On the basis of disaggregated data, this report indicates that its source is the increasing international procurement of electronic investment goods by the ICT services sector. The estimates on the TFP impact of diffusion-based R&D for ICT services are also consistent with the finding that domestic R&D is more important in large countries but that foreign R&D is more important in smaller ones.

The potency of R&D over time. Finally, some fundamental questions about the potency of R&D over time and the importance of technology diffusion to policies aimed at improving productivity are addressed. Regarding the first issue, the results show some evidence of a decline in the direct R&D coefficient in manufacturing in the 1980s. At the same time, however, they show that R&D spillovers have an increasingly large impact on services. Considering the importance of services in the economy and the increasing impact of technology diffusion on the ICT services group, one is tempted to emphasise that, through domestic and international diffusion, manufacturing R&D activities have increasingly economy-wide benefits.

Some of the pessimism regading the potency of R&D or the Solow "productivity paradox" is due to the fact that services statistics have not yet shown rapid productivity growth despite the large flows of high-technology products into services. It is therefore important to draw attention to the various economic and institutional factors behind low productivity growth in services as well as to measurement errors in productivity statistics. Deregulation and ways to use new technologies more efficiently (learning best practices, changes in work organisation) will be important to the process of translating the economic potential of new technologies into measurable productivity growth. Similarly, an open trade and investment regime is important for productivity growth simply because international spillovers of high-technology products benefit both importing and exporting countries. Finally, to the extent that ICT clusters are a major element in the process of generating and diffusing technology, policy efforts to liberalise their markets and to encourage further development of ICT technologies must continue.

Technology and competitiveness

Part III of the report reviewed some evidence on medium-term trends and structural shifts in trade and international competitiveness; it emphasised R&D-intensive industries and high-technology products and developed a simple model of technology and international specialisation.

Changing composition of world trade. There have been significant changes in the structure of international trade since the 1970s. The share of OECD countries in world merchandise trade has grown, while trade has increasingly consisted of trade in manufactured goods, mainly involving two-way trade in similar products (intra-industry trade). More than three-quarters of the exports of most OECD country groupings in 1991 were in manufactured goods, and more than a third in the machinery and transport class, compared to about a quarter in 1980. Notable is the large and increasing share of machinery and transport in total exports from Japan, as well as the extent to which exports of several non-OECD countries in Asia shifted between 1980 and 1991 and now resemble OECD country patterns. The changing structure of the trade of individual countries or country groupings is underscored by the evolution of regional shares of manufactured commodity classes in total world exports. Non-OECD countries of Asia have achieved gains of one- to two-fold in manufacturing classes, and Japan has gained about 3 percentage points in machinery and transport equipment over the same period.

The growing importance of high-technology trade. Exports from high-technology industries constituted about a quarter of manufactured exports of OECD countries in 1992, a share that has increased by 10 percentage points since 1970, largely at the expense of low-technology products. The bulk of the changes took place during the 1980s. Individual high-technology products making the most notable gains were computers and semiconductors, two out of only four products whose market shares more than doubled since 1980; other high-technology products with relatively important gains in market shares since 1980 were telecommunications equipment, pharmaceuticals, scientific instruments, and aircraft.

Increased exposure to international competition. The increased exposure to international competition in OECD countries is underscored by the increase in the weight of imported manufactured goods in the total domestic demand for goods in manufacturing. Despite large cross-country differences, import penetration increased in the manufacturing sector in every country, with the strongest increases by far in Spain and in the United States. The only two countries with barely any change were Italy and Japan. In the European Union, France, Germany, and the United Kingdom have broadly similar profiles of import penetration both at the level of total manufacturing and at a more disaggregated level. For all three, high-technology and science-based industries are the most import-intensive groupings. Import penetration in Italy is the lowest of the four large European countries and has barely increased since 1980. There is a great deal of variance among industries, with import penetration tending to be relatively high in instruments, computers and communications equipment, and particularly low in wood products and non-metallic minerals. Italy is also the only large EU country where import penetration has declined significantly in a number of industrial sectors since 1980.

Shifts in export specialisation. Of the larger OECD countries, the United States is relatively specialised in high-technology and science-based exports, even if that specialisation pattern has weakened somewhat since 1980. Japan is the country whose export specialisation has evolved the most, with a strong movement out of low-technology, labour-intensive exports and towards high- and medium-technology exports, or exports of industries characterised by scale economies and producing differentiated products. The EU countries, in contrast, have evolved in the direction of declining markets: between 1970 and 1992, the weak specialisation in high-technology, high-wage industries has been weakened further, and an already strong specialisation in low-technology, low-wage, labour-intensive industries has been reinforced.

Performance in export markets. Germany has consistently had the highest overall manufacturing export market share since 1980, largely owing to the success of exports of its medium- and low-technology industries. To the extent that the weight of these industries is declining in total OECD manufacturing exports, however, this performance will be difficult to sustain in the future. The share of the United States fluctuated widely during the 1980s, but in 1992 was at the same level as in 1980, just behind Germany. This stability can be traced to heavy losses in certain high-technology industries (computers, pharmaceuticals, aerospace) as well as in medium-technology exports, compensated by increases in exports of low-technology industries. The share of Japan, third on the list, has increased since 1980, even though it declined in the latter half of the 1980s, following appreciation of the yen.

Of the four largest European countries, France is the only one that increased its export market share in high-technology and science-based industries during the 1980s, almost exclusively owing to aerospace exports. This increase has not, however, compensated for export market share declines in medium- and low-technology industries. In the United Kingdom, market shares declined across all industry groupings, and particularly in labour-intensive industries. In Italy, market shares increased in labour-intensive manufacturing, strengthening the country's specialisation in this direction. Although their share remains very small in total OECD manufacturing exports, significant growth in export market shares can be seen in Ireland, Portugal, Spain and Turkey.

New forms of trade. Besides the shifts in the international orientation of economies and in their export performance, the recent period seems to be characterised by an increase in total trade of intra-industry and intra-firm trade, types of trade that do not conform to the product specialisation hypothesis in traditional trade theory. Intra-industry trade (IIT) is trade between countries within the same broad industry or product group. For almost all countries, the proportion of total trade from intra-industry transactions increased significantly in the period 1970-92. At the same time, important differences among countries remain, with the highest IIT indices in 1992 in the United Kingdom, France, and Italy (where over 80 per cent of total manufactures trade is accounted for by intra-industry transactions). Intra-firm trade (IFT) is also important, with figures for the United States and Japan showing intra-firm trade as over a third of total trade.

The simple model developed in Chapter 12 aimed to explore the relation between competitiveness, scale, and R&D, using OECD databases and the work on embodied technology flows developed in Part I. What is reported here constitutes a first step, and the results presented below should be taken simply as indicative.

The home market matters. The data clearly support the so-called "home-market effect", meaning that countries tend to develop a comparative advantage in industries for which there is --

compared to other countries -- strong domestic demand. This in accordance with the predictions of the so-called "new trade theories" based on assumptions of imperfect competition and economies of scale.

R&D as a factor in competitiveness. Some support is found for R&D as an important competitive factor, especially in high-technology industry and for European countries. There is no support for the proposition, associated with some "new growth theories", that investment in R&D and/or physical capital should have a larger impact in large countries. Direct R&D was found to be a more significant factor for competitiveness than spillovers. This does not mean that spillovers within and across borders may not have a sizeable economic impact, but that differences in the amount and composition of spillovers do not seem to matter much for the relative position of countries. Some interesting differences in the impact of domestic versus foreign spillovers across sectors and countries may warrant further research.

For the two remaining variables -- the ones that can be associated with the traditional factor-proportion theory -- the results are somewhat mixed. In particular, the wage variable had the wrong sign for many sectors and countries. If the pattern had been uniform, it would have been easier to interpret; as it is, it remains something of a puzzle. It can be said, however, that the data do not strongly support the idea that the wage level is an important factor in competitiveness/comparative advantage.

What is mainly new in these results compared to previous ones is the importance of the so-called "home-market effect". Except for some previous studies by Fagerberg (1995a, 1995b) scale effects have largely been ignored in the applied literature on this area. This is all the more surprising since this prediction has a solid base in economic theory. However, the preliminary and exploratory character of this study should be stressed. Further research is necessary to validate these results and to investigate in greater depth the question of how scale, R&D, and other factors interact in the competitive process.

Implications for policy

This report's analysis of the pattern of technology diffusion in OECD countries and of the impact of technology on productivity and competitiveness raises a number of policy issues. These cover a broad area. They relate to the nature of technology policy and in particular to the need for a balance between policy measures to encourage innovation and those to facilitate the adoption of new technologies, to the role of market competition for realising the economic potential of new technologies, to the capital investment that is necessary for acquiring technology, to trade and access to imported technology, and to the systemic characteristics of IT.

A technology policy addressing both innovation and diffusion

Traditionally, technology policy has been aimed at the innovation end of the process, concerning itself almost exclusively with restoring incentives for R&D investments through subsidies and tax credits or through strong property rights and standards. This approach has slowly given way to a parallel concern for the economic environment for the diffusion of innovations. A number of countries have put in place policy measures aimed at encouraging firms to adopt new technologies efficiently, either by removing regulatory and other obstacles, or by using the tax system and fiscal measures to encourage investment in new machinery or in assimilation of knowledge developed elsewhere.

The evidence presented in this report provides justification for this recent policy trend and suggests the need to go further. At the simplest level, more appropriate indicators for guiding policy are required: excessive reliance on certain simple indicators such as the economy's R&D intensity is too narrow and will not succeed in helping economies realise the full economic potential of new technologies. More substantially, policy needs to develop in the direction of recognising that, rather than being two distinct activities, innovation and diffusion are two facets of the same process. Developing firms' ability to absorb and use new technology effectively is far from a mechanical process; instead, it is a process which also improves their capacity to develop innovations themselves.

Thinking about the whole economy

Government programmes for diffusing technology tend to concentrate on transferring technology to the manufacturing sector. But one of the main findings of the report is to document the extent to which services -- such as finance, insurance, and real estate, wholesale and retail trade, and communication services -- are important acquirers of technology and the extent to which services productivity depends on the acquisition of technology developed in manufacturing. This suggests that technology policy must cease focusing exclusively on the manufacturing sector; reliance on the strength of a few high-technology manufacturing industries is not likely to deliver economy-wide productivity gains from new technologies. Practically speaking, this implies the need for diversity in policy measures aimed at diffusing best practices, for example, through "technology extension centres" that cover services areas as well. It also points to an important role for government in encouraging the diffusion of new technologies in the large section of services that is publicly owned or controlled (education, health system).

Competition in product markets matters

Another policy issue concerns the importance, for realising the social returns to innovative activity, of competitive pressures both on the industries that supply new technologies and on those are the main users. Monopoly structures in the industries that develop new technologies allow them to charge prices that permit them to appropriate most of the benefits of innovation. As a result, productivity gains in user industries are lower than they would be if supplier markets were more competitive. Policies in this respect need to strike a balance: ensuring that firms have sufficient incentives to innovate (through intellectual property rights) and that they cannot capture all the benefits from their innovations. Reforms of the patent system that favour early disclosure go in this direction.

An issue which has received less attention but is at least equally important concerns market structure conditions in technology-acquiring industries. Lack of competition and excessive regulation in the services sectors, for example, will blunt incentives to modernise by adopting the new technologies that are developed in manufacturing, and will certainly not spur innovation. There are important productivity gains to be reaped by the liberalisation of large parts of the services industries in Europe in this respect. Moves in this direction will encourage greater product innovation and variety, as well as higher productivity, lower prices, and increased demand for these services.

Protection has additional costs

Imported technology is an important channel of technology diffusion, especially for smaller countries and for EU countries that trade heavily with each other. Industrial globalisation and widespread international sourcing of technology imply that for most countries, the option of developing an exclusively national capacity in certain technology areas does not really exist. In such an environment, attempts to favour the development of certain new products or processes in domestic manufacturing industry through discriminatory practices will have as a by-product the increased cost to other domestic firms that rely on having access to the best available component, machinery, or materials technology, domestically or from abroad, as inputs into their production processes. Thus, in terms of technology diffusion, the costs of trade protection will include, in addition to consumers' traditional welfare costs, those incurred by producers, in manufacturing and in services, who source technologically advanced equipment and components from abroad.

Capital investment facilitates technology diffusion

The discussion of the role of capital investment in the diffusion of manufacturing R&D has various policy implications. First, since investment is a major source of more sophisticated production systems in the services sector, policies might be directed towards facilitating access to equipment containing new technology by lowering investment costs, promoting further technical change in the high-technology manufacturing sector, and encouraging higher levels of investment. The information technology cluster (computer, communications equipment, communications services, finance and insurance, and business services), in particular, has played an increasing role in capital-based R&D diffusion; public policy might therefore usefully ensure the availability of the necessary social infrastructures. The ongoing "information highway" programme and other related plans will help strengthen the links between IT clusters by promoting investment in the sectors involved.

Information technology is particularly important

The report highlights the predominance and increasing importance of the IT cluster for technology diffusion and the growing weight of high-technology products in international trade. This implies that not all technologies should be given the same priority when it comes to diffusion; some have wider application than others. Given limited resources, the first priority of diffusion programmes should be to diffuse the information and materials technologies that answer the needs of many sectors. Technology policy needs to pay particular attention to the network characteristics of IT and to the potential for realising economy-wide gains from its widespread application. The policy issues here include encouraging the creation of networks of firms and encouraging public institutions to facilitate the generation of future IT applications, developing market-driven rules for standards setting, and liberalising product markets, in manufacturing as well as in services, in order to increase the incentives for widespread adoption and diffusion.

ANNEXES

Annex 1 Embodied R&D Indicators

The methodology on constructing embodied R&D indicators used in this paper builds on the seminal work of Terleckyj (1974) which used input-output data to measure intersectoral flows of technologies. This type of technology flow indicators focuses on R&D embodied in products purchased by an industry (intermediate inputs and investment goods). The concept of the "R&D embodiment" relies on the fact that market commodity flows among industries can be regarded as the means for the transfer of technology developed by supplying industries. The use of input-output tables can help capture interindustrial flows of technology which are not otherwise observable.

In contrast to a previous OECD work (Sakurai, Wyckoff & Papaconstantinou (1993)) which directly uses input-output tables to capture embodied R&D in purchased products, the current R&D embodiment indicators have been formulated on the basis of a Leontief inverse, taking into account the cumulative nature of interindustrial R&D flows. The merit of the Leontief inverse model enables the measurement of second-round R&D gains for a specific industry of R&D performed by industries elsewhere. Such multiplier effects in R&D embodiment estimates can be important. The semiconductor industry for example undertakes a large amount of R&D in many OECD countries. New models of automobiles or airplanes are increasingly equipped with high-quality electronic components for automatic engine control or advanced navigation systems. However, these downstream users of electronic products frequently do not directly purchase them from semiconductor industry; instead those products are already embodied in parts which were manufactured by engine and instrument producers. The use of direct input-output coefficients fails to take into account of such technological advance embodied in electronic parts in the calculation of the R&D content of autos or airplanes and only the Leontief inverse model can provide the precise measurement of total R&D embodiment in products by its nature of multisectoral multipliers.

In an input-output framework, two kinds of technological gains can be traced: industrial R&D embodiment and the R&D content of final demand (domestic final demand and exports). The latter aspect was first introduced by Davis (1988). For measuring industrial R&D gains, the input-output database provides four major components of indirect R&D indicators for each industry: (i) R&D gains embodied in purchased domestically produced intermediate inputs; (ii) R&D embodied in imported intermediate inputs; (iii) R&D embodied in purchased domestically produced capital goods; and (iv) R&D embodied in imported capital goods. The imported portions of technology can be further broken down into countries of import origin: for example, in the United States, sourcing countries of the imports are separated into 12 regions: other six G7 countries, Australia, Denmark, the Netherlands, other OECD, DAEs+China and the rest of the world (see below for the description of the trade database). The total R&D gains for a industry is a total sum of these four components.

