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What is the 'Knowledge Economy'? Knowledge Intensity and Distributed Knowledge Bases

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WHAT IS THE 'KNOWLEDGE ECONOMY'? KNOWLEDGE INTENSITY AND DISTRIBUTED KNOWLEDGE BASES.[1]

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TABLE OF CONTENTS

ABSTRACT

In recent years public policies for science, technology and innovation have attracted increased attention as a result of claims that knowledge-intensive industries are now at the core of growth, and that we are now entering a completely new form of 'knowledge society'. The objectives of this paper are firstly to examine what various authors mean by the concept of a knowledge economy or learning economy; secondly to describe quantitatively the creation and use of knowledge across industries; thirdly to develop an approach to understanding the knowledge intensity of mature, 'traditional' or low-technology industries. In exploring this issue, the paper first uses *Community Innovation Survey* data to describe some empirical dimensions of knowledge creation in Europe. It shows that knowledge investments are economy wide, not confined to high-tech sectors, and not confined to R&D. The paper then turns to concepts and a methodology for mapping the knowledge base of an economic activity. The aim is to generate a more nuanced understanding of the meaning of 'knowledge intensity' in production. The approach rests on what the paper terms 'distributed knowledge bases' that have a systemic and institutionally diffuse location. Knowledge for many key activities is distributed among agents, institutions and knowledge fields, and the problem is to understand the embodied and disembodied knowledge flows between them. An empirical example of such knowledge bases is described, for the food processing industry. The paper concludes by discussing how such 'distributed knowledge bases' might affect our conceptions of the knowledge economy and suggests links to current policy challenges in both developed and developing economies.

INTRODUCTION

The economics of innovation has always focused on learning, just as public policies for science, technology and innovation have always been aimed primarily at creating and diffusing knowledge. In recent years, however, learning and knowledge have attracted increasing attention as a result of claims that knowledge-intensive industries are now at the core of growth, and that we are now entering a new type of knowledge-driven economy or even a completely new form of 'knowledge society'.

What does it mean to speak of a 'knowledge-intensive' industry or a 'knowledge-based' economy, however? These terms are often used in a superficial and uncritical way, and there is a real need to consider whether they are anything more than slogans. The objectives of this

paper are firstly to assess some of the issues involved in the concept of a knowledge economy or learning economy, and to criticise the idea that the knowledge economy should be identified with high-technology industries (as conventionally defined). Against this background I describe some empirical dimensions of knowledge creation in Europe, showing that knowledge creation is a sectorally distributed, economy wide process, not dependent on R&D. Then, concepts and a methodology for mapping the knowledge base of an economic activity are developed. The paper discusses the concept of a 'distributed knowledge base' for industries, and argues that the term 'knowledge economy' is only meaningful if we see it in terms of widely-spread knowledge intensity across economic activities, including so-called 'low technology' sectors. The latter are often far more intensive as creators and users of knowledge than usually acknowledged, but this knowledge is usually distributed across many agents and organizations.

THE KNOWLEDGE ECONOMY

There are many who argue that we are moving towards a new 'knowledge-based economy' or 'knowledge society', in which the role and significance of knowledge as an input to economic processes has fundamentally changed. In some cases it is argued that this rests on advances in information technology that are leading to a 'paradigm shift'. The idea here seems to be that there are basic changes in economic functioning, and changes in the economic rules of the game, for both business and policymakers. Proponents of such views can be found in business, where the 'new economy' or 'new paradigm' concept has survived the collapse of stock prices in ICT and Internet-related companies, as well as in policy-making, and in innovation analysis.

THE MEANING OF KNOWLEDGE

What does it mean to speak of the 'knowledge economy' however? At the outset, it must be said that there is no coherent definition, let alone theoretical concept, of this term: it is at best a widely-used metaphor, rather than a clear concept. The OECD has spoken of knowledge-based economies in very general terms, as meaning "those which are directly based on the production, distribution and use of knowledge and information".[2] This definition is a good example of the problems of the term, for it seems to cover everything and nothing: all economies are in some

[2] OECD, **The Knowledge Based Economy**, OECD/GD (96) 102, p.7.

way based on knowledge, but it is hard to think that any are *directly* based on knowledge, if that means the production and distribution of knowledge and information products.

