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OCDE/GD(96)102

THE KNOWLEDGE-BASED ECONOMY

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris 1996

FOREWORD

The OECD economies are increasingly based on knowledge and information. Knowledge is now recognised as the driver of productivity and economic growth, leading to a new focus on the role of information, technology and learning in economic performance. The term "*knowledge-based economy*" stems from this fuller recognition of the place of knowledge and technology in modern OECD economies.

OECD analysis is increasingly directed to understanding the dynamics of the knowledge-based economy and its relationship to traditional economics, as reflected in "*new growth theory*". The growing codification of knowledge and its transmission through communications and computer networks has led to the emerging "*information society*". The need for workers to acquire a range of skills and to continuously adapt these skills underlies the "*learning economy*". The importance of knowledge and technology diffusion requires better understanding of knowledge networks and "*national innovation systems*". Most importantly, new issues and questions are being raised regarding the implications of the knowledge-based economy for employment and the role of governments in the development and maintenance of the knowledge base.

Identifying "*best practices*" for the knowledge-based economy is a focal point of OECD work in the field of science, technology and industry. This report discusses trends in the knowledge-based economy, the role of the science system and the development of knowledge-based indicators and statistics. It is excerpted from the *1996 Science, Technology and Industry Outlook*, which is derestricted on the responsibility of the Secretary-General of the OECD.

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SUMMARY

OECD science, technology and industry policies should be formulated to maximise performance and well-being in "*knowledge-based economies*" – economies which are directly based on the production, distribution and use of knowledge and information. This is reflected in the trend in OECD economies towards growth in high-technology investments, high-technology industries, more highly-skilled labour and associated productivity gains. Although knowledge has long been an important factor in economic growth, economists are now exploring ways to incorporate more directly knowledge and technology in their theories and models. "*New growth theory*" reflects the attempt to understand the role of knowledge and technology in driving productivity and economic growth. In this view, investments in research and development, education and training and new managerial work structures are key.

In addition to knowledge investments, **knowledge distribution** through formal and informal networks is essential to economic performance. Knowledge is increasingly being codified and transmitted through computer and communications networks in the emerging "*information society*". Also required is tacit knowledge, including the skills to use and adapt codified knowledge, which underlines the importance of continuous learning by individuals and firms. In the knowledge-based economy, innovation is driven by the interaction of producers and users in the exchange of both codified and tacit knowledge; this interactive model has replaced the traditional linear model of innovation. The configuration of *national innovation systems*, which consist of the flows and relationships among industry, government and academia in the development of science and technology, is an important economic determinant.

Employment in the knowledge-based economy is characterised by increasing demand for more highly-skilled workers. The knowledge-intensive and high-technology parts of OECD economies tend to be the most dynamic in terms of output and employment growth. Changes in technology, and particularly the advent of information technologies, are making educated and skilled labour more valuable, and unskilled labour less so. Government policies will need more stress on upgrading human capital through promoting access to a range of skills, and especially the capacity to learn; enhancing the *knowledge distribution power* of the economy through collaborative networks and the diffusion of technology; and providing the enabling conditions for organisational change at the firm level to maximise the benefits of technology for productivity.

The **science system**, essentially public research laboratories and institutes of higher education, carries out key functions in the knowledge-based economy, including knowledge production, transmission and transfer. But the OECD science system is facing the challenge of reconciling its traditional functions of producing new knowledge through basic research and educating new generations of scientists and engineers with its newer role of collaborating with industry in the transfer of knowledge and technology. Research institutes and academia increasingly have industrial partners for financial as well as innovative purposes, but must combine this with their essential role in more generic research and education.

In general, our understanding of what is happening in the knowledge-based economy is constrained by the extent and quality of the available **knowledge-related indicators**. Traditional national accounts frameworks are not offering convincing explanations of trends in economic growth, productivity and employment. Development of indicators of the knowledge-based economy must start with improvements to more traditional input indicators of R&D expenditures and research personnel. Better indicators are also needed of knowledge stocks and flows, particularly relating to the diffusion of information technologies, in both manufacturing and service sectors; social and private rates of return to knowledge investments to better gauge the impact of technology on productivity and growth; the functioning of knowledge networks and national innovation systems; and the development and skilling of human capital.

1. THE KNOWLEDGE-BASED ECONOMY: TRENDS AND IMPLICATIONS

A. Introduction

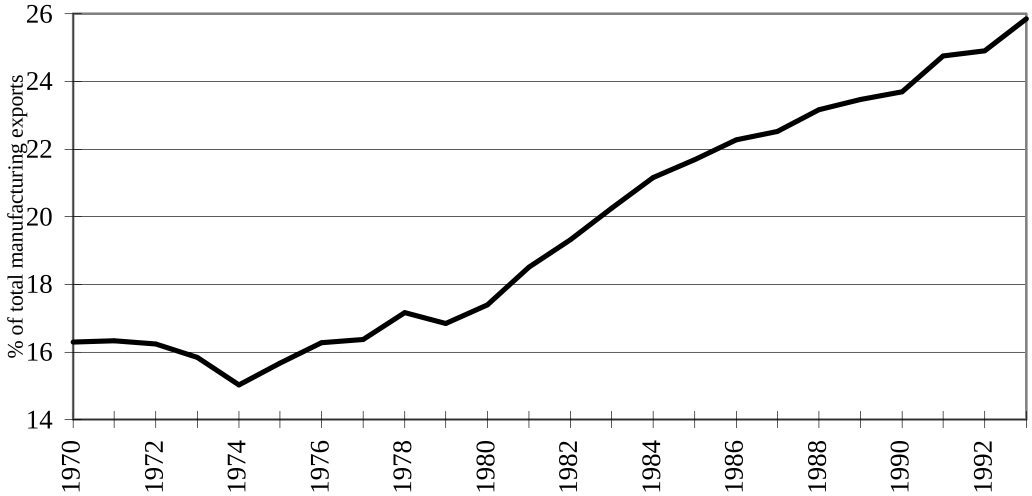
The term “*knowledge-based economy*” results from a fuller recognition of the role of knowledge and technology in economic growth. Knowledge, as embodied in human beings (as *“human capital”*) and in technology, has always been central to economic development. But only over the last few years has its relative importance been recognised, just as that importance is growing. The OECD economies are more strongly dependent on the production, distribution and use of knowledge than ever before. Output and employment are expanding fastest in high-technology industries, such as computers, electronics and aerospace. In the past decade, the high-technology share of OECD manufacturing production (Table 1) and exports (Figure 1) has more than doubled, to reach 20-25 per cent. Knowledge-intensive service sectors, such as education, communications and information, are growing even faster. Indeed, it is estimated that more than 50 per cent of Gross Domestic Product (GDP) in the major OECD economies is now knowledge-based.

Table 1. Shares of high-technology industries in total manufacturing
Percentages

	Exports		Value added	
	1970	1993[1]	1970	1994[1]
North America				
Canada	9.0	13.4	10.2	12.6
United States	25.9	37.3	18.2	24.2
Pacific Area				
Australia	2.8	10.3	8.9	12.2
Japan	20.2	36.7	16.4	22.2
New Zealand	0.7	4.6	..	5.4
Europe				
Austria	11.4	18.4	..	..
Belgium	7.2	10.9	..	..
Denmark	11.9	18.1	9.3	13.4
Finland	3.2	16.4	5.9	14.3
France	14.0	24.2	12.8	18.7
Germany	15.8	21.4	15.3	20.1
Greece	2.4	5.6	..	..
Ireland	11.7	43.6	..	..
Italy	12.7	15.3	13.3	12.9
Netherlands	16.0	22.9	15.1	16.8
Norway	4.7	10.7	6.6	9.4
Spain	6.1	14.3	..	13.7
Sweden	12.0	21.9	12.8	17.7
United Kingdom	17.1	32.6	16.4	22.2

1. Or nearest available year.
Source: OECD, DSTI, STAN database.

Figure 1. Total OECD high-technology exports
Percentage of total OECD manufacturing exports



Source: OECD, DSTI, STAN database.

Investment is thus being directed to high-technology goods and services, particularly information and communications technologies. Computers and related equipment are the fastest-growing component of tangible investment. Equally important are more intangible investments in research and development (R&D), the training of the labour force, computer software and technical expertise. Spending on research has reached about 2.3 per cent of GDP in the OECD area. Education accounts for an average 12 per cent of OECD government expenditures, and investments in job-related training are estimated to be as high as 2.5 per cent of GDP in countries such as Germany and Austria which have apprenticeship or dual training (combining school and work) systems. Purchases of computer software, growing at a rate of 12 per cent per year since the mid-1980s, are outpacing sales of hardware. Spending on product enhancement is driving growth in knowledge-based services such as engineering studies and advertising. And balance-of-payments figures in technology show a 20 per cent increase between 1985 and 1993 in trade in patents and technology services.

It is skilled labour that is in highest demand in the OECD countries. The average unemployment rate for people with lower-secondary education is 10.5 per cent, falling to 3.8 per cent for those with university education. Although the manufacturing sector is losing jobs across the OECD, employment is growing in high-technology, science-based sectors ranging from computers to pharmaceuticals. These jobs are more highly skilled and pay higher wages than those in lower-technology sectors (*e.g.* textiles and food-processing). Knowledge-based jobs in service sectors are also growing strongly. Indeed, non-production or *"knowledge"* workers – those who do not engage in the output of physical products – are the employees in most demand in a wide range of activities, from computer technicians, through physical therapists to marketing specialists. The use of new technologies, which are the engine of longer-term gains in productivity and employment, generally improves the *"skills base"* of the labour force in both manufacturing and services. And it is largely because of technology that employers now pay more for knowledge than for manual work.

B. Knowledge and economics

These trends are leading to revisions in economic theories and models, as analysis follows reality. Economists continue to search for the foundations of economic growth. Traditional *"production functions"* focus on labour, capital, materials and energy; knowledge and technology are external influences on production. Now analytical approaches are being developed so that knowledge can be included more directly in production functions. Investments in knowledge can increase the productive capacity of the other factors of production as well as transform them into new products and processes. And since these knowledge investments are characterised by increasing (rather than decreasing) returns, they are the key to long-term economic growth.

It is not a new idea that knowledge plays an important role in the economy. Adam Smith referred to new layers of specialists who are men of speculation and who make important contributions to the production of economically useful knowledge. Friedrich List emphasised the infrastructure and institutions which contribute to the development of productive forces through the creation and distribution of knowledge. The Schumpeterian idea of innovation as a major force of economic dynamics has been followed up by modern Schumpeterian scholars such as Galbraith, Goodwin and Hirschman. And economists such as Romer and Grossman are now developing new growth theories to explain the forces which drive long-term economic growth.

According to the **neo-classical production function**, returns diminish as more capital is added to the economy, an effect which may be offset, however, by the flow of new technology. Although technological progress is considered an engine of growth, there is no definition or explanation of technological processes. In new growth theory, knowledge can raise the returns on investment, which can in turn contribute to the accumulation of knowledge. It does this by stimulating more efficient methods of production organisation as well as new and improved products and services. There is thus the possibility of sustained increases in investment which can lead to continuous rises in a country's growth rate. Knowledge can also spill over from one firm or industry to another, with new ideas used repeatedly at little extra cost. Such spillovers can ease the constraints placed on growth by scarcity of capital.

Technological change raises the relative marginal productivity of capital through education and training of the labour force, investments in research and development and the creation of new managerial structures and work organisation. Analytical work on long-term economic growth shows that in the 20th century the factor of production growing most rapidly has been human capital, but there are no signs that this has reduced the rate of return to investment in education and training (Abramowitz, 1989). Investments in knowledge and capabilities are characterised by increasing (rather than decreasing) returns. These findings argue for modification of neo-classical equilibrium models – which were designed to deal with the production, exchange and use of commodities – in order to analyse the production, exchange and use of knowledge.