Using simple algebra, individual R&D variables can be defined as follows. First, the balance equations of gross output in an open static input-output system can be written as:

$$X = A^d X + F^d + E \qquad \text{(A-1)}$$

where X is the vector of gross outputs, A^d is the matrix of domestic input-output coefficients, F^d final demand vector for domestic outputs and E is the exports vector (for simplicity, suffixes of country and years are omitted). Solving the domestic balance equation for X, we obtain the equilibrium production to satisfy given final demand:

$$X = (I - A^d)^{-1}[F^d + E] \qquad \text{(A-2)}$$

We then define the direct R&D intensity as R&D expenditures per gross output for industry i.

$$r_i = \frac{R_i}{X_i} \qquad (i = 1,2,\ldots n) \qquad \text{(A-3)}$$

Although it is widely recognised that R&D investment has a certain lag before its commercialisation (average lag is 2-3 years in the existing literature) and as an indicator of product sophistication R&D stock variables are more appropriate than flow ones, current R&D expenditures were employed in estimating flows of technology for a particular year.

Combining equation (A2) with (A3), the vector of domestic total R&D embodiment , T^d can then be defined by pre-multiplying the diagonalised matrix of sectoral R&D coefficients (A3) to equation (A2):

$$T^d = \hat{r}(I - A^d)^{-1}[F^d + E] \qquad \text{(A4)}$$

where hat (^) denotes a diagonal matrix whose elements consist of the corresponding vector.

Equation (A-4) connects domestic R&D embodiment with final demand components (domestic final demand and exports). The *total domestic R&D embodiment per unit of final demand for industry j* can be then defined as the *j*th column sum of the above coefficients matrix:

$$rf_j = \sum_{i=1}^{n} r_i b_{ij} \qquad (j = 1, 2, \ldots, n) \qquad \text{(A-5)}$$

where b_{ij} are the elements of inverse $B = (I-A^d)^{-1}$. Since the *j*th column sum of the Leontief inverse B measures the total (direct and indirect) impacts on domestic production when final demand for the *j*th sector changes by unity, equation (A-5) provides the total amount of R&D per unit of the final delivery of output j.

The calculation of total R&D embodiments in purchased intermediate goods for industry j is slightly different from the above equation (A-5). The traditional Leontief multipliers B tells us how much R&D is directly and indirectly embodied in one unit of final demand for output j, but not how much R&D is embodied in industry output j. From an industrial aspect, the measure of industry's R&D embodiment thus should be defined from an output basis in order to address the latter question. As shown for example by Miller and Blair (1985) p.328, the modification of the standard Leontief model can be easily done by using the following output-to-output based multipliers:

$$\begin{bmatrix} 1 - a^d_{11} & -a^d_{12} & \cdots & -a^d_{1,n-1} \\ -a^d_{21} & 1 - a^d_{22} & \cdots & -a^d_{2,n-1} \\ \vdots & \vdots & \vdots & \vdots \\ -a^d_{n-1,1} & -a^d_{n-1,2} & \cdots & 1 - a^d_{n-1,n-1} \end{bmatrix}^{-1} \begin{bmatrix} a^d_{1,n} \\ a^d_{2,n} \\ \vdots \\ a^d_{n-1,n-1} \end{bmatrix} = \begin{bmatrix} \frac{b_{1,n}}{b_{n,n}} \\ \frac{b_{2,n}}{b_{n,n}} \\ \vdots \\ \frac{b_{n-1,n}}{b_{n,n}} \end{bmatrix} = B^*_n \qquad \text{(A-6)}$$

The above adjusted multiplier vector indicates the direct and indirect output requirements from all the sectors excluding industry j to produce one unit of *output* for industry n (suppose for convenience that industry $j = n$). We thus define the adjusted multiplier matrix as $B^* = [B_1, B_2, ..., B_n]$.

This *output* multipliers are less than or equal to traditional Leontief multipliers defined by *final demand* since the propagation process of interindustrial demand can be reduced by the exclusion of industry j in propagation, keeping the industry's output constant during this process and hence R&D amounts conducted by this industry. While the use of the traditional Leontief multipliers cannot avoid the double-accounting of the R&D embodiment of industry j by the extent of increase in industry j's output during the propagation, the use of such adjusted multipliers enables us to exactly define total R&D embodiments of industry j by the simple sum of direct R&D actually conducted by this industry and indirect R&D embodied in the purchased products (total R&D = direct R&D + indirect R&D). This model is useful to define direct and indirect R&D intensities without including double-counting of these R&D elements.

Using the elements of matrix B^*, the R&D embodied in domestic intermediate inputs for industry j can be obtained by pre-multiplying the direct R&D intensity as:

$$TINT^d_j = \sum_{i \neq j}^{n-1} r_i b^*_{ij} X_i \qquad \text{(A-7)}$$

The *R&D embodied in purchased domestic capital goods for industry j* can be defined as:

$$TINV^d_j = \sum_{i=1}^{n} r_i \left(\sum_{k=1}^{n} b_{ik} I^d_{kj} \right) \qquad \text{(A-8)}$$

where I^d_{kj} is industry j's investment expenditures for *i*th product. Since investment expenditures are one of the components of final demand, the traditional Leontief inverse can be applied to define the indirect R&D embodied in purchased capital goods. However, the above definition of capital-embodied R&D counts only the R&D embodied in current capital formation and neglects the R&D embodied in the stock of capital operated for production so that actual R&D contribution is likely to be underestimated. Since the revision of this part of the model requires huge additional data (time-series data on investment flows matrix, investment deflators, etc.), the static formulation is retained.

Compared with the treatment of domestic R&D flows, the formulation of imported R&D is quite simple in the sense that current model does not consider the interindustrial propagation effects in acquired R&D counting. First, *R&D embodied in purchased imported intermediate inputs for industry j* is defined simply by multiplying foreign direct R&D intensities with the imported amount of intermediate demand as:

$$TINT^m_j = \sum_{i=1}^{n} \sum_{k=1}^{l} r_{ik} \alpha_{ik} X^m_{ij} \qquad \text{(A-9)}$$

where X^m_{ij} is the intermediate demand for product i by industry j and α_{ik} the import share of country k for import i.

Similarly, *R&D embodied in purchased imported capital goods for industry j* can be defined as:

$$TINV^m_j = \sum_{i=1}^{n} \sum_{k=1}^{l} r_{ik} \alpha_{ik} I^m_{ij} \qquad \text{(A-10)}$$

where I^m_{ij} is the investment demand for product i by industry j and α_{ik} the import share of country k for import i.

Since both equation (A-9) and (A-10) do not take into account indirect effects, the imported R&D elements are generally underestimated in the model. The refinement of current formulae is difficult for some reasons: one difficulty relates to whether such indirect effects should be taken into account by using the inverse of the producing country or that of the importing country; in the former case the model should be solved simultaneously across countries as every country is linked to another by international trade. Another question is whether the indirect ripple of imported R&D should be counted as if it were done for domestic products. In counting indirect R&D, the distinction of imported and domestic products may not be appropriate because down-steam industries (auto) can acquire the R&D gains from imported high-tech machines installed in up-stream industries (iron). Due to such difficulties, we use the above simplest type of equations to evaluate the amount of imported R&D component for both intermediate and capital goods.

Lastly, *total R&D embodiment for industry j* can be defined as the simple sum of these four R&D components:

$$TTTL_j = R_j + TINT^d{}_j + TINV^d{}_j + TINT^m{}_j + TINV^m{}_j \qquad \text{(A-11)}$$

The first term of equation (A-11) shows the amount of direct R&D and the other four terms denotes denote the measures of indirect R&D embodied in the industry j's purchase of either intermediate or capital goods domestically and from abroad. The intensity version of these indicators, i.e., R&D embodiment per unit of output, can be simply calculated by dividing each term of the above equation by the amount of output X_j.

It is noted that the use of the adjusted Leontief multipliers in equation (A-6) allows the complete separation between direct R&D R_j and its domestic indirect effects $TINT_j^d$, avoiding the double counting of R&D embodiment. In addition, the above formula is also consistent with its intensity version, because $TINT_j^d$ is defined on the basis of the *output* of industry j, not of the *final demand* for industry j. As shown in the main text, these R&D indicators were used to capture the impact of inter-industrial flows of technology on productivity growth. Since the above indicators are defined not only for manufacturing sectors which are major R&D-conducting sectors but also for non-manufacturing sectors which typically depend on sectors within manufacturing for much of new technology, it is possible to measure the indirect productivity effects in downstream industries which are able to acquire better quality capital or materials produced by research-intensive industries.

Annex 2 Estimation of Total Factor Productivity (TFP)

The OECD input-output database provides the detailed input balance for a specific industry j:

$$p_j^* X_j = \sum_{i=1}^{n} p_i^d X_{ij}^d + \sum_{i=1}^{n} p_i^m X_{ij}^m + p_j^l L_j + p_j^k K_j \qquad \text{(A-12)}$$

where P^*_j is the net price of gross output exclusive of net indirect tax (indirect tax minus subsidies), X_j is the volume of output in industry j, P^d_i is the price of output in industry i, X^d_{ij} is the industry i's output purchased by industry j, P^m_i is the price of the imported product i competitive to the output of industry i, X^m_{ij} is the import i purchased by industry j, P^l_j is the price of labour input in industry j, L_j is the volume of labour input, P^k_j is the price of capital input in industry j and K_j is the capital stock in industry j. Based on this sectoral account and following Jorgenson (1980) and Kuroda and Shimpo (1991), sectoral TFP index were derived from the following procedures.

Growth rates of real value added

While the calculated sectoral TFP index uses gross output as a production indicator, value added also plays a important role in the model, especially in building a consistent aggregate TFP index from the sectoral level. We therefore start with defining growth rates of both sectoral and aggregate value added by the Divisia indexes.

From equation (A-12), the nominal value added by industry can be defined as:

$$p_j^v V_j = p_j^l L_j + p_j^k K_j = p_j^* X_j - \sum_{i=1}^{n} p_i^d X_{ij}^d - \sum_{i=1}^{n} p_i^m X_{ij}^m \qquad \text{(A13)}$$

where p^v_j and V_j is respectively the value added deflator and real value added for industry j. Since equation (A-13) holds in every point in time, it can be expressed in differential form between the two points in time. As described below in detail, the *Divisia index* plays an important role in the differential approach.

Differentiating equation (A-13) with respect to time and dividing both sides the equation by $p_j^v V_j$:

$$\frac{\dot{p}_j^v}{p_j^v} + \frac{\dot{V}_j}{V_j} = \left[\frac{p_j^* X_j}{p_j^v V_j}\frac{\dot{p}_j^*}{p_j^*} - \sum_{i=1}^{n}\frac{p_i^d X_{ij}^d}{p_j^v V_j}\frac{\dot{p}_i^d}{p_i^d} - \sum_{i=1}^{n}\frac{p_i^m X_{ij}^m}{p_j^v V_j}\frac{\dot{p}_i^m}{p_i^m}\right]$$
$$+ \left[\frac{p_j^* X_j}{p_j^v V_j}\frac{\dot{X}_j}{X_j} - \sum_{i=1}^{n}\frac{p_i^d X_{ij}^d}{p_j^v V_j}\frac{\dot{X}_{ij}^d}{X_{ij}^d} - \sum_{i=1}^{n}\frac{p_i^m X_{ij}^m}{p_j^v V_j}\frac{\dot{X}_{ij}^m}{X_{ij}^m}\right]$$

where a dotted variable indicates the time derivative of this variable (for z, $\dot{z} = dz/dt$). The first parenthesis in the right-hand side of the above equation is the Divisia price index of value added in differential form, and the second the Divisia volume index of sectoral value added. In other words, the Divisia growth rates of sectoral real value added are obtained by subtracting the Divisia price index of value added from the growth of sectoral nominal value added.

In order to apply the above differential equations to the discrete data available, the discrete Divisia approximation, called the *translog index*, is usually employed.[1] The translog index of constant-price value added can be defined for two discrete points of time, say T and T-1 as:

$$\begin{aligned}\ln V_j(T) - \ln V_j(T-1) &= [\ln p_j^v(T)V_j(T) - \ln p_j^v(T-1)V_j(T-1)] \\ &- \frac{1}{2}[v_j^v(T-1)+v_j^v(T-1)]\cdot[\ln p_j^*(T) - \ln p_j^*(T-1)] \\ &+ \sum_{i=1}^{n}\frac{1}{2}[v_{ij}^d(T) + v_{ij}^d(T-1)]\cdot[\ln p_i^d(T) - \ln p_i^d(T)] \\ &+ \sum_{i=1}^{n}\frac{1}{2}[v_{ij}^m(T)+ v_{ij}^m(T-1)]\cdot[\ln p_i^m(T) - \ln p_i^m(T)]\end{aligned}$$

where ln is natural logarithm, v_j^v are the reciprocal of nominal value added ratio in industry j and v_{ij}^d, v_{ij}^m (i= 1,2,.. n) are the value shares of domestic and imported inputs in industry j relative to the value added, defined respectively as:

$$\begin{aligned}v_j^v(T) &= p_j^*(T)X_j(T)/p_j^v(T)V_j(T) \quad (j = 1,2,...n) \\ v_i^d(T) &= p_i^d(T)X_{ij}^d(T)/p_j^v(T)V_j(T) \quad (i = 1,2,...n;\ j = 1,2,...n) \\ v_{ij}^m(T) &= p_i^m(T)X_{ij}^m(T)/p_j^v(T)V_j(T) \quad (i = 1,2,...n;\ j = 1,2,...n)\end{aligned}$$

Aggregate gross domestic product (GDP) can be defined simply as the sum of sectoral value added:

$$p^v V = \sum_{j=1}^{n} p_j^v V_j = \sum_{j=1}^{n}(p_j^l L_j + p_j^k K_j) \qquad \text{(A-14)}$$

where p^v and V are GDP deflator and real GDP in factor price, respectively.

The growth rate of real GDP, however, cannot be derived directly from the simple sum of sectoral real value added because of the underlying aggregation problem emanating from different movements of sectoral deflators of value added. To avoid such aggregation bias, we use the Divisia index of real GDP as follows.

By differentiating equation (A-14) logarithmically with respect time, we obtain:

$$\frac{\dot{p}^v}{p^v} + \frac{\dot{V}}{V} = \sum_{j=1}^{n}\frac{p_j^v V_j}{p^v V}\frac{\dot{p}_j^v}{p_j^v} + \sum_{j=1}^{n}\frac{p_j^v V_j}{p^v V}\frac{\dot{V}_j}{V_j} \qquad \text{(A-15)}$$

The above equation shows that the nominal GDP growth rate can be expressed as the sum of the Divisia price index of GDP deflator (the first term in the right-hand side) and the Divisia quantity index of

1. Let y=(X_1, X_2,...X_n) and define the growth rate between the time T and T-1 by the logarithmic growth formula ln $y(T)/y(T$-1).
The translog quantity index or the so-called Törnqvist-Theil index is then given by

$$\ln\frac{y(T)}{y(T-1)} = \sum_{i=1}^{n}\frac{1}{2}(s_i(T) + s_i(T-1))\ln\frac{X_i(T)}{X_i(T-1)}$$

where $s_i(T) = [\partial y(T)/\partial X_i(T)\cdot X_i(T)]/[\Sigma\partial y(T)/\partial X_i(T)\cdot X_i(T)]$ is the share of X_i at time T. Since mean weights are used, an interaction term can disappear in discrete decomposition. The index has been extensively used in the literature as a discrete approximation of the Divisia index. As Diewert (1974) has shown, it is exact for an homogenous translog function. Since this function provide a second-order approximation to an arbitrary function, it is also superlative.

aggregate real GDP growth rate. The discrete approximation for the Divisia growth rate of the real GDP can be thus defined as:

$$\ln V(T) - \ln V(T-1) = [\ln p^v(T)V(T) - \ln p^v(T-1)V(T-1)]$$
$$- \sum_{j=1}^{n} \frac{1}{2}[w_j^v(T) + w_j^v(T-1)] \cdot [\ln p_j^v(T) - \ln p_j^v(T-1)]$$

where $w_j^v(T)$ is the value share of value added for industry j in time T: $w_j^v(T) = p_j^v(T)V_j(T)/p(T)V(T)$.

