National Innovation Systems

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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FOREWORD

Systemic approaches are giving new insight into innovative and economic performance in the OECD countries. Technology-related analysis has traditionally focused on inputs (such as research expenditures) and outputs (such as patents). But the interactions among the actors involved in technology development are as important as investments in research and development. And they are key to translating the inputs into outputs. The study of *national innovation systems* directs attention to the linkages or web of interaction within the overall innovation system.

An understanding of these systems can help policy makers develop approaches for enhancing innovative performance in the *knowledge-based economies* of today. The smooth operation of innovation systems depends on the fluidity of knowledge flows – among enterprises, universities and research institutions. Both *tacit knowledge*, or know-how exchanged through informal channels, and *codified knowledge*, or information codified in publications, patents and other sources, are important. The mechanisms for knowledge flows include joint industry research, public/private sector partnerships, technology diffusion and movement of personnel.

Identifying *best practices* for both the knowledge-based economy and national innovation systems is a focal point of OECD work in the field of science, technology and industry. This publication discusses the first phase of the work on national innovation systems and the attempt to develop indicators to map knowledge flows. Current work is focused on measuring institutional linkages, human resource flows, industrial clusters and innovative firm behaviour. This publication is part of the work of the Committee for Scientific and Technological Policy and is derestricted on the responsibility of the Secretary-General of the OECD.

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SUMMARY

The national innovation systems approach stresses that the **flows of technology and information** among people, enterprises and institutions are key to the innovative process. Innovation and technology development are the result of a complex set of relationships among actors in the system, which includes enterprises, universities and government research institutes. For policy-makers, an understanding of the national innovation system can help identify leverage points for enhancing innovative performance and overall competitiveness. It can assist in pinpointing mismatches within the system, both among institutions and in relation to government policies, which can thwart technology development and innovation. Policies which seek to improve networking among the actors and institutions in the system and which aim at enhancing the innovative capacity of firms, particularly their ability to identify and absorb technologies, are most valuable in this context.

The **measurement and assessment** of national innovation systems has centred on four types of knowledge or information flows: 1) *interactions among enterprises*, primarily joint research activities and other technical collaborations; 2) *interactions among enterprises, universities and public research institutes*, including joint research, co-patenting, co-publications and more informal linkages; 3) *diffusion of knowledge and technology to enterprises*, including industry adoption rates for new technologies and diffusion through machinery and equipment; and 4) *personnel mobility*, focusing on the movement of technical personnel within and between the public and private sectors. Attempts to link these flows to firm performance show that high levels of technical collaboration, technology diffusion and personnel mobility contribute to the improved innovative capacity of enterprises in terms of products, patents and productivity.

There are many different **approaches to analysing national innovation systems**. Firm-level *innovation surveys* question enterprises on their sources of knowledge most relevant to innovation and allow a ranking of different linkages by industrial sector and country. *Cluster analysis* focuses on the interactions between particular types of firms and sectors, which can be

grouped according to their technological and networking characteristics. Patterns of knowledge flows can differ markedly from cluster to cluster and also within countries specialised around different industrial clusters (*e.g.* forestry, chemicals). Innovation systems can also be analysed at *different levels*: sub-regional, national, pan-regional and international. While the national level may be the most relevant due to the role of country-specific interactions in creating a climate for innovation, international technology flows and collaborations are taking on growing significance.

Future research will focus on improving the indicators used to map interactions in national innovation systems as well as the linkages to the innovative performance of firms and countries. These indicators are at an early stage of development and do not approach the robustness of more conventional measures such as R&D expenditures. A main goal is to improve the comparability of studies across countries by encouraging those engaging in analysis of innovation systems to focus first on measuring a core set of knowledge flows using similar indicators. At the same time, specific analyses will be directed to deepening the understanding of certain types of flows in national innovation systems, namely: 1) *human resource flows*; 2) *institutional linkages*; 3) *industrial clusters*; and 4) *innovative firm behaviour*.

INTRODUCTION

A. Definition

Analysis of technology performance and policies has traditionally focused on *inputs* (such as expenditures on research and development and the number of research personnel) and *outputs* (such as patents), the measurement of which is standardized across OECD countries (OECD, 1996*a*). However, the limitations of this approach have become evident over time. While these indicators are important sources of information about the content and direction of technological endeavour, their ability to measure the general "*innovativeness*" of an economy is small. Conventional indicators do not offer convincing explanations of trends in innovation, growth and productivity. And they present a somewhat static snapshot of technology performance which neglects how the various actors in a country interact in the innovation process. Recent theory underlines the significance of the interactions or linkages among the people and institutions involved in technology development in translating the inputs into outputs.

The concept of **national innovation systems** rests on the premise that understanding the linkages among the actors involved in innovation is key to improving technology performance. Innovation and technical progress are the result of a complex set of relationships among actors producing, distributing and applying various kinds of knowledge. The innovative performance of a country depends to a large extent on how these actors relate to each other as elements of a collective system of knowledge creation and use as well as the technologies they use. These actors are primarily private enterprises, universities and public research institutes and the people within them. The linkages can take the form of joint research, personnel exchanges, cross-patenting, purchase of equipment and a variety of other channels. There is no single accepted definition of a national system of innovation. What is important is the web of interaction or the system, as reflected in the definitions given in **Box 1**.

Box 1

National innovation systems: definitions

A national system of innovation has been defined as follows:

- " .. *the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies*." (Freeman, 1987)
- " .. *the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge ... and are either located within or rooted inside the borders of a nation state*." (Lundvall, 1992)
- "*... a set of institutions whose interactions determine the innovative performance ... of national firms*." (Nelson, 1993)
- " .. *the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country*." (Patel and Pavitt, 1994)
- "*.. that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies*." (Metcalfe, 1995)

B. Rationale

The national innovation system approach has taken on increased analytical importance in the technology field due to three factors: 1) the recognition of the economic importance of knowledge; 2) the increasing use of systems approaches; and 3) the growing number of institutions involved in knowledge generation.

The study of national innovation systems focuses on **flows of knowledge**. Analysis is increasingly directed to improving performance in "*knowledge-based economies*" – economies which are directly based on the production, distribution and use of knowledge and information (OECD, 1996*b*). Knowledge, as embodied in human beings (as "*human capital*") and in technology, has always been central to economic development. But only over the last few years has its relative importance been recognised, just as that importance is growing. Economic activities are becoming more and more knowledge-intensive as seen in the growth in high-technology industries and the increasing demand for highly skilled people. Investments in knowledge, such as in research and development, education and training, and innovative work approaches are considered key to economic growth.

The national innovation systems approach reflects the increasing attention given to the economic role of knowledge. Here, the emphasis is on mapping knowledge flows as a complement to measuring knowledge investments. These flows, particularly of knowledge "*codified*" in publications, patents and other sources, are both increasing and becoming easier to detect due largely to information technology. The intent is to evaluate and compare the main channels for knowledge flows at the national level, to identify bottlenecks and to suggest policies and approaches to improve their fluidity. Put simply, this involves tracing the links and relationships among industry, government and academia in the development of science and technology. Such analysis may ultimately lead to the ability to measure the "*knowledge distribution power*" of a national innovation system, which is considered one determinant of growth and competitiveness.

The national innovation systems approach also reflects the rise of **systemic approaches** to the study of technology development as opposed to the "*linear model of innovation*". In the linear model, knowledge flows are modeled quite simply: the initiator of innovation is science and an increase in scientific inputs into the pipeline will directly increase the number of new innovations and technologies flowing out of the downstream end. In reality, however, ideas for innovation can come from many sources and any stage of research, development, marketing and diffusion. Innovation can take many forms, including adaptations of products and incremental improvements to processes.

Innovation is thus the result of a complex interaction between various actors and institutions. Technical change does not occur in a perfectly linear sequence, but through feedback loops within this system. In the centre of this system are the firms, the way they organise production and innovation and the channels by which they gain access to external sources of knowledge. These sources might be other firms, public and private research institutes, universities or transfer institutions – either regional, national or international. Here, the innovative firm is seen as operating within a complex network of co-operating and competing firms and other institutions, building on a range of joint ventures and close linkages with suppliers and customers.

As economic activities become more knowledge-intensive, a large and **growing number of institutions** with specialised expertise of very different kinds are now involved in the production and diffusion of knowledge. The determinants of success of enterprises, and of national economies as a whole, are ever more dependent on their effectiveness in gathering and utilising knowledge from these institutions – whether they be in the private sector, public sector or academia. Moreover, each country has its own institutional profile depending on the governance regime for enterprises, the organisation of the university sector and the level and orientation of government-funded research. There are marked differences in the relative roles and weight of different institutions in national innovation systems, which partly accounts for the focus on the country level.