Incorporating knowledge into standard economic production functions is not an easy task, as this factor defies some fundamental economic principles, such as that of scarcity. Knowledge and information tend to be abundant; what is scarce is the capacity to use them in meaningful ways. Nor is knowledge easily transformed into the object of standard economic transactions. To buy knowledge and information is difficult because by definition information about the characteristics of what is sold is asymmetrically distributed between the seller and the buyer. Some kinds of knowledge can be easily reproduced and distributed at low cost to a broad set of users, which tends to undermine private ownership. Other kinds of knowledge cannot be transferred from one organisation to another or between individuals without establishing intricate linkages in terms of network and apprenticeship relationships or investing substantial resources in the codification and transformation into information.

C. Knowledge codification

In order to facilitate economic analysis, distinctions can be made between different kinds of knowledge which are important in the knowledge-based economy: know-what, know-why, know-how and know-who. Knowledge is a much broader concept than information, which is generally the "*know-what*" and "*know-why*" components of knowledge. These are also the types of knowledge which come closest to being market commodities or economic resources to be fitted into economic production functions. Other types of knowledge – particularly know-how and know-who – are more "*tacit knowledge*" and are more difficult to codify and measure (Lundvall and Johnson, 1994).

- ◊ **Know-what** refers to knowledge about "*facts*". How many people live in New York? What are the ingredients in pancakes? And when was the battle of Waterloo? are examples of this kind of knowledge. Here, knowledge is close to what is normally called information – it can be broken down into bits. In some complex areas, experts must have a lot of this kind of knowledge in order to fulfil their jobs. Practitioners of law and medicine belong to this category.
- ◊ **Know-why** refers to scientific knowledge of the principles and laws of nature. This kind of knowledge underlies technological development and product and process advances in most industries. The production and reproduction of know-why is often organised in specialised organisations, such as research laboratories and universities. To get access to this kind of knowledge, firms have to interact with these organisations either through recruiting scientifically-trained labour or directly through contacts and joint activities.
- ◊ **Know-how** refers to skills or the capability to do something. Businessmen judging market prospects for a new product or a personnel manager selecting and training staff have to use their know-how. The same is true for the skilled worker operating complicated machine tools. Know-how is typically a kind of knowledge developed and kept within the border of an individual firm. One of the most important reasons for the formation of industrial networks is the need for firms to be able to share and combine elements of know-how.
- ◊ This is why **know-who** becomes increasingly important. Know-who involves information about who knows what and who knows how to do what. It involves the formation of special social relationships which make it possible to get access to experts and use their knowledge efficiently. It is significant in economies where skills are widely dispersed because of a highly developed division of labour among organisations and experts. For the modern manager and organisation, it is important to use this kind of knowledge in response to the acceleration in the rate of change. The know-who kind of knowledge is internal to the organisation to a higher degree than any other kind of knowledge.

Learning to master the four kinds of knowledge takes place through different channels. While know-what and know-why can be obtained through reading books, attending lectures and accessing databases, the other two kinds of knowledge are rooted primarily in practical experience. Know-how will typically be learned in situations where an apprentice follows a master and relies upon him as the authority. Know-who is learned in social practice and sometimes in specialised educational environments. It also develops in day-to-day dealings with customers, sub-contractors and independent institutes. One reason why firms engage in basic research is to acquire access to networks of academic experts crucial for their innovative capability. Know-who is socially embedded knowledge which cannot easily be transferred through formal channels of information.

The development of **information technology** may be regarded as a response to the need for handling the know-what and know-why portions of knowledge more effectively. Conversely, the existence of information technology and communications infrastructures gives a strong impetus to the process of codifying certain types of knowledge. All knowledge which can be codified and reduced to information can now be transmitted over long distances with very limited costs. It is the increasing codification of some elements of knowledge which have led the current era to be characterised as "*the information society*" – a society where a majority of workers will soon be producing, handling and distributing information or codified knowledge.

The digital revolution has intensified the move towards knowledge codification and altered the share of codified *vs.* tacit knowledge in the knowledge stock of the economy. Electronic networks now connect a vast array of public and private information sources, including digitised reference volumes, books, scientific journals, libraries of working papers, images, video clips, sound and voice recordings, graphical displays as well as electronic mail. These information resources, connected through various communications networks, represent the components of an emerging, universally accessible digital library.

Due to codification, knowledge is acquiring more of the properties of a commodity. Market transactions are facilitated by codification, and diffusion of knowledge is accelerated. In addition, codification is reducing the importance of additional investments to acquire further knowledge. It is creating bridges between fields and areas of competence and reducing the "*dispersion*" of knowledge. These developments promise an acceleration of the rate of growth of stocks of accessible knowledge, with positive implications for economic growth. They also imply increased change in the knowledge stock due to higher rates of scrapping and obsolescence, which will put greater burdens on the economy's adjustment abilities. While information technologies are speeding up the codification of knowledge and stimulating growth in the knowledge-based economy, they have implications for the labour force.

D. Knowledge and learning

While information technologies may be moving the border between tacit and codified knowledge, they are also increasing the importance of acquiring a range of skills or types of knowledge. In the emerging information society, a large and growing proportion of the labour force is engaged in handling information as opposed to more tangible factors of production. Computer literacy and access to network facilities tend to become more important than literacy in the traditional sense. Although the knowledge-based economy is affected by the increasing use of information technologies, it is not synonymous with the information society. The knowledge-based economy is characterised by the need for continuous learning of both codified information and the competencies to use this information.

As access to information becomes easier and less expensive, the skills and competencies relating to the selection and efficient use of information become more crucial. **Tacit knowledge** in the form of skills needed to handle codified knowledge is more important than ever in labour markets. Codified knowledge might be considered as the material to be transformed, and tacit knowledge, particularly know-how, as the tool for handling this material. Capabilities for selecting relevant and disregarding irrelevant information, recognising patterns in information, interpreting and decoding information as well as learning new and forgetting old skills are in increasing demand.

The accumulation of tacit knowledge needed to derive maximum benefit from knowledge codified through information technologies can only be done through **learning.** Without investments oriented towards both codified and tacit skill development, informational constraints may be a significant factor degrading the allocative efficiency of market economies. Workers will require both formal education and the ability to acquire and apply new theoretical and analytical knowledge; they will increasingly be paid for their codified and tacit knowledge skills rather than for manual work. Education will be the centre of the knowledge-based economy, and learning the tool of individual and organisational advancement.

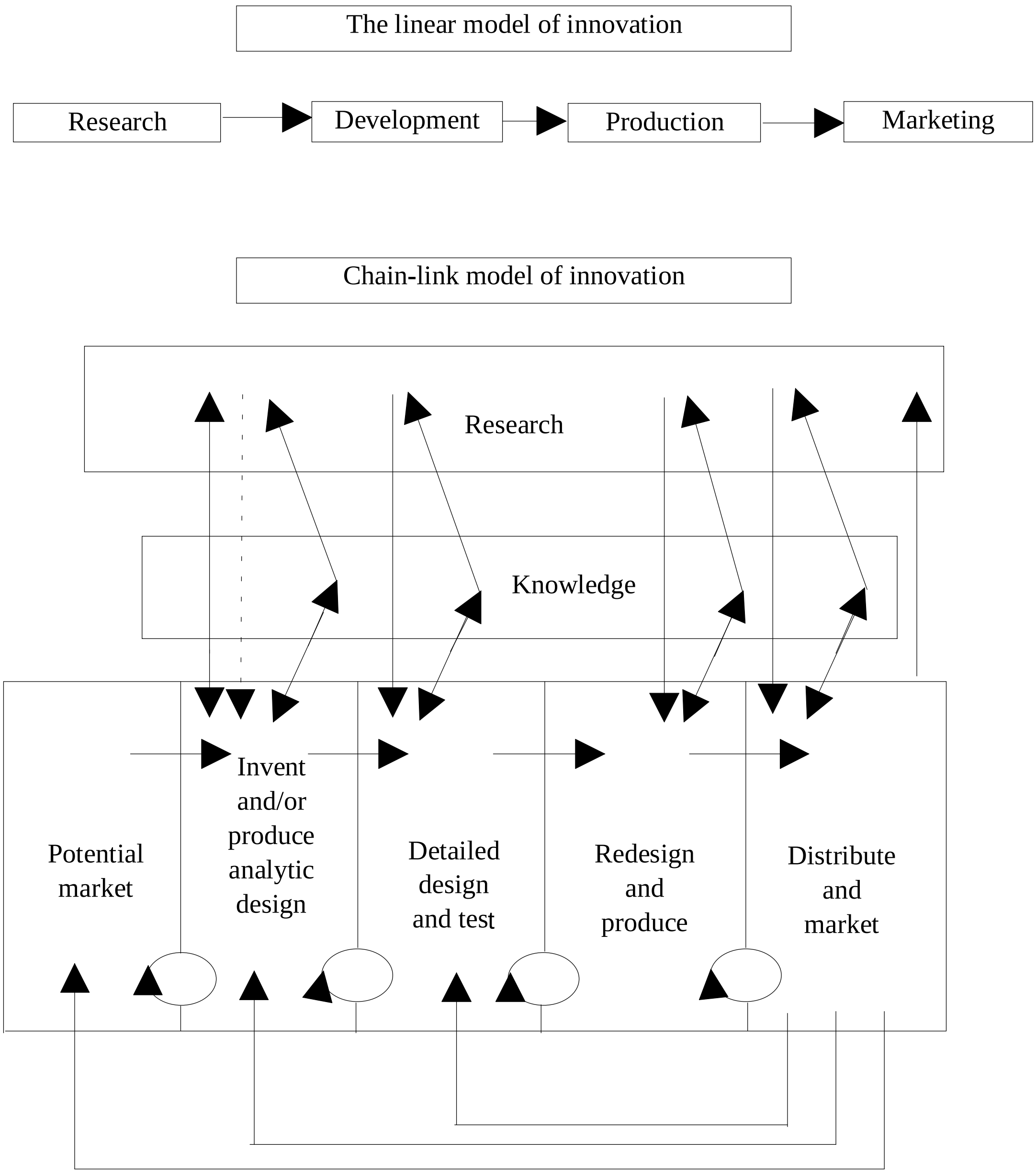
This process of learning is more than just acquiring formal education. In the knowledge-based economy "*learning-by-doing*" is paramount. A fundamental aspect of learning is the transformation of tacit into codified knowledge and the movement back to practice where new kinds of tacit knowledge are developed. Training and learning in non-formal settings, increasingly possible due to information technologies, are more common. Firms themselves face the need to become learning organisations, continuously adapting management, organisation and skills to accommodate new technologies. They are also joined in networks, where interactive learning involving producers and users in experimentation and exchange of information is the driver of innovation (EIMS, 1994).

E. Knowledge networks

The knowledge-based economy places great importance on the **diffusion and use of information** and knowledge as well as its creation. The determinants of success of enterprises, and of national economies as a whole, is ever more reliant upon their effectiveness in gathering and utilising knowledge. Strategic know-how and competence are being developed interactively and shared within sub-groups and networks, where know-who is significant. The economy becomes a hierarchy of networks, driven by the acceleration in the rate of change and the rate of learning. What is created is a network society, where the opportunity and capability to get access to and join knowledge- and learning-intensive relations determines the socio-economic position of individuals and firms (David and Foray, 1995).