As mentioned above, the translog price index (p^v) shown at the second term of the right-hand side of equation (A-15) is not necessarily equal to the implicit deflator of aggregate GDP, $\tilde{p}^v$, which is calculated by dividing nominal GDP by the simple sum of the sectoral real value added. The following relationship holds between the two price indexes.

$$p^v V = \sum_{j=1}^{n} p_j^v V_j = \tilde{p}^v \sum_{j=1}^{n} V_j \tag{A-16}$$

They are only equal if and only if the sectoral value added deflator p_j^v is identically equal to (p^v) across the sectors and value added shares w_j^v are constant over time across the sectors.

Sectoral TFP index

Total factor productivity (TFP) is generally defined as the ratio of the volume of production Y relative to total volume of input Q ($TFP=Y/Q$). The growth rate of TFP is thus computed as:

$$\frac{\dot{TFP}}{TFP} = \frac{\dot{Y}}{Y} - \frac{\dot{Q}}{Q} \tag{A-17}$$

TFP growth is thus the residual between the rate of change in production and that in production inputs. If the rate of change in production is equal to the rate of change in inputs between two points in time, TFP can be zero so that there is no change in technological efficiency between the two years. On the other hand, if production increases more rapidly than the growth of inputs, positive TFP growth is assumed to reflect improvements in technological efficiency in production.

The detailed information on various factor inputs available from the input-output data enables us to formulate the index of sectoral TFP in the disaggregated form of Divisia input indexes as:

$$\frac{\dot{TFP}_j}{TFP_j} = \frac{\dot{X}_j}{X_j} - \sum_{i=1}^{n} \frac{p_i^d X_{ij}^d}{p_j^* X_j} \frac{\dot{X}_{ij}^d}{X_{ij}^d} - \sum_{i=1}^{n} \frac{p_i^m X_{ij}^m}{p_j^* X_j} \frac{\dot{X}_{ij}^m}{X_{ij}^m}$$
$$- \frac{p_j^l L_j}{p_j^* X_j} \frac{\dot{L}_j}{L_j} - \frac{p_j^k K_j}{p_j^* X_j} \frac{\dot{K}_j}{K_j}$$

where various factor inputs are weighted averages of rate of change in individual factor inputs by their value shares in gross output. The translog indexes of sectoral TFP can be thus expressed as the difference between successive logarithms of sectoral output less a weighted average of the differences between successive logarithms of sectoral intermediate (separated by domestically produced and imported), labour and capital inputs with weights given by average value shares between two points in time:

$$
\begin{aligned}
\ln TFP_j(T) - \ln TFP_j(T-1) = {} & [\ln X_j(T) - \ln X_j(T-1)] \\
& - \sum_i \frac{1}{2}[s^d_{ij}(T) + s^d_{ij}(T-1)][\ln X^d_{ij}(T) - \ln X^d_{ij}(T-1)] \\
& - \sum_i \frac{1}{2}[s^m_{ij}(T) + s^m_{ij}(T-1)][\ln X^m_{ij}(T) - \ln X^m_{ij}(T-1)] \\
& - \frac{1}{2}[s^l_j(T) + s^l_j(T-1)][\ln L_j(T) - \ln L_j(T-1)] \\
& - \frac{1}{2}[s^k_j(T) + s^k_j(T-1)][\ln K_j(T) - \ln K_j(T-1)]
\end{aligned}
$$

where:

$$
\begin{aligned}
s^d_{ij}(T) &= p^d_i(T)X^d_{ij}(T)/p^*_j(T)X_j(T) \quad (i = 1,2,...,n;\ j = 1,2,...n) \\
s^m_{ij}(T) &= p^m_i(T)X^m_{ij}(T)/p^*_j(T)X_j(T) \quad (i = 1,2,...,n;\ j = 1,2,...,n) \\
s^l_j(T) &= p^l_j(T)L_j(T)/p^*_j(T)X_j(T) \quad (j = 1,2,...,n) \\
s^k_j(T) &= p^k_j(T)K_j(T)/p^*_j(T)X_j(T) \quad (j = 1,2,...,n)
\end{aligned}
$$

Aggregate TFP Index

As shown below, this alternative sectoral TFP formula facilitates to construct aggregate TFP index from sectoral TFP series. The sectoral aggregate TFP can be then defined as the weighted average of sectoral TFP in the following way.

$$
\sum_{j=1}^{n} \frac{p^*_j X_j}{p^v V} \frac{\dot{TFP}_j}{TFP_j} = \sum_{j=1}^{n} \frac{p^v_j V_j}{p^v V} \frac{\dot{V}_j}{V_j} - s_L \cdot \sum_{j=1}^{n} \frac{p^l_j L_j}{\sum_j p^l_j L_j} \frac{\dot{L}_j}{L_j} - s_K \cdot \sum_{j=1}^{n} \frac{p^k_j K_j}{\sum_j p^k_j K_j} \frac{\dot{K}_j}{K_j} \qquad \text{(A-19)}
$$

where:

$$
s_L = \sum_j \frac{p^l_j L_j}{p^v V}, \quad s_K = \sum_j \frac{p^k_j K_j}{p^v V}
$$

Note that this aggregated measure of TFP is constructed by the Divisia aggregate indexes of sectoral value added, labour and capital inputs, not by simply aggregating sectoral data on value added, labour and capital.

Resource allocation effects

The disaggregated framework explained here enables us to incorporate the impacts of structural change or resource allocation effects on economic growth. The importance of this effect may be clear from the fact that the improvement of the allocation of resources can contribute to growth even though technical change does not occur. In a simple aggregate productivity analysis, this effect is usually ignored and included into "the residual" in the growth accounting. However, since the bottom-up, sectoral approach used here needs to make a clear link between sectoral productivity and aggregated productivity, it must be treated as a distinguished source of economic growth with the residual factor. Development of this section relies on the formulation of Kuroda and Shimpo (1991).

Aggregate TFP is also measurable by directly using already aggregated data in macroeconomic accounts, not by following the Divisia aggregation of sectoral data. In this case, the aggregated social balance equation is shown as:

$$p^v V = p^l L + p^k K \tag{A-20}$$

The aggregate TFP can be then defined as:

$$\frac{\dot{TFP}}{TFP} = \frac{\dot{V}}{V} - s_L \frac{\dot{L}}{L} - s_K \frac{\dot{K}}{K} \tag{A-21}$$

where:

$$V = \sum V_j \quad L = \sum L_j \quad K = \sum K_j \quad s_L = \frac{p^l L}{p^v V} \quad s_K = \frac{p^k K}{p^v V}$$

The difference between Divisia aggregation and the simple sum of each variable is thus equivalent to assuming the equality of value added and factor price deflators across different sectors as well as the homogeneity of such volume variables as value added, labour and capital regardless of the sectors. Accordingly, if these two assumptions hold, the Divisia price indexes of value added, labour and capital (p^v, p^l, p^k) become equal to their implicit deflators ($\tilde{p}^v$, $\tilde{p}^l$ and $\tilde{p}^k$) so that the Divisia volume indexes for these variables are reduced to the growth rate of the simple sum of each variable across the sectors shown as below:

$$\frac{\dot{V}}{V} = \Sigma \frac{p_j^v V_j}{p^v V} \cdot \frac{\dot{V}_j}{V_j} = \Sigma \frac{\tilde{p}^v V_j}{p^v V} \cdot \frac{\dot{V}_j}{V_j} = \Sigma \frac{V_j}{V} \cdot \frac{\dot{V}_j}{V_j} = \frac{\Sigma \dot{V}_j}{V}$$

$$\frac{\dot{L}}{L} = \Sigma \frac{p_j^l L_j}{p^l L} \cdot \frac{\dot{L}_j}{L_j} = \Sigma \frac{\tilde{p}^l L_j}{p^l L} \cdot \frac{\dot{L}_j}{L_j} = \Sigma \frac{L_j}{L} \cdot \frac{\dot{L}_j}{L_j} = \frac{\Sigma \dot{L}_j}{L}$$

$$\frac{\dot{K}}{K} = \Sigma \frac{p_j^k K_j}{p^k K} \cdot \frac{\dot{K}_j}{K_j} = \Sigma \frac{\tilde{p}^k K_j}{p^k K} \cdot \frac{\dot{K}_j}{K_j} = \Sigma \frac{K_j}{K} \cdot \frac{\dot{K}_j}{K_j} = \frac{\Sigma \dot{K}_j}{K}$$

Rearranging the terms of equation (A-32) by using equation (A-32), the following relationships between sectoral TFP and the aggregate TFP index can be obtained:

$$\frac{\dot{TFP}}{TFP} = \sum_j \frac{p_j^* X_j}{p^v V} \frac{\dot{TFP}_j}{TFP_j} + \sum_j \frac{(\tilde{p}^v - p_j^v) V_j}{p^v V} \frac{\dot{V}_j}{V_j} + \sum_j \frac{(p_j^l - \tilde{p}^l) L_j}{p^v V} \frac{\dot{L}_j}{L_j} + \sum_j \frac{(p_j^k - \tilde{p}^k) K_j}{p^v V} \frac{\dot{K}_j}{K_j} \tag{A.22}$$

The above equation[2] indicates that the aggregate TFP growth given by equation (A-21) can be decomposed into the following four components. The first term of the right-hand side of the equation presents the weighted average of sectoral TFP growth with weights defined by the sectoral proportion of nominal gross output to nominal value added (reciprocal of sectoral value added ratios). Since the sum of the weights are necessarily more than unity, *ceteris paribus*, the aggregate TFP growth rate becomes larger than the simple average of the sectoral TFP growth.

The factors responsible for the difference between these two TFP indexes can be broken down into the other three terms in the right-hand side which represent the TFP contributions of reallocational change in value added, labour and capital inputs among the sectors. To see these resource allocation effects on growth more easily, the above equation can be rearranged by substituting it with equation (A-21) as:

$$\frac{\dot{V}}{V} - \sum_j \frac{(\tilde{p}^v - p_j^v)V_j}{p^v V}\frac{\dot{V}_j}{V_j}$$
$$= s_L\frac{\dot{L}}{L} + \sum_j \frac{(p_j^l - \tilde{p}^l)L_j}{p^v V}\frac{\dot{L}_j}{L_j} + s_K\frac{\dot{K}}{K} + \sum_j \frac{(p_j^k - \tilde{p}^k)K_j}{p^v V}\frac{\dot{K}_j}{K_j} + \sum_j \frac{p_j^* X_j}{p^v V}\frac{T\dot{F}P_j}{TFP_j}$$

The left-hand side of this equation indicates that Divisia aggregate GDP growth rate is decomposed into two elements: GDP growth rate estimated from the simple aggregate account and the structural factor emanating from the difference of value added deflators among sectors. Hence, if the sectors whose value added deflators are higher than the average deflator have rapidly grown, the second-term in the left-hand side becomes negative and Divisia aggregate GDP growth is enhanced. Since the value added deflator can be defined as value added per unit of net output, the increasing share of high-value added sectors alongside with economic development is likely to bring about higher economic growth.

Aggregate GDP growth in the left-hand side of the equation can be decomposed into three contributing factors: labour, capital and technical change. Factor input contributions can be decomposed into that due to the growth of aggregate volume of labour and capital as well as reallocation effects of labour and capital among different sectors whose marginal productivity are not even. Therefore, if labour is released from lower-wage to higher-wage sectors, the fourth term is likely to become positive. The same is also true for capital input. Finally, the last term in the right-hand side of the equation indicates the weighted average of sectoral TFP growth as mentioned on the above. A crucial advantage of the above growth accounting is that this formulation enables us to separate resource allocation effects from the "residual" which were included in the early aggregate growth accounting studies (for example, see Solow (1957)).

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2. The derivation of equation (A.22) is as follows.

$$\frac{T\dot{F}P}{TFP}\cdot p^v V = \sum_j \tilde{p}^v \dot{V}_j - \sum_j \tilde{p}^l \dot{L}_j - \sum_j \tilde{p}^k \dot{K}_j = \sum_j \tilde{p}^v \dot{V}_j - \sum_j p_j^v \dot{V}_j + \sum_j p_j^v \dot{V}_j - \sum_j \tilde{p}^l \dot{L}_j - \sum_j \tilde{p}^k \dot{K}_j$$
$$= \sum_j \left(\frac{\dot{TFP}_j}{TFP_j}\cdot p_j^* X_j + p_j^l \dot{L}_j + p_j^k \dot{K}_j\right) + \left(\sum_j \tilde{p}^v \dot{V}_j - \sum_j p_j^v \dot{V}_j\right) - \sum_j \tilde{p}^l \dot{L}_j - \sum_j \tilde{p}^k \dot{K}_j$$
$$= \sum_j \frac{\dot{TFP}_j}{TFP_j}\cdot p_j^* X_j + \sum_j (\tilde{p}^v - p_j^v)\dot{V}_j + \sum_j (p_j^l - \tilde{p}^l)\dot{L}_j + \sum_j (p_j^k - \tilde{p}^k)\dot{K}_j$$

Annex 3. Model used in estimation of impact of R&D and of technology diffusion

The model used for the estimation of the relationship between TFP growth and R&D is built on the popular production function approach where R&D is incorporated as one of the production factors as used in many preceding studies. To formulate this relationship, we use the following extended Cobb-Douglas function[3]:

$$X = A e^{\lambda t} K_R^{\gamma} K^{\alpha_K} L^{\alpha_L} M^{\alpha_M} \tag{A.23}$$

where X is real gross output, a function of intermediate inputs M, capital K, labour L, and stock of research and development R. λ is an index of technological change unrelated to research and development (a proxy of the rate of change in disembodied technology), A is a constant. α_i (i=K, L, M) are the output elasticities with respect to inputs, K, L and M and constant returns to scale among these three inputs ($\alpha_K+\alpha_L+\alpha_M = 1$) are assumed. γ indicates the output elasticity of R&D stock.

Since the direct estimation of the above production function needs R&D stock data, we adopt the following indirect approach to avoid the difficulties in constructing consistent R&D stock data across the countries. Dividing both sides of the above equation by $K^{\alpha_K} L^{\alpha_L} M^{\alpha_M}$, the level of total factor productivity is defined as follows.

$$TFP = \frac{X}{K^{\alpha_K} L^{\alpha_L} M^{\alpha_M}} = A K_R^{\gamma} e^{\lambda t} \tag{A.24}$$

Differentiating logarithmically (A.24) with respect to time and using the definition of the output elasticity of R&D stock, γ, we obtain:

$$\frac{TFP}{TFP} = \lambda + \left(\frac{\partial X}{\partial K_R} \cdot \frac{K_R}{X}\right)\frac{K_R}{K_R} = \lambda + \left(\frac{\partial X}{\partial K_R}\right)\frac{K_R}{X} \equiv \lambda + \rho \frac{R}{X} \tag{A.25}$$

where R is *net* R&D investment expenditures and ρ is the marginal productivity of R&D capital stock, or simply the rate of return of R&D expenditures.

Equation (A.25) is the basic theoretical model in which the TFP growth rate can be expressed as a function of the R&D intensity of an industry. Assuming that the rate of depreciation of the R&D stock is negligibly small, the net R&D intensity in the equation can be replaced by the *gross* R&D intensity which is the only currently available data. The impact of R&D on productivity growth is then estimated by the coefficient ρ given data on TFP growth and R&D intensity. Since our interest lies not only in the impact of performed R&D but also on that of embodied R&D acquired from the purchase of domestic and imported intermediate products, domestic and imported capital goods, we use the following extended model to answer how and to what extent embodied R&D from other industries or from abroad can affect productivity in the user industries.