There are many channels through which knowledge can flow between these institutions and a variety of approaches to measuring these flows. The discussion below focuses on four basic knowledge flows among actors in a national innovation system: 1) *interactions among enterprises*; 2) *interactions among enterprises, universities and public research laboratories*; 3) *diffusion of knowledge and technology to firms;* and 4) *movement of personnel*.

C. Policy relevance

For policy makers, an understanding of the national innovation system can help **identify leverage points** for enhancing innovative performance and overall competitiveness. It can assist in pinpointing mismatches within the system, both among institutions and in relation to government policies, which can thwart technology development and innovation. Countries differ in the way in which knowledge flows are structured and in the relative importance of different types of institutions, actors and linkages for their respective production systems. There is no doubt that there are countries in which institutional interactions occur more easily than in others. A number of framework policies relating to regulations, taxes, financing, competition and intellectual property can ease or block the various types of interactions and knowledge flows. Technological innovation takes place within a specific industrial structure and national context; a better understanding of this context or system will lead to better government technology and innovation policies.

Empirical studies find persistent differences in the long-term performance of countries and markedly different patterns of national technological specialisation. Even among countries that show a broad convergence in macroeconomic performance as do the OECD countries, their technological profiles and innovation capabilities diverge considerably. It is believed that countries tend to develop along certain technological paths or "*trajectories*" determined by past and present patterns of knowledge accumulation. Which path a country takes is determined largely by institutional factors, often specific to a country, including the broad range of interactions which characterise the national innovation system.

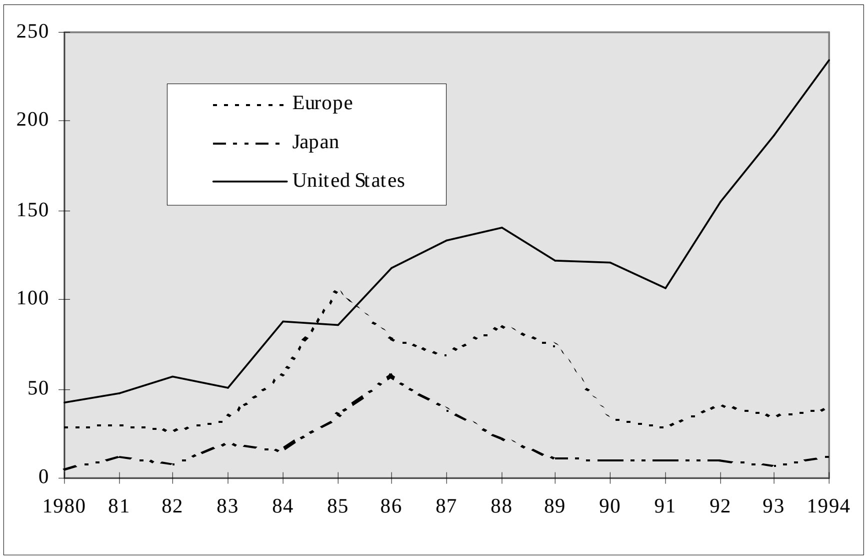
KNOWLEDGE FLOWS IN NATIONAL INNOVATION SYSTEMS

A. Joint industry activities

Since the business sector is the main performer of research and development and source of innovation in OECD economies, one of the most significant knowledge flows in a national innovation system is that stemming from technical collaboration among enterprises as well as their more informal interactions. In most countries, R&D collaborations between firms and strategic technical alliances are growing rapidly. This is especially evident in new fields such as biotechnology and information technologies, where development costs are particularly high. Firms collaborate to pool technical resources, achieve economies of scale and gain synergies from complementary human and technical assets. Also important, but more difficult to measure, are the informal linkages and contacts among firms whereby knowledge and know-how are transferred, including relationships among users and producers and the role of competitors as both a source for and stimulus to innovation.

In studies of national innovation systems, technical collaborations within industry can be mapped using firm surveys as well as **literature-based surveys**. An example of the latter is "*literature-based alliance counting*", which gathers information on industry alliances through reviews of newspaper and journal articles, specialised books and journals as well as corporate annual reports and industry directories. This method, however, can only give a rough indication of the number and growth of different types of alliances and is biased by reporting, industry structure and practices and other factors. The *Co-operative Agreements and Technology Indicators* (CATI) database developed at the Maastricht Economic Research Institute on Innovation and Technology (MERIT) contains information on nearly 13 000 co-operative agreements involving over 6 000 parent companies. As shown in **Figure 1**, new technical alliances in selected fields are increasing within the innovation system of the United States but appear to be levelling off in Japan as well as at the European regional level. In Japan, more informal co-operation among enterprises may be key to technology development, while the European Union framework programmes may be the primary vehicle for technical co-operation in Europe.

Figure 1. **New industry technology alliances, 1980-94**

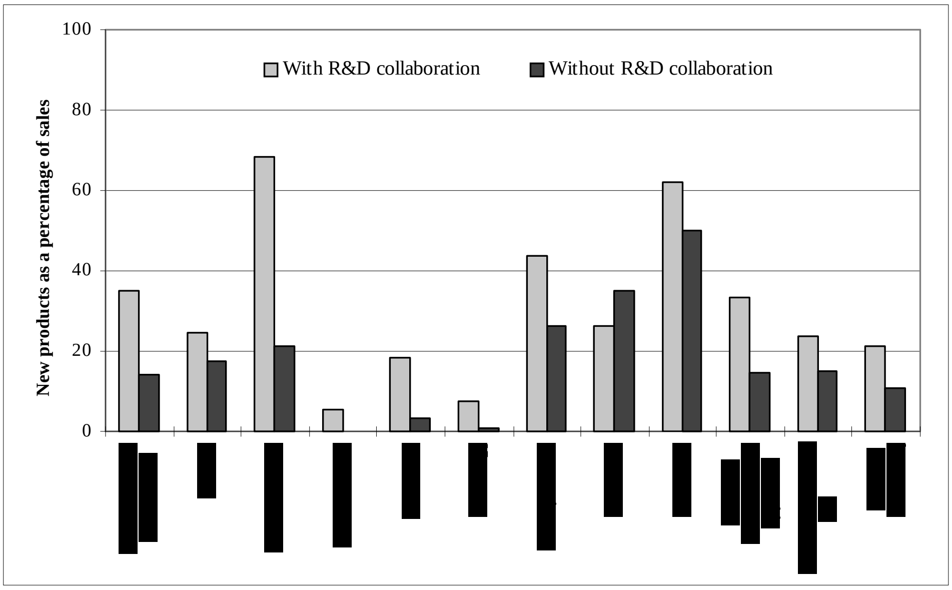


Note: Includes all agreements reported for biotechnology, information technologies and new materials.
Source: Haagedoorn (1994).

Assessments of the **importance of collaborative enterprise activities** in national innovation systems show that such co-operation can contribute to firm innovative performance. Innovation system studies in Norway and Finland indicate that the share of new products in overall sales is higher among firms involved in co-operative ventures, although other factors may have also contributed to this finding (***see* Figure 2)**. Similar studies in Germany find that research co-operation correlates with improved innovative performance in most sectors. Evaluations of co-operative research programmes in the European Union also reveal considerable indirect outcomes in terms of "*behavioural additionality*", *i.e.* an increase in competences and skills that positively influence a firm's innovative capacity, such as networking capabilities and the ability to identify and adapt useful technology. Not revealed in these analyses are the role of the informal contacts among competing firms and those involved in horizontal and vertical relationships. These linkages are also prime contributors to net innovative capacity, but may be more fully captured through cluster analyses, firm surveys and other techniques.

Figure 2. **Research collaboration and product development**

Products changed during the last three years as a share of sales by industry in Norway, 1992



Source: Smith *et al.* (1995).

B. Public/private interactions

Another primary knowledge flow in national innovation systems are **linkages between the public and private research sectors**. On one side, the public component consists primarily of public research institutes and universities. On the other side are private enterprises. The quality of the public research infrastructure and its links to industry may be one of the most important national assets for supporting innovation. Government-supported research institutes and universities are main performers of generic research and produce not only a body of basic knowledge for industry, but are also sources of new methods, instrumentation and valuable skills. Increasingly, the research conducted at these institutions is being supported by enterprises who are collaborating with the public sector in joint technology projects, contracting specific research or financing staff and researchers. In addition to such R&D collaboration, the public research sector serves as an overall repository of scientific and technical knowledge in specific fields. The general ability of industry to access that knowledge is important. This can be through patent data, published information about new scientific discoveries, knowledge embedded in new instruments and methodologies, access to scientific networks and spin-off firms nurtured in technology incubators.

