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Progress Towards the Knowledge-Based Economy

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Abstract

During the last decade, policy-makers have increasingly devoted attention to the factors that influence the rate and direction of innovation. In particular, developments in the ICT sector have been discussed as a currently dominant source of both technological change and overall economic growth. The visible limitations of this approach and an improved understanding of the innovation process have widened the perspective. Essentially, industrial innovation is a process of knowledge creation and the outcome depends on the learning that takes place at the level of individuals, firms, sectors and nations. Consequently, analytical concepts which focus on capabilities and competencies, as well as other factors which constitute a specific learning environment, have attracted attention.

In this paper[1], we start by discussing the essential assumptions and implications of concepts such as the Knowledge-Based Economy; by comparing current ideas with earlier approaches which focused on the role of information and ICTs, some distinct features will be drawn to attention. The subsequent section is devoted to the two main dimensions of knowledge generation: skill base and interactivity. Both aspects are conducive to the examination of empirical evidence at the country level. Finally, policy options from the perspective of knowledge will be discussed. As several examples of the policies which support innovation reveal, Member States have developed new strategies which address the challenge of improving the framework for knowledge generation in the economy.

[1] This paper has been produced as part of WIFO's background report for the European Competitiveness Report 2001. I am deeply indebted to Jörg Borrmann (University Vienna), Heinz Hollenstein (ETH Zürich), Leonhard Jörg (Technopolis Austria), Keith Pavitt (SPRU) as well as colleagues from WIFO – in particular, Michael Peneder and Gerhard Schwarz – for some very helpful discussions during the work.

The Knowledge-Based Economy as an analytical concept

Since the early 1990s, a number of socio-economic concepts have based their explanations of structural change in industrialised economies on the growing importance of information and knowledge. The Information Society (IS), for example, has become a visionary metaphor of current developments, which have been brought about by the availability of an ever increasing variety of low cost ICT. The widespread use of ICT in the creation, processing and distribution of information has provoked drastic changes at all levels of economic activity (intra-firm, inter-firm, international). More recently, the notion of the Digital Economy – sometimes the Internet Economy – has been used to emphasise, inter alia, that electronic networks alter the way economic transactions are carried out, as well as the positions of market participants[2].

Similar to information and the use of ICT, the creation and exploitation of knowledge has become the focal point of competing theories of structural change in the economy. Knowledge, as opposed to information, has a much broader scope, including practical skills and competencies. Furthermore, technology can be regarded as another specific body of knowledge, which is used in the production of goods and services[3]. Conversely, information is confined to explicit, well-structured and codified knowledge[4]. Concepts, such as the Knowledge-Based Economy (KBE) or the Learning Economy, point out that the accumulation of knowledge (learning) and the capability to use it are the driving forces behind an emerging stage of economic development[5].

Irrespective of what side one takes, ICT does play a crucial role in the explanation of structural change. More or less by definition, the developments within the ICT sector and the diffusion of ICTs require thorough treatment, if the IS framework is chosen. Even if knowledge is at the heart of the explanatory framework, there are at least two reasons for including ICT in our investigations:

- First, the ICT sector ranks amongst the most knowledge-intensive, if investments in intangibles, such as R&D, training and software are considered characteristic of knowledge-based industries and services. For example, in most countries, the R&D intensity of ICT industries as a whole is significantly higher than the manufacturing average[6]. Similarly, when compared to other industries, both IT services and ICT manufacturing show an outstanding share of investment in software.
- Second, after an accelerated diffusion during the 1990s, ICTs have become commonly used tools when it comes to supporting access to relevant and timely information. Applications, such as

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[2] The literature on the Information Society and related concepts saw tremendous growth during the 1990s. See, for example, Brynjolfsson – Kahin (2000), DOC (1999), Durmont – Dryden (1997), European Commission (1994a, 1994b), Eliasson et al. (1990).

[3] See e.g. Freeman (1982). Johnson (1992, p.28) defines technology as knowledge used in the production process: "Knowledge used in the production process is called technology, and new (or recombined or rediscovered) knowledge, introduced into the economy, is called innovation."

[4] See e.g. Lundvall (1997).

[5] See e.g. Cowan – Paal (2000), Lundvall – Borrás (1997) and OECD (1996a). Knowledge-based or learning-based concepts are rooted in the understanding of industrial innovation, which was developed in the late 1980s and early 1990s. The literature on National Innovation Systems – see e.g. Lundvall (1992) and Nelson (1993) – has been particularly important.

[6] See e.g. OECD (2000d). It is also remarkable that ICT sectors account for a major share of all business R&D in some countries - for example, in 1997, for more than one-third of all business R&D in Ireland and Finland, and more than one-fifth in countries such as Canada, France, Italy, Japan, Sweden and the USA.

World Wide Web and Internet, enable faster diffusion of codified knowledge and networking[7]. To a certain extent, applications of ICT are key technologies and share common characteristics with general purpose technologies[8].