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3 . The Cobb-Douglas formulation is not consistent with the TFP estimates derived from sectoral accounts in the Divisia index form (see Milana (1995) on this criticism). Although consistency can be achieved when the translog function is employed, this problem is neglected in this paper because of insufficient data to estimate the parameters of this function.

$$\frac{TFP}{TFP} = \lambda + \rho_1 \frac{R}{X} + \rho_2 \frac{TINT^d}{X} + \rho_3 \frac{TINV^d}{X} + \rho_4 \frac{TINT^m}{X} + \rho_5 \frac{TINV^m}{X} \qquad \text{(A.26)}$$

where $TINT^d$ is embodied R&D in the purchased domestic intermediate inputs, $TINV^d$ is embodied R&D in the purchased domestic investment goods, $TINT^m$ is embodied R&D in the purchased intermediate inputs, and $TINV^m$ is embodied R&D in the purchased imported investment goods. These four embodied R&D variables were developed in a previous study (OECD, 1994a, see also Annex 1 for the derivation of the embodied R&D variables).[4]

For the empirical implementation of the model, several considerations had to be taken into account in order to design better statistical experiments within the limits imposed by our data. First, our preliminary correlation analysis revealed a strong multicolinearlity among explanatory variables, particularly between the direct R&D intensity and the embodied R&D intensity in intermediate inputs. As long as reliable econometric methods are not available to solve this problem, some of the explanatory variables in equation (A.26) had to be aggregated in advance by assuming the same coefficients among variables concerned. From the theoretical point of view, the following alternative specifications were considered to reconcile the multicolinearity problems:

- R&D or total R&D intensity (sum of all R&D variables)
- R&D and/or total acquired R&D
- R&D and/or the acquired R&D embodied in intermediate inputs and the acquired R&D embodied in investment goods
- Domestic R&D (direct R&D plus domestically acquired R&D) and imported R&D

Note that the R&D data used were only available for manufacturing industries; for services sectors the relevant data are the above four acquired R&D variables only.

The first variant of the model roughly estimates the rate of return of total R&D-related expenditures (direct R&D and embodied R&D). The second model estimates separately the return on direct R&D and that on acquired R&D under the assumption of equal coefficients for different types of acquired R&D. The third in addition distinguishes separately the impact of R&D embodied in intermediate goods as distinct from the R&D embodied in investment goods, irrespective of whether the goods were domestically produced or imported. The fourth, a specification similar to that used in Coe and Helpman (1994), distinguishes different rate of returns for domestically available R&D and R&D inputs obtained through imports, assuming the

4. Although similar models have been used in the literature, there are potential difficulties in interpreting the results. Among others, Schankerman (1981) has pointed out the double counting of research inputs. This generally happens because the capital, labour and intermediate inputs used in R&D activities are already included in the inputs used to calculate TFP growth rates. An important implication of this double counting is that estimated coefficients ρ should be interpreted as an *excess* rate of return, in other words, social benefits of R&D, which is the amount of the total return which remains after the private return for capital and labour has already been removed. If the adjustment is made for inputs to eliminate such double counting effects, the estimated coefficients can provide an estimate of the total impact of research, including both the private and social returns. The other important difficulty occurs from possible duplication of R&D activities among firms. R&D investment is duplicated in the sense that some firms duplicate R&D conducted by other firms and/or invent around previous patents by developing slightly improved or somewhat different versions of existing products. In addition, a large part of R&D expenditures is directed towards gathering information already known, regenerating results once known, or perhaps systematising and reordering prior results. Hence, R&D expenditures will overstate the true increase in the stock of technological knowledge. Since the independent variable in equation (3) or (4) will then systematically be too large, the estimated regression coefficients may correspondingly be subject to substantial downward bias. See the US Bureau of Labour Statistics (1989) for more complete reviews on the shortcoming underlying the model.

same R&D coefficients between intermediate and capital inputs and between direct R&D and domestically acquired R&D.

Another issue concerns data handling. In general, TFP and R&D data have three dimensions (periods, countries, and industries). Each dimension has its own shortcomings: a) complete time-series data are not available -- three or four time periods for each country; b) the number of countries to be covered is only 10; c) the sectoral disaggregation is limited for at most 24 sectors with a somewhat different aggregation scheme across countries. Given these limitations on our data, underlying data have been adjusted to build models with cross-country time-series pooled data with sufficiently large samples.

For the sample period, periodical data have been separated into two sub-periods for each country -- the 1970s and 1980s, as we have interested in the possibility of structural change in the R&D and productivity relationship between the two decades. Although this reduces the sample size, this averaging procedure is practically useful in order to avoid the unfavourable impacts of cyclical fluctuation on TFP growth rates in the regression. TFP growth rates in each sub-period were simply averaged in terms of annual rates and periodical average of R&D variables were estimated by weighting the R&D intensity in each time point with as weights the number of years in each sub-period. In this sense, we do not explicitly take into account the time-lags of R&D on productivity growth.

Another adjustment was done for the industrial classification and data were organised in two different classifications. The first grouped industries largely into manufacturing and services sectors assuming the same R&D coefficient (marginal productivity) within the group and across the countries (agriculture and mining were excluded in this model and the services sector was defined to also include electricity, gas and water and construction). This distinction can be legitimate because direct R&D intensity is available only for manufacturing.

Moreover, in order to investigate the R&D impact at a more disaggregated sectoral level, the second model distinguishes the following seven industrial groups: a primary sector, a light-manufacturing sector (food, textiles, other manufacturing sector), a heavy-manufacturing sector (pulp and paper, chemicals, non-metallic mineral products, basic metals), a machinery sector (fabricated metal, general machinery, electrical machinery, transport equipment and instruments), utilities and construction, an ICT services sector (transport and communication, finance, insurance and real estate and business services sector) and another services sector (trade and CSPS).

Further breakdown of industries is not practically possible because different aggregation schemes are used for several countries in our database (for example computer and office equipment is included in general machinery in the United States, but in electrical machinery in Japan). However, this second model mitigates the restricted assumption on R&D coefficients in the first model by allowing different marginal productivities of R&D stock across individual seven industrial group, while we still have to assume the same coefficients across industries within each group and across the countries.

Pooled data were thus constructed for manufacturing and services or for seven industrial groups separately for the 1970s and the 1980s across the 10 OECD countries. The separation of countries into for example G7 vs. others was not explicitly attempted in this paper because of the limited number of non-G7 countries in the database. Combining these data into one regression allows us to estimate country averages of each R&D coefficient separately for the 1970s and the 1980s for manufacturing, services, or separately for each of the seven industrial groups. For example, when the explanatory variables are aggregated into direct R&D (R) and total acquired R&D (RACQ) and seven industrial groups are distinguished, the regression model can be specified as follows:

$$\left(\frac{\dot{TFP}}{TFP}\right)^t_{ijk} = \alpha^t_i + \beta^t_j\left(\frac{R}{X}\right)^t_{ijk} + \delta^t_j\left(\frac{RACQ}{X}\right)^t_{ijk} + \varepsilon^t_{ijk} \quad \text{(A.27)}$$

where suffix t refers the 1970s or 1980s, i for countries (1,...10), j for each group of industries, k for industries in each group j (k=1,...N_{ij}), a^t_i is the country-specific constant for each period, β^t_j and δ^t_j are the rate of return of R&D and of acquired R&D embodied in purchased products respectively and ε^t_{ijk} is a stochastic error term. Country specific time dummies are introduced in order to allow for country-specific effects in each time-period not attributable to R&D and embodied R&D performance. All the models were estimated by the ordinary least squares (OLS) method.

Annex 4 The OECD databases used

A number of OECD databases were employed in the project: the so-called STAN database family developed in the Directorate for Science, Technology and Industry (R&D expenditures, input-output tables, bilateral trade and industrial STAN) as well as the International Sectoral Database (ISDB) developed in the Statistics Department.

The STAN database family attains a relatively finer level of manufacturing disaggregation (22 industries), using a common industrial classification (ISIC Revision 2) which allows the identification of technology- and trade-intensive industries such as pharmaceutical, aerospace, computers, and communication equipment & semiconductors (see Table A-1). This industrial detail helps identify clusters of industries that share R&D through embodiment and analyse the role of international trade in the acquisition of technology developed abroad. The databases explained below commonly cover all the 10 OECD countries analysed in the project -- Australia, Canada, Denmark, France, Germany, Italy, Japan, the Netherlands, the United Kingdom and the United States.

Analytical Database of Business Enterprise R&D (ANBERD)

The ANBERD database was constructed with the objective of creating a consistent data set of R&D performed by the business sector that overcomes the problems of international comparability and time discontinuity associated with the official Business Enterprise R&D (BERD) data provided to the OECD by Member countries. To achieve this level of consistency, many of the data points have been estimated on the basis of additional information available in Member countries and through the use of pure statistical interpolation techniques (spline function). The first version of the database is described in OECD (1992b).

The database includes time-series data of sectoral intramural R&D expenditures for 22 ISIC manufacturing and several service sectors from 1973 to 1991, though this project does not use its services segment due to the underlining availability problems in several countries. This time series data set is currently available only in current prices. The countries currently covered are Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, the United Kingdom, and the United States. Although an R&D stock variable is more appropriate to investigate the level of technological knowledge in industries, reliable data to construct this variable are not sufficiently provided, especially for sectoral R&D deflators and the rate of depreciation.

Input-Output tables

Input-output tables constitute the core data of our analysis. The OECD input-output database was originally developed to assist the OECD Industry Committee in making international comparisons of structural adjustment in industry (see OECD (1992a)). The database currently covers the 10 OECD countries cited above.

The OECD input-output tables distinguishes interindustrial flows of domestically produced and imported products (i.e., non-competing import type) and consists of the following five sub-matrices:

- Domestic flows matrix (industry × industry)

- Imported flows matrix (industry × industry)
- Domestic investment flows matrix (industry × industry)
- Imported investment flows matrix (industry × industry)
- Value added components matrix (value added category × industry)

Except for the value added component matrix, these matrices are available in both current and constant price in national currency basis (the base-year of price deflators differs across the 10 countries). Industries are disaggregated into 36 ISIC sectors, of which the 22 manufacturing sectors are comparable with those of ANBERD and other databases. Available years of the data are different by country, but typically contain three to five points of years, spanning from the early-1970s to the mid-1980s or to 1990 which allows a historical analysis of industrial structure: Australia; 1968, 1974, 1986 and 1990; Canada; 1971, 1976, 1981, 1986 and 1990; Denmark; annually from 1966 to 1990; France; 1972, 1977, 1980, 1985 and 1990; Germany; 1978, 1986, 1988 and 1990; Italy; 1985 only; Japan; 1970, 1975, 1980, 1985 and 1990; Netherlands; 1972, 1977, 1981 and 1986; United Kingdom; 1968, 1979, 1984 and 1990; United States; 1972, 1977, 1982, 1985 and 1990.

The current sectoral disaggregation of the I-O database, however, has been suffering from several missing sectors for most countries which preclude exact sectoral comparison internationally. In particular, the extent of missing sectors is more serious in the disaggregation of investing industries (i.e., column sectors) in capital flow matrices than in intermediate flows matrix across the countries (see Table A-2).

These missing sectors set a limit to establishing consistency between the databases in STAN. For example, other OECD data used in our analysis (R&D, employment and trade, etc.) should be more aggregated by sector within a country, even though other data have complete sectoral profiles. For international comparisons, further aggregation must be made to keep sectoral consistency across the countries so that the original information can be lost in every step of such aggregation process.

Bilateral Trade Database

The bilateral trade database includes detailed trade flows for manufacturing industry from one country or geographical area to another. For each importing/exporting country, exports to and imports from the full list of partner countries or regions is provided (see OECD (1994b)). The data have been drawn from the foreign trade component of the OECD Statistics Directorate's COMTAP (Compatible Trade and Production) Database.

Industry coverage is 22 manufacturing sectors, following the same manufacturing classification as in used at input-output and ANBERD databases. The period covered spans from 1967 to 1992, providing manufacturing imports and imports in current US dollars of 14 OECD countries from and to the trading partners (14 OECD countries, the rest of OECD, 12 developing countries, and the rest of the world). In this project, trading partners were further aggregated for each of 10 OECD countries concerned into 12 trading partners or regions: other 9 OECD countries, the rest of the OECD, China plus the so-called Dynamic Asian Countries (Hong Kong, Malaysia, Singapore, South Korea, Thailand and Taiwan), and the rest of the world. The data were then combined with input-output database to generate regional distribution of exports and imports in input-output tables by those 12 regions.

Industrial STAN Database

The Industrial STAN database was created to facilitate international comparisons of industrial structure and performance in detailed sectoral level. It fills the gap that exists between detailed survey level data which lacks international comparability and the System of National Accounts that is internationally comparable but only available at fairly aggregated industrial levels. It must be noted that this internationally comparable data is achieved through an estimation process by the Secretariat own (OECD (1994c)).

The database currently covers 16 countries (Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Korea, Mexico, Netherlands, Norway, Sweden, United Kingdom and the United States) for the years 1970 to 1991 in two different industrial classification based on the ISIC Revision 2. The first classification uses 49 industries and the second, which is compatible with other STAN family databases, has 26 adjusted industry groupings. The following main five variables are currently available in current price only in OECD National Accounts compatible form: Production (gross output), Value added (sectoral GDP), Gross fixed capital formation (investment for construction and machinery & equipment), Number engaged (employees plus self-employed, owners proprietors and unpaid family workers) and Labour compensation (wages & salaries and other supplementary labour costs such as employer's compulsory pension, medical payments, etc.). It also provides exports and imports by sector, obtainable as the regional aggregate from the above bilateral trade database.

International Sectoral Database (ISDB)

The International Sectoral Database has been created by the OECD Statistics Department as part of the continuing study of industrial structure and economic performance in OECD Member countries (Meyer zu Schlochtern (1994)). The database uniquely combines a range of data series related primarily to sectoral output and primary factor inputs (labour and capital) in a compatible manner with the OECD National Accounts Statistics.

This annual database covers at maximum the period 1960 to 1990 but comparable only from 1970 for 14 OECD countries: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, the United Kingdom and the United States. Major variables included are: gross domestic product, total employment (engaged persons) and employees, gross fixed capital formation and gross capital stock, compensation of employees, gross operating surplus and net indirect taxes. Since most of them are available in both current and constant prices and for the latter case 1985 local currency or US dollars converted values using 1985 purchasing power parity are employed.

The ISDB database has an unique advantage in covering a significant number of variables concerning output and resource allocation in both current and constant prices. It also complements the STAN industrial database by extending beyond the manufacturing sector to include primary and services sectors. Its manufacturing detail, however, is limited to 13 industries (almost corresponding to ISIC two-digit sectors). Thus for detailed manufacturing analysis for productivity and employment, a combined data set for such variables as total employment, factor shares of income had to be created. Since the only source of capital stock data are the ISDB, the calculation of sectoral total factor productivity has been done following the ISDB sectoral disaggregation (at maximum level 24 sectors in economy as a whole).

ANNEX TABLES

Annex Table1. **R&D expenditures and embodied technology**

		Direct manufacturing R&D expenditures	Estimated indirect technology embodied in gross output	Technology multiplier (Total/direct)
United States (Million US$)				
	1972	20535	31495	1.5
	1977	28867	47933	1.7
	1982	56178	93876	1.7
	1985	77525	127338	1.6
	1990	95086	157465	1.7
Japan (Billion Yen)				
	1970	1235	2076	1.7
	1975	1589	3208	2.0
	1980	2984	6076	2.0
	1985	5722	10808	1.9
	1990	8901	17043	1.9
Germany (Million DM)				
	1978	18381	31931	1.7
	1986	36276	61554	1.7
	1990	45401	80456	1.8
France (Million FF)				
	1972	10747	18152	1.7
	1977	18604	33537	1.8
	1980	28650	51229	1.8
	1985	57639	102748	1.8
	1990	87690	147232	1.7
United Kingdom (Million	1968	899	1246	1.4
	1979	2706	4443	1.6
	1984	4293	7227	1.7
	1990	7079	13031	1.8
Italy (Billion Lira)				
	1985	4705	10274	2.2
	1990	8864	..	..
Canada (Million C$)				
	1971	421	935	2.2
	1976	601	1580	2.6
	1981	1693	4266	2.5
	1986	2703	6959	2.6
	1990	3475	8624	2.5
Australia (MIllion A$)				
	1968	190	346	1.8
	1974	192	440	2.3
	1986	1132	3331	2.9
	1990	1101	..	..
Denmark (Million Krone)				
	1972	634	1304	2.1
	1990	5335	8588	1.6
	1972	1669	2749	1.6
	1986	5131	9586	1.9
	1990	5335	10446	2.0
Netherlands (Million Guilders)				
	1972	1669	2749	1.6
	1977	2410	4192	1.7
	1981	3162	5941	1.9
	1986	5131	9586	1.9

Source: OECD STAN Input-Output database; ANBERD database.