Knowledge flows between the public and private sectors can be measured in a variety of ways, but there are four main techniques that have been used in national innovation surveys:

1. **Joint research activities** – Using the most accessible measure, the number of joint research and technical activities between firms and universities/research institutes can be counted using data published by government funding agencies, universities and other sources. This includes both contract research and financing of university staff to conduct research. As studies of the innovation system in the Netherlands have shown, income from industry contract research at Dutch universities almost doubled in the period 1989-92, indicating the growing level of industry-university linkages (***see*** **Table 1)**.

Table 1**. Industry/University collaboration in the Netherlands**

University income from contract-research, 1989-92,million US$ and percentage

	1989	1990	1991	1992
Income from contract research / education (million US$)	247.7	391.3	444.5	544.7
Income from contract research / education as a percentage of total income (%)	12.2	14.9	16.2	17.4

Note: Figures derived from the annual accounts of a group of 13 leading universities.
Source: den Hertog *et al.* (1995).

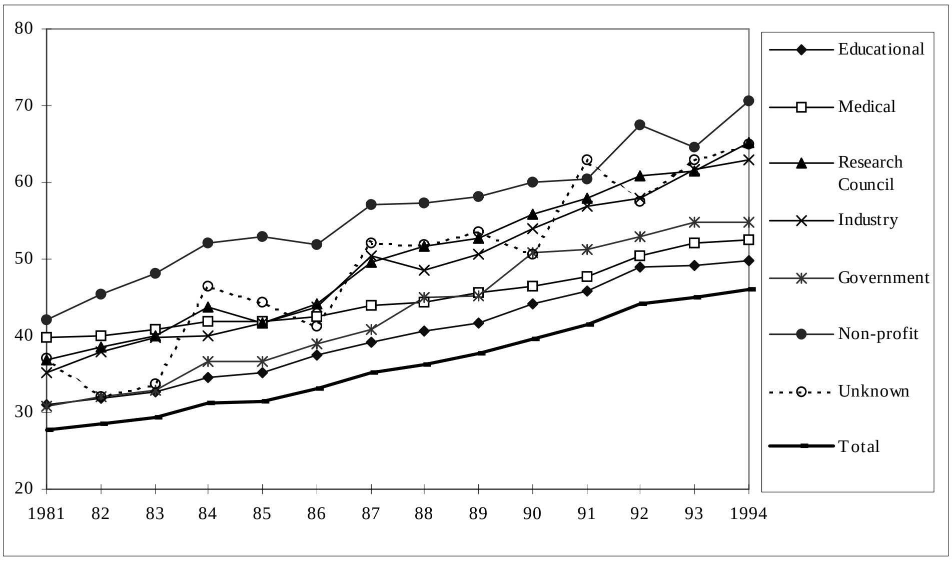
2. **Co-patents and co-publications** – The number of co-patents or co-publications developed by enterprises in collaboration with a university or research institute can be compiled by analysing patent records and publication indices. Computer technology makes it possible to scan published patents and science-based articles to gain an idea of the collaboration between firms and public entities by technical field and over time. For example, analysis of publications of researchers from major science-based companies in the United Kingdom revealed that a large part (a quarter to a third) of these papers were written in collaboration with a university or other publicly funded research institution (Hicks *et al.*, 1993). A related study of the United Kingdom shows the rapid increase in co-publications among the different actors in the UK innovation system (***see*** **Figure 3)**.

3. **Citation analysis** – Since it is the practice of users of technical knowledge and ideas to cite their sources, *citation analysis* can used be to assess the degree to which enterprises draw upon the information contained in either the patents or publications of universities and research institutes. Studies of the United States, for example, show that sectors such as biology, biotechnology and physics rely more heavily on university patents than other industries (***see*** **Table 2)**

4. **Firm surveys** – Surveys of firms reveal the extent to which they consider universities and public research institutes as sources of knowledge useful in their innovative activities. These surveys also capture more informal networking between industry and the public research sector. As would be expected, such surveys reveal that the utility of public knowledge differs greatly by industrial sector. In Europe, the industries ranking public research institutes as important included more science-based sectors such as utilities, pharmaceuticals and aerospace (***see*** **Figure 4**).

Figure 3. **Co-publications in the United Kingdom**

Collaborative papers by sector (%)



Source: Hicks and Katz (1996).

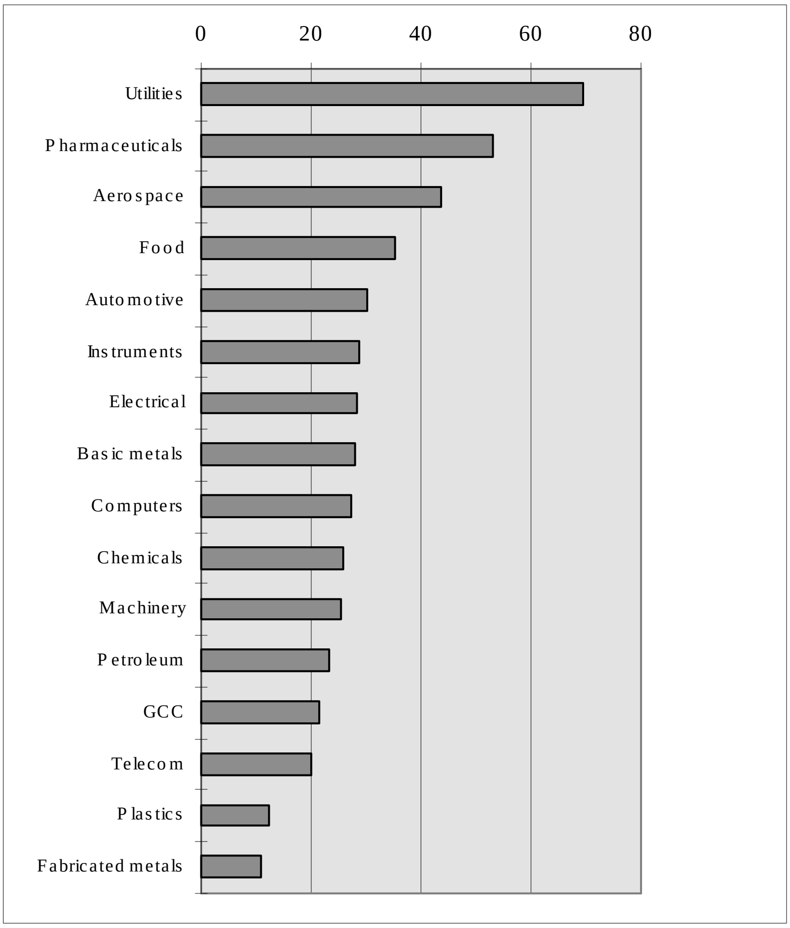
Table 2. **University patents relevant to industry in the United States**

Patent class	Total patents	University patents	University share (%)
Genetic engineering/recombinant DNA	321	58	18.1
Molecular biology and microbiology	1 417	171	12.1
Superconductor technology	233	25	10.7
Drugs: bio-affecting and body-treating	1 490	147	9.9
Robots	251	12	4.8
Semiconductor device manufacturing	755	23	3.0
Active solid state devices (*e.g.* transistors)	1 535	34	2.2
Optics: systems and elements	2 280	41	1.8
Electrical computers and data processing	6 474	53	0.8
Communications	2 026	14	0.7

Source: Rosenberg and Nelson (1994).

Figure 4. **Importance of public research institutes to industry in Europe**

Percentage of respondents rating public research institutes as important



Note: Respondents in the firms were asked to rate the importance of public research institutes on a seven-point scale (where 1 = not important and 7 = very important). The figures indicate the percentage of respondents in each industry rating this source five or higher on that scale.
Source: MERIT (1995).

Studies of national innovation systems to date reveal that the public research sector may be more important as an **indirect source of knowledge** than as a direct source of scientific or technical discovery. This tends to vary by sector and is less true for science-based industries and sectors such as construction and energy, where there may be direct flows from scientific discovery to technological development. However, for the most part, direct linkages are limited due to time-lags between basic research and innovation, the considerable adaptation efforts required on the part of industry and the multiple sources of technological innovation.