Despite the importance of information (codified knowledge) and ICT as specific bodies of knowledge, the Knowledge-Based Economy also encompasses such concepts as the Information Society or Information Economy for at least two reasons[9]:

- A major difference between the two concepts is the complex nature of learning processes enabling the creation of new knowledge. During the cumulative process of enlarging the stock of knowledge, different forms of learning (e.g. learning-by-doing, learning-by using) take place and different kinds of useful knowledge must be absorbed[10]. Furthermore, the division of labour in each stage of the innovation process – ranging from the basic research end of the spectrum to the incremental improvements of already marketed products – requires frequent interaction and communication both within as well as between (specialised) organisations (in-house functions, suppliers, customers, collaborators, etc.). As a result, co-operation is a common feature of innovating firms[11].
- Although the widespread use of ICT raises important questions, such as those of re-organisation, improvement of user skills, infrastructure requirements, etc., the transmission of information can be considered a rather 'trivial' process, as opposed to the transfer of knowledge in general. Even when information is distributed or accessed via fairly complex communication systems with sophisticated functions, the repair of malfunctions is a purely technical matter. Lundvall (1997) has argued that the limitations of the transferability of tacit knowledge persist, even though it can, to a certain extent, be embodied in products, process equipment and software systems, such as business information systems and expert systems. Human skills which are required to absorb, allow for and promote change cannot be fully automated. If tacit, non-codified knowledge is involved, parties transferring knowledge face new forms of problems. For example, the transfer of knowledge between organisations or countries might require (i) substantial institutional learning[12], (ii) a transfer of individuals – moving knowledge by moving people – or (iii) an indefinite period of learning-by-using at the receiving side.

It becomes rather clear that the capability to participate in learning processes is essential for 'knowledge-based' organisations and economies. Innovation as an interactive learning process is based

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[7] See e.g. OECD (2000b).

[8] A general purpose technology (GPT) is "[...] a technology that initially has much scope for improvement and eventually comes to be widely used, to have many uses, to have many Hicksian and technological complementarities" (Lipsey et al., 1998, p. 43).

[9] See e.g. OECD (1996, p.13): "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, regarding both codified information and the competency to use this information."

[10] See e.g. Rosenberg (1982, 120ff.) and Johnson (1992).

[11] For a brief discussion of innovation models, see for example Rothwell (1994) or Dodgson – Bessant (1996). In the context of industrial innovation, Patel – Pavitt (1998) distinguish between 'specialisation by discipline within science and technology' and 'specialisation by corporate function inside the business firm'. Data from the recent Community Innovation Survey (CIS-II) reveal that during the innovation process, more than a quarter of innovating firms in Europe participate in collaborative ventures.

[12] Using a fairly broad definition of institutions as "sets of habits, routines, rules, norms and laws, which regulate the relations between people and shape human interactions" (Johnson, 1982, p.26), allows us to transfer the concept of learning from individuals to organisations and even countries.

on the individual and institutional competencies to extend the already accumulated stock of knowledge[13] via the combination with knowledge from external sources. Access to distinct bodies of knowledge is essential and makes interactions indispensable. The acquisition of external knowledge might be as simple as the singular purchase of embodied knowledge (e.g. skilled human capital, machinery, etc.); however, it might also require the formation of specialised teams, which frequently interact either on the basis of projects which can be terminated or in permanent collaborative ventures.

What follows for a student of the Knowledge-Based Economy? First, the variety of forms of knowledge represented by individuals, information and technology matters, when innovation is understood as a cumulative process in which new knowledge is created by combining knowledge which already exists. It is also important to remember that both the sources (where has the knowledge been produced?) as well as the learning processes (how has it been produced?) may differ. Due to complementarities among the bits and pieces, the outcome of the innovation process depends on the availability of linkages enabling both interactions among all actors involved, as well as a smooth flow of knowledge. It follows that, for example, a lack of skills hinders innovation even when the most sophisticated technologies are available, and vice versa. Similarly, a country with an outstanding stock of scientific knowledge might show a poor innovative performance due to missing links to domestic industry. Furthermore, each stage[14] of the innovation process has specific knowledge needs (e.g. knowledge about the laws of nature in basic research, knowledge about user needs during the design of a product, etc.).

Second, in the Knowledge-Based Economy, innovation and diffusion are two sides of one coin. Once fed into the system, knowledge becomes part of the accumulated stock of knowledge within an economy and can be used in further (future) innovative activities. For example, as soon as an innovating firm comes up with a new product (e.g. machinery, software, etc.), new knowledge will be available for further innovative activities: within the producing firm, knowledge has been accumulated (during the innovation process), which will be available for the development of future products (e.g. a new version) or for collaboration with others. Simultaneously, on the user-side, the product will increase the stock of embodied knowledge and, for example, the machinery (or software) will make contributions to process innovation or product innovation within the user-firm (inter-firm knowledge spillovers)[15].

Third, from a knowledge perspective, human capital and ICTs play key roles. Ultimately, innovative activities are carried out by people; individual learning, interaction and communication are far from becoming fully automated processes. The availability and flow of knowledge can be hampered by the tacit dimension of individual skills and capabilities. Consequently, a lack of human capital will limit the speed of innovation, as well as the diffusion processes. ICTs seem to be another driving force in the Knowledge-Based Economy. ICTs (as a set of technologies) represent an ever increasing body of knowledge, which has an impact on learning processes in all parts of the economy. As an infrastructure for the distribution of, as well as access to codified knowledge, some rather simple ICT applications such as PCs have already become indispensable tools.