The weakness, or even complete absence, of definition is actually pervasive in the literature. The definitional problems often seem to follow from reluctance to consider what knowledge is in epistemological or cognitive terms. Almost the only way in which this matter is addressed in the literature is via the concepts of codified and tacit knowledge. However these are themselves hazy (as well as not necessarily distinguishable) concepts and they do not say much about the cognitive content of knowledge. Issues concerning the cognitive of epistemological characteristics of knowledge go far beyond the scope of this paper, but it is important to point out that 'knowledge' is in most forms of discourse a highly differentiated and to some extent hierarchical concept. It normally has to do with understanding, with the resolution of perplexity or uncertainty. But this may take many different forms. It may involve explicit theoretical concepts or principles, data generation procedures, canons of evidence and so on, all linked into some kind of explanatory structure. It is this type of knowledge that raises major questions concerning truth content, and that has been the domain of the philosophy of science. At another point on the spectrum, knowledge may involve simply the transmission of data in the context of comprehensible practical guidelines for use. These differences correspond to psychological or cognitive differences in those who 'know'. At one extreme knowledge requires a transformative internalising of some new principle, and at the other it simply involves accessing an intelligible account of how to do something. Such differences – and of course much finer categories could be pointed to - are important in determining what we are talking about with respect to knowledge, but they are often ignored within the literature. Related to this is the matter of institutions. At whatever level we think about the nature of knowledge, institutions are required as generative frameworks and as a kind of social memory (the latter being a precondition for transmission), and these too are of very different forms. The point about making these very preliminary distinctions is that because the literature rarely makes any attempt to grapple with the elusiveness of knowledge itself, it is often able to slide between very different implicit notions of knowledge, and this is one of the many imprecisions that make the notion of 'knowledge economy' so rhetorical rather than analytically useful.

FOUR APPROACHES TO THE KNOWLEDGE ECONOMY

Leaving aside such general definitional problems there seem to be four basic views about the changed significance of knowledge:

Firstly, there are those who believe that knowledge is quantitatively and in some sense qualitatively more important than before as an input. Peter Drucker, for example, suggests that 'Knowledge is now becoming the *one* factor of production, sidelining both capital and labour.'[3] Along the same lines, the OECD has suggested that "…the role of knowledge (as compared with natural resources, physical capital and low-skill labour) has taken on greater importance. Although the pace may differ, all OECD economies are moving towards a knowledge-based economy".[4]

Secondly, there is the idea that knowledge is in some way more important as a product than it has been hitherto - that we are seeing the rise of new forms of activity based on the trading of knowledge products.

Thirdly, there is the view that codified knowledge (as opposed to tacit, person-incorporated skills) is in some ways more significant as a component of economically relevant knowledge bases. Thus Abramowitz and David argue that 'Perhaps the single most salient characteristic of recent economic growth has been the secularly rising reliance on codified knowledge as a basis for the organisation and conduct of economic activities…'.[5]

Finally, there are those who argue that the knowledge economy rests on technological changes in ICT, since innovation in computing and communications changes both physical constraints and costs in the collection and dissemination of information. So for some, the rise of ICT technologies and the complex of ICT industries is coterminous with the move to a knowledge society. Lundvall and Foray argue a more sophisticated view: 'Even if we should not take the ICT revolution as synonymous with the advent of the knowledge-based economy, both phenomena are strongly interrelated … the ICT system gives the knowledge-based economy a new and different technological base which radically changes the conditions for the production and distribution of knowledge as well as its coupling to the production system'.[6]

How valid are these claims? It is hard both to distinguish among and to assess these ideas, either in terms of the role of knowledge in general, or in trends. For example, when we speak of the 'knowledge economy' in a general way we should bear in mind that all economic activity rests on some form of knowledge, not only in our society but in all forms of human society.

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[3] P. Drucker, 'From capitalism to knowledge society' in D. Neef (ed.) **The Knowledge Economy**, (Woburn MA: Butterworth) 1998, p.15.

[4] OECD, **The Knowledge-Based Economy: A Set of Facts and Figures**, (OECD:Paris), 1999p.7.