In contrast, indirect spillovers from public research to the private sector – through general access to the knowledge base and technical networks – are considerable for many sectors. There is also a significant *localisation effect*, whereby the knowledge flows from the public sector to industry may be most important in a specific locale or region. The study of more localised or regional innovation systems is a complement to the study of knowledge flows at the national level. There is a notable trend towards the creation of specialised **knowledge centres** near leading universities and oriented towards research and development on particular technologies, *e.g.* computer software, biotechnology, communications. High-technology companies, both domestic and foreign, and research institutes tend to gather in these locales to gain access to formal and informal technical networks. In the United States, examples include Silicon Valley in California (near Stanford Univesity and the University of California), a biotechnology cluster in the Boston area (near the Massachusetts Institute of Technology) and a communications cluster in New Jersey (near Princeton University and the former Bell Laboratories).

The relative importance of the public research sector as a source of knowledge for industry also **differs considerably on a national basis** due to the varying importance of these institutions in the national setting. Public research institutes and laboratories are more important in some countries, *e.g.* in Europe, than in others as developers and diffusers of applied technologies which are useful to industry. In the United States, universities often form a core around which technology-based firms and research institutes gather in more informal localised innovation centres. Through innovation systems studies, some countries have identified institutional mismatches which could be impeding knowledge flows. For example, Austria noted the marginal position of its research institutes, which are oriented disproportionately towards the public sector and not of significant practical use to the enterprise sector. Although universities in the Netherlands received high ratings as R&D partners, their direct impact on industrial innovation was deemed by enterprises to be limited. One remedy has been tried by countries such as Germany and the Netherlands which have established specific *bridging institutions* to link public R&D institutions more closely to industry.

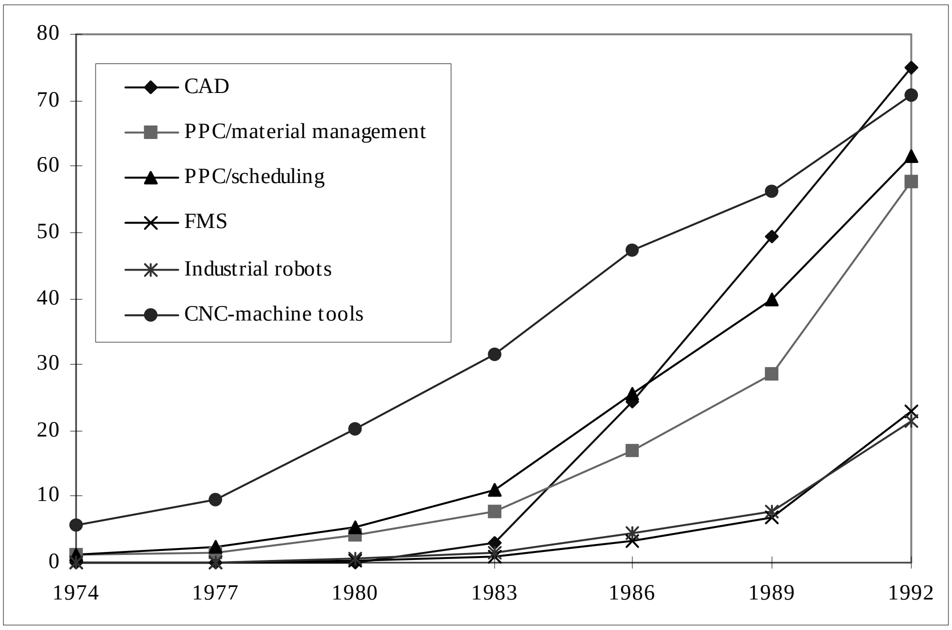
C. Technology diffusion

The most traditional type of knowledge flow in the innovation system may be the dissemination of technology as new equipment and machinery. Typically, the diffusion of innovations is a slow-moving process that takes place over years. The adoption rate for technologies varies substantially from one sector to another and according to the national context and a variety of firm-level characteristics. However, the innovative performance of firms increasingly depends on putting technology to work by adopting and using innovations and products developed elsewhere. Knowledge about technologies may come from customers and suppliers as well as competitors and public institutions. Technology diffusion is particularly important for traditional manufacturing sectors and service industries who may not be R&D performers or innovators themselves. For this reason, governments have adopted a variety of schemes and programmes to diffuse technology to industry, from manufacturing extension centres to demonstration projects to technology brokers (OECD, 1997*a*).

Firm surveys have traditionally been used to track the use of different types of technology in industry. Questionnaires ask manufacturing firms about their use of advanced manufacturing technologies or service firms about their use of information technologies. Adoption rates of new technologies can be tracked over time and the use of specific technologies in industry can be measured. For example, firm surveys in Germany show diffusion curves for selected computer-based manufacturing technologies, which after twenty years are used in a large share of enterprises (***see*** **Figure 5)**. Increasingly, surveys are focusing on dissemination of information technology, including computers, communication equipment and semiconductors, among a broad range of manufacturing and service sectors. However, such surveys do not generally reveal the source of the equipment or technology, which limits their usefulness in tracking technology flows among actors within an innovation system.

Figure 5**. Diffusion of computer-integrated manufacturing technologies in Germany**

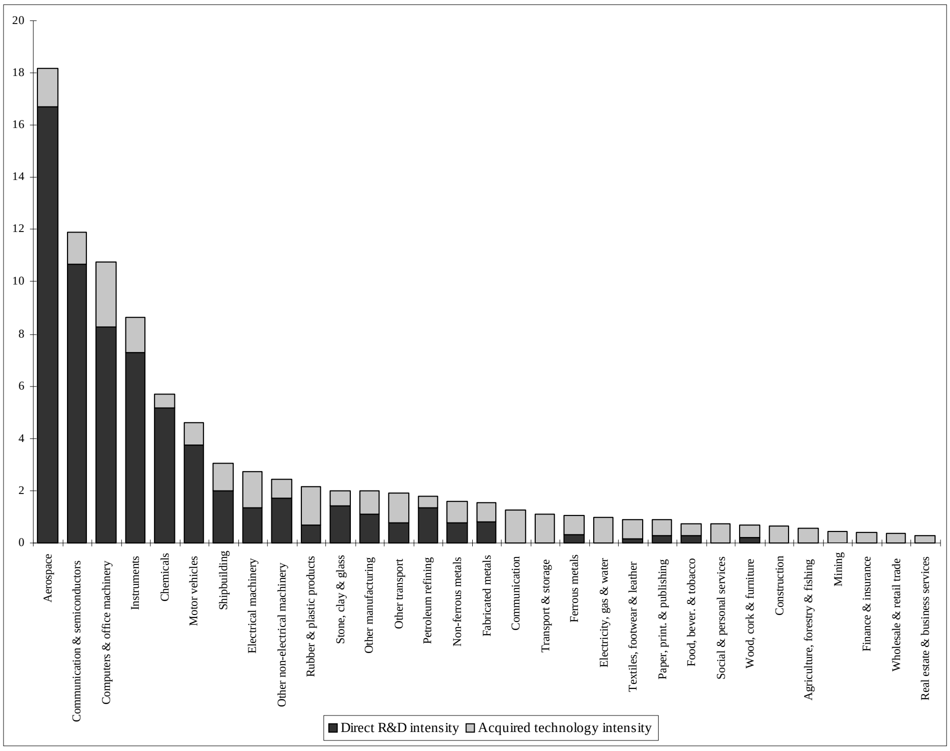
First-user rate, percentage



Source: Dreher (1996).

An approach explored at the OECD measures technology diffusion by tracing interindustry flows of R&D through purchases of machinery and equipment. Such **embodied technology diffusion** is assessed through input-output matrices which track the exchange of goods among industrial sectors having different R&D intensities (R&D expenditures per unit of output). In this way, purchased inputs (both of intermediate and investment goods and from one country to another) act as carriers of technology across sectors. This methodology also allows the separation of: 1) the technology generated by the industry itself through its own R&D; and 2) the technology acquired through purchases of domestic and foreign goods. Profiles of countries can be constructed which indicate the extent to which different sectors are dependent on *acquired technology* obtained through diffusion flows (***see*** **Figure 6**). Comparative analysis indicates that some countries are better able to diffuse technology across industrial sectors (OECD, 1996*c*).

Figure 6**. Embodied technology flows in the United States, 1993**



Source: OECD (1996*c*).