The network characteristic of the knowledge-based economy has emerged with changes to the **linear model of innovation** (Figure 2). The traditional theory held that innovation is a process of discovery which proceeds via a fixed and linear sequence of phases. In this view, innovation begins with new scientific research, progresses sequentially through stages of product development, production and marketing, and terminates with the successful sale of new products, processes and services. It is now recognised that ideas for innovation can stem from many sources, including new manufacturing capabilities and recognition of market needs. Innovation can assume many forms, including incremental improvements to existing products, applications of technology to new markets and uses of new technology to serve an existing market. And the process is not completely linear. Innovation requires considerable communication among different actors – firms, laboratories, academic institutions and consumers – as well as feedback between science, engineering, product development, manufacturing and marketing.

Figure 2. Models of innovation



Source: Klein, S.J. and N. Rosenberg (1986), "An Overview of Innovation", in R. Landau and N. Rosenberg (eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, National Academy Press, Washington, DC.

In the knowledge-based economy, firms search for **linkages to promote inter-firm interactive learning** and for outside partners and networks to provide complementary assets. These relationships help firms to spread the costs and risk associated with innovation among a greater number of organisations, to gain access to new research results, to acquire key technological components of a new product or process, and to share assets in manufacturing, marketing and distribution. As they develop new products and processes, firms determine which activities they will undertake individually, in collaboration with other firms, in collaboration with universities or research institutions, and with the support of government.

Innovation is thus the result of numerous interactions by a community of actors and institutions, which together form what are termed **national innovation systems**. Increasingly, these innovation systems are extending beyond national boundaries to become international. Essentially, they consist of the flows and relationships which exist among industry, government and academia in the development of science and technology. The interactions within this system influence the innovative performance of firms and economies. Of key importance is the "*knowledge distribution power*" of the system, or its capability to ensure timely access by innovators to the relevant stocks of knowledge. Efforts are just beginning to quantify and map the diffusion paths of knowledge and innovation in an economy – considered the new key to economic performance (Table 2).

Table 2. Mapping national innovation systems: 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, K., E. Dietrichs and S. Nås (1995), "The Norwegian National Innovation System: A Pilot Study of Knowledge Creation, Distribution and Use", paper presented at the OECD Workshop on National Innovation Systems, Vienna, 6 October.

F. Knowledge and employment

The knowledge-based economy is marked by increasing labour market demand for more highly skilled workers, who are also enjoying wage premiums (Table 3). Studies in some countries show that the more rapid the introduction of knowledge-intensive means of production, such as those based on information technologies, the greater the demand for highly skilled workers. Other studies show that workers who use advanced technologies, or are employed in firms that have advanced technologies, are paid higher wages. This labour market preference for workers with general competencies in handling codified knowledge is having negative effects on the demand for less-skilled workers; there are concerns that these trends could exclude a large and growing proportion of the labour force from normal wage work.

Table 3. Employment trends in manufacturing
Growth rates over the period 1970-94, percentages

	Total manufacturing	Skilled	Unskilled	High-wage	Medium-wage	Low-wage
OECD-19	-0.3	0.1	-0.7	0.2	-0.2	-0.7
Australia	-0.7	-0.1	-1.3	-0.6	-0.4	-1.1
Canada	0.3	0.3	0.3	1.4	0.3	0.0
Denmark	-0.8	-0.3	-1.3	0.8	-0.5	-1.5
Finland	-1.3	-0.3	-2.1	1.3	-0.6	-2.7
France	-1.2	-0.4	-1.8	-0.6	-1.1	-1.5
Germany	-0.8	-0.5	-1.1	0.4	-0.7	-1.5
Italy	-0.7	-0.4	-0.9	-1.1	-0.4	-0.8
Japan	0.2	0.9	-0.2	1.2	0.4	-0.3
Netherlands	-1.5	-1.1	-2.1	-0.8	-1.1	-2.4
Norway	-1.5	-0.8	-2.1	0.2	-1.3	-2.1
Sweden	-1.5	-0.8	-2.4	0.5	-1.5	-2.2
United Kingdom	-2.3	-1.7	-2.9	-2.0	-2.4	-2.4
United States	-0.1	0.0	-0.3	-0.1	0.1	-0.5

Source: OECD, DSTI, STAN database.

The *OECD Jobs Study* noted a tendency in the 1980s towards a polarisation in labour markets. In the United States, relative wages for less-skilled workers declined while the overall unemployment rate remained low. The United Kingdom was marked by a similar growing wage gap between skilled and unskilled workers. In the other major European countries, there was no polarisation in terms of wages but the employment situation worsened for unskilled workers. Japan largely avoided an increase in polarisation in both wages and job opportunities. While labour market policies and other government regulations contribute to these different outcomes, they also reflect changes in technology which have made educated and skilled labour more valuable, and unskilled labour less so (OECD, 1994).

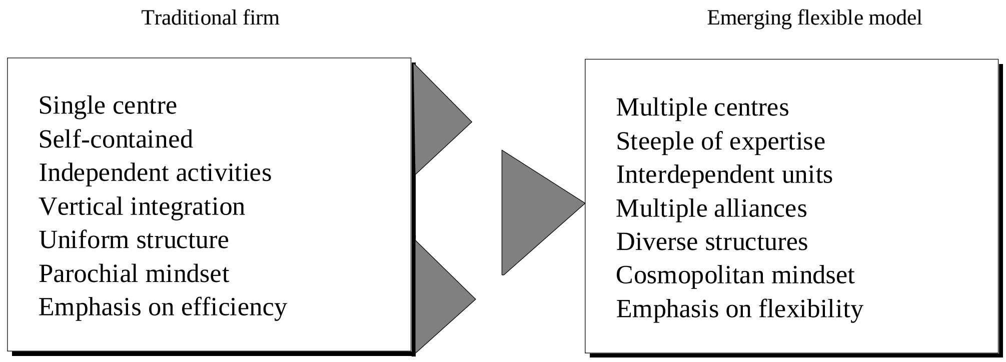
Three different hypotheses have been proposed to explain current labour market trends in the OECD countries: globalisation; biased technological change; and developments in firm behaviour.

◊ One hypothesis is that **globalisation** and intensified international competition have led to decreased relative demand for less-skilled workers in the OECD countries. Empirical work, however, shows that increasing imports from low-wage countries may contribute to some unemployment, but that the scale of the import increase is so limited that it could not possibly by itself explain more than a small part of the phenomenon (Katz and Murphy, 1992).

◊ An alternative explanation is that **technological change** has become more strongly biased in favour of skilled workers. The evidence is somewhat scattered, but studies of the use of information technology highlight this tendency. Data show that the polarisation of wages and employment opportunities is most dramatic in firms which have introduced computers and other forms of information technology in the workplace (Krueger, 1993; Lauritzen, 1996).

◊ Some scholars point to institutional change in the labour market and **changes in firm behaviour** as the main reason for falling real wages for low-skilled workers in some OECD countries. New high-performance workplaces and flexible enterprises stress worker qualities such as initiative, creativity, problem-solving and openness to change, and are willing to pay premiums for these skills (Figure 3). Moreover, the weakening of trade unions in some countries may have a negative impact on the relative position of the least-skilled workers, because it has led employers to implement a low-wage strategy in which delocalisation and outsourcing are important elements.

Figure 3. The flexible enterprise



Source: Bahrami, H. (1992), "The Emerging Flexible Organisation", *California Management Review*.

One problem with these hypotheses is that much of the analysis is based on United States' data, which may not be applicable to other countries. Another weakness is that the three hypotheses have generally been tested separately and regarded as alternatives to each other, when it is more plausible that they interact in their impact on jobs. More likely, these three phenomena – increases in the pace of internationalisation; technological change; and their consequent impact on the way firms organise themselves – have combined to intensify the demand for rapid learning at all levels of the economy. While there are dislocations in the labour market in the short term, enlightened approaches to knowledge accumulation and learning should lead to enhanced growth and job creation in the longer term.

G. Government policies

OECD countries continue to evidence a shift from industrial to post-industrial knowledge-based economies. Here, productivity and growth are largely determined by the rate of technical progress and the accumulation of knowledge. Of key importance are networks or systems which can efficiently distribute knowledge and information. The knowledge-intensive or high-technology parts of the economy tend to be the most dynamic in terms of output and employment growth, which intensifies the demand for more highly skilled workers. Learning on the part of both individuals and firms is crucial for realising the productivity potential of new technologies and longer-term economic growth.

Government policies, particularly those relating to science and technology, industry and education, will need a new emphasis in knowledge-based economies. Acknowledgement is needed of the central role of the firm, the importance of national innovation systems and the requirements for infrastructures and incentives which encourage investments in research and training (OECD, 1996*b*). Among the priorities will undoubtedly be:

◊ **Enhancing knowledge diffusion** – Support to innovation will need to be broadened from "*mission-oriented*" science and technology projects to "*diffusion-oriented*" programmes. This includes providing the framework conditions for university-industry-government collaborations, promoting the diffusion of new technologies to a wide variety of sectors and firms, and facilitating the development of information infrastructures.

◊ **Upgrading human capital** – Policies will be needed to promote broad access to skills and competencies and especially the capability to learn. This includes providing broad-based formal education, establishing incentives for firms and individuals to engage in continuous training and lifelong learning, and improving the matching of labour supply and demand in terms of skill requirements.

◊ **Promoting organisational change** – Translating technological change into productivity gains will necessitate a range of firm-level organisational changes to increase flexibility, particularly relating to work arrangements, networking, multi-skilling of the labour force and decentralisation. Governments can provide the conditions and enabling infrastructures for these changes through appropriate financial, competition, information and other policies.

II. THE ROLE OF THE SCIENCE SYSTEM IN THE KNOWLEDGE-BASED ECONOMY

A. Introduction

A country's science system takes on increased importance in a knowledge-based economy. Public research laboratories and institutions of higher education are at the core of the science system, which more broadly includes government science ministries and research councils, certain enterprises and other private bodies, and supporting infrastructure. In the knowledge-based economy, the science system contributes to the key functions of: *i)* **knowledge production** – developing and providing new knowledge; *ii)* **knowledge transmission** – educating and developing human resources; and *iii)* **knowledge transfer** – disseminating knowledge and providing inputs to problem solving.

Despite their higher profile in knowledge-based economies, science systems in OECD countries are now in a period of transition. They are confronting severe budget constraints combined with the increasing marginal costs of scientific progress in certain disciplines. More importantly, the science system is facing the challenge of reconciling its traditional functions with its newer role as an integral part of a larger network and system – the knowledge-based economy.

B. Knowledge production

The science system has traditionally been considered the primary producer of new knowledge, largely through basic research at universities and government laboratories. This new knowledge is generally termed "*science*" and has traditionally been distinguished from knowledge generated by more applied or commercial research, which is closer to the market and the "*technology*" end of the spectrum. In the knowledge-based economy, the distinction between basic and applied research and between science and technology has become somewhat blurred. There is debate as to the exact line between science and technology and whether the science system is the only or main producer of new knowledge. This debate is relevant because of different views on the appropriate role of government in funding the production of various types of knowledge.

Scientific knowledge is broadly applicable across a wide and rapidly expanding frontier of human endeavour. Technological knowledge stems more from the refinement and application of scientific knowledge to practical problems. Science has been considered that part of knowledge which cannot or should not be appropriated by any single member or group in society, but should be broadly disseminated. It is the fundamental knowledge base which is generic to technological development. Because of this, much of science is considered a "*public good*", a good in which all who wish can and should share if social welfare is to be maximised. The public-good character of science means that, like other public goods such as environmental quality, the private sector may underinvest in its creation since it is unable to appropriate and profit adequately from its production. The government therefore has a role in ensuring and subsidising the creation of science to improve social welfare, just as it does in regulating environmental protection.