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[13] The available stock of knowledge includes, inter alia, costless by-products of routine activities (learning-by-doing, learning-by-using) and formerly targeted efforts in R&D.

[14] This does not imply any plead for linear models of innovation, because even interactive and iterative processes can be regarded a sequence of (virtual) stages.

[15] The example of an innovating firm should also make clear that innovative activities (learning processes) cause spillover effects; learning performed in order to solve a problem in a specific context will – at least for some time – make knowledge available which can be used for other purposes.

Finally, the characteristics of learning processes during the creation and use of knowledge have important implications for the design and implementation of policies which support innovation. To put it simply, policy plays an important role because it provides a general framework for learning, which shapes the extent and structure of innovative activities in an economy. Governments can shape the way into the KBE by addressing (i) the creation and (ii) the use of new knowledge. Single bodies of knowledge, such as science, skills and technology (for example ICT) can also be addressed. However, since innovation is an interactive learning process, based on the combination of different forms of knowledge stemming from a plenitude of sources, the provision of a framework which stimulates interactions between the parties involved in innovative activities has become ever more important.

In summary, the Knowledge-Based Economy as an analytical concept addresses the role of knowledge and learning processes in the economy. It is an extended version of the Information Society, which has focussed on information and ICTs. Knowledge – as opposed to information (codified knowledge) – is at the heart of the explanatory framework and the creation of new knowledge (innovation) is that which must be investigated. Innovative activities, understood as learning processes, are by nature (i) cumulative, (ii) interactive and (iii) require different forms of knowledge (regarding information, skill bases, and technology).

Dimensions of knowledge generation

In principle, the notion of the Knowledge-Based Economy is derived from the fact that economic activities are mirrored in the sphere of knowledge. Rather general claims about the growing importance of the generation, distribution and use of knowledge as a 'new' and distinctive feature of economic development have provoked critique because all economic activity has always rested on knowledge, not only in our society but in all forms of human society.[16] As a result, the growth of knowledge itself is rather a sign of the cumulative nature of knowledge, than a proof of structural change.

Nevertheless, some developments which took place during the last decade within the sphere of knowledge generation, seem to justify the notion of the KBE. Some emerging trends appear to be important, because they – in one way or another – either reflect structural change in the economy, or impact on the direction, as well as on the mode of knowledge generation. Attempts to capture the KBE have pointed at developments such as the increasing codification of knowledge, the role of software as a source of innovation, the role of information as a commodity, the expansion of services, the internationalisation of industrial R&D, the rapid diffusion of electronic commerce, the spread of New Technology-Based Firms (NTBFs), etc. To a certain extent, all these trends offer useful insights into economic developments within firms and specific sectors. However, their scope is limited, when it comes to evaluating their relevance to innovative activities in the overall economy.

In what follows, we will investigate the rather general question of structural change in the generation of knowledge, by looking at its dynamics along two main dimensions: individuals and interactions. Skills will be addressed first. Based on the discussion in the preceding chapter, innovation is a learning process and the overall skill base of an economy – in other words, the capability of its individuals to participate in innovative activities – is one of the determinants of success[17]. As argued earlier, all learning processes rest on interactions between specialised individuals and organisational units; consequently, not only the level of resources devoted to industrial innovation, but also the pattern of interaction and collaboration are important.

The skill base: Steady growth of higher education

Innovation rests on human skills and competencies, which are required to absorb knowledge from different sources and to generate novel combinations. Conversely, flows of knowledge can be

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[16] Cowan – Paal (2000, p. 10) note that "[...] palaeolithic society was by any standards 'knowledge-based', and palaeontologists have demonstrated the existence of well-formed bodies of knowledge with respect to animal behaviour, pyrotechnology, materials, mining, symbolic communication and even medicine [...]". For a critical discussion of concepts of the KBE see also Smith (2000a, 2000b). Referring to Machlup, Chris Freeman formulated a critique of another strand of KBE-concepts as early as 1982: "[...] if a very wide definition of 'knowledge industries' is adopted, then Machlup has demonstrated that they already employed a quarter of the United States labour force in 1959. [...Machlup] estimated that over 30 per cent of the US labour force were engaged in occupations essentially concerned with producing and handling information rather than goods." (Freeman, 1982, p. 5).

[17] In this chapter, we use three indicators of human resources (attainment of education, human resources in science and technology, and R&D personnel). From the point of view of investment in knowledge generation, one additional measure, intangible investments (R&D, software, public spending on education) deserves to be mentioned. OECD (1999a) shows that since the mid-1980s, "investment in knowledge has grown slightly more rapidly than GDP in the OECD area". The indicator is problematic because a major proportion stems from public spending on education. Consequently, differences in efficiency and the institutional setting of educational systems limits cross-country comparisons. See also Smith (2000a, p.5) who questions other claims commonly derived from this indicator.

hampered by a lack of skills or a limited transferability of knowledge (tacit, non-codified knowledge). It is, for example, rather obvious that the absorbent capacity of individuals matters and electronic access to more and better information alone is not sufficient for the generation of new knowledge.

During the innovation process, the necessary cognitive skills can be of rather general nature or highly specialised. Research and development for example, has a distinct need for individuals with an education in Science & Engineering (S&E) in one or several disciplines. Despite the importance of R&D in the innovation process, the education and training of the general labour force has an impact on innovative performance. As a result, an innovating economy needs a labour force which has a significant proportion of members in both the high-skilled and medium-skilled segments.