Most studies show that technology diffusion at a broad level has **positive impacts on productivity** in industry. The dissemination of technology is also shown to be as important as R&D investments to innovative performance in many cases. For example, technology diffusion was found to have a greater impact on productivity growth in Japan than direct R&D expenditures in the period 1970-93. The intense use of advanced machinery and equipment in production contributed even more to the improvement of the technology intensity of Japan's economy than did research spending (OECD, 1996*c*). This underlines that a narrow focus on stimulating research spending or a preoccupation with technology-intensive sectors may lead to the neglect of promoting technology diffusion, which is essential to the evolution of the overall national innovation system.

Surveys of technology diffusion have sought to identify **barriers to the adoption of technologies** by firms. Among the main factors identified for the failure to take up technology are lack of information, lack of financing and lack of technical expertise. More in-depth research shows that general organisational and managerial deficiencies are also at fault. Firms need a broad range of skills of the appropriate kind and mix if the adoption of technology is to be successful. The most innovative firms are those with the ability to access outside knowledge and to link into knowledge networks, including informal contacts, user-supplier relations and technical co-operation; they also need the ability to adapt the technology and knowledge to their own needs. The process of innovation, through which technologies are created and used, is more and more a collective endeavour, shaped by institutional and knowledge-sharing systems.

D. Personnel mobility

The movement of people and the knowledge they carry with them (often termed "*tacit knowledge*") is a key flow in national innovation systems. Personal interactions, whether on a formal or informal basis, are an important channel of knowledge transfer within industry and between the public and private sectors. Sometimes, it is not so much the specific knowledge transferred which is important, but rather the general approach to innovation and competence to solve problems. The ability to locate and identify information and to access networks of researchers and personnel is a valuable knowledge asset. In most studies of technology diffusion, it is shown that the skills and networking capabilities of personnel are key to implementing and adapting new technology. Investments in advanced technology must be matched by this "*adoption capability*" which is largely determined by the qualifications, overall tacit knowledge and mobility of the labour force.

Different approaches have been taken to measuring personnel mobility. The most promising technique has been the use of **labour market statistics** to track the movement of personnel categorised by skill level between industrial sectors and between industry and universities/research institutes. The Nordic countries have carried out a number of studies on the mobility of people in national innovation systems. In Norway, data on the number of researchers moving in and out of research institutes (from or to universities, other research institutes or industry) are being compiled (***see*** **Table 3)**. In 1992, the outward mobility from Norwegian research institutes was about 6 per cent of the total employed, a decline from an 8 per cent mobility rate in 1991. The recruitment rate in 1992 was 11 per cent reflected in a net growth of the number of researchers. In Sweden, labour market data are being used to track the mobility of Ph.D scientists and engineers through time and across public institutions, universities and different industrial sectors (***see*** **Figure 7**).

Table 3**. Mobility of researchers in Norway**

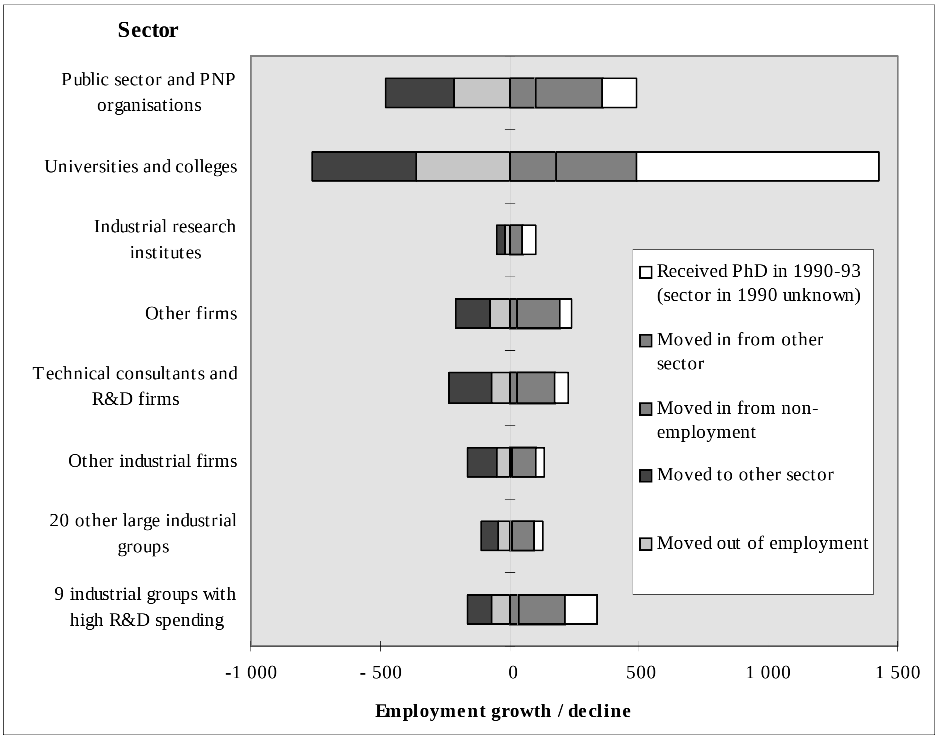
Number of job shifts recorded, 1992

	To research institutes	From research institutes
Higher education candidates	173	--
Higher education researchers	104	83
Other research institutes	41	29
Abroad	20	19
Public sector	49	33
Business sector	71	95

Source: Smith *et al.* (1995).

Figure 7**. Mobility of scientists in Sweden**

Inflows and outflows of S&E PhDs by sector, 1990-93



Source: Stenberg *et al.* (1996).

The Nordic studies show that a high level of mobility of qualified personnel contributes to the overall skill level of the labour force as well as to the **innovative performance** of the economy. In terms of flows, the highest movement is found among graduates from universities to industry and to research institutes, as would be expected. There is a lower mobility rate of university researchers and research institute personnel to industry. In addition, a majority of researchers entering the business sector did not continue their research work, but switched to other activities within the firm. Movement of personnel from research institutes to universities is moderate as is the mobility rate of technical personnel within industry itself. While personnel mobility is an important indicator of the fluidity of knowledge flows in innovation systems, also to be considered are more informal networks among researchers (professional associations, conferences, etc.) but these are far more difficult to measure.

ANALYTICAL APPROACHES TO NATIONAL INNOVATION SYSTEMS

A. Innovation surveys

A more comprehensive approach to mapping national innovation systems is contained in firm-level innovation surveys, which question firms on their sources of knowledge relevant to innovation. These surveys also gather data on firm R&D expenditures and other innovation inputs as well as R&D-related performance and other innovation outputs. From the national innovation systems perspective, they are the most broad-based source of information on the general patterns of technological collaboration and information use of firms. These data provide a rich source of qualitative information about the interactions of various actors in innovation systems from the firm perspective, including inter-industry activities, alliances with the public sector and personnel movements.

Two innovation surveys are most well-known: the *Community Innovation Survey* (CIS) and the *Policies, Appropriability and Competitiveness for European Enterprises* (PACE) Project. The **Community Innovation Survey** was developed between 1991 and 1993 as a joint initiative between DG XIII of the European Commission and EUROSTAT and collected firm-level data for 40 000 manufacturing enterprises in Europe. This was the first harmonized survey on innovation and it covered the following main topics: expenditure on activities related to product innovation; outputs and sales of new or improved products; sources of information relevant to innovation; technology transfer and acquisition; R&D performance and technological collaboration; and perceptions of factors promoting or hampering innovation. A second CIS survey, building on the methodological and analytical lessons learned in the first phase, is being launched in 1997. In addition, the OECD and EUROSTAT are working towards the standardization of innovation surveys across countries through revisions to the *Oslo Manual. Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*, first published in 1992 (OECD, 1997*b*).

Regarding knowledge flows, no comprehensive analysis of the results of the first CIS survey has been made; rather, studies have been done for specific countries and industrial sectors using CIS data. The CIS survey asked firms to rank the importance of thirteen different **sources of information** relevant to innovation, which can be grouped into: 1) information sources within the firm or its group; 2) market sources such as suppliers, customers and consultants; 3) public research sources including universities and government laboratories; and 4) generally available information sources, such as patents, conferences or meetings. The results for two sectors, computers and chemicals, were very similar. For the European computer and office machinery sector, the key information sources for firms are their own knowledge resources and their customers (Malerba *et al.*, 1996). A second group of innovation sources are the firms' competitors and generally available information (***see*** **Table 4)**. With regard to the European chemicals industry, important information for innovation is derived from internal sources, primarily basic research, and clients and customers. For both computers and chemicals, the least important source of information are public research institutes, including government laboratories; universities rank only slightly higher (Albach *et al.*, 1996). This points to the importance of user-producer relationships in the innovative process and the lesser links between industry and the government research infrastructure.