Annex Table 2. **The technology content of production**

	United States 1990	Japan 1990	Germany 1990	France 1990	United Kingdom 1990	Italy 1985	Canada 1990	Australia 1986	Netherlands 1986
Primary sector	74	98	141	84	69	73	46	115	77
Manufacturing sector	121	104	115	135	132	112	148	117	160
High tech manufacturing	244	167	149	332	340	322	541	210	456
Aerospace	218	552	239	774	647	902	570	632	1397
Computers *	443	310	236	682	522	727	1386	..	403
Communications equipment	192	116	..	179	276	461	786	263	
Pharmaceuticals	..	117	..	206	98	303	131	135	366
Electrical machinery	230	152	122	165	158	110	117	186	388
Scientific instruments	235	161	144	129	211	172	225	194	329
Medium tech manufacturing	114	119	141	136	121	160	193	152	222
Motor vehicles	126	123	163	139	142	161	326	170	372
Chemicals **	78	62	107	147	120	166	104	246	184
Low tech manufacturing	82	66	76	68	64	57	46	90	76
Private services	92	97	84	76	86	93	78	99	64
Electricity, gas & water	159	159	155	69	78	73	136	21	107
Construction	92	99	98	72	42	94	57	151	83
Wholesale & retail trade	66	39	52	36	66	37	22	72	40
Transport & storage	184	148	188	194	79	175	154	105	134
Communication	235	160	200	237	261	424	423	123	113
Finance & insurance	94	31	50	20	90	42	17	241	18
Real estate & business services	51	91	53	70	85	67	48	34	27
Social & personal services	108	162	130	79	120	130	148	143	78

* Includes communications equipment for Germany; includes el. machinery for France.

** Includes pharmaceuticals in the case of the US, Germany.

1. This index is calculated as the ratio of the share of technology acquired by each industry in the total embodied technology in the economy to the corresponding share in production. A value of 100 means that an industry's weight in technology acquisitions is the same as its share in production.

Source: OECD, DSTI/EAS Division; calculations from STAN and ANBERD databases ?????????

Annex Table 3a. **The five Industries most dependent on investment-based technology acquisition**

		Share of R&D obtained from investment (%)	Share of industry in total private investment (%)			Share of R&D obtained from investment (%)	Share of industry in total private investment (%)
USA	1 Finance & insurance	85.7	6.5	**UK**	1 Finance & insurance	80.5	10.6
1990	2 Electricity, gas & water	75.5	9.8	**1990**	2 Communication	75.8	5.7
	3 Communication	74.9	4.3		3 Real estate & business services	72.7	13.2
	4 Transport & storage	70.5	8.2		4 Transport & storage	56.5	6.5
	5 Wholesale & retail trade	62.9	17.8		5 Petroleum refining	54.1	1.2
Japan	1 Communication	94.3	2.7	**Canada**	1 Electricity, gas & water	91.8	8.9
1990	2 Electricity, gas & water	84.3	9.2	**1990**	2 Communication	91.0	4.5
	3 Real estate & business services	83.3	19.8		3 Real estate & business services	86.3	5.9
	4 Finance & insurance	69.2	1.7		4 Social & personal services	84.7	7.9
	5 Petroleum refining	67.4	0.5		5 Hotels & restaurants	71.1	1.5
Germany	1 Communication	85.8	4.4	**Australia**	1 Finance & business service	69.8	19.2
1990	2 Transport & storage	61.8	5.9	**1986**	2 Transport & storage	64.0	11.4
	3 Finance & insurance	61.5	2.6		3 Wholesale & retail trade	58.8	15.3
	4 Electricity, gas & water	59.2	5.6		4 Basic metal products	54.8	4.3
	5 Wholesale & retail trade	58.0	6.8		5 Mining	49.5	9.2
France	1 Finance & insurance	88.0	2.7	**Netherlands**	1 Communication	81.9	2.4
1990	2 Communication	82.5	2.7	**1986**	2 Transport & storage	75.9	8.2
	3 Transport & storage	71.1	7.5		3 Wholesale & retail trade	75.5	7.0
	4 Social & personal services	68.5	41.6		4 Real estate & business services	74.1	23.8
	5 Hotels & restaurants	64.9	2.8		5 Electricity, gas & water	69.8	5.2
Italy	1 Communication	93.1	3.5	**Denmark**	1 Mining	74.4	1.5
1985	2 Finance & insurance	86.2	1.8	**1990**	2 Finance & insurance	73.4	1.9
	3 Real estate & business services	78.7	30.9		3 Communication	72.8	3.2
	4 Petroleum refining	77.5	3.4		4 Electricity, gas & water	66.6	7.5
	5 Wholesale & retail trade	73.7	6.5		5 Transport & storage	61.1	15.2

Annex Table 3b. **The five Industries least dependent on investment-based technology acquisition**

		Share of R&D obtained from investment (%)	Share of industry in total private investment (%)			Share of R&D obtained from investment (%)	Share of industry in total private investment (%)
USA	1 Other Transport	7.2	0.1	**UK**	1 Computers & office machinery	1.8	0.2
1990	2 Computers & office machinery	8.0	0.5	**1990**	2 Aerospace	1.8	0.4
	3 Aerospace	9.0	0.6		3 Communication equipment	5.6	0.9
	4 Motor vehicles	9.3	1.6		4 Rubber & plastic products	6.1	0.6
	5 Rubber & plastic products	10.4	1.1		5 Instruments	7.7	0.2
Japan	1 Aerospace	3.7	0.0	**Canada**	1 Shipbuilding	0.7	0.0
1990	2 Other Transport	8.0	0.1	**1990**	2 Communication equipment	1.5	0.2
	3 Construction	9.6	2.2		3 Computers & office machinery	1.7	0.1
	4 Communication equipment	11.2	1.0		4 Aerospace	1.7	0.2
	5 Rubber & plastic products	13.7	1.0		5 Motor vehicles	2.0	1.1
Germany	1 Aerospace	7.2	0.2	**Australia**	1 Electricity, gas & water	5.5	0.2
1990	2 Shipbuilding	8.6	0.1	**1986**	2 Construction	10.7	5.9
	3 Rubber & plastic products	11.8	1.1		3 Chemicals, oil & coal	13.6	2.6
	4 Construction	12.7	1.6		4 Fabricated metal and machinery	14.7	2.6
	5 Non-ferrous metals	14.8	0.3		5 Transport equipment	21.8	4.1
France	1 Aerospace	2.5	0.6	**Netherlands**	1 Aerospace	2.5	0.1
1990	2 Shipbuilding	6.0	0.1	**1986**	2 Computers & office machinery	4.2	0.1
	3 Other non-electrical machinery	8.9	1.1		3 Shipbuilding	5.1	0.2
	4 Communication equipment	10.3	0.6		4 Instruments	5.2	0.1
	5 Motor vehicles	12.4	1.8		5 Other manufacturing	8.2	0.1
Italy	1 Aerospace	1.9	0.1	**Denmark**	1 Transport mach. & instruments	7.6	0.8
1985	2 Computers & office machinery	2.5	0.2	**1990**	2 Electrical machinery	8.7	0.8
	3 Communication equipment	3.4	0.5		3 Non-electrical equipment	10.3	2.2
	4 Pharmaceuticals	6.8	0.3		4 Chemicals	12.5	2.7
	5 Other non-electrical machinery	9.1	1.4		5 Social & personal services	13.9	1.3

Source: OECD, STAN Input-Output database.

Annex Table 4. **Largest gain in technology intensity from acquired technology**

Country Sectors	Intensity				
Australia 1986	Total	Domestic	Imported	Origin	Share
1. Transport equipment	1.17	0.30	0.87	JPN	36.7
2. Fabricated metal and machinery	0.80	0.35	0.45	USA	31.2
3. Construction	0.73	0.50	0.23	USA	30.1
4. Chemicals, oil & coal	0.68	0.25	0.43	USA	24.3
5. Social & personal services	0.66	0.28	0.38	USA	39.8
Total	0.48	0.25	0.23	USA	34.8
Canada 1990	Total	Domestic	Imported	Origin	Share
1. Computers & office machinery	6.82	0.35	6.47	USA	77.0
2. Communication & semiconductors	3.87	0.08	3.79	USA	73.1
3. Shipbuilding	3.33	1.95	1.38	USA	73.0
4. Aerospace	2.80	0.09	2.71	USA	78.1
5. Communication	2.08	1.48	0.60	USA	74.0
Total	0.49	0.17	0.33	USA	75.2
Denmark 1990	Total	Domestic	Imported	Origin	Share
1. Electrical machinery	1.38	0.32	1.06	ROO	24.1
2. Transport machinery & instrument	1.06	0.36	0.71	GER	24.4
3. Chemicals	1.00	0.16	0.84	ROO	30.3
4. Non-electrical equipment	0.79	0.20	0.60	GER	26.1
5. Agriculture, forestry & fishing	0.65	0.35	0.30	ROO	28.2
Total	0.41	0.17	0.24	ROO	27.8
France 1990	Total	Domestic	Imported	Origin	Share
1. Aerospace	4.42	1.74	2.68	USA	51.2
2. Computers & office machinery	3.89	1.04	2.85	USA	45.1
3. Shipbuilding	1.45	0.57	0.88	USA	18.5
4. Communication	1.35	1.08	0.27	USA	27.8
5. Other Transport	1.27	1.08	0.19	GER	28.7
Total	0.61	0.35	0.26	USA	31.9
Germany 1990	Total	Domestic	Imported	Origin	Share
1. Aerospace	2.54	0.66	1.88	FRA	46.1
2. Shipbuilding	1.83	1.47	0.36	ROO	26.0
3. Computers & office machinery	1.77	0.65	1.12	USA	25.8
4. Rubber & plastic products	1.72	1.24	0.49	ROO	28.2
5. Communication	1.50	1.22	0.28	ROO	23.4
Total	0.75	0.55	0.20	ROO	22.9

Country Sectors	Intensity				
Italy 1985	Total	Domestic	Imported	Origin	Share
1. Aerospace	3.25	0.21	3.04	USA	53.1
2. Computers & office machinery	2.62	0.28	2.35	USA	31.9
3. Communication & semiconductors	1.66	0.26	1.40	GER	23.7
4. Communication	1.53	0.85	0.68	GER	21.8
5. Pharmaceuticals	1.09	0.35	0.74	ROO	28.6
Total	0.36	0.19	0.17	GER	22.9
Japan 1990	Total	Domestic	Imported	Origin	Share
1. Aerospace	5.16	0.64	4.51	USA	93.4
2. Computers & office machinery	2.91	2.37	0.54	USA	73.2
3. Other Transport	2.10	2.06	0.04	DAE	33.6
4. Shipbuilding	1.91	1.84	0.07	USA	55.1
5. Rubber & plastic products	1.90	1.84	0.06	USA	34.3
Total	0.94	0.87	0.07	USA	57.8
Netherlands 1986	Total	Domestic	Imported	Origin	Share
1. Aerospace	8.12	0.44	7.68	USA	45.9
2. Computers & office machinery	2.34	0.95	1.39	USA	27.3
3. Electrical machinery	2.26	0.08	2.17	GER	28.0
4. Motor vehicles	2.16	0.83	1.34	ROO	31.4
5. Pharmaceuticals	2.12	0.24	1.89	ROO	34.1
Total	0.58	0.18	0.40	GER	26.3
UK 1990	Total	Domestic	Imported	Origin	Share
1. Aerospace	4.17	0.37	3.81	ROW	62.9
2. Computers & office machinery	3.37	0.80	2.56	USA	34.0
3. Communication & semiconductors	1.78	0.26	1.52	USA	25.2
4. Communication	1.69	1.02	0.66	USA	20.6
5. Instruments	1.37	0.62	0.75	USA	21.9
Total	0.60	0.27	0.33	USA	20.0
US 1990	Total	Domestic	Imported	Origin	Share
1. Computers & office machinery	3.02	1.91	1.11	DAE	45.3
2. Communication	1.60	1.48	0.13	DAE	38.6
3. Instruments	1.60	1.33	0.28	DAE	34.2
4. Electrical machinery	1.57	1.34	0.23	DAE	31.5
5. Aerospace	1.49	1.06	0.43	FRA	22.9
Total	0.68	0.59	0.09	JPN	29.8

Source: OECD, STAN Input-Output database.

Annex Table 5. **Share of Imports by Country of Origin**
Comparison of Dollar Flows and Weighted Technology Content

Destination Country	Origin Country	Share based on technology Content	Share based on currency value	Ratio of Technology Currency Value
Australia (1986)	USA	34.8	20.9	1.7
	JPN	23.6	23.7	1.0
	GER	8.3	8.5	1.0
Canada (1990)	USA	75.2	67.1	1.1
	JPN	7.3	7.8	0.9
	DAE	5.4	6.5	0.8
Denmark (1990)	ROO	27.8	29.3	0.9
	GER	22.9	24.0	1.0
	USA	12.6	5.9	2.1
France (1990)	USA	31.9	8.6	3.7
	GER	20.1	21.1	1.0
	ROO	14.6	24.5	0.6
Germany (1990)	ROO	22.9	28.0	0.8
	USA	18.3	7.0	2.6
	FRA	17.2	12.7	1.4
Italy (1985)	GER	22.9	23.3	1.0
	USA	20.5	6.7	3.0
	ROO	15.6	19.2	0.8
Japan (1990)	USA	57.8	27.7	2.1
	DAE	14.7	24.3	0.6
	GER	7.6	7.5	1.0
Netherlands (1986)	GER	26.3	30.1	0.9
	ROO	22.5	26.8	0.8
	USA	20.0	7.8	2.6
United Kingdom (1990)	USA	20.0	9.5	2.1
	ROW	19.0	13.2	1.4
	GER	14.8	17.3	0.9
United States (1990)	JPN	29.8	21.2	1.4
	DAE	23.9	20.1	1.2
	ROW	11.6	16.2	0.7

Source: OECD, STAN Input-Output database.

Annex Table 6. **Index of use of types of acquired technology**
Aggregated by sectors Exhibiting Disproportionarely Large Use

Technology Cluster	Information			Transportation	Consumer Goods	Materials			Fabrication		
Acquiring Sector	High Technology	Communication Services	FIRB	Transportation and Storage Services	Wholesale and Retail Trade	Agriculture	Low Technology	Medium Technology	Mining	EGW	Construction
Australia (1986)			1.8	3.9	0.5	1.5			3.4	1.0	1.1
Canada (1990)	1.6	2.0	1.5	3.0	1.6	2.6	2.5	1.1	4.2	1.1	2.7
Denmark (1990)		2.1	1.3	3.3	0.3	1.4			2.6	1.7	1.1
France (1990)	1.5	2.3	1.8	3.2	0.5	2.4	1.8	1.8	2.6	1.8	2.3
Germany (1990)	1.3	2.3	1.2	4.3	0.9	1.3	1.2	1.2	2.6	1.3	1.2
Italy (1985)	1.6	2.7	1.8	4.1	0.2	1.7	1.6	1.6	2.6	1.5	1.5
Japan (1990)	1.5	2.4	1.6	3.8	1.0	1.2	1.3	1.2	2.2	1.2	1.3
Netherlands (1986)	1.3	1.5	1.4	3.2	0.3	1.0	1.1	1.9	2.0	1.5	1.7
United Kingdom (1990)	1.3	2.2	1.1	2.8	2.9	2.0	1.6	1.7	5.3	1.2	2.4
United States (1990)	1.5	1.9	1.5	3.3	3.9	1.9	1.6	1.7	2.8	0.8	2.6
Average	1.5	2.2	1.5	3.5	1.2	1.7	1.6	1.5	3.0	1.3	1.8
Variance	0.7	2.6	0.8	8.9	1.7	1.4	1.1	0.9	7.0	0.5	1.8

Source: OECD, STAN Input-Output database.