TABLE 1: Percentage of the population that has attained at least upper secondary education or tertiary education, by age group (1998)

	At least upper secondary education					At least tertiary-type B				
	55-64	45-54	25-64	35-44	25-34	55-64	45-54	25-64	35-44	25-34
Portugal	12	14	20	20	29	7	8	9	9	11
Spain	12	23	33	38	53	8	14	20	21	32
Italy	19	35	41	50	55	7	8	9	9	11
Greece	22	36	44	52	66	8	13	16	19	22
Ireland	31	41	51	56	67	11	16	21	22	29
Belgium	34	51	57	61	73	14	22	25	28	34
United Kingdom	53	58	60	62	63	17	23	24	25	26
France	41	56	61	63	75	11	18	21	20	30
The Netherlands	50	56	64	68	74	17	23	24	26	27
Finland97	41	62	68	78	84	18	27	29	33	36
Austria 97	56	68	73	78	84	6	10	11	13	12
Sweden	60	73	76	80	87	20	29	28	31	31
Denmark	67	78	78	80	85	19	27	25	27	27
Germany	76	84	84	87	88	19	25	23	26	22
EU-14 (Country mean)	41	53	58	62	70	13	19	20	22	25
USA	80	87	86	88	88	27	37	35	36	36
Japan	57	77	80	91	93	13	23	30	40	45
Standard deviation EU-14	20.358	20.594	18.351	18.483	16.521	5.248	7.329	6.652	7.529	8.394
Coeff. of variation	0.497	0.389	0.316	0.298	0.236	0.404	0.386	0.333	0.342	0.336

Source: OECD (2000c) and WIFO calculations.

The level of educational attainment is a proxy of the skills available in the labour force (’stock of human capital’). Countries still differ widely in the distribution of educational attainment across their populations (TABLE 1). However, differences between the educations attained by younger and older persons have been shrinking. For example, a comparison of the educations attained by persons aged 25-34 with those aged 55-64 shows tremendous growth in the number of persons completing an upper secondary education; a similar trend is evident in tertiary education. Consequently, this indirect measure of human capital reveals steady growth in the skill base available to the economy in all European countries. Compared to the United States, the European Union is still in a position of catching up –for Japan, this situation is reversed.[18]

The progress made during the last decade can be measured by comparing the rates of graduates in the age groups 35-44 and 25-34. TABLE 1 shows that Europe has progressed both in upper secondary education (from 62% to 70%) and in tertiary education (from 22% to 25%). From the point of view of cohesion, it is of particular interest that Spain and Ireland made significant progress in both upper

[18] For a comprehensive discussion of the empirical evidence see OECD (2000c).

secondary education (Spain: from 38% to 53%; Ireland: from 56% to 67%) and in tertiary education (Spain: from 21% to 32%; Ireland: from 22% to 29%). However, Europe is still well behind the United States, and improving the qualification structure of the overall labour force will require time. As a result, initiatives for adult training and education have been gaining importance.

Table 2: Human resources in science and technology; R&D personnel as a % of the labour force.

	HRSTC as a % of the labour force		R&D personnel as a % of the labour force	
	1994	1999	1985	1998
Belgium	17.5	19.5	1.19	1.22
Denmark	17.1	18.5	1.31	1.99
Germany	12.3	14.4	1.78	1.48
Greece	10.8	12.7 1)	0.64	1.02
Spain	8.9	12.7	0.60	1.02
France	14.6	15.0	1.37	1.51
Ireland	11.2	13.9 2)	0.55	1.17
Italy	6.8	8.1	0.65	0.81
Luxembourg	12.8	17.1	..	..
The Netherlands	15.1	16.8	1.17	1.91
Austria	6.3 3)	6.6	1.16	1.16
Portugal	6.8 1)	7.2	0.33	0.61
Finland	17.4 1)	18.0	1.33	2.43
Sweden	19.5 2)	20.9	1.53	2.35
United Kingdom	13.0	14.8	1.37	1.28
European Union	..	13.5	1.18	1.27
EU unweighted av.	12.673	14.413	1.077	1.392
Standard deviation	4.236	4.392	0.462	0.537
Coeff. Of variation	0.334	0.305	0.429	0.386