[5] M. Abramowitz and P. David, 'Technological change and the rise of intangible investments: the US economy's growth path in the twentieth cenutury' in OECD**, Employment and Growth in the Knowledge-Based Economy** (OECD: Paris), 1996, p.35

[6] B-Å. Lundvall and D. Foray, 'The knowledge-based economy: from the economics of knowledge to the learning economy', OECD **Employment and Growth in the Knowledge-Based Economy** (OECD: Paris), 1996, p.14.

Paleolithic and Neolithic society was by any standards knowledge-based, and paleoanthropologists have demonstrated the existence of apparently well-formed bodies of knowledge with respect to animal behaviour, pyrotechnology, materials, mining, symbolic communication, the aerodynamic properties of weapons, cosmology and even medicine in these societies.[7] Tribal peoples of our own time, such as the Bushmen of southern Africa or Australian aborigines, clearly possess sophisticated environmental and technical knowledge.[8] Looking to the recent past, the industrial economy of the nineteenth century was intensively knowledge-based, and many claims about the new 'knowledge economy' could plausibly have been made a hundred years ago. Indeed nineteenth century commentators such as Andrew Ure and Charles Babbage claimed exactly that. Karl Marx argued that a distinguishing feature of mid-nineteenth century capitalism was 'the conscious application of science', and he explicitly treated separation of the conception and execution of tasks (that is, of a knowledge function) as central to mechanisation.[9]

What about the more specific claims outlined above? Let us look at them briefly, in turn. The point here is not to have a full discussion. It is simply that even a brief examination can indicate the need for qualification of claims about the advent of a knowledge society.

The argument that 'knowledge is sidelining capital' rests on the implicit idea that we can separate knowledge accumulation (and hence technological advance) from capital accumulation. While this idea is central to neoclassical production theory (it is the entire basis of the residual concept), it is highly questionable: knowledge cannot be incorporated into production except via investment, and the function of investment is often to implement new knowledge in production technology. There is no real separability. At a more aggregate level, the claim that 'knowledge

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[7] For an overview of the archaeological evidence on these technical accomplishments, and debates on its interpretation, see R. Rudgely**, The Lost Civilisations of the Stone Age** (New York: The Free Press), 1999.

[8] 'The monotonous western desert of long, low sandhills and gravel knolls lacked real seasons, making food unpredictable. Yet …the aborigines considered food less a problem than the terrifying lack of water. [The anthropologist Dr Richard] Gould summed up this habitat as the world's "most unreliable and impoverished". Yet these Australians lived a healthy, contented and fulfilled life. They survived not so much through great physical endurance as through knowledge - their "cognitive map" of where to find food and, especially, water.' M. Symons, 'Aboriginal Life', in C. Spencer and C. Clifton (eds) **The Faber Book of Food**, (London: Faber) 1996, pp. 70-71.

[9] In a fascinating Appendix to **Capital** Vol I, drafted in the early 1860s, Marx wrote: 'The social productive forces of labour … come into being through co-operation, division of labour within the workshop, the use of machinery, and in general the transformation of production by the conscious use of the sciences, of mechanics, chemistry, etc. for specific ends, technology, etc. and similarly, through the enormous increase of scale corresponding to such developments (for it is only socialized labour that is capable of applying the general products of human development, such as mathematics, to the immediate process of production; and, conversely, progress in these sciences presupposes a certain level of material production).' Karl Marx, **Capital**, Vol 1, (Harmondsworth:Penguin 1976), p.1024.

is sidelining capital' cannot be sustained by empirical data. The OECD has produced series comparing investment in physical capital and investment in 'knowledge' (meaning public spending on education, total R&D and software). For the OECD as a whole, physical investment is about two and a half times greater than 'knowledge' investment as a percentage of GDP. In terms of growth rates, 'knowledge' investment is growing faster than physical investment in the USA, the Nordic countries and France. But physical capital investment is growing faster than 'knowledge' investment in Italy, Japan, Australia, Belgium, Germany, Austria, the Netherlands and the UK.[10] The data does not therefore support any general claim that knowledge is increasing in importance in aggregate investment. Although it is common among polemicists to claim that knowledge is now in some sense more important than capital, there exists no substantive analysis which would substantiate this claim.