Annex Table 7. **Share of Acquired Technology by Source Cluster**

	Share of Acquired Technology from	**Information Technology**	**Transportation & Distribution**	**Consumer Goods**	**Materials**	**Fabrication**
Australia (1986)	All Sources	40.3	15.9	0.9	30.1	12.9
	Imports	57.4	20.3	0.6	21.8	0.0
	ratio of imports to all	1.4	1.3	0.7	0.7	0.0
Canada (1990)	All Sources	47.6	27.3	0.9	18.3	5.9
	Imports	50.6	33.7	0.4	9.9	5.4
	ratio of imports to all	1.1	1.2	0.4	0.5	0.9
Denmark (1990)	All Sources	24.3	10.8	1.3	33.9	29.7
	Imports	24.2	13.8	1.2	35.6	25.1
	ratio of imports to all	1.0	1.3	1.0	1.0	0.8
France (1990)	All Sources	39.7	22.2	1.0	28.0	9.1
	Imports	35.1	36.5	0.7	20.2	7.6
	ratio of imports to all	0.9	1.6	0.7	0.7	0.8
Germany (1990)	All Sources	38.1	17.2	0.5	31.5	12.6
	Imports	42.9	22.1	0.7	27.9	6.4
	ratio of imports to all	1.1	1.3	1.3	0.9	0.5
Italy (1985)	All Sources	34.7	17.5	0.8	35.8	11.2
	Imports	43.2	22.4	1.1	27.3	5.9
	ratio of imports to all	1.2	1.3	1.5	0.8	0.5
Japan (1990)	All Sources	33.9	9.5	1.3	44.3	11.0
	Imports	47.0	24.1	1.3	23.9	3.6
	ratio of imports to all	1.4	2.5	1.0	0.5	0.3
Netherlands (1986)	All Sources	47.8	17.3	1.9	24.7	8.3
	Imports	44.7	23.4	1.0	22.9	8.0
	ratio of imports to all	0.9	1.4	0.5	0.9	1.0
United Kingdom (1990)	All Sources	40.4	22.3	1.3	29.4	6.6
	Imports	44.7	31.4	0.7	17.8	5.4
	ratio of imports to all	1.1	1.4	0.6	0.6	0.8
United States (1990)	All Sources	49.1	16.9	0.8	26.5	6.6
	Imports	56.2	21.3	0.6	14.4	7.6
	ratio of imports to all	1.1	1.3	0.7	0.5	1.1

Source: OECD, STAN Input-Output database.

Annex Table 8. Productivity level by industry

Total manufacturing = 100

	Canada		Mexico		United States		Australia		Japan		Belgium		Denmark		Finland	
	1970	1993	1970	1992	1970	1993	1970	1992	1970	1993	1970	1992	1970	1993	1970	1993
Total manufacturing	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
Food, beverages, tobacco	130.9	103.6	103.3	91.0	104.1	99.3	128.0	111.6	174.3	78.2	160.1	114.8	103.4	143.7	114.8	96.8
Textiles, footwear, leather	46.0	57.0	73.3	54.5	47.0	53.8	47.6	59.4	57.4	33.5	66.1	69.1	49.5	57.7	59.5	58.1
Wood and wood products	72.8	70.6	97.5	64.9	73.3	60.8	90.8	55.8	58.8	52.9	69.5	65.0	76.2	67.2	72.4	60.5
Paper, printing	128.6	95.1	110.6	106.7	117.7	78.9	68.2	90.2	161.4	84.1	114.7	94.9	134.3	94.4	145.8	112.7
Chemicals	116.0	140.1	120.7	134.9	127.9	133.7	164.7	158.4	124.2	125.0	134.1	195.0	113.0	131.8	165.4	131.1
Pharmaceuticals	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Non-met.mineral products	128.7	97.7	82.1	106.0	100.3	90.4	74.0	147.8	126.3	87.4	127.4	133.4	153.4	130.3	108.0	91.9
Basic metals	132.8	138.8	165.3	194.5	147.0	114.5	138.6	159.8	234.9	162.4	93.8	131.5	87.7	130.4	94.9	117.2
Fabr. metal prod. and mach.	90.4	106.7	99.5	115.4	102.7	114.7	105.3	89.0	69.3	111.4	87.7	68.3	100.1	80.3	87.7	102.7
Non-electrical machinery	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Computers, office mach.	..	..	..	..	..	..	..	..	..	..	..	.	..	..	..	..
Electrical machinery	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Communic. equip. and semic.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Motor vehicles	130.6	138.3 [4]	145.7	165.3 [5]	154.1	88.7 [5]	126.1	77.6	179.8	129.4 [5]	..	..	..	..	131.3	67.6 [6]
Aerospace	71.6	82.8 [4]	..	..	170.9 [1]	134.9 [5]	112.6 [2]	51.7	..	..	..	.	..	..	128.6	36.2 [6]
Scientific instruments	..	..	177.2	63.9 [5]	101.4	116.8 [5]	109.6	80.5	43.6	76.4 [6]	90.9	84.3	69.5	90.0 [6]	138.0	116.3 [6]
Other manufacturing	91.3	59.0	142.9	77.5	97.0	77.5	56.9	40.2	147.1	221.5	132.3	49.6	114.5	137.5	85.4	80.6
High-technology ind.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Medium-technology ind.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Low-technology ind.	104.6	92.0 [4]	91.1	91.8 [5]	95.0	85.3 [5]	89.6	93.0	111.0	72.9 [5]	..	..	97.7	101.9 [3]	103.2	98.6 [6]
Resource-intensive ind.	117.0	100.2 [4]	100.9	94.4 [5]	104.4	93.8 [5]	117.0	107.3	135.4	80.3 [6]	125.8	109.9	109.3	122.0 [5]	105.6	92.4 [6]
Labour-intensive ind.	69.1	68.7 [4]	76.3	73.2 [5]	69.6	73.9 [5]	68.9	64.3	71.9	64.7 [6]	72.5	59.7	68.0	86.1 [5]	66.5	72.3 [6]
Scale-intensive ind.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.
Specialised supplier ind.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.
Science-based ind.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.

	France		Germany		Italy		Netherlands		Norway		Portugal		Sweden		United Kingdom	
	1970	1993	1970	1993	1970	1993	1970	1993	1970	1993	1977	1993	1970	1993	1970	1993
Total manufacturing	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
Food, beverages, tobacco	123.5	116.0	119.8	102.3	140.4	145.1	82.9	107.5	123.0	89.2	140.8	161.1	89.2	87.9	175.7	161.4
Textiles, footwear, leather	65.9	65.8	55.7	65.8	75.4	72.1	53.6	62.8	54.0	57.8	59.4	66.9	64.5	53.7	50.8	47.4
Wood and wood products	62.4	66.6	79.8	63.5	51.8	65.6	100.0	58.1	74.4	67.7	63.2	81.4	107.4	92.1	112.2	72.7
Paper, printing	121.3	86.7	93.0	93.6	115.9	116.5	105.2	93.0	113.2	102.7	131.4	169.9	111.4	105.1	118.7	106.7
Chemicals	168.1	164.7	163.0	146.1	82.3	133.0	195.6	166.9	110.1	146.5	172.1	141.3	155.9	165.9	102.6	118.5
Pharmaceuticals	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.	..
Non-met.mineral products	110.1	111.9	97.5	103.5	107.3	93.1	110.4	87.9	122.1	81.8	74.6	115.4	95.1	85.6	130.7	117.1
Basic metals	101.4	109.0	96.2	103.7	103.4	116.6	155.6	128.6	112.7	169.2	129.6	285.2	81.3	126.4	80.8	82.9
Fabr. metal prod. and mach.	90.7	88.9	97.7	95.2	124.3	105.7	89.1	83.7	96.6	94.1	142.1	100.8	105.1	101.5	87.9	87.4
Non-electrical machinery	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Computers, office mach.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.	..
Electrical machinery	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.	..
Communic. equip. and semic.	..	..	..	..	..	..	..	..	..	..	..	.	..	..	..	..
Motor vehicles	..	..	..	..	..	..	182.7	62.0 [5]	194.6	69.6 [5]	..	..	223.3	84.8 [4]	106.3	110.7 [5]
Aerospace	..	..	125.4	94.2 [6]	..	..	197.8	57.9 [5]	54.1	114.8 [5]	..	..	143.9	103.0 [4]	..	..
Scientific instruments	48.9	85.5 [6]	106.9	98.8 [6]	166.3	100.4 [6]	102.4	105.2 [5]	100.3	96.1 [5]	102.8	..	143.0	170.0 [4]	33.3	108.7 [6]
Other manufacturing	90.8	62.6	95.1	89.6	69.6	68.5	106.6	92.2	107.5	94.6	75.5	35.9	28.8	12.5	336.2	315.3
High-technology ind.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.	..
Medium-technology ind.	..	..	..	..	..	..	..	..	..	..	..	..	..	.	.	..
Low-technology ind.	..	..	97.5	95.7 [5]	..	..	98.3	99.0 [5]	96.3	89.4 [5]	..	..	92.6	98.8 [4]	103.8	101.1 [5]
Resource-intensive ind.	141.4	134.1 [6]	128.8	109.6 [5]	98.2	108.0 [6]	121.7	119.2 [5]	113.7	102.9 [5]	106.0	122.9 [6]	103.9	102.7 [4]	151.1	132.8 [6]
Labour-intensive ind.	79.7	71.5 [6]	72.2	79.0 [5]	98.3	76.5 [6]	66.5	73.7 [5]	74.1	75.9 [5]	70.6	69.5 [4]	72.8	63.9 [4]	80.8	74.9 [6]
Scale-intensive ind.	..	..	..	..	..	..	..	..	..	..	..	..		..	..	.
Specialised supplier ind.	..	..	..	..	..	..	..	..	..	..	.	..	.	..		.
Science-based ind.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.	..

1 1972
2 1981
3 1989
4 1990
5 1991
6 1992

Source : OECD, STAN database (DSTI, EAS Division), March 1995.

Annex Table 9. Growth Accounting Results at Macroeconomic Level

(%)

		Divisia Aggregates				Aggregate Account				Resource reallocation effects**			
		GDP Growth	Labour Contribution	Capital Contribution	TFP Growth	GDP Growth	Labour Contribution	Capital Contribution	TFP Growth	GDP a	Labour b	Capital c	TFP a+b+c
United States	**1972-90**	**2.83**	**1.35**	**1.07**	**0.42**	**2.76**	**1.45**	**0.96**	**0.35**	**-0.07**	**-0.10**	**0.11**	**-0.06**
	1972-77	2.58	1.34	1.17	0.06	2.28	1.43	1.06	-0.21	-0.29	-0.09	0.11	-0.27
	1977-82	1.30	1.05	1.17	-0.92	1.44	1.13	1.01	-0.70	0.14	-0.08	0.16	0.22
	1982-85	5.21	1.92	1.01	2.29	4.79	2.04	0.89	1.86	-0.42	-0.12	0.11	-0.43
	1985-90	3.19	1.30	0.90	0.99	3.34	1.42	0.85	1.07	0.15	-0.12	0.05	0.08
Japan	**1970-90**	**4.38**	**0.78**	**2.19**	**1.41**	**4.45**	**0.58**	**2.11**	**1.76**	**0.07**	**0.20**	**0.08**	**0.36**
	1970-75	4.43	0.60	3.31	0.52	4.76	0.22	3.20	1.34	0.33	0.38	0.11	0.82
	1975-80	4.37	0.76	1.82	1.79	4.31	0.57	1.80	1.94	-0.06	0.19	0.02	0.15
	1980-85	4.02	0.65	1.64	1.74	4.03	0.54	1.54	1.96	0.01	0.11	0.10	0.22
	1985-90	4.70	1.13	2.00	1.58	4.71	1.01	1.89	1.81	0.01	0.12	0.11	0.24
Germany	**1978-90**	**2.31**	**0.38**	**1.00**	**0.94**	**2.43**	**0.33**	**0.97**	**1.13**	**0.12**	**0.05**	**0.03**	**0.20**
	1978-86	1.61	0.07	1.03	0.51	1.74	0.02	1.00	0.72	0.13	0.05	0.02	0.20
	1986-88	2.67	0.44	0.89	1.35	2.80	0.40	0.86	1.55	0.13	0.04	0.03	0.20
	1988-90	4.73	1.55	0.98	2.21	4.82	1.50	0.93	2.38	0.08	0.04	0.04	0.17
France	**1972-90**	**2.59**	**0.31**	**0.70**	**1.57**	**2.67**	**-0.24**	**0.71**	**2.20**	**0.08**	**0.55**	**0.00**	**0.63**
	1972-77	3.43	0.26	1.14	2.04	3.23	0.02	1.13	2.08	-0.20	0.23	0.01	0.04
	1977-80	1.51	0.22	0.76	0.53	2.31	-0.21	0.72	1.80	0.81	0.43	0.04	1.27
	1980-85	1.54	-0.82	0.45	1.91	1.45	-1.49	0.44	2.50	-0.09	0.67	0.01	0.59
	1985-90	3.44	1.56	0.49	1.39	3.54	0.75	0.54	2.25	0.11	0.81	-0.06	0.86
Italy*	**1970-90**	-	-	-	-	**3.09**	**0.37**	**0.91**	**1.81**	-	-	-	-
	1970-75	-	-	-	-	2.81	0.17	1.19	1.45	-	-	-	-
	1975-80	-	-	-	-	4.86	0.81	0.92	3.13	-	-	-	-
	1980-85	-	-	-	-	1.40	0.12	0.76	0.51	-	-	-	-
	1985-90	-	-	-	-	3.27	0.37	0.76	2.13	-	-	-	-
United Kingdom	**1968-90**	**2.13**	**0.08**	**0.62**	**1.43**	**2.16**	**0.18**	**0.68**	**1.30**	**0.03**	**-0.10**	**-0.06**	**-0.13**
	1968-79	1.91	-0.10	0.72	1.29	2.07	-0.16	0.79	1.45	0.17	0.06	-0.07	0.16
	1979-84	0.75	-1.08	0.38	1.45	0.61	-0.92	0.51	1.02	-0.14	-0.16	-0.14	-0.43
	1984-90	3.68	1.37	0.63	1.68	3.59	1.70	0.63	1.26	-0.09	-0.33	0.00	-0.42
Canada	**1971-90**	**3.28**	**1.40**	**1.11**	**0.77**	**3.29**	**1.66**	**1.04**	**0.59**	**0.01**	**-0.25**	**0.06**	**-0.18**
	1971-76	4.68	2.01	1.33	1.34	4.78	2.12	1.26	1.40	0.10	-0.11	0.07	0.06
	1976-81	3.02	1.72	1.33	-0.03	3.08	2.15	1.26	-0.33	0.06	-0.43	0.07	-0.30
	1981-86	2.52	0.30	1.12	1.10	2.46	0.64	1.01	0.81	-0.05	-0.35	0.11	-0.29
	1986-90	2.82	1.64	0.53	0.65	2.72	1.73	0.55	0.45	-0.10	-0.10	-0.01	-0.21
Australia	**1968-89**	**3.73**	**1.45**	**1.22**	**1.05**	**3.76**	**1.42**	**1.11**	**1.22**	**0.03**	**0.03**	**0.11**	**0.17**
	1968-74	4.86	1.72	1.59	1.55	4.84	1.74	1.35	1.75	-0.02	-0.02	0.24	0.20
	1974-86	2.72	1.13	1.04	0.55	2.80	1.06	0.99	0.76	0.08	0.07	0.05	0.21
	1986-89	5.49	2.18	1.23	2.09	5.38	2.23	1.13	2.03	-0.11	-0.06	0.10	-0.06
Denmark	**1972-90**	**1.77**	**-0.15**	**0.71**	**1.21**	**1.91**	**-0.17**	**0.66**	**1.43**	**0.14**	**0.03**	**0.05**	**0.22**
	1972-77	1.11	-0.43	0.82	0.72	1.35	-0.51	0.83	1.03	0.24	0.09	-0.01	0.31
	1977-80	1.58	-0.65	0.60	1.63	1.70	-0.70	0.60	1.79	0.11	0.05	0.00	0.16
	1980-85	2.42	0.24	0.58	1.61	2.43	0.26	0.45	1.72	0.02	-0.03	0.12	0.11
	1985-90	1.90	0.06	0.81	1.03	2.09	0.06	0.73	1.30	0.18	0.01	0.08	0.27
Netherlands	**1972-86**	**2.74**	**-0.13**	**0.99**	**1.88**	**2.80**	**-0.15**	**1.07**	**1.87**	**0.06**	**0.02**	**-0.09**	**0.00**
	1972-77	5.16	-0.22	1.16	4.22	5.24	-0.24	1.26	4.22	0.08	0.02	-0.10	0.00
	1977-81	0.70	0.04	0.99	-0.33	0.63	0.03	1.08	-0.47	-0.08	0.02	-0.09	-0.15
	1981-86	1.93	-0.17	0.82	1.29	2.09	-0.20	0.89	1.40	0.16	0.02	-0.07	0.11
Simple average 10 countries	1970-1990	2.86	0.61	1.07	1.19	2.91	0.56	1.03	1.32	0.05	0.05	0.03	0.13

*) Due to the lack of periodical input-output data, Italian results are shown only in the simple aggregate form which were extracted from the OECD International Sectoral Data Base.