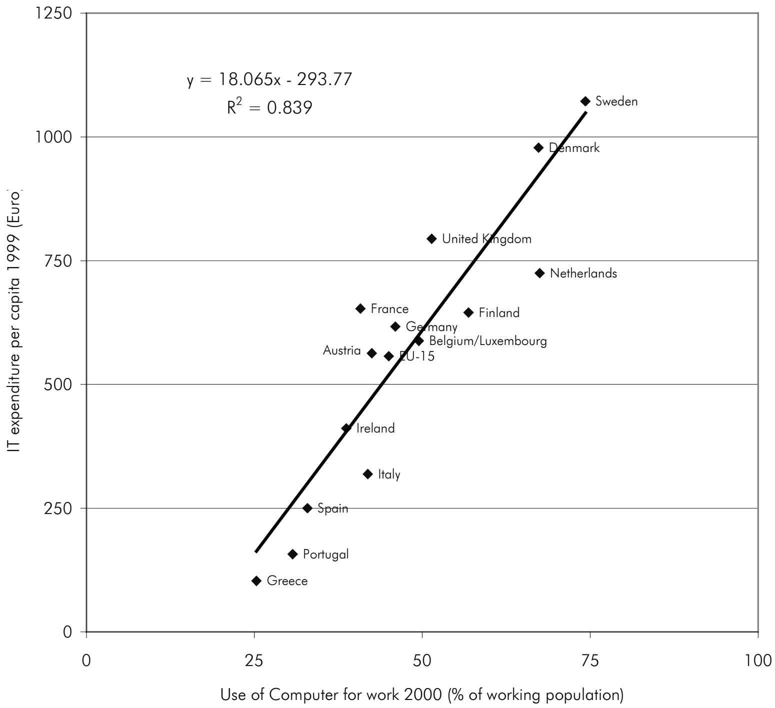
Source: SST Eurostat; European Commission (2001, p. 130 and p.61).
HRSTC... Number of persons with a tertiary education, who are also working in a S&T profession.
1) 1998; 2) 1997; 3) 1995.

While the level of education attained is a proxy of the potential of available human resources, employment data reveal the actual use of human resources in a country. Two indicators are of particular interest: (i) the proportion of persons who have tertiary educations and work in an S&T occupation (HRSTC) and (ii) R&D personnel as a percentage of the labour force (TABLE 2). According to the Community Labour Force Survey (CLFS), nearly 23.5 million people in the EU have a tertiary education and work in an S&T occupation. In 1999, Sweden had the highest overall level (20.9%) followed by Belgium (19.5%), Denmark (18.5%) and Finland (18%). Similar to educational attainment, HRSTC reveals significant improvement in the human resources dimension throughout the 1990s in the vast majority of European countries; some of them, most notably Spain, Ireland and Luxembourg, even grew more quickly.

For most innovative activities, R&D is particularly important, and human resources are the key to success. Over the longer term (during the period 1985 to 1998), R&D personnel as a percentage of the total labour force grew – with the Nordic countries Finland, Sweden, and Denmark leading the field (TABLE 2). Despite marked increases in a number of countries, growth in the European Union was moderate (an increase from 1.18% to 1.27%), reflecting significant decreases in the proportion of R&D personnel in Germany and the United Kingdom; the latter was the only member of the EU with a slight decrease in R&D personnel, as estimated in terms of volume. Again, from the point of view of cohesion, it is of particular interest that Greece, Ireland, Portugal and Spain doubled their stock of research personnel. As a consequence, in these countries the increase of R&D personnel as a percentage of the economically active population was particularly high.

From the point of view of skills, one additional aspect deserves to be mentioned: technical change and the danger of an eroding skill base. During the 1990s, ICTs became a common form of infrastructure for social and economic life and thereby challenged the educational system[19]. For example, in the European Union, PC-density (PCs per 10,000 inhabitants) rose from 930 in 1992 to about 2,500 in 1999; during the same period, Internet-density (estimated Internet-users per 10,000 inhabitants) in the EU saw an even more dramatic increase (from 31 to about 1,600). In many countries, computers are common as well, as increasingly indispensable tools for the majority of the working population (FIGURE 1). As a result, not only the infrastructure, but also the skills required for the creation, processing and distribution of codified knowledge have changed dramatically.

FIGURE 1: IT-intensity and use of computer for work



Source: EITO (2001), Eurobarometer, Nov. 2000.

In conclusion, the educations attained by workers and general skill levels have risen across the European Union. In most countries, both R&D personnel, as well as the number of persons with third level educations, who are working in science & technology professions has grown. During the innovation process, high quality labour is particularly important. As a result of the uneven pattern of development, further efforts to improve the qualification structure in the overall labour force will be necessary in most Member States. Furthermore, technical change – in particular the growing importance of ICTs as common tools at work – demands a comprehensive response from education and training policies.

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[19] For a discussion of information and communication technologies in the EU during the 1990s, see also the European Competitiveness Report 2000 (European Commission, 2000, pp.35-42). The relationship between ICT investment and growth of output, as well as productivity, will be discussed in detail in this year's Competitiveness Report, which also includes an annex on skill shortages in ICT and policy responses.

Shifting the frontier of knowledge: Innovation as an interactive process

Innovation is a complex learning process and firms draw knowledge from a 'distributed knowledge-base'[20]; from the perspective of the innovating firm, relevant knowledge used during this process is not only internal, but distributed according to source and type of knowledge. The specialisation of "knowledge-generators" makes external links, such as inter-firm-linkages indispensable. The Community Innovation Survey (CIS2) [21] produced new evidence on the role of external sources and knowledge-flows:

- The structure of innovation expenditures reveals that both internal problem-solving activities and embodied knowledge – 'technology' in the form of machinery, equipment and software – play important roles in the innovation process. On average, about 75% of total innovation expenditures are spent on intramural R&D and machinery & equipment. While in large firms, the share of R&D tends to be higher (on average about 58%; machinery & equipment about 16%), small firms show a reverse pattern (R&D about 21%; machinery & equipment 56%).
- During the innovation process, the innovating firm interacts – or even collaborates – with other institutions. In manufacturing, about 45% of process innovators and 67% of product innovators developed the innovation on their own. In both fields, the percentage of firms which collaborated with other firms is significant: 29% of process innovators and 25% of product innovators. The partners of collaborating firms vary widely: On average, the most common partners are customers (21%), followed by suppliers of equipment, materials, components & software (20%) and universities and other institutes of higher education (15%).