Some argue that there is no longer a meaningful **distinction between science and technology** in the knowledge-based economy (Gibbons *et al.*, 1994). They present the view that the methods of scientific investigation have been massified and diffused throughout society through past investments in education and research. The consequence is that no particular, or each and every, site of research investigation, public or private, can be identified as a possible originating point for scientific knowledge. In addition, there may no longer be a fundamental difference in the character of scientific and technological knowledge, which can be produced as joint products of the same research activity. Studies of the research process have demonstrated that incremental technological improvements often use little scientific input and that the search for technological solutions can be a productive source of both new scientific questions and answers. As a result, the traditional base of the science system, research institutions and universities, cannot be assumed to dominate the production of scientific knowledge.

In this view, firms in the private sector will invest in basic research, despite its possible spillovers to competitors, if they can capture enough value from the use or process of pursuit of this knowledge in their other activities to justify investing in its creation. This argument suggests a major revision in the justification of public support for scientific research and the need for policies to focus on the interaction among all the possible sources of scientific knowledge. Public funding of research might be needed to increase the variety of exploitable knowledge that might eventually find its way into commercial application. For these scholars, the extent to which scientific knowledge can be appropriated, directly or indirectly, makes it necessary to modify or reject the idea that science is a public good.

In recent years, the proportion of total **research and development (R&D) financed by industry** has increased relative to the government share in almost all OECD countries. Industry now funds almost 60 per cent of OECD R&D activities and carries out about 67 per cent of total research (Table 4). At the same time, however, overall growth in R&D spending is declining. In the OECD countries, growth in national R&D spending has been on a downward trend since the late 1980s, and it fell in absolute terms in the early 1990s. R&D expenditures have now levelled off to account for about 2.3 per cent of GDP in the OECD area. Within this slowing R&D effort, it is believed that spending on basic research may be suffering in some countries (although not in the United States where the share of basic research in the overall R&D effort has grown). In some major OECD countries, government funding for basic research is not increasing, and in some important areas it is decreasing. At the same time, the private sector appears to be cutting back on long-term, more generic research projects.

There is also some scepticism as to the ability of the private sector to conduct adequate amounts of truly basic research. In industry, basic research tends to be a search for new knowledge that may be applicable to the needs of a company; it is not usually research driven simply by curiosity or more general demands. It is also a small part of the overall industrial R&D effort. In the United States, for example, industry R&D spending is 70 per cent on development (design, testing, product or process prototypes and pilot plants), 22 per cent on exploratory or applied research and 8 per cent on basic research (IRI, 1995). There are important questions as to whether sufficient scientific knowledge would be generated without government assistance and subsidies. There are calls for more international co-operation in basic research to economise on resources and achieve the scale benefits of joint activities. But in the long term nations that have not invested in the production of science may be unable to sustain advances in the knowledge-based economy.

Table 4. Trends in national R&D spending
Percentages

	By source of funds							
	Business enterprise		Government		Other national sources		Abroad	
	1981	1993	1981	1993	1981	1993	1981	1993
Japan (adjusted)	67.7	73.4	24.9	19.6	7.3	7.0	0.1	0.1
North America	48.4	57.6	49.3	39.6	2.0	2.3		
EU-15	48.7	53.2	46.7	39.7	1.1	1.4	3.5	5.7
Total OECD	51.2	58.8	45.0	36.2	2.4	2.9		
	By sector of performance							
	Business enterprise		Government		Higher education		Private non-profit	
	1981	1993	1981	1993	1981	1993	1981	1993
Japan (adjusted)	66.0	71.1	12.0	10.0	17.6	14.0	4.5	4.9
North America	69.3	70.3	12.6	10.8	15.1	15.7	3.0	3.2
EU-15	62.4	62.6	18.9	16.5	17.4	19.5	1.4	1.4
Total OECD	65.8	67.4	15.0	12.7	16.6	17.1	2.6	2.9

Source: OECD, DSTI, STIU database.

C. Knowledge transmission

The science system is a crucial element in knowledge transmission, particularly the **education and training of scientists and engineers**. In the knowledge-based economy, learning becomes extremely important in determining the fate of individuals, firms and national economies. Human capabilities for learning new skills and applying them are key to absorbing and using new technologies. Properly-trained researchers and technicians are essential for producing and applying both scientific and technological knowledge. The science system, especially universities, is central to educating and training the research workforce for the knowledge-based economy

Data show that the **production of new researchers** in the OECD may be slowing along with lower growth of R&D investments (Table 5). In the 1980s, there was substantial growth in the number of researchers in the OECD area (defined as all those employed directly in R&D in the public and private sectors), almost 40 per cent in 1981-89 or the equivalent of 65 000 to 70 000 new researchers per year. However, this was less rapid than the 50 per cent growth in R&D expenditures in the same period. Both spending and human resource development are proceeding at a slower pace in the 1990s. The growth in researchers in universities and government research institutions has been slower than in the private sector, which employs about 66 per cent of OECD research personnel. Regardless of their sector of employment, these human resources are produced by the science system. Less research in universities, laboratories and industry means fewer careers in science and insufficient development of future scientists and engineers.

In addition to lower research budgets, universities are facing other difficulties. One problem is **providing a broad-based education** to an increasing number of citizens while also directing high-level training through research at the graduate and post-graduate levels. In most OECD countries, there has been a sharp increase in both the number of students and the proportion of young people enrolled in higher education, leading to tensions between educational quantity and quality.

Universities confront the need to continue high-quality research and research training in the context of diminishing resources and more overall student demands. At the same time, there appears to be a divergence developing between marketplace needs for new researchers and the qualifications and orientation of the supply of new doctorates. There is a third problem of gaining the interest of young people in careers in science, which could have serious implications not only for the availability of researchers and engineers, but also for the awareness of the general public with regard to the economic value of science and technology.

Table 5. Trends in total researchers
Full-time equivalent

	Average annual growth rate		Percentage change from preceding year
	1981-85	1985-89	1993/92
United States	3.9	3.6	1.9
Canada	6.8	4.2	2.2
Japan (adjusted)	5.2	4.7	3.2
Australia	6.3	7.3	
North America	4.0	3.6	0.2
EU-15	1.5	4.1	
Total OECD	**3.4**	**4.1**	**1.0**

Source: OECD, DSTI, STIU database.

The science system is thus facing challenges in reconciling its knowledge production role, even more important in the knowledge-based economy, and its knowledge transmission or educational function. Many people believe that the primary mission of the university is educational, reproducing and expanding the stock of individuals that embody the accumulated knowledge and problem-solving skills needed in modern societies. The fact that universities are, to varying degrees among the OECD countries, also involved in the creation of new knowledge may be seen as a by-product or joint product of their educational mission. In practice, the educational mission of universities shapes their approach to conducting research through the assignment of important research roles for students and their participation in technical activities. As universities attempt to find ways around fiscal limitations, there may be substantial variety in the extent to which they maintain the primacy of their educational mission. Resource constraints make it more difficult to maintain the necessary linkages and balance between research and education.

D. Knowledge transfer

The science system plays an important role in transferring and disseminating knowledge throughout the economy. One of the hallmarks of the knowledge-based economy is the recognition that the **diffusion of knowledge** is just as significant as its creation, leading to increased attention to "*knowledge distribution networks*" and "*national systems of innovation*". These are the agents and structures which support the advance and use of knowledge in the economy and the linkages between them. They are crucial to the capacity of a country to diffuse innovations and to absorb and maximise the contribution of technology to production processes and product development.

In this environment, the science system has a major role in creating the enabling knowledge for technological progress and for developing a common cultural basis for the exchange of information. Economies are characterised by different degrees of "*distribution power*" in their ability to transfer knowledge within and across networks of scientific researchers and research institutions. The distribution power of an economy depends partly on the incentives and existence of institutions, such as those of higher education, for distributing knowledge. Effective distribution of knowledge, however, also depends upon investing in the skills for finding and adapting knowledge for use, and in developing bridging units or centres. There are thus choices to be made between investments in the production of, and in the capabilities for diffusing and using, scientific knowledge.

In the knowledge-based economy, the science system must balance not only its roles of knowledge production (research) and knowledge transmission (education and training) but also the third function of transferring knowledge to economic and social actors, especially enterprises, whose role is to exploit such knowledge. All OECD countries are placing emphasis on developing linkages between the science system and the private sector in order to speed knowledge diffusion. As a result, incentives are being given by governments for universities and laboratories to involve industrial partners in the selection and conduct of their research activities.

In the case of higher education, **university/industry collaborations** bring with them opportunities to increase the relevance of the university's educational mission and to stimulate new research directions. They provide a means both for the efficient transfer of economically useful knowledge and for advanced training in skills required by industry. Traditionally, much of the knowledge produced in public facilities and universities has been prohibited from being patented by the private individuals involved in creating it, and salaries and equipment have been paid out of public funds. Now, joint research projects and other linkages are calling heightened attention to economic issues such as exclusive licensing, intellectual property rights, equity ownership, conflict of interest, length of publication delays and commingling of funds.

There are other issues, however, that may create a more profound effect on the contribution of universities to science. Large amounts of industry research funding may induce the participating universities to specialise their efforts in ways that will prove detrimental over the long run to the range and character of research they are able to conduct. An increasing share (as much as 50 per cent in some universities) of the resources allocated to university research is derived from contracts with industry, thus making the universities more and more dependent on the private sector for funding and steering the overall research activity in a more commercial direction. As university/industry collaboration becomes the norm in many areas of basic research, the traditional contribution of academia to the production of scientific knowledge may weaken under the burden of increasing its economic relevance.

There are also concerns that university/industry collaboration is tending to consolidate excellent researchers in a handful of universities or research centres. Collaborative efforts often require geographic proximity and a large base of expertise to establish complementary infrastructure and to assure the transfer of relevant knowledge. Such concentrations of research, whether organised as science parks or simply arising from the concentration of existing industrial research activities, may disadvantage smaller schools or centres. Moreover, concentration of research efforts may constrain the ability of the excluded institutions to offer students contact with high-quality research efforts. However, these concerns may be unfounded in light of the increasing ability for researchers to be linked electronically through information and communications technologies.

The **public or governmental component** of the science system is facing many of the same questions. The structure of research councils is being modified to emphasise strategic areas, to promote synergies between disciplines and to involve the private sector. Industry is being asked to help define the areas in which research, including basic research, should be done. Government laboratories are forming joint ventures with the private sector. In the knowledge-based economy, governments are earmarking more funds for science activities considered to merit priority by virtue of their economic and social relevance (such as information technology and biotechnology). But this may lead government research organisations to be so susceptible to changes in national priorities and needs that it may invalidate or fundamentally alter their research missions.

In addition to forming linkages with industry to further the diffusion of knowledge, universities and laboratories are more frequently asked to directly **contribute to problem solving** in technological investigations. Despite its generic character, the science system has always been important for generating knowledge about fruitful opportunities and practical dead-ends in more applied research and for contributing directly to strategic or commercial outcomes. This problem-solving function is being given more emphasis in the knowledge-based economy. For example, the advent of flexible manufacturing systems has created new demands for scientific insights into materials, production processes and even management. The growing preponderance in economic output of service industries requires scientific knowledge on organisational improvements and networking to sustain productivity advances. Similarly, much of the new information and communication technologies are science-based, and science still has much to offer to help these technologies maximise their contributions to production and employment.