**) Resource allocation effects measure effects of compositional change of GDP, labour and capital among sectors on aggregate TFP growth. If there is no compositional changes during the period, this effects will vanish and both macro and Divisia aggregate TFP estimates will be identical. This indicator will take negative values if sectoral shifts of GDP in a particular period were of increasing shares of high-value added sectors, or labour or capital moves into sectors with lower wages or capital costs relative to their averages. Conversely, the positive values of this measure means structural change was increasing low-value added sectors or primary factors moved into those with higher factor prices.

Annex Table 10. Growth Decomposition Results at a broad Sectotal Level

Per Cent

	1970s						1980s					
	Gross Output Growth	Sources of growth					Gross Output Growth	Sources of growth				
		Domestic Interme-diate	Imported Interme-diate	Labour	Capital	TFP Growth		Domestic Interme-diate	Imported Interme-diate	Labour	Capital	TFP Growth
Total Private Business Sector												
United States	1.86	0.84	0.11	0.58	0.57	-0.25	3.37	1.20	0.20	0.78	0.47	0.72
Japan	4.09	2.01	0.22	0.29	1.10	0.46	4.15	1.98	0.19	0.40	0.81	0.78
Germany	-	-	-	-	-	-	2.60	1.22	0.29	0.17	0.47	0.45
France	2.98	1.34	0.39	0.13	0.51	0.52	2.60	1.09	0.29	0.16	0.23	0.83
United Kingdom	2.28	1.04	0.42	-0.05	0.34	0.54	2.97	1.33	0.39	0.13	0.22	0.90
Canada	3.83	1.57	0.37	0.93	0.66	0.30	2.78	1.09	0.38	0.45	0.44	0.42
Australia	3.14	1.18	0.20	0.66	0.62	0.47	2.99	1.13	0.18	0.69	0.56	0.43
Netherlands	3.93	1.19	1.09	-0.06	0.54	1.17	1.67	0.51	0.41	-0.02	0.45	0.32
Denmark	1.56	0.76	0.18	-0.26	0.37	0.52	2.23	0.92	0.25	0.07	0.33	0.67
Simple Average	2.63	1.10	0.33	0.25	0.52	0.41	2.54	1.05	0.26	0.28	0.40	0.55
Manufacturing Sector												
United States	0.68	0.38	0.15	0.02	0.35	-0.22	3.19	1.21	0.40	0.12	0.19	1.28
Japan	4.03	2.06	0.25	-0.07	0.68	1.11	4.34	2.46	0.21	0.14	0.65	0.88
Germany	-	-	-	-	-	-	2.08	1.20	0.41	0.06	0.12	0.28
France	2.55	0.97	0.55	-0.15	0.24	0.72	1.39	0.62	0.27	-0.55	0.14	0.91
United Kingdom	1.07	0.42	0.60	-0.39	0.23	0.21	1.20	-0.26	0.26	-0.73	0.10	1.83
Canada	3.10	1.37	0.67	0.33	0.26	0.48	2.38	0.82	0.75	0.11	0.25	0.46
Australia	2.02	1.33	0.33	-0.10	0.30	0.17	1.91	0.98	0.23	-0.17	0.22	0.66
Netherlands	3.45	1.25	1.91	-0.44	0.26	0.47	1.56	0.60	0.52	-0.28	0.21	0.51
Denmark	1.92	1.16	0.33	-0.42	0.18	0.67	1.41	0.66	0.42	0.15	0.19	-0.01
Simple Average	2.09	0.99	0.53	-0.14	0.28	0.40	1.95	0.83	0.35	-0.12	0.21	0.68
Private Services Sector												
United States	2.83	1.14	0.09	0.99	0.73	-0.12	3.66	1.35	0.09	1.28	0.67	0.27
Japan	4.52	2.08	0.20	0.86	1.56	-0.18	4.26	1.72	0.18	0.69	0.96	0.71
Germany	-	-	-	-	-	-	3.34	1.37	0.17	0.38	0.86	0.55
France	3.51	1.61	0.23	0.75	0.83	0.09	3.79	1.65	0.28	1.11	0.30	0.44
United Kingdom	3.52	1.69	0.25	0.46	0.51	0.61	4.66	2.84	0.50	0.95	0.35	0.03
Canada	4.87	1.56	0.16	1.54	0.87	0.74	3.15	1.39	0.16	0.86	0.56	0.20
Australia	3.68	1.11	0.14	1.14	0.67	0.63	3.41	1.14	0.15	1.14	0.64	0.34
Netherlands	4.10	1.09	0.53	0.36	0.74	1.39	1.68	0.47	0.34	0.20	0.58	0.09
Denmark	1.25	0.44	0.00	-0.01	0.54	0.29	2.45	1.19	0.17	0.19	0.38	0.52
Simple Average	3.14	1.19	0.18	0.68	0.72	0.38	3.04	1.31	0.20	0.68	0.53	0.31

Note:

1) The figures are expressed as weighted averages of each sub-sector with their production weights. Total includes agriculture and mining as well as manufacturing and services. Services includes public utilities and construction indices.

2) Because of different availabilty of Input-Output data across countries, the measured periods in the 1970s and 1980s are different. For the 1970s, 19: for the US, 1970-80 for Japan, 1972-80 for France, 1968-79 for the UK, 1971-81 for Canada, 1968-86 for Australia, 1972-80 for Denmark, 1972-81 Netherlands. Similarly, we chose for the 1980s as 1982-90 for the US, 1980-90 for Japan, 1978-90 for Germany, 1980-90 for France, 1970-90 for the 1981-90 for Canada, 1974-89 for Australia, 1980-90 for Denmark, 1977-86 for Netherlands.

Annex Table 11. TFP and R&D Regression: Manufacturing Sector

Unweighted regressions

Right hand variables (estimated coefficients and t-statistics in parenthesis)

	RD		RTL		RTA		RTI		RTC		RDA		RMA		RDT		Adj.
Eq.	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	R2
(1)																	0.13
(2)	0.17	0.15															0.21
	(3.10)	(3.40)															
(3)			0.15	0.13													0.21
			(3.17)	(3.29)													
(4)	0.14	0.17			0.29	-0.16											0.21
	(2.01)	(2.94)			(0.74)	-(0.56)											
(5)													0.04	0.09	0.16	0.13	0.20
													(0.08)	(0.26)	(2.62)	(2.43)	
(6)	0.13	0.17									1.05	-0.87	0.00	0.12			0.21
	(1.94)	(2.92)									(1.28)	-(1.49)	-(0.01)	(0.34)			
(7)	0.14	0.17					0.28	-0.15	-2.08	-0.80							0.20
	(2.10)	(2.94)					(0.70)	-(0.53)	-(0.75)	-(0.36)							

Weighted regressions with average sectoral shares of gross output

Right hand variables (estimated coefficients and t-statistics in parenthesis)

	RD		RTL		RTA		RTI		RTC		RDA		RMA		RDT		Adj.
Eq.	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S	R2
(1)																	0.27
(2)	0.12	0.14															0.31
	(2.33)	(3.37)															
(3)			0.11	0.12													0.31
			(2.39)	(3.34)													
(4)	0.09	0.14			0.24	0.00											0.31
	(1.38)	(2.53)			(0.61)	(0.01)											
(5)													0.20	0.12	0.10	0.12	0.31
													(0.44)	(0.37)	(1.72)	(2.44)	
(6)	0.09	0.14									0.42	-0.45	0.19	0.13			0.30
	(1.31)	(2.59)									(0.45)	-(0.72)	(0.43)	(0.42)			
(7)	0.10	0.14					0.25	0.00	-2.65	0.09							0.31
	(1.53)	(2.50)					(0.64)	(0.00)	-(1.07)	(0.04)							

1. Dependent variable is the average annual TFP growth in each period.
2. All regression models include country-specific dummies in both period. Therefore, the coefficients in each explanatory variables tend to explain resulting variance across the industries and countries in a period.
3. All the explanatory variables are in terms of the R&D amount per unit of gross output, ie, intensities. Abbrebiation for each variable are: RD= direct R&D, RTL=total (direct plus acquited) R&D , TRA=total acquired R&D, RTI=R&D embodied in purcahsed intermediate inputs, RTC=R&D embodied in purchased investment goods, RDA=domestically acquired R&D, RMA = acquired R&D through imports and RDT =direct R&D plus domestically acquired R&D.

Annex Table 12. **TFP and R&D Regression: Services Sector**

Unweighted regressions

	Right hand variables (estimated coefficients and t-statistics in parenthesis)									
	RTA		RTI		RTC		RDA		RMA	
Equation	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S
(1)										
(2)	1.34 (2.81)	1.91 (3.50)								
(3)					1.67 (3.35)	2.51 (4.31)				
(4)							0.69 (1.15)	1.22 (1.64)	4.22 (2.39)	3.64 (2.59)
(5)			-0.90 -(0.67)	-0.41 -(0.37)	1.69 (3.36)	2.50 (4.26)				

Weighted regressions with average sectoral shares of gross output

	Right hand variables (estimated coefficients and t-statistics in parenthesis)									
	RTA		RTI		RTC		RDA		RMA	
Equation	70S	80S	70S	80S	70S	80S	70S	80S	70S	80S
(1)										
(2)	0.40 (0.71)	1.32 (2.30)								
(3)					1.07 (1.62)	2.29 (3.32)				
(4)							-0.25 -(0.33)	0.34 (0.41)	2.90 (1.45)	3.46 (2.39)
(5)			-1.37 -(1.28)	-0.40 -(0.44)	1.14 (1.71)	2.28 (3.31)				

1. Dependent variable is the average annual TFP growth in each period.
2. All regression models include country-specific dummies in both period. Therefore, the coefficients each explanatory variables tend to explain resulting variance across the industries and countries in a p
3. All the explanatory variables are in terms of the R&D amount per unit of gross output, ie, intensitie Abbrebiation for each variable are: RD= direct R&D, RTA=total acquired R&D, RTI=R&D embodiec purcahsed intermediate inputs, RTC=R&D embodied in purchased investment goods, RDA=domestic: acquired R&D, RMA = acquired R&D through imports and RDT =direct R&D plus domestically acq R&D.

Annex Table 13. **TFP and R&D: Regressions by group of industries (unweighted OLS regression)**

Industry groups	Regression 1			Regression 2			Regression 3		
		1970s	1980s		1970s	1980s		1970s	1980s
Primary sector	Embodied R&D	-0.39	2.52						
(Agriculture,		(-0.34)	(2.99)						
Mining)				Domestic	0.50	-1.07	Capital	-10.57	10.32
					(0.28)	(-0.79)		(-2.34)	(2.55)
				Imported	-2.67	17.56	Intermediate	7.01	-2.51
					(-0.59)	(4.57)		(1.91)	(-0.98)
Light Manufacturing	Direct R&D	-1.36	-0.40	Direct R&D	-1.81	-0.44	Direct R&D	-1.41	-0.36
(Food,		(-1.19)	(-0.40)		(-1.48)	(-0.45)		(-1.24)	(-0.36)
Textiles,	Embodied R&D	2.00	0.67						
Wood,		(1.59)	(0.73)						
Other manufacturing)				Domestic	3.46	0.93	Capital	0.50	2.27
					(1.67)	(0.70)		(0.06)	(0.31)
				Imported	0.16	0.42	Intermediate	1.87	0.23
					(0.06)	(0.21)		(1.02)	(0.14)
Heavy Manufacturing	Direct R&D	-0.37	0.18	Direct R&D	-0.39	0.15	Direct R&D	-0.36	0.18
(Paper & pulp,		(-1.17)	(0.67)		(-1.21)	(0.54)		(-1.16)	(0.65)
Chemicals,	Embodied R&D	0.60	0.68						
Stone, clay & glass,		(0.57)	(0.81)						
Basic metals)				Domestic	0.51	1.12	Capital	0.97	0.76
					(0.31)	(0.82)		(0.23)	(0.22)
				Imported	1.15	0.61	Intermediate	0.04	0.57
					(0.65)	(0.45)		(0.02)	(0.41)
Machinery sector	Direct R&D	0.26	0.21	Direct R&D	0.24	0.19	Direct R&D	0.27	0.21
(General machinery,		(2.20)	(2.00)		(1.95)	(1.85)		(2.25)	(2.00)
Electrical machinery,	Embodied R&D	-0.27	-0.10						
Instruments,		(-0.50)	(-0.26)						
Transport machinery,				Domestic	0.18	-0.10	Capital	-2.74	-1.76
Metal products)					(0.18)	(-0.13)		(-0.48)	(-0.46)
				Imported	-0.38	0.06	Intermediate	-0.25	0.03
					(-0.56)	(0.11)		(-0.37)	(0.06)
Utility Services	Embodied R&D	-0.86	-0.74						
(Electricity, gas & water,		(-1.08)	(-1.05)						
Construction)				Domestic	-1.19	-0.28	Capital	-0.70	-1.43
					(-1.04)	(-0.27)		(-0.55)	(-1.16)
				Imported	0.95	-2.28	Intermediate	-1.59	-0.27
					(0.37)	(-0.90)		(-1.10)	(-0.23)
ICT Services	Embodied R&D	1.40	1.48						
(Transport,		(3.14)	(3.26)						
Communication,				Domestic	0.71	1.02	Capital	2.49	2.36
Finance & insurance,					(1.18)	(1.46)		(3.26)	(2.79)
Real estate & busin. serv.)				Imported	4.92	2.93	Intermediate	-3.53	-1.38
					(2.77)	(2.24)		(-1.20)	(-0.57)
Other services	Embodied R&D	-0.40	-0.55						
(Trade,		(-0.47)	(-0.69)						
Hotels & restaurants,				Domestic	-0.03	-0.37	Capital	-1.60	3.73
CSPS)					(-0.02)	(-0.30)		(-0.86)	(1.52)
				Imported	-1.47	-1.00	Intermediate	0.49	-4.77
					(-0.31)	(-0.34)		(0.21)	(-2.01)
Adj. R2	0.10			0.14			0.12		
Sample size	384			384			384		

Note: Not reported in the table, each regression includes country-specific time dummies for each period.