Close linkages, in particular collaboration, have become a common pattern of innovation, on both local (regional), as well as global scales. There is wide evidence that localised interaction – the formation of industrial districts and clusters – offers advantages for collective learning[22]. Innovating firms might benefit not only from proximity in a geographical, cultural and social sense, but also from the localised capabilities of a region (e.g., a region's infrastructure and institutional endowment)[23]. Consequently, innovation policies address the needs of localised knowledge creation by improving the region's distinct institutional endowment (for example, the provision of specific human resources, science parks, assistance through formal and informal networking).

In an increasingly globalised world economy, the distributed knowledge-base of innovating firms is not confined to a (spatially) narrow environment. MERIT's CATI-Database on international strategic technology alliances reveals that industrial firms increasingly form strategic technology alliances for transferring technology or joint research between domestic and international partners. For example, the number of new partnerships set up annually increased from about 30-40 in the early 1970s to around 600 or more in the 1980s and 1990s. Inter-firm-co-operation has become increasingly

[20] The term "distributed knowledge base" has been used in Smith (2000b) for mapping knowledge-flows across particular industries.

[21] Selected results of the Community Innovation Survey (CIS2), which was organised by the European Commission and conducted during 1997/98 in 17 EEA countries, are presented in European Commission (2001, pp. 93-110).

[22] For example, Amin – Wilkinson (1999), Cooke – Morgan (1994) and Marceau (1994). Collective learning may be defined as "the creation and further development of a base of common or shared knowledge among individuals within a productive system." (Lawson, 1999, p. 159)

[23] See Maskell – Malmberg (1999). Lundvall – Borrás (1997) discuss policy instruments and programmes aimed at sustaining existing networks or creating new linkages.

concentrated in a small number of high-technology industries. During the 1990s, the growth of inter-firm technology collaboration was particularly high in biotechnology (TABLE 3)[24].

TABLE 3: International Strategic Technology Alliances: 1980-1998, by technology (counts, share in %)

	1980-1984	1985-1989	1990-1994	1995-1998	CAGR 1981-1998	CAGR 1991-1998
Information Technology	469 (36.5)	927 (36.5)	1132 (45.7)	1135 (42.7)	9.99	2.75
Biotechnology	230 (17.9)	499 (19.6)	490 (19.8)	633 (23.8)	7.81	11.56
New Materials	122 (9.5)	317 (12.5)	186 (7.5)	146 (5.5)	8.17	0.70
Aerospace & Defense	82 (6.4)	137 (5.4)	225 (9.1)	139 (5.2)	-0.81	-12.24
Automotive	51 (4.0)	169 (6.7)	60 (2.4)	130 (4.9)	-0.62	4.45
Chemicals (non-biotech)	150 (11.7)	231 (9.1)	246 (9.9)	183 (6.9)	1.58	1.51
Other	182 (14.2)	260 (10.2)	138 (5.6)	289 (10.9)	0.92	13.25
Total	1286 (100)	2540 (100)	2477 (100)	2655 (100)	5.67	3.33

Source: WIFO calculations based on CATI (MERIT).

The interactive nature of the innovation processes is not confined to inter-firm linkages. As mentioned above, universities and institutes of higher education do play an important role in the collaborations of innovating firms. The interplay between science and industry is multifaceted, as the inter-sectoral co-authorship of scientific publications[25] and the bibliometrics of patent documents[26] reveal. For example, in a number of fields of technology, the citation linkage between patents and scientific papers is rapidly growing. Since scientific findings provide, at the very least, important background information, the absorption of tacit knowledge in science-related fields requires a certain degree of scientific education. Furthermore, basic science can, inter alia, offer access to research methods, as well as enable participation in international knowledge-networks.[27]

During the last decades, changes have evolved in both the mode of knowledge generation and its content. Some fields of economically relevant knowledge have seen tremendous growth. Patenting data from the USPTO[28] reveal that Biotech and ICT are among the fastest growing fields of inventive activity. For example, during the first half of the 1980s, certain patent classes such as *Active Solid-State Devices (includes e.g. transistors), Semiconductor Device Manufacturing, Data Processing, Electrical computers, Drugs, Bio-Affecting and Body Treating Compositions, Molecular Biology and Microbiology* accounted for a significantly lower proportion of patents granted than in the second half

[24] For a detailed discussion of research partnerships see Hagedoorn – Link – Vonortas (2000).

[25] See e.g. Godin – Gingras (2000).

[26] See e.g. Meyer (2000).

[27] For a comprehensive discussion of linkages between science and technology, see, e.g. Rosenberg (1982) and Pavitt (1993).

[28] U.S. Patent and Trademark Office.

of the 1990s. Due to the extraordinary growth in the ICT-sector, patents classified as electrical have now outnumbered chemical patents and challenge the lead of mechanical inventions (TABLE 4).