The notion that knowledge is more important as a product usually rests on claims about the growing significance of knowledge-intensive business services. Despite some rather tricky statistical issues in defining these services, and in determining whether some services are an independent source of growth or primarily an effect of vertical disintegration in manufacturing, the evidence is strong that these sectors are growing (certainly growing more rapidly than high technology sectors in manufacturing), and playing an important role in inter-industry diffusion of knowledge. There has been a strong growth in Europe and the U.S. in the share of business services in inter-industrial trade.[11] So there is good evidence that this is an area of real change, though it must be said that it remains relatively small as an activity. There has been of course a debate about whether this phenomenon represents a real change in knowledge use, or whether it is a statistical artefact driven largely by spin-offs from manufacturing. Be that as it may, the importance of this phenomenon lies not in such services as an autonomous source of growth, but as a connecting process within the innovation system. This should direct our attention to economy-wide aspects of the use of knowledge, rather than to knowledge products themselves as an independent activity.

In terms of the use of codified knowledge, there is no doubt that both the extension of formal education, and the uses of codified results of science are rising. In general the only employment categories that are rising across OECD economies are those for people with higher education. As regards codified science, perhaps the clearest indicator is the growth of citations to basic science in patents, a very sharp upward trend in recent years. The argument is that patents are becoming more heavily based on formal codified scientific and engineering knowledge, the

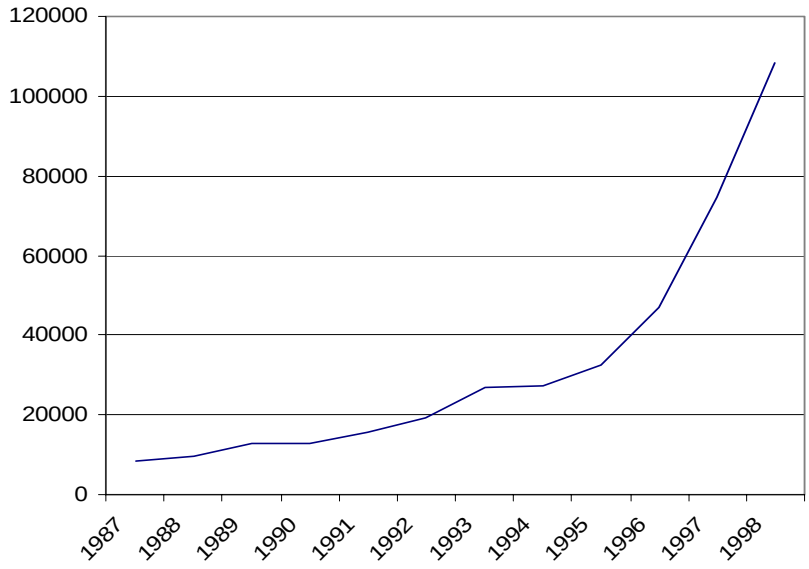
[10] See 'Investment in tangibles and knowledge', **The Knowledge-Based Economy: A Set of Facts and Figures**, OECD:Paris, 1999, p.9.

[11] For an excellent systematic overview of the issues and evidence related to knowledge-intensive business services, see Johan Hauknes, **Services in innovation – innovation in services. SI4S final report**, STEP Group Report S1 1998, especially pp.29-48.

evidence for which is citations to relevant literature on the opening page of the patent. Figure 1 shows the growth in the total number of citations in US patents to scientific and technical literature:

Figure 1

Number of citations on U.S. patents to scientific and technical articles: 1987-98



Source: National Science Board, *Science and Engineering Indicators - 2000*, Arlington, VA: National Science Foundation, 2000, p.6-54.

However both the education and patenting trends require careful interpretation – it is not clear either that they are new, or that they represent some new role for knowledge. For example, there is a long-standing debate about educational qualifications: do they represent a real knowledge input to production, or are they some kind of signalling mechanism in the labour market, referring to the capabilities of specific employees? If education provides some kind of direct input to production, then the links in terms of content ought to be traceable. This is clearly possible in some sectors (such as recruitment of molecular biology PhDs by pharmaceutical firms), but it is far less clear in others.