In part because of its increased importance in the knowledge-based economy, the science system finds itself torn between more traditional areas of research and investigations that promise more immediate returns. Many argue that if scientists are to create the knowledge that will generate the new technologies of the next century, they should be encouraged to have their own ideas, not continue with those that industry already has. There should be sufficient scope to allow scientists to set research directions guided by their own curiosity, even when these are not seen as immediately valuable to industry. On the other hand, some of the most important scientific insights have come from the solution of industrial problems. The knowledge-based economy is raising the profile of the science system, but also leading to a more intense probing of its fundamental identity.

E. Government policies

Even though we know the contributions of the science system to the production, transmission and transfer of knowledge, there has not been great progress in measuring the extent of these contributions. A related problem is establishing a standard of accountability for public research funding, a problem that is of growing significance for future government support of the science system. Although there is widespread belief that public funding for scientific research has produced substantial benefits, there is concern with how these benefits may be measured and related to funding levels.

Efforts to **measure the contribution of scientific knowledge** to the economy are difficult for several reasons. First, because most scientific knowledge is freely disclosed, it is hard to trace its use and therefore its benefits as it is employed within private economic activities. Second, the results of scientific investigation are often enabling rather than directly applicable to technological innovation, further obscuring any overt trace of their beneficial impact. Third, new scientific knowledge may save resources that would otherwise be spent in exploring scientific or technological dead-ends and these resource savings are not observed. As a result, cost-benefit analysis, a leading method for evaluation of public investments, is likely to understate the benefits of scientific research.

Efforts to more precisely define and measure the science system are occurring in an era of growing public financial stringency throughout the OECD countries. Current indicators offer little assistance in addressing the overall **impact of science on the economy** or for evaluating how funding allocations should be made between newly developing and established fields of investigation. The need for a better understanding of the contributions of the science system to OECD economies is heightened by debates about the nature of scientific knowledge and the role of governments. Adding to, and complicating, these issues is the evolving role of the science system in diffusing and transferring knowledge to the private sector to enhance economic growth and competitiveness. The challenge for the science system, and for governments, is to adapt to its new role in the knowledge-based economy while not losing sight of the essential need for sufficient levels of pure, generic non-commercial research.

III. INDICATORS FOR THE KNOWLEDGE-BASED ECONOMY

A. Introduction

Economic indicators are measures that summarise at a glance how an economic system is performing. Since their development in the 1930s, and particularly after World War II, the national accounts and measures such as Gross Domestic Product (GDP) have been the standard economic indicators of the OECD countries. Based on detailed censuses that survey economic activity at the establishment level, they measure broad aggregates such as total production, investment, consumption and employment and their rates of change. These traditional indicators guide the policy decisions of governments and those of a broad range of economic actors, including firms, consumers and workers. But to the extent that the knowledge-based economy works differently from traditional economic theory, current indicators may fail to capture fundamental aspects of economic performance and lead to misinformed economic policies.

The **traditional economic indicators** have never been completely satisfactory, mostly because they fail to recognise economic performance beyond the aggregate value of goods and services. Feminists challenge the concept of GDP because it fails to take into account household work. Environmentalists maintain that traditional indicators ignore the costs of growing pollution, the destruction of the ozone layer and the depletion of natural resource endowments. Social critics point out divergence between traditionally measured economic performance and other facets of human welfare. In response to these criticisms, work is proceeding on extending censuses to include a set of household activities, such as cleaning, food preparation and child care. Attempts are being made to "*green*" the national accounts through indicators which track depletion of forests and minerals, and air and water pollution. Novel indicators have also been proposed to measure social welfare more directly, taking into account crime rates, low-income housing, infant mortality, disease and nutrition.

Measuring the performance of the knowledge-based economy may pose a greater challenge. There are systematic obstacles to the creation of intellectual capital accounts to parallel the accounts of conventional fixed capital. At the heart of the knowledge-based economy, knowledge itself is particularly hard to quantify and also to price. We have today only very indirect and partial indicators of growth in the knowledge base itself. An unknown proportion of knowledge is implicit, uncodified and stored only in the minds of individuals. Terrain such as knowledge stocks and flows, knowledge distribution and the relation between knowledge creation and economic performance is still virtually unmapped.

B. Measuring knowledge

The methodology for measuring GDP and most other macroeconomic indicators is specified by the United Nations System of National Accounts, which are structured around input-output tables that map intersectoral transactions. In the national accounts framework, the gross output of each establishment is measured by its market value and summed across sectors and/or regions. Net output by sector or region is obtained by subtracting out intermediate purchases. National GDP is the sum of net outputs across sectors and regions. To the extent that input-output proportions are stable, this double-entry framework translates input statistics into output indicators. Thus employment, strictly speaking an input, can also be interpreted as an indirect indicator of the level of national output.

In the knowledge-based economy, problems emerge with the conceptual framework of the national accounts. Not least is the issue of subsuming knowledge creation into a measurement system designed for traditional goods and services. The pace of change complicates the task of measuring aggregate output and raises questions about the use of input measures as output indicators. Factors which are not sufficiently incorporated into the national accounts framework include qualitative changes in products, the costs of change and rapid product obsolescence.

Knowledge is not a traditional economic input like steel or labour. When traditional inputs are added to the stock of economic resources, the economy grows according to traditional **production function *"recipes"***. For example, more labour can increase GDP by an amount that depends on current labour productivity, or more steel can increase production of autos, housing or tools by predictable amounts according to the current state of the arts. New knowledge, in contrast with steel or labour, affects economic performance by changing the "*recipes*" themselves – it provides product and process options that were previously unavailable.

While new knowledge will generally increase the economy's potential output, the quantity and quality of its impact are not known in advance. There is no production function, no input-output *"recipe"* that tells, even approximately, the effect of a "*unit*" of knowledge on economic performance. Knowledge, unlike conventional capital goods, has no fixed capacity. Depending on entrepreneurship, competition and other economic circumstances, a given new idea can spark enormous change, modest change or no change at all. Increased resources devoted to knowledge creation are likely to augment economic potential, but little is known as to how or how much. Thus the relationship between inputs, knowledge and subsequent outputs are hard to summarise in a standard production function for knowledge.

It is also difficult to stabilise the price of knowledge by the trial and error discipline of repeated transactions in the market. There are no company knowledge records nor census of knowledge creation or exchange. In the absence of knowledge markets, there is a lack of the systematic price information that is required to combine individual knowledge transactions into broader aggregates comparable to traditional economic statistics. In knowledge exchanges, a purchaser has to gauge the value of new information without knowing exactly what it is he is to buy. New knowledge creation is not necessarily a net addition to the economically relevant knowledge stock, since it may render old knowledge obsolete.

There are thus **four principal reasons** why knowledge indicators, however carefully constructed, cannot approximate the systematic comprehensiveness of traditional economic indicators:

◊ *there are no stable formulae or "recipes" for translating inputs into knowledge creation into outputs of knowledge;*

◊ *inputs into knowledge creation are hard to map because there are no knowledge accounts analogous to the traditional national accounts;*

◊ *knowledge lacks a systematic price system that would serve as a basis for aggregating pieces of knowledge that are essentially unique;*

◊ *new knowledge creation is not necessarily a net addition to the stock of knowledge, and obsolescence of units of the knowledge stock is not documented.*

The problem of developing new indicators is itself an indication of the unique character of the knowledge-based economy. Were we faced with trivial modifications to the traditional accounting system, a few add-on measures might suffice. To fully understand the workings of the knowledge-based economy, new economic concepts and measures are required which track phenomena beyond conventional market transactions. In general, improved indicators for the knowledge-based economy are needed for the following tasks:

◊ *measuring knowledge inputs*;

◊ *measuring knowledge stocks and flows*;

◊ *measuring knowledge outputs*;

◊ *measuring knowledge networks; and*

◊ *measuring knowledge and learning.*

C. Measuring knowledge inputs

Students of the knowledge-based economy have to date focused on new knowledge formation or knowledge inputs. The principal knowledge indicators, as collected and standardised by the OECD, are: *i)* expenditures on research and development (R&D); *ii)* employment of engineers and technical personnel; *iii)* patents; and *iv)* international balances of payments for technology (Figure 4). Some of these activities are classified by sponsorship or source of funding (government and industry) and by sector of performance (government, industry, academia). Major emphasis has been placed on the input measures of R&D expenditures and human resources. Despite significant advances in recent years, these traditional indicators still have a number of shortcomings with respect to mapping the knowledge-based economy.

Figure 4. OECD manuals on knowledge indicators

Type of data	Title
R&D	Proposed Standard Practice for Surveys of Research and Experimental Development (*Frascati Manual* 1993)
R&D	Main Definitions and Conventions for the Measurement of Research and Experimental Development (R&D) (A Summary of the *Frascati Manual* 1993)
Technology balance of payments	Proposed Standard Method of Compiling and Interpreting Technology Balance of Payments Data (*TBP Manual* 1990)
Innovation	OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data (*Oslo Manual* 1992)
Patents	Using Patent Data as Science and Technology Indicators (*Patent Manual* 1994)
Human resources	The Measurement of Human Resources Devoted to S&T (*Canberra Manual* 1995)

Indicators of **R&D expenditures** show direct efforts to enlarge the knowledge base and inputs into the search for knowledge. Indicators relating to research personnel approximate the amount of problem solving involved in knowledge production. But only a small fraction of all inputs into knowledge creation are attributable to formal R&D expenditures and official research personnel. Successful R&D draws on ideas from many different sources, including informal professional exchanges, users' experiences and suggestions from the shop floor. In addition, current indicators count formal R&D conducted by the public sector, academia and large manufacturing firms, and tend to understate research expenditures by small firms and service-sector enterprises. As data collection improves, the importance of the services sector to R&D and innovation is only now being fully recognised.

Patents, since they represent ideas themselves, are the closest to direct indicators of knowledge formation; of all the traditional knowledge indicators, patents most directly measure knowledge outputs (rather than inputs). Patent data have certain advantages in that most countries have national patent systems organised on centralised databases, the data cover almost all technological fields, and patent documents contain a large amount of information concerning the invention, technology, inventor, etc. There are several ways to analyse patent data, including categorising patents by geographic area and industrial product group. However, differences in national patenting systems introduce bias which make comparisons difficult. In general, not all new applications of knowledge are patented and not all patents are equally significant. Patents also represent practical applications of specific ideas rather than more general concepts or advances in knowledge.

The **technology balance of payments** measures international movements of technical knowledge through payments of licensing fees and other direct "*purchases*" of knowledge, and thus is more appropriately a flow measure than an input measure. But there is no claim that the technology balance of payments measures the full flow of technical knowledge between any two countries. International transfers of knowledge through employment of foreign personnel, consulting services, foreign direct investment or intra-firm transfers are important avenues of diffusion that are not factored into these indicators. International joint ventures and co-operative research agreements are also instrumental in the global diffusion of knowledge.

D. Measuring knowledge stocks and flows

In order to improve the measurement of the evolution and performance of the knowledge-based economy, indicators are needed of the stocks and flows of knowledge. It is much easier to measure inputs into the production of knowledge than the stock itself and related movements. In the case of traditional economic indicators, the transmission of goods and services from one individual or organisation to another generally involves payment of money, which provides a "*tracer*". Knowledge flows often don't involve money at all, so that alternative "*markers*" must be developed to trace the development and diffusion of knowledge.

Measuring the stock of physical capital available to an economy is an awesome task, so that measuring the **stock of knowledge capital** would seem almost impossible. Yet measuring knowledge stocks could be based on current science and technology indicators if techniques were developed for dealing with obsolescence. For example, annual R&D inputs could be accumulated for various countries and industries and then amortised using assumptions concerning depreciation rates. In this way, measures of R&D stock relative to production have been used to estimate rates of return to R&D investment. Similarly, stocks of R&D personnel could be estimated based on annual increases in researchers in particular fields, depreciated by data on personnel movements and occupational mobility. The patent stock might be approximated using data on use and expiration of periods of exclusive rights.