TABLE 4: Utility patents granted by the USPTO in technological classes

	Period 1 (1990-1994)		Period 2 (1995-1999)		Share by classes (%)			Increase between periods
	Patents granted	Average	Patents granted	Average	Period 1	Period 2	2000	Increase of patents granted (%)
Chemical Classes	142782	28556	177506	35501	29.5	28.4	26.9	24.32
Mechanical Classes	216823	43364	246701	49340	44.8	39.5	39.4	13.78
Electrical Classes	124726	24945	199750	39950	25.8	32.0	33.7	60.15
All Classes	484331	96866	623957	124791	100	100	100	28.83

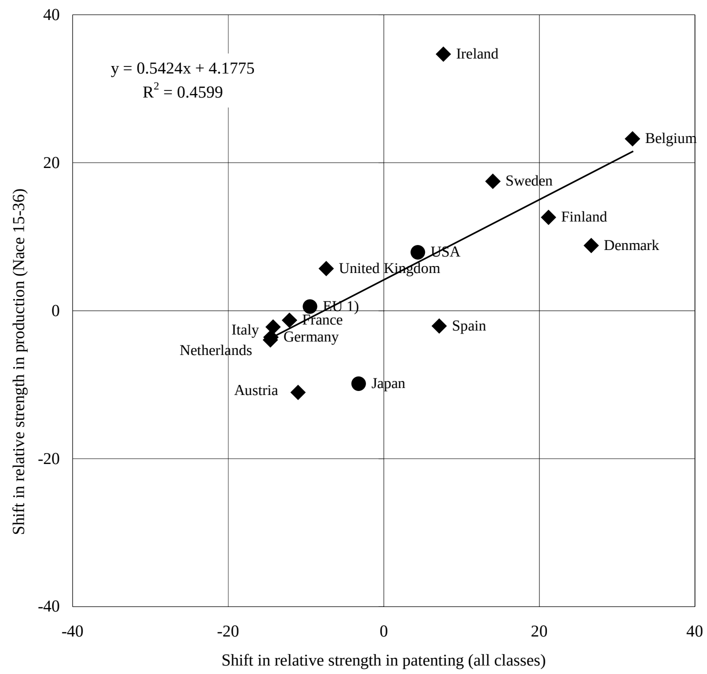
Source: WIFO calculations based on U.S. Patent and Trademark Office.

In conclusion, policies aimed at improving the general conditions and particular circumstances affecting the capabilities of firms to innovate must take the interactive nature of innovation processes into account. Innovation is a complexly networked activity and innovating firms depend on inputs from a knowledge base that is distributed according to spatial considerations, as well as specialisation. Not only the localised capabilities of a region, but also the international knowledge-flows matter. Especially for science-related fields (e.g. biotech and ICT), which have shown particularly strong growth in terms of inventive activity, both the locally provided research infrastructure – in particular universities – and knowledge from international sources are vital.

Policy options from a knowledge perspective

Traditional measures of technological activity suggest that the creation of new knowledge has important economic implications. For example, FIGURE 2 shows the dynamics of inventive activity and the dynamics of manufacturing production during the 1990s. Countries with an increasing share of patents relative to the Triad tend to increase their share of economic output in manufacturing. Similarly, in addition to spillover effects, firm-level evidence reveals a positive impact of R&D on the growth of firms.[29] Consequently, investments in knowledge creation are clearly vital to growth, and innovation policy is therefore a central concern of governments.

FIGURE 2: Dynamics of Inventive Activity and Production in the 1990s[30]



Source: WIFO calculations based on information from the U.S. Patent and Trademark Office.

Within the analytical framework of the Knowledge-Based Economy, the main policy goals are the improvement of innovative capabilities and the expansion of innovative activities within an economy. The major difference to traditional approaches is the underlying systemic view of strategies and measures. Innovation is understood as an interactive learning process based on different modes of learning, different types and sources of knowledge, and specific capabilities at the individual and

[29] See e.g. Wieser (2001).

[30] The shift in the relative strength in patenting is calculated via the average number of patents granted to one country relative to the number of patents granted to all countries in the Triad during the periods 1990-1994 and 1995-1998; the shift between these two periods (in %) is interpreted as a measure of the dynamics during the 1990s. Due to the limited availability of data, the indicator has been calculated for Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Spain, Sweden, the United Kingdom and the USA; by the same token, for calculations, this sample represents the Triad. The dynamics of production were calculated analogous to the dynamics of inventive activity.

institutional levels. Policies supportive of the KBE intend to foster both the creation of new knowledge (improving the stock of knowledge), as well as the establishment of a framework for the better exchange and utilisation of knowledge (BOX 1); the ideal policy mix addresses both innovative activities and the diffusion of technologies and applications because the use of technologies might well add to the existing stock of knowledge. This becomes quite clear in the case of ICT, and as a consequence, several initiatives by Member States are formulated under headings such as Information Society and Network Economy.

BOX 1: The "new" diversity of innovation support policies

During the 1990s, innovation policy was gaining importance in all EU Member States. Depending on their particular needs, and with varying degrees of emphasis, countries were developing new strategies and increasingly addressing the challenge of providing a framework which stimulates both the extent and direction of innovative activities, as well as interactions between the parties involved. Increasingly, policies were going beyond the traditional demarcation line of science and technology policy. The effectiveness of these policies was improving due to the provision of links with other policies and the stimulation of interactions between them.