Finally there is the role of ICT. Knowledge refers to understanding and competence. It is clearly true that ICT makes major changes to our ability to handle data and information. It is sometimes argued that there is a distinction between knowledge and information, and that therefore that the data moved or analysed by ICT methods are not themselves knowledge, and that therefore ICT does not necessarily create knowledge or even extend knowledge. However this distinction between information and knowledge seems to me to be either a mistake or at least overdrawn,

since neither information nor data can exist in the absence of background concepts and a knowledge referent. Nevertheless ICTs are primarily an information management and distribution resource, and a major question that follows is, how does an information resource relate to the production and use of knowledge in society? Lundvall and Foray are almost certainly right in saying that ICT plays a new role in knowledge production and distribution, but this is a re-organisation of the technical and financial terms on which a resource (information) is available. It does not in itself expand the realm of accessible knowledge, let alone justify talking about a new mode of economic or social functioning.

The claims about the move to a knowledge economy, sketched above, rest on analytical and empirical support that varies from sophisticated (but questionable) to nonexistent. It seems that we are some way from really being able to assess the strength of these different perspectives, or whether they really add up to implying a new type of economy. Claims about the knowledge economy actually vary sharply in status. On the one hand, there are hand-waving exercises by special interests. On the other, there are serious attempts to disentangle elements of change in the current situation. The main problem faced by the serious literature is that most of the conceptual approaches to defining a knowledge society raise difficult empirical questions that are rarely followed through in the literature. The critical considerations sketched above therefore provide a problem for those who wish to speak of a new knowledge-based society. It is certainly true that knowledge accumulates over time, and that it changes the quality and quantity of output very significantly. But does this obvious point mean we are entering some new form of society that is qualitatively different in terms of the use of knowledge? The burden of proof here is on those who claim that the ‘knowledge society’ exists and is above all qualitatively new as a form of society. The conclusion suggested here is that none of those who have used the term have succeeded in conceptualising the phenomenon, let alone demonstrating that something new has happened. This does not mean that thinking in terms of knowledge is unimportant or irrelevant. It simply means that more care should be taken in formulating and using the term. Knowledge has been and continues to be a core foundation of the economic process. It remains important therefore for scholars and policymakers to have an adequate view of the relevance, structure and characteristics of knowledge across industries.

KNOWLEDGE-INTENSIVE INDUSTRIES?

Before moving to a discussion of knowledge in industry, it is necessary to make a diversion via the concept of ‘high-technology’. In much policy analysis it is common to use the terms 'high-technology' or 'knowledge intensive industries' in a somewhat loose way, as though in fact they

are both meaningful and interchangeable terms. But we ought to remember that the term ‘high technology’ is a rather recent invention, and that its meaning is far from clear.

The standard approach in this area rests on a classification developed by the OECD in the mid-1980s.[12] The OECD distinguished between industries in terms of R&D intensities, with those (such as ICT or pharmaceuticals) spending more than 4% of turnover being classified as high-technology, those spending between 1% and 4% of turnover (such as vehicles or chemicals) being classified as medium-tech, and those spending less than 1% (such as textiles or food) as 'low tech'. In fact the OECD discussion of this classification was rather careful, and offered many qualifications. Chief among these is the point that direct R&D is but one indicator of knowledge content, and that technology intensity is not mapped solely by R&D. Unfortunately the qualifications were forgotten in practice, and this classification has taken on a life of its own; it is widely used, both in policy circles and in the press, as a basis for talking about knowledge-intensive as opposed to traditional or non-knowledge-intensive industries.

This is a serious problem, since the OECD classification as it is used rests on only one indicator, namely intramural R&D. This is open to two important objections. First, it is by no means the only measure of knowledge-creating activities. Second, it ignores the fact that the knowledge that is relevant to an industry may be distributed across many sectors or agents: thus a low-R&D industry may well be a major user of knowledge generated elsewhere. This issue will be discussed in a more empirical manner below.