Table 4. **Sources of information in the European computer sector**

Ranking of information sources using CIS data

	Overall weight
Internal sources	
Intra-firm	69.3
Intra-group	28.4
Market sources	
Clients and customers	70.1
Competitors	43.6
Suppliers (materials and components)	37.2
Suppliers (equipment)	23.8
Consultants	7.5
Education and research	
Universities	9.9
Technical institutes	6.7
Government laboratories	4.8
Generally available information	
Fairs, exhibitions	46.7
Conferences, meetings, journals	45.2
Patent disclosure	10.7
Others	4.6

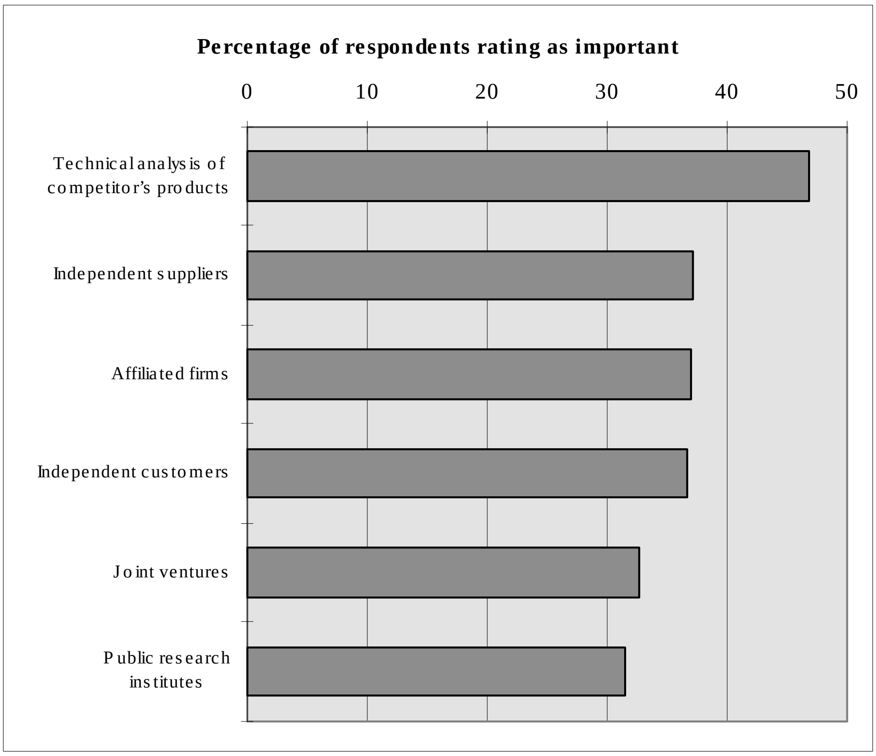
Source: Malerba *et al.* (1996).

The PACE Survey was designed to study the opinions of R&D managers from the European Union's largest manufacturing firms concerning the types and goals of innovation, external sources of technical knowledge, public research, methods to protect innovation (*e.g.* patents), government support to innovation and obstacles to profiting from innovation. This survey was funded by the European Commission and implemented by MERIT together with three other European research institutes. Findings show the most important external source of knowledge for firms is the interaction between the firm and its suppliers and customers and the technical analysis of competitors' products (see Figure 8). Joint ventures are valuable sources of knowledge in sectors where R&D projects are expensive and complex. Although the role of public research in national systems of innovation is acknowledged, firms believe they need to further tighten their links with the public research infrastructure.

Innovation surveys have been conducted at the national level in various non-European OECD countries with similar results. For example, a 1994 survey of Australian firms who had undertaken product or process innovation during the previous three years underlined the importance of internal R&D as an innovation source (***see* Table 5)**. However, a high proportion of businesses (30 per cent) ranked this source as not important, reflecting the "*all or nothing*" nature of R&D and the problems faced by small firms. Most firms emphasized their suppliers and customers as the most significant source of ideas and information, highlighting the importance of networking. Government laboratories, private research institutes and higher education institutions were considered relatively unimportant, indicating that insufficient collaboration between business and both public and private sector research agencies is a widespread OECD problem (Sheehan *et al.*, 1995).

Figure 8. **External sources of knowledge for innovation**

Ranking of sources based on PACE survey



Note: Respondents in 16 industries were asked to rate the importance of each source or method of technical knowledge on a seven-point scale (where 1 = not important and 7 = very important). The figures indicate the percentage of respondents rating each source/method five or higher on that scale.
Source: MERIT (1995).

Table 5. **Sources of information for innovation in Australia**

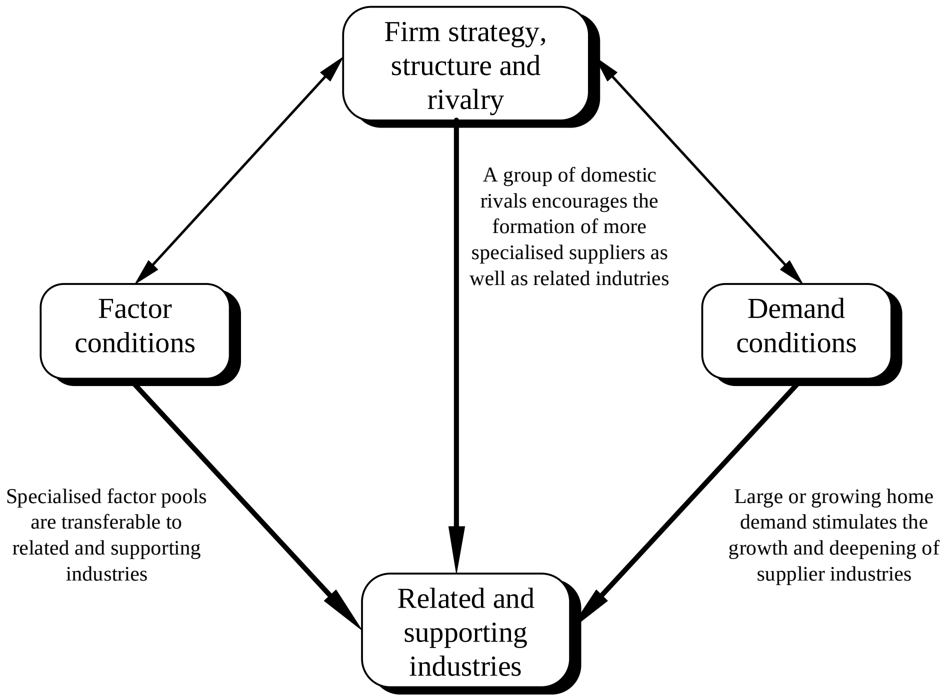
Source	Very significant (%)	Crucial (%)	Composite rating (%)
Internal sources within the business group			
R&D area	21.8	20.1	2.9
Other areas	15.8	4.8	2.4
External market/commercial sources			
Within your industry	24.8	10.3	2.9
Outside your industry	6.0	1.3	1.8
Suppliers of materials and components	15.8	7.2	2.5
Suppliers of equipment	17.0	5.1	2.4
Clients or customers	28.7	19.4	3.3
Consultancy firms	3.7	0.7	1.4
Educational/research institutes			
Higher education institutes	1.1	0.8	1.3
Government laboratories	1.0	0.1	1.2
Private research institutes	1.1	0.6	1.2
Generally available information			
Patent disclosures	1.7	1.5	1.3
Professional conferences and meetings	4.5	0.7	1.7
Professional journals	5.9	1.2	1.8
Fairs/exhibitions	11.8	3.1	2.1

Source: Sheehan *et al.* (1995).

B. Cluster interactions

Countries are increasingly using a "*cluster approach*" to analysing knowledge flows in national innovation systems in recognition of the close interaction between certain types of firms and industries. These interactions may evolve around key technologies, shared knowledge or skills or producer-supplier relationships. Nations, whatever their overall level of innovative performance, do not usually succeed across the whole range of industries, but "*in clusters of industries connected through vertical and horizontal relationships*" (Porter, 1990). According to the "diamond scheme", clusters of related and supporting industries can be created through demand patterns for products, rivalry among firms as well as specialised factors or inputs such as skilled personnel or natural resources (***see* Figure 9)**. Patterns of knowledge flows can differ markedly from cluster to cluster and also within countries specialised around different clusters.