The measures are not necessarily novel. Establishing additional publicly-funded programmes, implementing initiatives intended to shape the scientific research agenda and stimulating the interaction between science and industry is not new at all. However, the design and implementation of the measures reflects changes in perspective. An improved understanding of innovation as an interactive learning process based on the innovative capabilities of individuals, firms, and regions has prompted diversity in practice. Science has proven to be an increasingly important body of knowledge and, in a dynamic view, technology-based firms in new growth areas attract the attention they deserve.

Innovation rests on human skills

Recent reforms in Member States have increasingly addressed the supply of human resources and in particular, the need for trained scientists and engineers. For example, in order to consolidate its position as a leading research nation, the Swedish Government has decided to invest in 16 graduate schools, specialising in fields which reflect priority research areas. Similarly, Austria has made major efforts to reform its university system. Since 1994, the government has developed 43 'Fachhochschule' study programmes (polytechnics), in close co-operation with industry; a primary goal has been to alleviate the problem that research students often lack the skills required by employers. Furthermore, a 1999 amendment of the University Studies Act allows for shorter university courses of study (bachelor's degree). Over the longer term, the Austrian system of higher education will resemble the German and Finnish systems, which comprise two parallel sectors (universities and polytechnics). Several countries, including Finland, have already reacted to the increasing demand for lifelong learning and offer a wide range of short-term courses for graduates of higher education, as well as continuing education for professionals.

Enhancing innovative capabilities of firms

In most member countries, public support for industrial R&D has a long tradition and, during the 1990s, some governments decided to increase R&D funding significantly. For example, in Portugal, the budgetary share allocated to science & technology doubled from 1.08% in 1988 to 2.08% in 1999, and the Finnish government increased public R&D funding by FIM 1.5 billion between 1997 and 1999. A number of countries have introduced new R&D tax schemes or have modified existing provisions. In many cases, the design of tax incentives supports policy objectives beyond a mere extension of business R&D expenditures and contributes, for example, to an increase in human capital or supports the special needs of start-ups and SMEs. A tax reduction scheme in the Netherlands allows employers to reduce income tax and social security payments for R&D-employees. Belgium operates a system of R&D tax credits and tax benefits for firms which hire R&D personnel. The British Government introduced tax incentives in order to stimulate R&D in SMEs.

Strengthen the innovative competencies of regions

From a regional point of view, the formation of networks and clusters enhances the competitiveness of local firms and improves the region's attractiveness as a business location. In some Member States, networking and cluster initiatives date back to the early 1990s; others have designed initiatives only recently. In Spain, for instance, the National Plan for R&D 2000-2003 designates 12 strategic, sectoral high-growth areas for which programmes will be co-ordinated with regional policies – implemented by Spanish autonomous communities – and linked to existing clusters. The British Government announced in its budget for the year 2000 a £50m Innovative Clusters Fund, designed to allow Regional Development Agencies (RDAs) to co-finance business incubation and small scale infrastructure; £15m was allocated to RDAs for 2000-01. Additional funds have since been allocated to boost the funding for 2001-02 to £54m. This new Regional Innovation Fund will be used by RDAs to support clusters and networks of businesses. Similar initiatives in Austria, Denmark, Germany, Ireland, the Netherlands and Sweden will encourage knowledge-sharing between (specialised) firms and establish regional partnerships (involving municipalities, local business associations, universities and regional authorities).

Securing world-class research in science

Publicly funded research infrastructure and universities constitute an important element in national systems of innovation. During the 1990s, several countries developed programmes aimed at the creation of specialised Centres of Excellence (CoE) in scientific research. As a result, a leading position in well-defined priority areas, the absorption of knowledge developed abroad and participation in international knowledge-networks will be improved. During the last decade, several countries have chosen this approach. For example, the Danish National Research Foundation supports 25 Centres of Excellence; the Dutch Government has introduced BROCHURE (Bonus incentive scheme for research schools); and Finland extended its CoE Programme to the funding of umbrella organisations which produce core facilities and infrastructure, which can be shared by several research groups.

Industrial rejuvenation: Technology-based firms in new growth areas

New technology-based firms (NTBFs), which – at least over the longer term – will fulfil an important role in the economy, face severe difficulties in accessing key resources, including finance, human resources, managerial skills, etc. Start-up policies are increasingly adopting a systemic approach of going beyond the mobilisation of risk capital. The French Innovation Law of 1999 is quite typical: The law encourages the transfer of technologies from public research into the economy and the founding of innovative enterprises. Furthermore, it places significant emphasis on the creation of NTBFs through incubators within universities and public research infrastructures, as well as the establishment of national and regional priming funds. Incubators – e.g. the Danish Technology Incubators, the Dutch Twinning Programme, and the Irish 'Campus Companies', - are in close association with the existing innovation infrastructure (science and technology parks, universities, venture capital industries, etc.). The focus of the NTBF's entrepreneurial activities is mostly in science-based areas such as biotech and ICT. Consequently, initiatives include measures to enhance networking, as well as to improve the climate for spin-off creations from universities. The German EXIST programme, for example, supports several regional networks of universities, research institutes, venture capitalists, private companies and consultants, chambers of trade and commerce, science parks and business centres.

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