Even so it is not clear that this classification helps us, even in a limited analysis of trends. One great problem is that in fact the high-tech sector thus defined is small, and there are therefore some difficulties in arguing that it is driving the growth process. In the OECD, for example, the USA has the largest share of high-tech in manufacturing, but this is only 15.8% of manufacturing output, which in turn is only 18.5% of GDP. So the high-tech sector is less than 3% of GDP. It is hard to see how either the direct or indirect impacts of such a small component of output could have a significant effect on overall economic growth. Most discussions of the role of high-tech are conducted in terms of share analyses. This can easily confuse matters. In virtually all of the OECD economies the share of high-tech in total manufacturing has risen in the longer term, and this is widely used as an argument for the claim that such industries are central to growth. However this is complicated by the fact that that the share of manufacturing in total output has been in long-term decline. So between 1980 and 1995, for example, the high-tech share of US manufacturing increased from 10.5% to 15.8%, while the share of manufacturing in GNP decreased from 21.6% to 18.5%. What this actually implies is that the share of high-tech manufacturing in total GNP rose over fifteen years by well

under one percentage point.[13] Despite this, it is not uncommon to see quite sweeping claims made for the high-tech sector, which are not supported by readily available evidence. For example, OECD's *Knowledge Based Economy* claims that 'Output and employment are expanding fastest in high-technology industries, such as computers, electronics and aerospace'.[14] But the OECD's own 'Scoreboard of Indicators' actually shows long-term *negative* growth rates of employment in high-tech manufacturing in eleven of fifteen OECD countries for which data are presented (including the USA, where high-tech employment declined at a faster rate than manufacturing employment generally).

Such problems have not led to any questioning of the high-tech/low-tech distinction. On the contrary, the high-medium-low-tech approach has recently been extended, to divide the medium-tech category into medium-high and medium-low technology industries. Such classificatory manoeuvres cannot, however, alter the fundamental limitations of the category, and ought to cause us to question the identification of knowledge intensive and high-tech industries.

FIRMS AND INDUSTRY EXPENDITURES ON KNOWLEDGE CREATION: THE EMPIRICAL EVIDENCE

Much analysis of knowledge creation rests on R&D data, particularly intramural R&D carried out by firms. However it is mistaken to over-identify knowledge creation with intramural R&D, partly for conceptual and partly for practical reasons. Conceptually, R&D data tends to rest on a view of innovation that overemphasizes the discovery of new scientific or technical principles as the point of departure of an innovation process (an approach sometimes called the 'linear model' of innovation). It sees innovation as a set of development stages originating in research, and it is this prior significance of research that licences using R&D as a key knowledge indicator. From a practical point of view, the definitions of R&D in the OECD's Frascati Manual, which structure R&D data collection in OECD economies, exclude a wide range of activities that involve the creation or use of new knowledge in innovation.[15]

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[12] See OECD, **OECD Science and Technology Indicators, No 2: R&D, Innovation and Competitiveness**, (OECD:Paris), pp. 58-61.
[13] All of the data here is drawn from OECD, **Science, Technology and Industry, Scoreboard of Indicators**, 1997.
[14] Op. Cit., p.9.
[15] The Frascati Manual's definition of research, if taken seriously, would have to include things like market research, which often involves rather sophisticated social investigation. The development definition, on any reasonable interpretation, should include more or less all activities related to innovation. However the Frascati Manual also contains a list of exclusions.

By contrast, modern innovation theory sees knowledge creation in a much more diffuse way. Firstly, innovation rests not on discovery but on learning. Learning need not necessarily imply discovery of new technical or scientific principles, and can equally be based on activities which recombine or adapt existing forms of knowledge; this in turn implies that activities such design and trial production (which is a form of engineering experimentation) can be knowledge-generating activities. A second key emphasis in modern innovation analysis is on the external environment of the firm. Firms interact with other institutions is a range of ways; these include purchase of intermediate or capital goods embodying knowledge. The installation and operation of such new equipment is also knowledge creating. Then there is the purchase of licences to use protected knowledge. Finally, firms seek to explore their markets. Given that innovations are economic implementations of new ideas, then the exploration and understanding of markets, and the use of market information to shape the creation of new products, are central to innovation. These points imply a more complex view of innovation in which ideas concerning the properties of markets are a framework for the recombination and creation knowledge via a range of activities; in this framework R&D is important, but tends to be seen as a problem-solving activity in the context of innovation processes, rather than an initiating act of discovery.