Annex Table 14 **Revealed comparative advantage in manufacturing exports (1)**

		High techn.	Medium techn.	Low techn.	High wage	Medium wage	Low wage	Resource intensive	Labour intensive	Scale intensive	Specialised supplier	Science based
United States	1970	159	110	64	136	95	64	77	48	89	123	206
	1992	151	90	74	118	95	82	88	62	82	110	178
Canada	1970	55	124	92	129	101	64	140	26	145	50	64
	1992	55	117	113	123	93	75	153	33	150	50	52
Japan	1970	124	78	114	64	122	102	40	139	123	105	66
	1992	144	114	46	108	121	55	21	52	115	156	102
Austria	1970	70	73	142	33	118	146	104	173	91	99	27
	1992	71	97	127	63	128	111	90	148	100	116	45
Belgium	1970	44	95	128	86	106	105	130	133	119	52	27
	1992	40	116	127	107	76	130	141	160	122	46	37
Denmark	1970	73	62	151	43	78	208	234	88	49	97	65
	1992	73	59	181	49	97	188	247	105	54	87	78
Finland	1970	20	36	200	17	143	118	134	68	152	44	5
	1992	54	60	194	48	168	71	114	57	146	81	33
France	1970	86	94	110	103	87	119	103	116	106	79	89
	1992	93	96	112	107	85	114	120	98	106	76	104
Germany (2)	1970	97	125	76	115	107	70	57	95	109	132	84
	1992	82	119	85	104	104	84	71	95	113	112	76
Greece	1970	15	60	177	47	87	188	227	154	93	10	10
	1992	17	32	263	32	60	277	285	320	37	20	10
Ireland	1970	72	22	192	31	42	287	303	150	25	26	90
	1992	158	58	115	110	62	151	186	65	59	69	198
Italy	1970	78	99	111	92	88	135	86	195	70	117	72
	1992	61	92	142	56	106	161	92	247	69	107	54
Netherlands	1970	98	63	139	103	70	153	193	101	76	72	72
	1992	79	78	147	99	79	136	202	91	87	63	88
Portugal	1970	46	37	189	40	48	268	199	268	46	34	26
	1992	48	40	227	42	62	259	137	372	55	60	16
Spain	1970	37	63	166	61	78	189	208	143	76	56	25
	1992	56	110	122	116	84	101	126	101	132	63	49
Sweden	1970	74	84	129	66	140	67	74	59	136	109	56
	1992	84	89	126	82	137	64	87	60	120	107	77
United Kingdom	1970	105	117	82	109	98	96	87	123	89	112	114
	1992	123	95	86	113	93	89	93	95	89	94	146

1. Revealed comparative advantage (RCA) for a particular industry (or industry grouping) is defined as the ratio of the share of the country's exports in that industry in its total manufacturing exports to the share of total exports by that industry (or industry grouping) in OECD manufacturing exports. With exports denoted by X, for a country k, the RCA of an industry i is given by $100 [X(i,k) / X(+,k)] / [X(i,+) / X(+,+)]$.

2. Figures for Germany up to and including 1990 refer to the western part of Germany only; from 1991 onwards they refer to the whole of Germany.

Source: OECD, STAN database (DSTI, EAS Division).

Table 11. Intra industry trade in the G 7 countries by product group

SITC section		0 Food	1 Beverages	2 Raw materials	3 Mineral fuels	4 Oils and fats	5 Chemicals	6 Manuf. goods	7 Mach./ transport	8 Miscall. manuf.	9 Other n.e.c
United States	1970	22.9	19.1	41.5	18.8	19	52.7	60.2	46.9	41.3	60.5
	1980	24.9	26.4	38.8	6.4	15.7	63.7	62.1	56.8	50	63.2
	1990	50.6	24.7	56.2	16.8	67.5	74.3	62.1	71	45.6	80.9
Japan	1970	14.8	25.9	2.8	2.5	42.7	56.2	19.4	30.2	43.3	62.3
	1980	11.5	6.5	4.3	0.9	54.7	63.9	24.1	16.8	46.5	77
	1990	9.5	9.4	6.8	4.3	40	66.3	43.1	27.1	42.5	71.8
Germany	1970	31.2	36.7	29.1	27.6	52.7	58.5	69.6	49.5	63.3	76.3
	1980	46.5	51.8	35.4	22.6	59.5	69.3	76.4	54.9	68.5	75.6
	1990	58.5	57.4	43	28.2	68.8	74.5	80.6	65.8	70.6	82.4
France	1970	46.5	61.7	46.7	20.9	47.5	80.8	72.5	75.9	77.2	3.7
	1980	49.5	35.4	52.8	22.8	66.1	72.8	80	76.3	82.6	26.7
	1990	59.7	30.2	53.3	25.9	75.3	72	83.4	83.4	77.3	92.2
United Kingdom	1970	18.8	38.3	21.8	31.7	16.9	66.1	62.1	56.4	76.7	58.4
	1980	39.8	53.4	33.7	94.2	42.9	71.4	79.4	72.8	82.5	64
	1990	46	69.5	33.7	83.5	39.8	76.4	76.4	83.3	77.1	77.6
Italy	1970	23.1	47.4	20.5	6.3	29.5	78.1	53.7	70.9	32.8	78.7
	1980	23.9	43.1	21.5	27.1	42.6	81.3	58.5	70.3	34.8	60.1
	1990	36.5	45.6	25	30.6	62.2	70.7	64.1	69.3	39.9	63.9
Canada	1970	29.7	43.4	24.8	57.8	41.5	39.4	35.4	63.3	46.2	40.3
	1980	28	82.2	33.7	45.2	18.5	36.1	40.3	67	47.4	35.5
	1990	39.4	90.9	31.8	72.5	51.2	54.7	51.7	67.9	44.9	88.7

Source: OECD, NEXT database; EAS Division.

Annex Table 16. **Factors affecting competitiveness in high, medium and low R&D sectors, 1985**

Equation 3.1

$$S = -0.14 + \underset{(3.77)}{}\ 0.32\ RD^{H} + 0.16\ SIZE^{H} - 0.39\ INV^{H} + 0.17\ SIZE^{M} + 0.24\ INV^{M} + 0.33\ INV^{L}$$

(3.77) (3.19) (3.09) (2.20) (2.99) (1.49) (2.65)

$\bar{R}^2$ = 0.18
n = 183

Equation 3.2

$$S = -0.13 + 0.34\ RD^{H} + 0.17\ SIZE^{H} - 0.43\ INV^{H} + 0.18\ SIZE^{M} + 0.28\ INV^{M} + 0.32\ INV^{L}$$

(3.20) (3.37) (3.21) (2.33) (3.11) (1.61) (2.51)

$$-0.18\ RD^{LARGE} - 0.04\ INV^{LARGE}$$

(1.18) (0.15)

$\bar{R}^2$ = 0.18
n = 183

Note: For definition of variables, see text. The dependent variable is a normalized version of Balassa's revealed comparative advantage indicy (see text). The independent variables are expressed relative to the within industry mean. All variables are in log-forms. H, M, L refers to high, medium and low R&D intensity. Large refers to United States and Japan.

$\bar{R}^2$ is R^2 adjusted for degrees of freedom.

Annex Table 17. Factors affecting competitiveness, industry level, 1985

Industry	Direct R & D	Domestic spillovers	Foreign spillovers	Investment	Market size	Wage	$\bar{R}^2$	n
1. Aerospace	1.13 (3.41)*			-1.80 (2.64)*			0.82	8
2. Office machinery & computers	0.43 (9.01)*	0.33 (4.04)*		0.17 (1.24)	-0.13 (1.98)***	-0.25 (1.50)	0.95	10
3. Drugs				1.19 (1.96)**		1.13 (1.27)	0.22	9
4. Communications & semiconductors	-0.90 (3.13)*				0.16 (2.00)**	1.00 (1.97)**	0.66	10
5. Instruments		0.41 (9.73)*			0.08 (3.03)**	-0.24 (2.02)***:	0.96	7
6. Electrical Machinery	0.42 (2.80)*		-0.24 (2.20)**				0.47	10
7. Motor vehicles	-0.38 (2.40)**			0.64 (1.15)	0.48 (4.03)*		0.67	10
8. Industrial chemicals	0.32 (1.91)***	-0.58 (2.06)**			0.17 (1.38)	0.59 (1.29)	0.35	10
9. Non electrical machinery			0.70 (2.12)**	0.57 (2.30)**	0.84 (2.73)*	-1.37 (1.62)***	0.51	10
10. Stone, clay & glas				0.91 (2.20)**	0.21 (2.12)**		0.31	10
11. Rubber & plastic products	0.48 (1.67)***	-0.84 (1.75)***	0.27 (1.18)		0.51 (1.95)***		0.22	10
12. Non ferrous metals	-0.19 (1.13)		-1.29 (2.06)***	-0.51 (1.38)	-0.0-9 (1.06)	.1.62 (2.03)***	0.20	10
13. Fabricated metal products	0.20 (1.26)	-0.25 (1.51)	.0.17 (1.48)	0.31 (1.52)	0.27 (1.77)***	-0.62 (1.08)	0.55	10
14. Ferrous metals	0.33 (1.36)	-1.17 (3.09)*			0.22 (2.66)*	-0.66 (1.72)***	0.56	10
15. Shipbuilding		-0.38 .(1.57)***	-0.31 (2.22)***	-0.45 (1.52)***		-1.26 (2.11)**	0.66	10
16. Food, drink & tobacco			0.55 (3.79)*			1.09 (2.37)*	0.72	10
17. Paper & printing		-0.56 (2.85)*	1.06 (4.18)*	1.50 (2.40)**	0.80 (4.20)*		0.67	10
18. Textiles, footwear & leather	0.24 (1.14)		-0.43 (1.88)***	-3.09 (2.67)*		1.28 (1.59)***	0.57	10
19. Wood, cork & furniture	0.39 (2.00)***	-1.012 (2.72)**	0.67 (3.11)*	0.61 (1.41)	0.52 (2.65)**		0.71	10

Note: For definition of variables, see text. The dependent variable is a normalized version of Balassa's revealed comparative advantage index. The independent variables are expressed relative to the within industry mean. Variables are in log forms.

$\bar{R}^2$ is R^2 adjusted for degrees of freedom.

n is number of observations.

* shows significance at test, 5% level, two-tailed test-

** shows significance at test, 10% level, two-tailed test.

*** shows significance at test, 20% level, two-tailed test.

Annex Table 18. **Factors affecting competitiveness, country level, 1985**

Country	Direct R & D	Domestic spillovers	Foreign spillovers	Investment	Market size	Wage	$\bar{R}^2$	n
United States		0.36 (1.45)	-0.20 (2.02)**		1.23 (3.61)*		0.58	19
Netherlands					0.30 (2.18)*	1.82 (2.91)*	0.35	19
Japan			-0.45 (2.17)*	1.03 (1.62)***	0.69 (1.88)*		0.45	19
Italy				0.57 (2.60)*	0.32 (2.11)**	-0.28 (1.28)	0.48	19
United Kingdom	0.33 (3.50)*				0.27 ((1.33)	-1.03 (2.88)*	0.42	19
France	0.24 (2.57)*		-0.31 (3.02)*		1.10 (4.33)*	-0.73 (2.94)*	0.59	19
Denmark	0.24 (1.84)**			0.12 (1.77)***	0.35 (2.70)*	1.73 (1.95)**	0.59	19
Germany	0.10 (1.01)			0.25 (1.28)	0.32 (2.12)**		0.12	19
Canada		-0.39 (2.05)**		0.71 (2.33)*	0.84 (2.31)*	1.92 (2.01)**	0.54	19
Australia					0.44 (1.61)*	5.28 (5.96)*	0.70	19

Note: For definition of variables, see text. The dependent variable is a normalized version of Balassa's revealed comparative advantage indicy (see text). The independent variables are expressed relative to the within industry mean. All variables are in log-forms.

$\bar{R}^2$ is R^2 adjusted for degrees of freedom.
n is number of observations.
* shows significance at test, 5% level, two-tailed test-
** shows significance at test, 10% level, two-tailed test.
*** shows significance at test, 20% level, two-tailed test.

Annex Table 19 Possible Concordance between STAN and ISDB Industrial Classification

OECD STAN Database Family*			OECD International Sectoral Database (ISDB)		
No.	ISIC	Industry name	No.	ISIC	Industry name
1	1	Agriculture, forestry & fishery	1	1	Agriculture, forestry & fishery
2	2	Mining	2	2	Mining
3	31	Food, drink & tobacco	3	31	Food, drink & tobacco
4	32	Textiles, foot wear & leather	4	32	Textiles, foot wear & leather
5	33	Wood, cork & furniture	5	33	Wood, cork & furniture
6	34	Paper, printing & publishing	6	34	Paper, printing & publishing
7	351+352-3522	Basic chemicals	7	35	Chemicals
8	3522	Pharmaceutical			
9	353+354	Oil and coal products			
10	355+356	Rubber & plastics			
11	36	Stone, clay & glass	8	36	Stone, clay & glass
12	371	Ferrous metals	9	37	Basic metal products
13	372	Non-ferrous metals			
14	381	Fabricated metal products	10	381	Fabricated metal products
15	382-3825	Other non-electrical machinery	11	382	Agricultural and industrial machinery
16	3825	Computers and office equipment			
17	383-3832	Electrical machinery	12	383	Electrical machinery
18	3832	Communication equipment and semiconductors			
19	3841	Shipbuilding	13	384	Transport machinery
20	3842+3844+3849	Other transport equipment			
21	3843	Motor vehicles			
22	3845	Aircraft			
23	385	Instruments	14	385	Instruments
24	39	Other manufacturing	15	39	Other manufacturing
25	4	Electricity, gas & water	16	4	Electricity, gas & water
26	5	Construction	17	5	Construction
27	61+62	Wholesale & retail trade	18	6	Wholesale & retail trade, restaurant & hotels
28	63	Hotels and restaurants			
29	71	Transport & storage	19	7	Transport, storage & communications
30	72	Communications			
31	81+82	Finance & insurance	20	81+82	Finance, insurance & real estate
32	83	Real estate and business services	21	83	Real estate and business services
33	9	Community, social & personal services	22	9	Community, social & personal services

* Data for non-manufacturing sectors are only available in the I-O database and are not covered by other databases (ANBERD, Bilateral Trade and Industrial STAN)

Annex Table 20 Sectoral Availability in Intermediate and Investment Flows Matrix

ISIC Sectors	Australia*		Canada		Denmark		France		Germany		Italy		Japan**		Netherlands		United Kingdom		United States	
	INT	INV	INT	INV	INT	INV	INT	INV	INT	INV	INT	INV	INT	INV	INT	INV	INT	INV	INT	INV
1 Agriculture, forestry and fishing																				
2 Mining & quarrying																				
3 Food drinks & tobacco																				
4 Textiles, footwear & leather																				
5 Wood, cork & furniture		x						x												
6 Paper, print & publishing																				
7 Chemicals		+8, 9				+8, 9, 10			+8	+8				+8						+8
8 Pharmaceuticals		x				x			x	x				x						x
9 Petroleum refining		x				x								x						
10 Rubber & plastic products		x				x								x						
11 Stone, clay & glass		x																		
12 Ferrous metal		+13				+13									+13	+13				
13 Non-ferrous metals		x				x									x	x				
14 Fabricated metal		+15to18,2																		
15 Other non-electrical machinery		x			+16	+16		+23												
16 Computers & office machinery	x	x			x	x		+17, 18						x						
17 Electrical machinery		x				+18		x	+18	+18				+16, 18	+18	+18				
18 Communication & semiconductors	+16	x				x		x	x	x				x	x	x				
19 Shipbuilding		+20,21,22				x		+22	+20	+20				+20,21,22						
20 Other Transport		x			+21, 22	+19, 21to2		+21	x	x				x						
21 Motor vehicles		x			x	x		x						x						
22 Aerospace		x			x	x		x						x						
23 Instruments		x				x		x												
24 Other manufacturing		+5,10,11						+5						+9, 10						
25 Electricity, gas & water																				
26 Construction																				
27 Wholesale & retail trade						+28														+28
28 Hotels & restaurants	x	x				x								x						x
29 Transport & storage		+30																		
30 Communication		x																		
31 Finance & insurance		+32					+32	+32												
32 Real estate & business services		x					x	x												
33 Social & personal services	+28, 34	+28												+28						

INT= Intermediate flow matrix. INV= Investment flow matrix. x = unavailable sector (set to zero)

*) Investment data only available for 1986/87.

**) Complete 36 sectors are available for 1985 and 1990 investment data.

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