Figure 9. Influences on the development of industry clusters



Source: Porter (1990).

According to the best-known **taxonomy of innovating firms**, clusters can be categorised as: 1) science-based; 2) scale-intensive; 3) supplier-dominated; or 4) specialised suppliers (Pavitt, 1984). Each type has its own characteristics as regards predominant forms of knowledge flows. For the *science-based clusters* (*e.g.* pharmaceuticals, aerospace), direct access to basic research and to public research institutes and universities is important to complement their own research activities. These sectors are highly R&D- and patent-intensive and tend to exhibit closer collaboration with the public research sector. *Scale-intensive clusters* (*e.g.* food-processing, vehicles) tend to establish links with technical institutes and universities without performing much research on their own; their innovative performance depends on their ability to import and build upon science developed elsewhere, particularly with regard to process improvements. *Supplier-dominated clusters* (*e.g.* forestry, services) tend to import technology mainly in the form of capital goods and intermediary products; their innovative performance is largely determined by their ability to interact with their suppliers as well as extension services. *Specialised supplier clusters* (*e.g.* computer hardware and software) are R&D intensive and emphasize product innovations, generally working closely with each other, customers and users.

In studies of national innovation systems, countries have used different approaches to identifying clusters of industries. For the most part, they group sectors according to the intersectoral intensity of different types of knowledge flows, including: 1) *embodied technology flows* (the purchase of products and intermediate goods from other sectors) and producer-user interactions; 2) *technical interactions* as measured by the structure of patenting, citations of patents and scientific publications in other sectors, and joint research activities; and 3) *personnel mobility* or the level and flows of skilled workers in and out of sectors.

For example, Finland has characterised the innovation performance of its **forestry cluster** of industries – including wood and wood products, pulp and paper products, furniture, publishing and printing and related machinery – on the basis of specific knowledge flows. These include embodied knowledge flows between the forest-related industries and machinery suppliers (***see* Table 6**), the number of firms conducting co-operative research, the increased skill levels of employees through formal vocational training, purchased technology in the form of patents and licences, and links to the public research infrastructure. A densely knit network of knowledge distribution among these related firms and sectors has resulted in the strong economic position of the cluster in Finland and gives it an advantage relative to its main competitors.

Table 6. **Technology flows to the Finnish forestry cluster, 1989**

Percentage shares of total technology inputs acquired from high-technology source industries

	User industry				
High-tech source industry	Wood	Furniture	Pulp, paper products	Publishing and printing	Pulp and paper machinery
Drugs	1.9	0.6	0.6	0.9	0.1
Computers, office machines	1.0	0.8	1.1	1.0	0.2
Electrical equipment for industry	2.3	2.9	2.8	4.9	1.6
Radio, TV, telecom equipment	1.5	3.8	0.8	1.5	0.5
Instruments, optical equipment	0.9	1.4	0.7	0.7	0.5
TOTAL	7.6	9.5	6.0	9.0	2.9

Source: Numminen (1996).

Similarly, Norway has identified its aquaculture cluster as an important system of interrelated sectors. Typically classified as a low-technology industry, aquaculture or the breeding of fish is rather the subject of substantial technical spillovers from other industries, particularly acoustics, optics, electronics and information technologies (Smith *et al.*, 1995). In the Netherlands, innovation systems approaches have identified a number of important industrial clusters by combining case studies with statistical methods, including mapping of embodied technology flows. Among the most active clusters in the Dutch economy are construction, chemicals, health, agro-food and multimedia (den Hertog *et al.*, 1995). In the United States, there are significant innovative clusters centred on pharmaceuticals/biotechnology and information technology (computer software and hardware) located on the West and East coasts. Germany has identified industrial clusters in robotics and industrial design, while Japan has a communications technology cluster in the Tokyo area.

C. International knowledge flows

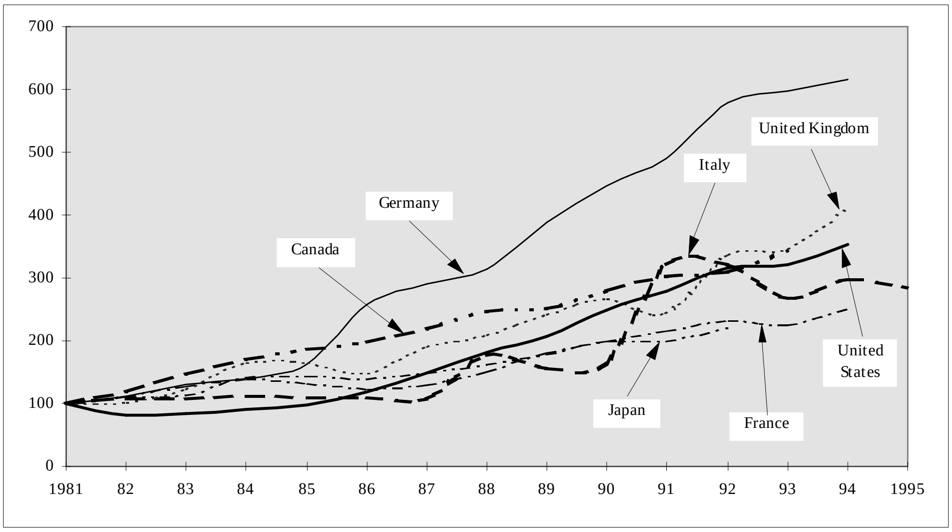
While the national level remains the most important for conceptualising innovation systems due to the importance of country-specific interactions in creating a climate for innovation, the role of international knowledge flows must also be acknowledged. Globalisation of industry and internationalisation of production, research and other firm activities mean that knowledge flows are growing worldwide. There is an increased openness of national innovation systems with regard to many forms of knowledge flows, including technology acquired from abroad in capital and intermediate goods, purchases of foreign patents and licences, technical alliances between firms of different countries, trade in services such as technical consultancies, foreign direct investment and internationally co-authored publications. Despite these growing international linkages, however, innovative capacity still seems to be primarily determined at the national level with subnational systems playing a contributing role.

The development of indicators of international knowledge flows is well advanced at a general level. These include data on the flows of technology payments, global diffusion of patents, trade in embodied technology and joint R&D consortia. All of these indicators are increasing over time for all OECD countries, although at a different level and pace. Collectively, they indicate the growing significance of inputs of international knowledge and expertise to national innovation systems. As yet, however, their relationship to domestic or national innovative capacity has not been systematically established.

For example, the **technology balance of payments** indicator shows the increasing flows of "*know-how*" among the major OECD countries (***see* Figure 10**). This covers the licensing or sale of patents and trade-marks, technological know-how and intellectual services such as engineering studies and R&D services, and reflects the transmission of technology or expertise which does not necessary involve the purchase of machinery and equipment. Recent data on total transactions for selected OECD countries show a three-fold increase in sales since the early 1980s, with inflows and outflows increasing even more rapidly for countries such as Germany. The United States is far and away the largest net exporter of know-how in the OECD area, followed by the United Kingdom, Sweden and the Netherlands. The largest purchasers of international technological know-how are Germany and Spain.

Figure 10**. Trends in technology balance of payments: total transactions**

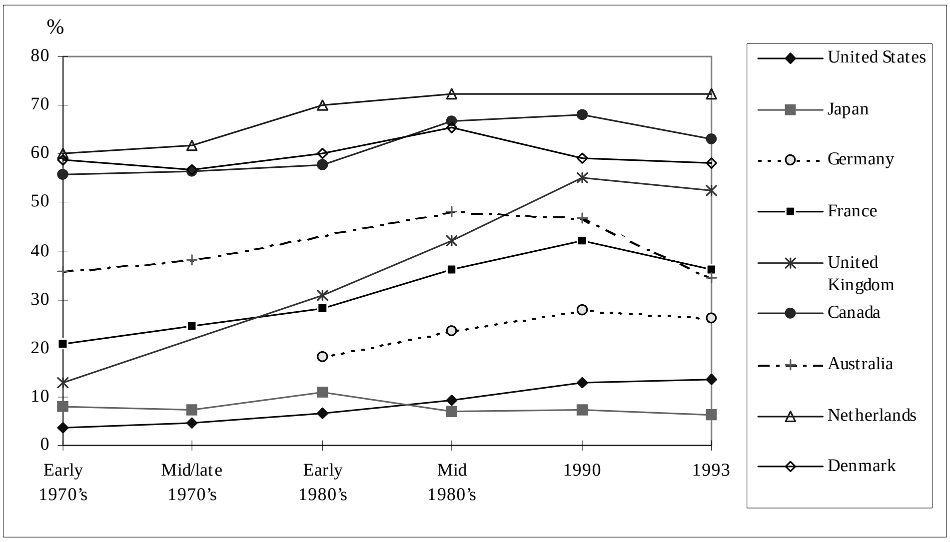
Index: 1981=100



Note: Figures were converted to US$ using PPPs.
Source: OECD (1996*d*).