A more difficult challenge is measuring the **flows of knowledge**, or the proportion of knowledge stock which enters into the economy during some time period. Two proxy indicators are most frequently used to measure knowledge flows: *i)* embodied diffusion, or the introduction into production processes of machinery, equipment and components that incorporate new technology; and *ii)* disembodied diffusion, or the transmission of knowledge, technical expertise or technology in the form of patents, licences or know-how.

Overall **flows of embodied knowledge**, particularly embodied technology or R&D, can be measured using input-output techniques. Technology flow matrices have been constructed as indicators of inter-industry flows of R&D embodied in intermediate and capital goods. This methodology allows separation of the equipment-embodied technology used by a particular industry into the technology generated by the industry itself and the technology acquired through purchases. In this way, estimates can be made of the proportions of R&D stock which flow to other industries and the extent to which industries are sources of embodied knowledge inputs (Table 6). Analysis of embodied technology diffusion shows that inter-sectoral flows vary by country. Countries also differ in the amount of embodied technology acquired from abroad *vs.* that purchased domestically (Sakurai *et al.*, 1996).

Table 6. Measuring embodied technology

	Direct R&D intensities			Total technology intensities[1]		
	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

1. Including embodied or acquired technology.
Source: OECD, DSTI, STAN database.

Micro-level analyses of embodied knowledge flows focus on the diffusion and use of specific technologies in different sectors of the economy – an area of analysis which needs more standardisation across countries in order to allow international comparisons. Studies attempting to compare the diffusion of microelectronics in OECD countries have encountered severe statistical problems in defining the technologies, gathering data on use and calculating the share of total investment (Vickery, 1987). Existing comparative data are sketchy; they show generally that Japan and Sweden have the most widespread use of advanced manufacturing technologies (AMT), followed by Germany and Italy who have profited from AMT in their motor vehicle and mechanical engineering sectors. Industry in the United States uses relatively more of other types of computer-based engineering applications (OECD, 1995*b*).

More is known about technology diffusion patterns in individual countries. Canadian surveys, for example, have asked manufacturing firms about their use of 22 advanced manufacturing technologies, including computer-aided design and engineering (CAD/CAE), computer integrated manufacturing (CIM), flexible manufacturing systems, robotics, automated inspection equipment and artificial intelligence systems. Approximately 48 per cent of Canadian firms use these technologies, mostly in the area of inspection and communications. The attempt to relate technology use to performance showed that technology-using firms tended to have higher labour productivity and to pay higher wages than non-users (Baldwin *et al.*, 1995).

Information technology indicators are being developed which focus on the diffusion and use of information technologies – computers, software, networks – by businesses and households. These measures of technology flows, and factors facilitating and impeding such flows, such as pricing, give an indication of the rapid growth of the information society. For example, the OECD is compiling indicators of the number of personal computers, CD-ROMs, fax machines and modems per household in the OECD countries. Data show that the use of personal computers has more than doubled in the last decade, with about 37 per cent of US households having computers compared to 24 per cent in the United Kingdom and 12 per cent in Japan (Table 7).

Table 7. Diffusion of information technologies, 1994
Percentage of total households

	United States	Japan	United Kingdom	Germany	France
User terminals					
Personal computer	37	12	24	28	15
Video cassette recorder	88	73	84	65	69
Video game	42		19	8	20
Fax		8	2	4	3
PC modem	15		4	3	1
Network infrastructure					
Digital main lines (93)	65	72	75	37	86
House with cable	65		4	47	9
House passed by cable	83		16	56	23
House with satellite		27	11	20	2

Source: OECD, based on various sources, mainly ITU, EITO and Japan's Economic Planning Agency.

The knowledge-based economy is an interactive economy at both the national and international levels as illustrated by emerging indicators of computer and communications network infrastructure. Such measures show the ratio of households and businesses with outside computer linkages, cable connections and satellite services. More work is needed on indicators by country and region of the development of the Internet, the world-wide web of computer networks; these include host penetration, network connections, leased line business access, dial-up services and price baskets. Growth in the number of computers hooked to the Internet has been phenomenal – from 1 000 in 1984 to 100 000 in 1989 to over 4.8 million in 1995. It is estimated that the number of Internet users (as opposed to official host connections) exceeded 30 million in 1995 (OECD, 1995*b*).

Flows of disembodied knowledge are most often measured through citation analysis. In scholarly journals and patent applications, it is the practice that users of knowledge and ideas cite their sources. This makes it possible to map the interconnections among ideas in specialised areas. For example, the *Science Citation Index* provides a database for exploring inter- and intra-disciplinary flows of knowledge in the realm of basic research. Attempts have been made to map the interdependence of scientific ideas using a citation index (Small and Garfield, 1985; Leontief, 1993). In the future, computer capabilities may make it possible to scan and analyse enormous volumes of text, flagging complex similarities and differences and enabling us to identify knowledge flows beyond the areas where formal citation is practised.

Others have traced the linkages among areas of applied technical knowledge through patent citations, which are considered carriers of the R&D performed in the originating industry (Table 8). Based on a concordance of US patent classes and related research, input-output matrices have been constructed of US industry with the rows being the generating industry, the columns the user industry and the diagonal elements the intramural use of process technology. The patent data show that about 75 per cent of industrial R&D flowed to users outside the originating industry (Scherer, 1989). Similarly, improved data on international patent citations can help track technology flows on a global basis as could further refinements of technology balance of payments measures. But while the amount of knowledge subject to formal citation requirements includes the entire content of scientific literature and all patented ideas, these areas are only a limited part of the modern economy's knowledge base.

Table 8. University share of patents in technologies relevant to industry

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, N. and R.R. Nelson (1994), “American Universities and Technical Advance in Industry”, *Research Policy,* Vol. 23, No. 3.

E. Measuring knowledge outputs

The standard R&D-related measures do not necessarily show successful implementation or the amount and quality of outputs. Nevertheless, these input and flow indicators form the starting point for measuring knowledge outputs and for gauging social and private rates of return to knowledge investments. Rough indicators have been developed which translate certain knowledge inputs into knowledge outputs in order to describe and compare the economic performance of countries. These measures tend to categorise industrial sectors or parts of the workforce as more or less intensive in R&D, knowledge or information. The measures are based on the assumption that certain knowledge-intensive sectors play a key role in the long-run performance of countries by producing spill-over benefits, providing high-skill and high-wage employment and generating higher returns to capital and labour.

For example, the OECD maintains a classification of high-technology, medium-technology and low-technology manufacturing sectors based on their relative R&D expenditures or **R&D intensity** (ratio of R&D expenditures to gross output). Computers, communications, semiconductors, pharmaceuticals and aerospace are among the high-technology and high-growth OECD sectors and are estimated to account for about 20 per cent of manufacturing production. Output, employment and trade profiles can be drawn for countries, based on the relative role of their high-, medium- and low-technology sectors. However, current indicators of R&D intensity are now confined to manufacturing sectors and have not been developed for the fast-growing service portion of OECD economies. Nor do these indicators take into account R&D which may be purchased from other industrial sectors, either embodied in new equipment and inputs or disembodied in the form of patents and licences. More complete indicators of total R&D intensity, including both direct R&D efforts and acquired R&D, need to be developed (Table 9).

Table 9. Calculating industrial R&D intensity

Period 1970-80[1]	Period 1980-95[2]
High technology	**High technology**
1. Aerospace	1. Aerospace
2. Computers, office machinery	2. Computers, office machinery
3. Pharmaceuticals	3. Electronics-communications
4. Electronics-communications	4. Pharmaceuticals
5. Scientific instruments	**Medium-high technology**
6. Electrical machinery	5. Scientific instruments
Medium technology	6. Electronic machinery
7. Motor vehicles	7. Motor vehicles
8. Chemicals	8. Chemicals
9. Non-electrical machinery	9. Non-electrical machinery
10. Rubber and plastic equipment	**Medium-low technology**
11. Other manufacturing	10. Shipbuilding
Low technology	11. Rubber and plastic equipment
12. Other transport equipment	12. Other transport equipment
13. Stone, clay and glass	13. Stone, clay and glass
14. Petroleum refining	14. Non-ferrous metals
15. Shipbuilding	15. Other manufacturing
16. Non-ferrous metals	16. Fabricated metal products
17. Ferrous metals	**Low technology**
18. Fabricated metal products	17. Petroleum refining
19. Paper, printing	18. Ferrous metals
20. Food, beverages	19. Paper, printing
21. Wood and furniture	20. Textiles and clothing
22. Textiles and clothing	21. Wood and furniture

1. Based on direct R&D intensity: ratio of R&D expenditures to output in 22 manufacturing sectors in 11 OECD countries.
2. Based on direct and indirect R&D intensity: ratio of R&D expenditures and embodied technology flows per unit of output in 22 manufacturing sectors in 10 OECD countries.

Source: OECD, DSTI, STAN database.

In a similar vein, early studies in the United States constructed a statistical profile of a group of industries collectively dubbed the knowledge industries, essentially education, communications media, computers and information services. These knowledge industries were found to account for some 29 per cent of GNP and 32 per cent of the workforce in the United States in 1958 (Machlup, 1962). A later study showed that the proportion of knowledge production in the (adjusted) GNP increased from 29 per cent in 1958 to 34 per cent in 1980 (Rubin and Huber, 1984). A US government study included a similar list of sectors and added a secondary information sector which provided inputs to the manufacturing process for non-information products; the entire information sector was estimated to account for over 46 per cent of GNP in 1974, updated to 49 per cent in 1981 (US Department of Commerce, 1977).

A related methodological approach is to use employment and occupational data to categorise jobs according to their R&D, knowledge or information content. One early study used occupational classifications to assign jobs an informational component; information workers included those in the primary information sector, a large portion of the public bureaucracy and a few in remaining sectors. According to this study, information activities accounted for 47 per cent of GNP in the United States in 1967 (Porat, 1977). Recent Canadian studies have measured the knowledge-intensity of the manufacturing and services sectors by the proportion of total weeks worked in an industry by workers with university degrees. High-knowledge sectors include electronic products, health services and business services, which were found to have expanded since the early 1970s while output in medium- and low-knowledge industries has declined (Gera and Mang, 1995).

Occupational data has been used to estimate the proportion of economic effort devoted to creating, implementing and administering change. One study finds a variation among sectors in the proportion of non-production workers in total employment, ranging from as high as 85 per cent in sectors normally seen as high-technology to 20 per cent or less in slower-growth, more traditional industries (Carter, 1994). There appears to be a close connection between the proportion of non-production workers and the rate of change in a sector; the major function of non-production workers may be to create or react to change. In these sectors, more workers are engaged in the direct search for new products and processes, in implementing new technology on the shop floor and in opening new markets and reshaping organisations to accommodate changes in production. As a result, a growing proportion of costs are most likely the costs of change rather than the costs of production.

Indicators are needed which go beyond measuring R&D and knowledge intensity to assessing **social and private rates of return** (Table 10). Rates of return are generally estimated by computing the benefits (including discounted future benefits) *vs.* the costs of innovation. For example, early studies of the agricultural sector showed that public research was undervalued and that private investment did not naturally respond to the prospect of large returns to scientific research. One analysis estimated that social returns of 700 per cent had been realised from US$2 million in public and private investments in the development of hybrid corn from 1910-55 (Griliches, 1958). In another, the median private return to the innovations studied was 25 per cent, while the median social rate of return was 56 per cent (Mansfield *et al.*, 1977). A recent review of macro-level econometric studies of the United States concluded that the average rate of return to an innovation is between 20 and 30 per cent, while the social rate of return is closer to 50 per cent (Nadiri, 1993).

Table 10. Private and social rates of return to private R&D

Author (year)	Estimated rates of return	
	Private	Social
Nadiri (1993)	20-30	50
Mansfield (1977)	25	56
Terleckyj (1974)	29	48-78
Sveikauskas (1981)	7-25	50
Goto and Suzuki (1989)	26	80
Bernstein and Nadiri (1988)	10-27	11-111
Scherer (1982, 1984)	29-43	64-147
Bernstein and Nadiri (1991)	15-28	20-110

1. Nadiri, I. (1993), "Innovations and Technological Spillovers", NBER Working Paper No. 4423, Cambridge, MA.
2. Mansfield, E., J. Rapoport, A. Romeo, S. Wagner and G. Beardsley (1977), "Social and Private Rates of Return from Industrial Innovations", *Quarterly Journal of Economics*, Vol. 77, pp. 221-240.
3. Terleckyj, N. (1974), *Effects of R&D on the Productivity Growth of Industries: An Explorators Study*, National Planning Association, Washington, DC.
4. Sveikauskas, L. (1981), "Technology Inputs and Multifactor Productivity Growth", *Review of Economics and Statistics*, Vol. 63, pp. 275-282.
5. Goto, A. and K. Suzuki (1989), "R&D Capital, Rate of Return on R&D Investment and Spillover of R&D in Japanese Manufacturing Industries", *Review of Economics and Statistics*, Vol. 71, pp. 555-564.
6. Bernstein, J. and I. Nadiri (1988), "Interindustry Spillovers, Rates of Return and Production in High-tech Industries", *American Economic Review: Papers and Proceedings*, Vol. 78, pp. 429-434.
7. Scherer, F. (1984), "Using Linked Patent and R&D Data to Measure Interindustry Technology Flows", in *R&D, Patents and Productivity*, University of Chicago Press, pp. 417-464.
8. Bernstein, J. and I. Nadiri (1991), "Product Demand, Cost of Production, Spillovers, and the Social Rate of Return to R&D", NBER Working Paper No. 3625, Cambridge, MA.

Source: US Council of Economic Advisors (1995), *Supporting Research and Development to Promote Economic Growth: The Federal Government's Role*, October.

The importance of both innovation and technology for productivity growth and long-term economic growth is poorly understood; indicators are needed which capture the impacts of technological progress on the economy and employment. Measuring rates of return to R&D may be particularly challenging in the services sector where productivity is especially difficult to measure. Regression analysis can be used to estimate the returns to R&D in terms of total factor productivity growth. This is being attempted for both the manufacturing and services sectors and for performed and acquired (or embodied) R&D. On average, across ten OECD countries, the estimated rate of return of embodied R&D in terms of manufacturing productivity growth has been estimated at 15 per cent and in the services sector at over 100 per cent in the 1980s, illustrating the importance of technology diffusion (Sakurai *et al.*, 1996).

Indicators are also being developed of rates of return to R&D expenditures and acquisitions at the firm- or micro-level. In one study, the top R&D executives of major American firms were polled about the proportion of the firm's new products and processes that could not have been developed (without substantial delay) in the absence of academic research (Table 11). Extrapolating the results from this survey to the academic research investment and returns from new products and processes, a social rate of return of 28 per cent was calculated (Mansfield, 1991). Measuring financial return to a firm's own R&D involves assessing the fraction of sales derived from new products and estimates of cost savings from new process developments. Other measures are the projected future sales and income from R&D projects in the pipeline; customer or consumer evaluation of product quality and reliability; estimates of the effectiveness of the transfer of new technology to manufacturing lines; and percentage of research project outcomes published in technical reports (Tipping *et al.*, 1995).

Table 11. New innovations based on recent academic research
1975-85

Industry	Percentage that could not have been developed (without substantial delay) without recent academic research		Additional percentage developed with substantial aid from recent academic research	
	Products	Processes	Products	Processes
Information processing	11	11	17	16
Electronics	6	3	3	4
Chemicals	4	2	4	4
Instruments	16	2	5	1
Pharmaceuticals	27	29	17	8
Metals	13	12	9	9
Petroleum	1	1	1	1
Average	**11**	**8**	**8**	**6**

Source: Mansfield, E. (1991), "Academic Research and Industrial Innovation", *Research Policy*, Vol. 20.

F. Measuring knowledge networks

Current knowledge indicators – which are primarily measures of knowledge inputs and codified knowledge flows – are not adequate to describe the dynamic system of knowledge development and distribution which is at the heart of the knowledge-based economy. Stocks and flows of more **tacit forms of knowledge**, such as learning that depends on conversation, demonstration and observation, cannot be traced through these indicators. New indicators are needed that capture the innovation process and the distribution of knowledge among key actors and institutions in the economy. This essentially involves measuring "*national innovation systems*", including the ability of countries and systems to distribute knowledge among different actors and institutions.

Such indicators of knowledge creation and distribution are proceeding at the level of the individual firm through the vehicle of **innovation surveys**. These surveys capture information about the factors affecting the propensity of firms to innovate and how knowledge and innovation are diffused in the economy. Analyses explain the propensity to innovate in terms of traditional inputs such as investments in R&D, use of skilled labour and use of new domestic and imported equipment as well as other factors such as profitability, regulatory systems and institutional networking. Surveys have focused on "*geographical clustering*" or the effects of geographic location and the locus of individual plants on innovation (DeBresson, 1989). They have also examined "*industrial clusters*" or the interlinkages between user and supplier sectors or those based on key technologies and the effect on enterprise innovation (Roelandt *et al.*, 1995).

More comprehensive surveys, such as the Community Innovation Survey (CIS) and the PACE Project, aim at compiling complete firm-level innovation data sets. The CIS, which was implemented in 1993, covers all European Union countries and has a preliminary database of 40 000 manufacturing firms. Through this survey, data is being developed on firm expenditures on activities related to the development of new products, including R&D, training, design, market exploration, equipment acquisition and tooling-up; production and sales of incrementally and radically new products; sources of information relevant to information; R&D performance and technological collaboration; and perceptions of obstacles and stimuli to innovation. The CIS contains several questions on technological co-operation and information flows and may provide the basis for linking the general innovation performance of firms with their patterns of technological collaboration and information use.

The PACE Project (Policies, Appropriability and Competitiveness for European Enterprises Project), which covers large R&D-performing firms in Europe, asks a similar set of questions, including the types of information required in the development and introduction of technological change. The survey asked firms about the goals of innovation, external sources of knowledge, public research, methods to protect innovations, government programmes to support innovation and barriers to profiting from innovation. Initial findings show the most important external source of knowledge to be technical analysis of competitors' products. Joint ventures are important sources of knowledge in sectors where R&D projects are expensive and complex. In most countries, public research was considered an important part of the national system of innovation (MERIT, 1995).

Based in part on these innovation surveys, efforts are just beginning to map national innovation systems and the **knowledge distribution power** of economies through analysing two main flows: *i)* the distribution of knowledge among universities, public research institutions and industry; and *ii)* the distribution of knowledge within a market between suppliers and users (Smith, 1995). This systems approach provides information on flows, such as the proportion of knowledge, especially in basic science, which is transferred among researchers; the proportion of academic and public knowledge that is accessible to and used by industrial innovators; and the extent and rate of diffusion of new knowledge and technologies in industry (Table 12). Data is being collected on a national basis which allows us to measure these flows between different actors and institutions in a country's innovation system, such as has recently been done for Norway (Smith *et al.*, 1995).

Table 12. Mapping the distribution of knowledge

Percentage of business enterprises using external sources of knowledge, Netherlands, 1992

Cluster	Acquired knowledge total	Outsourcing of R&D to public R&D institutes	Outsourcing of R&D to private R&D institutes	Outsourcing of R&D to other companies	Informal contacts	Recruitment of qualified personnel
Construction	46	9	6	12	15	12
Chemical industry	49	19	6	17	23	8
Services						
Commercial	38	8	5	5	16	14
Non-commercial	48	21	11	5	19	23
Energy	78	44	29	23	20	12
Health	49	27	7	7	20	6
Agro-food	55	18	9	16	26	7
Manufacturing						
Metal-electro.	46	8	7	8	20	15
Furniture	53	23	8	23	22	4
Paper	42	14	5	18	18	8
Textiles	43	17	5	12	18	6
Other	66	28	-	11	44	23
Multimedia	32	1	3	2	13	9
Transports	27	9	5	1	11	9
Total	42	10	6	8	17	13

Source: Hertog, P. and P. Boekholt (1995), "Assessing Diffusion Capabilities of National Systems of Innovation: Case Study of the Netherlands", paper presented at the OECD Workshop on National Innovation Systems, Vienna, 6 October.

Indicators of interactions between the public, private and academic sectors are being explored which would measure **institutional capabilities to transfer knowledge** and include:

◊ number, specialisation and funding of co-operative research projects among universities, public research institutes and industry;

◊ number, specialisation and funding of university-industry research centres;

◊ number and technological specialisation of co-patenting and co-publication among universities, public research institutes and industry;

◊ personnel mobility and patterns of recruitment among universities, public research institutes and industry; and

◊ methods of access of firms to findings of university research, including publications, conferences, trained staff, informal contacts, temporary exchanges and contract or joint R&D.

Surveys are also being implemented to measure market interactions, or the **capabilities of the private sector** in transferring knowledge, based on:

◊ research co-operation within the enterprise sector, including number and relative importance of research joint ventures, technological collaboration or large co-operation programmes;

◊ participation of firms in industry-wide standardisation activities and informal research networks;

◊ rates of mobility of researchers across firms and sectors;

◊ methods of access of firms to findings of other firms and sectors, including published information, joint research, cross-licencing or purchase of licenses and patents; and

◊ degree of internationalisation, by examining these indicators at the international as well as the national level.

G. Measuring knowledge and learning

The advent of the knowledge-based economy raises questions about the efficiency and equity of education and training in what must also be a "*learning economy*". Economists have traditionally measured the development of human capital in terms of proxies, such as years of education or experience. Such measures do not reflect the quality of education or learning nor the economic returns to investment in education and training. The existence of a large non-formal sector in which individuals are undergoing on-the-job training poses significant measurement problems and reflects the difficulties involved in tracking more tacit forms of learning and knowledge transfer. To fill in some of these measurement gaps, the OECD has recently initiated a project to develop "*human capital indicators*", aimed particularly at measuring private and social rates of return to investment in education and training.

One approach to assessing **social rates of return** is to measure the impact of education expenditure and attainment levels in society at large on economic growth. A study of 29 countries found education accounting for up to a quarter of economic growth (Psacharopoulos, 1984). Another study of 24 countries (seven of which were OECD countries) reached similar conclusions (OECD, 1994). The finding that human capital investment can generate economic growth was shown in a study measuring the percentage of the working age population attending secondary school and the effects on productivity levels; it was found to be significant for the entire sample of countries and a sub-sample of 22 OECD countries (Mankiw *et al.*, 1992).

Measuring **private rates of return** has tended to look at changes in human skills and competencies at the individual or firm level and the impacts on firm performance. A number of studies have been conducted of the effects of on-the-job training on wages and productivity; these point to substantial positive effects on wages, typically ranging from 5 to 15 per cent, as well as positive impacts on productivity (OECD, 1996*c*). One analysis of a large US manufacturing firm revealed that an increase in training expenditure yielded a rate of return for the company of 20 to 35 per cent (Bartel, 1995). Other studies have found that the beneficial effects of enterprise training depend on collateral investment in technology (Lynch, 1995).