Studies of **embodied technology flows** show that, in most countries, the share of acquired technologies obtained from imports of capital goods and intermediary products is significant (***see*** **Figure 11**). This measure tracks flows of machinery, equipment and components that incorporate new technology (as measured by R&D expenditures) across countries. In general, larger countries obtain less of their acquired technology from abroad than smaller ones, which depend on imports for more than half. However, there are some large OECD countries such as Canada and the United Kingdom which obtain more than 50 per cent of their acquired technology from abroad. High-technology and science-based industries and clusters usually make more use of foreign sources of acquired technology. In most countries, there are a few sectors that are the main "gateways" for acquired technology flows from abroad, *e.g.* chemicals in Denmark and the Netherlands and motor vehicles in Germany. This reflects the differentiated pattern of technological specialisation and industrial clusters in their respective national innovation systems.

Figure 11**. Share of total acquired technology obtained through imports**



Source: OECD (1996*c*).

CONCLUSIONS

A. Policy implications

The study of national innovation systems offers **new rationales** and new approaches for government technology policies. Most government intervention in the technology area has been directed to correcting *market failures*, or the tendency of the private sector to underinvest in technology development due to the inability of firms to capture all of the benefits from such investments. In the interest of maximising returns to the general public, technology policies have focused on stimulating or supporting R&D spending by industry through instruments such as R&D tax credits and subsidies. The concept of national innovation systems directs the attention of policy makers to possible *systemic failures* which may impede the innovative performance of industry. The lack of interaction between the actors in the system, mismatches between basic research in the public sector and more applied research in industry, malfunctioning of technology transfer institutions, and information and absorptive deficiencies on the part of enterprises may all contribute to poor innovative performance in a country.

New types of policies are needed to address systemic failures, particularly policies directed to networking and improving firm absorptive capacities. **Networking** schemes put emphasis on improving the interaction of actors and the interplay of institutions within national innovation systems. Such policies stress the role of joint research activities and other technical collaboration among enterprises and with public sector institutions; schemes to promote research and advanced technology partnerships with government are valuable in this context. These policies give prominence to high levels of co-patenting, co-publication and personnel mobility, and implement intellectual property rules, labour market policies and exchange programmes to facilitate such collaboration. These policies recognise the importance of informal flows of knowledge and access to technical networks; supportive information technology policies and infrastructures are thereby implemented. They see the value of encouraging the development of innovative clusters and close producer-user relations among firms, and thus establish appropriate competition policy frameworks. In general, these policies seek to augment innovation networks and to design these flows, linkages and partnerships in the most efficient manner.

Enhancing the **innovative capacity of firms** is another policy priority. From the innovation systems perspective, this means improving enterprise ability to access the appropriate networks, to find and identify relevant technologies and information, and to adapt such knowledge to their own needs. It may mean a general upgrading of technical, managerial and organisational capabilities on the part of firms. It may mean more investment in internal research and development, personnel training and information technology. The purpose is to improve the ability of firms to acquire information and technology, either domestic or foreign, and to absorb it on a continuing basis. Technology policies should seek not just to diffuse equipment and technologies to firms but also to upgrade their ability to find and adapt technology themselves. Technology policies should aim not only at technology-based firms but also at firms with lesser technological capabilities, in traditional and mature industries, and in services sectors. And these policies should focus not just on upgrading the abilities of individual firms but also on enhancing the networking and innovative performance of clusters of firms and sectors.

B. Measurement issues

Measuring knowledge flows and mapping national innovation systems are still in the initial stages as indicated by the immature level of most of the statistical indicators discussed in this report. The measurement of knowledge distribution and interaction is difficult because there is a lack of data and information regarding this type of innovative activity. Conventional indicators (such as R&D expenditures, patents, production and trade in high-technology products) are significantly more robust but are able to draw only a rough picture of knowledge flows in the innovative process. The OECD is now seeking to develop new types of innovation flow indicators which are comparable across countries, including the mobility of human resources, the diffusion of knowledge through publications and patents, and the characterisation of innovative firms, both in manufacturing and services.

Depicting national innovation systems also suffers from a lack of **comparable approaches** across countries**.** Some countries and theorists take a more holistic view in including all types of technology-related inputs, outputs and flows in their studies of innovation systems. This is the perspective taken in many firm-level innovation surveys. Others focus only on the flows (*e.g.* joint R&D activities, personnel mobility, information sources) or particular types of linkages. The *cluster approach* is increasingly popular among innovation system theorists, who see value in identifying and evaluating the interactions among a smaller system or group of innovative firms. There are also diverse views on the appropriate level of analysis: the sub-national level, the national level, the pan-regional level or the international level. Systems of interaction and innovation exist to some extent at all these levels. The different levels increasingly interact to further complicate the task of analysing innovation systems.

Establishing the link between national innovation systems and **economic performance** is the ultimate goal. Studies of the various linkages within innovation systems have attempted to link the degree of interaction among actors to their innovative output in terms of new products, patents or productivity. Such analyses, while showing significant positive impacts, are still in the developmental stage due to initial difficulties in compiling data on the linkages or flows themselves. A next step would be to establish a better concordance between innovation-related flows and performance measures. If the measurement of knowledge flows were better co-ordinated at the national level and made more comparable, the effects on performance in different countries could be weighed. This could eventually lead to the ability to assess roughly the "*knowledge distribution power*" of national innovation system. Combined with input and output indicators, the innovation capabilities of locales, countries or regions could be more fully evaluated and understood. It is theorised that these capabilities, of which knowledge distribution power is a key component, have a direct influence on economic performance (David and Foray, 1995).

C. Future research

The OECD is building the linkages among the people in different countries engaged in work on national innovation systems. This is done through informal networking at meetings and workshops, as well as through more formal analyses of the components of innovation systems and the development of innovation indicators. The OECD is also engaged in improving the comparability of analyses of innovation systems across OECD countries by encouraging those engaging in innovation systems analysis to focus initially on measuring a core set of knowledge flows using similar indicators (***see* Box 2**).

At present, four different avenues of research on national innovation systems are being pursued by groups of OECD countries with the aim of deepening the understanding of different types of knowledge flows and developing improved compatibility of indicators. These groups are engaged in:

Mapping institutional linkages – Through questionnaires, existing evaluations and other sources, the degree and quality of public/private partnerships are being gauged. This includes the development of a typology of the institutional profiles of OECD countries based on the relative roles of their universities and research institutes and their links to enterprises.

Mapping human resource flows – Labour market data and other information sources are being used to track the flow of technical personnel between different sectors and institutions according to their level of expertise and qualifications.

Mapping industrial clusters – Input/output techniques, innovation surveys and bibliometrics are among the approaches being used to identify clusters of activities and to delineate the technical, sectoral and product specialisation patterns of national innovation systems.

Mapping innovative firms – Firm-level innovation surveys, diagnostics and benchmarking are the approaches for understanding what constitutes innovative firms, in both manufacturing and services sectors, particularly their interactions and networks with other actors in national innovation systems.

Box 2
Core knowledge flows in national innovation systems

Type of knowledge flow	**Main indicator**
Industry alliances	
Inter-firm research co-operation	Firm surveys Literature-based counting
Industry/university interactions	
Co-operative industry/University R&D Industry/University co-patents Industry/University co-publications Industry use of university patents Industry/University information-sharing	University annual reports Patent record analysis Publications analysis Citation analysis Firm surveys
Industry/research institute interactions	
Co-operative industry/Institute R&D Industry/Institute co-patents Industry/Institute co-publications Industry use of research institute patents Industry/Institute information-sharing	Government reports Patent record analysis Publications analysis Citation analysis Firm surveys
Technology diffusion	
Technology use by industry Embodied technology diffusion	Firm surveys Input-output analysis
Personnel mobility	
Movement of technical personnel among industry, universities and research	Labour market statistics University/Institute reports

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