More **micro-level or firm-level indicators** are needed to establish linkages between enterprise training, its impact on human capital and skill formation and the effects on firm performance (Table 13). While improvements have been made in the collection of data on vocational training in enterprises, firm surveys are needed to assess firm expenditure on training by type of training (general, technical, management), by staff category (worker, researcher, manager) and by type of firm (sector, size).

Table 13. Measuring job-related training

Percentage of the employed population in job-related training

		Age groups			
	Year	25-34	35-44	45-64	Total
During the 12-month period preceding the survey					
Canada	1991	32	35	23	30
Finland	1990	51	49	40	46
France	1992	43	27	11	27
Germany	1991	33	29	21	27
Norway	1991	40	42	30	37
Sweden	1993	36	33	41	36
Switzerland	1993	42	41	34	38
United States	1991	37	43	33	38
During the 4-week period preceding the survey					
Denmark	1991	17	17	11	15
Ireland	1992	5	4	2	4
Spain	1992	6	2	1	3
United Kingdom	1992	12	12	8	11

Source: OECD (1995), *Education and Employment*, Paris.

A related research effort should be devoted to identifying the human resources and critical skills required by industry to better match supply and demand for human capital. Data is now being collected by the OECD on employment by industry and occupation, which may be used in the future to track shifts in employment within and among industries, examine the evolution of skilled and unskilled employment over time, and identify factors which underlie job gains and losses in particular sectors. Also relevant is how technological and organisational change at the firm level (*e.g.* just-in-time management, flexible manufacturing, outsourcing, downsizing, etc.) may change demand for human resources. The OECD is initiating Flexible Enterprise Surveys in various Member countries to assess what developments might be expected in labour markets with respect to qualification requirements, staff training, average tenure and patterns of employment.

H. Conclusions

Our understanding of what is happening in OECD economies is constrained by the extent and quality of the available indicators. While advances are being made in economic theory and methodologies, these will not be fruitful unless they are applied to the right data. Traditional national accounts frameworks were designed in an earlier era when the economy was simpler and the role of knowledge and technical change was not fully acknowledged. As a result, this measurement framework is not offering reasonable explanations for trends in economic growth, productivity and employment. The contributions of R&D to productivity growth, the economic effects of the computer and information networks, the role of tacit learning and formal and informal economic interactions are among the phenomena which at present elude us.

To fill these gaps, work must first continue on improvements, extensions and new combinations of current knowledge indicators relating to R&D expenditures and research personnel, particularly to develop a clearer picture of the research and innovation role of the services sector. But indicators for the knowledge-based economy must go beyond measuring knowledge inputs to measuring stocks and flows, rates of return and distribution networks. The central role of learning also underlines the need for new indicators of human capital, training and labour requirements. Fruitful areas for further indicator development in the near term include:

◊ **Knowledge stocks and flows** – Statistical techniques could be developed to estimate knowledge stocks based on current R&D input and flow measures. Development of knowledge flow indicators would yield better measures of the R&D and knowledge intensity of industries and economies. This includes more extensive and comparable indicators of the acquisition and use of different types of technology by industry, particularly information technologies. More creative analysis of existing patent data at the national and international levels could help trace flows of disembodied knowledge.

◊ **Knowledge rates of return** – In order to assess knowledge outputs and evaluate the performance of knowledge-based economies, priority should be placed on developing improved indicators of the private and social rates of return to R&D and other knowledge inputs. This includes measuring returns to individuals, firms and societies in terms of employment, output, productivity and competitiveness, and could be based on both macro-level econometric analyses and firm-level surveys. One of the great challenges is to develop indicators and methodologies for gauging the impact of technology on productivity and economic growth.

◊ **Knowledge networks** – Given the importance of tacit as well as codified knowledge, diffusion as well as creation of knowledge, and *know-how* and *know-who* in the knowledge-based economy, indicators of the knowledge distribution power and other characteristics of innovation systems are key. Firm-level innovation surveys, as well as other measurement approaches, need to be developed to better characterise innovation processes and interactions among firms and a range of institutional actors in the economy.

◊ **Knowledge and learning** – Human capital indicators, particularly those relating to education and employment, are central measures for the knowledge-based economy. Measuring the private and social rates of return to investments in education and training will help point to means of enhancing the learning capacity of individuals and firms. Micro-level firm indicators on human resource requirements, employment and occupational mobility will help better match supply and demand for skills in the labour market.

REFERENCES

ABRAMOWITZ, M. (1989), *Thinking about Growth*, Cambridge University Press, Cambridge.

BALDWIN, J., B. DIVERTY and J. JOHNSON (1995), "Success, Innovation, Technology and Human Resource Strategies – An Interactive System", paper presented at the Conference on "The Effects of Technology and Innovation on Firm Performance and Employment", Washington, DC, 1-2 May.

BARTEL, A. (1995), "Training, Wage Growth and Job Performance: Evidence from a Company Database", *Journal of Labor Economics*, Vol. 13.

BECK, N. (1992), *Shifting Gears: Thriving in the New Economy*, Harper Collins Publishers, Toronto.

CARTER, A.P. (1994), "Production Workers, Metainvestment and the Pace of Change", paper presented at the meetings of the International J.A. Schumpeter Society, Munster, August.

DAVID, P. and D. FORAY (1995), "Accessing and Expanding the Science and Technology Knowledge Base", *STI Review*, No. 16, OECD, Paris.

DeBRESSON, C. (1989), "Breeding Innovation Clusters: A Source of Dynamic Development", *World Development*, Vol. 17, No. 1.

EUROPEAN INNOVATION MONITORING SYSTEM (EIMS) (1994), *Public Policies to Support Tacit Knowledge Transfer*, Proceedings of SPRINT/EIMS Policy Workshop, May 1993.

GERA, S. and K. MANG (1995), "Changing Canadian Industrial Structure Shifts in Output Growth", paper presented at the OECD Workshop on "Technology, Productivity and Employment: Macroeconomic and Sectoral Evidence", 19-20 June.

GIBBONS, M., C. LIMOGE, H. NOWOTNY, S. SCHWARTZMAN, P. SCOTT and M. TROW (1994), *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*, Sage Publications, London.

GRILICHES, Z. (1958), "Research Costs and Social Returns: Hybrid Corn and Related Innovations", *Journal of Political Economy*, October.

GROSSMAN, G.M. and E. HELPMAN (1994), "Endogenous Innovation in the Theory of Growth", *Journal of Economic Perspectives*, Vol. 8, No. 1.

INDUSTRIAL RESEARCH INSTITUTE (IRI) (1995), *Trends in Industrial Research Spending in the United States*, Washington, DC.

KATZ, L.P. and K.M. MURPHY (1992), "Changes in Relative Wages 1963-1987: Supply and Demand Factors", *Quarterly Journal of Economics*, February.

KRUEGER, R.B. (1993), "How Computers have Changed the Wage Structure: Evidence from Micro-Data, 1984-89", *Quarterly Journal of Economics*, February.

LAURITZEN, F. (1996), “Technology, Education and Employment”, in *Employment and Growth in the Knowledge-based Economy*, Proceedings of the Conference on “Employment and Growth in the Knowledge-based Economy”, Copenhagen, November 1994.

LEONTIEF, W. (1993), “Input-Output Analysis of the Structure of Scientific Knowledge”, paper presented at the Tenth International Conference on “Input-Output Techniques”, Seville.

LYNCH, L.M. (1995), “Employer-provided Training in the Manufacturing Sector: First Results from the United States”, paper presented at the the World Bank Conference on “Enterprise Training Strategies and Productivity”, Washington, DC, June.

LUNDVALL, B. and B. JOHNSON (1994), “The Learning Economy”, *Journal of Industry Studies*, Vol. 1, No. 2.

MACHLUP, F. (1962), *The Production and Distribution of Knowledge in the United States*, Princeton University Press, Princeton, NJ.

MANKIW, G., D. ROMER and D. WEIL (1992), “A Contribution to the Structure of Economic Growth”, *Quarterly Journal of Economics*, Vol. 106.

MANSFIELD, E. (1991), “Academic Research and Industrial Innovation”, *Research Policy*, Vol. 20.

MANSFIELD, E., J. RAPOPORT, A. ROMEO, S. WAGNER and G. BEARDSLEY (1977), “Social and Private Rates of Return from Industrial Innovations, *Quarterly Journal of Economics*, Vol. 77.

MERIT (1995), *PACE Report: Innovation Strategies of Europe's Largest Industrial Firms*, report prepared for the SPRINT Programme, European Commission.

NADIRI, I. (1993), “Innovations and Technological Spillovers”, NBER Working Paper No. 4423, Cambridge, MA.

OECD (1994), *The OECD Jobs Study: Evidence and Explanations*, Paris.

OECD (1995*a*), *Industry and Technology: Scoreboard of Indicators*, Paris.

OECD (1995*b*), *Information Technology Outlook*, Paris.

OECD (1996*a*), *Employment and Growth in the Knowledge-based Economy*, Paris.

OECD (1996*b*), *Technology, Productivity and Job Creation*, Paris.

OECD (1996*c*), *Transitions to Learning Economies and Societies*, Paris.

PORAT, M. (1977), *The Information Economy: Definition and Measurement*, US Government Printing Office, Washington, DC.

PSACHARAOPOULOS, G. (1984), “The Contribution of Education to Economic Growth”, in J.W. Kendrick (ed.), *International Comparisons of Productivity and Causes of the Slowdown*, Ballinger Publishing Co., Cambridge.

ROELANDT, T., P. BOEKHOLT, P. DEN HERTOG and H. VAN DER GAAG (1995), “Cluster Analysis as a Reduced Scale Model for the National Innovation System”, paper presented at the OECD Workshop on “National Innovation Systems”, Vienna, 6 October.

ROMER, P. (1994), The Origins of Endogenous Growth, *The Journal of Economic Perspectives*, Vol. 8.

RUBIN, M.R. and M.T. HUBER (1984), *The Knowledge Industry in the United States, 1960-1980*, Princeton University Press, Princeton, NJ.

SAKURAI, N., G. PAPACONSTANTINOU and E. IOANNIDIS (1996), "The Impact of R&D and Technology Diffusion on Productivity Growth: Evidence from Ten OECD Countries in the 1970s and 1980s", *STI Working Papers 1996/2*, OECD, Paris.

SCHERER, F. (1989), "Inter-Industry Technology Flows in the United States", in F. Scherer (ed.) *Innovation and Growth: Schumpeterian Perspectives*, MIT, Cambridge.

SMALL, H. and E. GARFIELD (1985), "The Geography of Science: Disciplinary and National Mappings", *Journal of Information Science*, Vol. 11.

SMITH, K. (1995), "Interactions in Knowledge Systems: Foundations, Policy Implications and Empirical Methods", *STI Review*, No. 16, OECD, Paris.

SMITH, K., E. DIETRICHS and S. NÅS (1995), "The Norwegian National Innovation System: A Pilot Study of Knowledge Creation, Distribution and Use", paper prepared at the OECD Workshop on National Innovation Systems, Vienna, 6 October.

TIPPING, J., E. ZEFFREN and A. FUSFELD (1995), "Assessing the Value of Your Technology", *Research Technology Management*, September-October.

US DEPARTMENT OF COMMERCE (1977), *The Information Economy*, US Government Printing Office, Washington, DC.

VICKERY, G. (1987), "Diffusing New Technologies: Micro-Electronics", *STI Review*, No. 2, OECD, Paris.