Many of the activities sketched above are in principle measurable. Collection of data on such phenomena has been attempted in probably the only systematic data source on non-R&D innovation expenditures, namely the Community Innovation Survey (hereafter CIS), which collects data not only on R&D but also on non-R&D innovation expenditures including training, market research related to new product development, design, expenditures on patents and licenses, and most importantly on capital investment (again related to new product development).

In this section we draw on some results from CIS data from the Europe-wide survey of 1992, on the general firm and industry distributions of R&D and non-R&D expenditures on innovation. The data relates to the 1992 CIS, and the results are drawn from an EIMS report on innovation expenditures in European industry. We divide the data into three categories: capital investment

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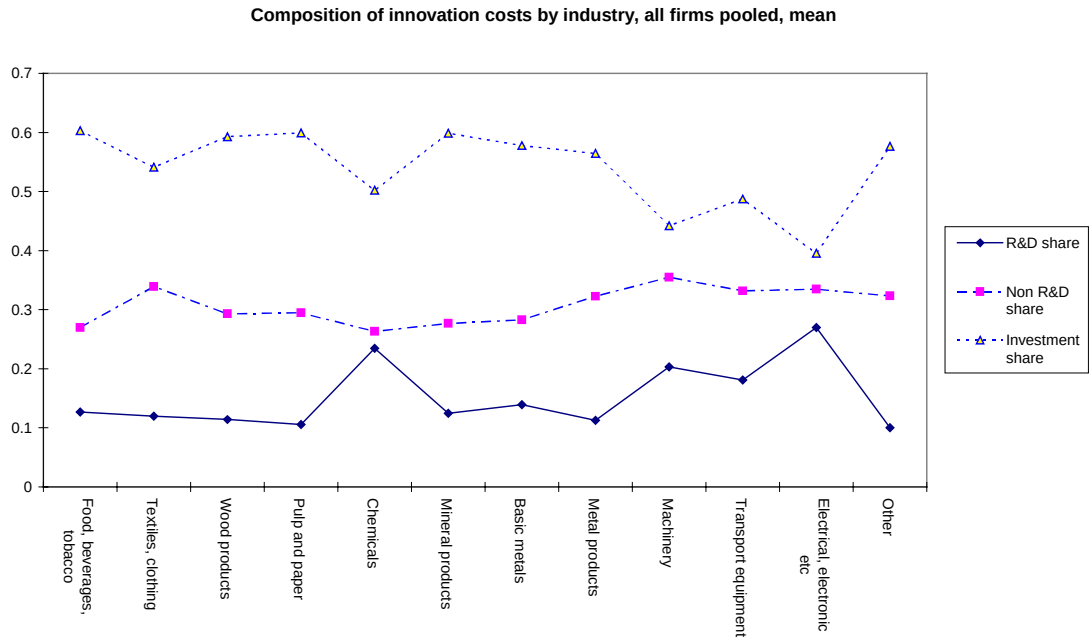
The most important of these are summarised in Table 2.2, which gives guidance on how to divide R&D from non-R&D. Prototypes are included in R&D. But pilot plants and industrial design are only included if 'the primary purpose is R&D'. This is equivalent to saying that 'they are R&D if they are R&D' - its does not really help. All improvements in production processes are excluded from R&D. Engineering development and trial production may be R&D or may not - it is rather arbitrary. Trial production is included 'if it implies... further design and engineering'. Trouble shooting, patent and licence work, market research, testing, data collection and development related to compliance with standards and regulations are all excluded. If taken seriously by respondents to R&D surveys, this would exclude virtually all development work from Research and Development data. OECD, **Proposed Standard Practice for Surveys of Research and Experimental Development ('Frascati Manual')** (OECD:Paris), 1993.

related to new product development, R&D, and non-R&D expenditures (covering training, market research, design, trial production and tooling up, and IPR costs).

The first point, perhaps a rather obvious one, is simply that R&D is but one component of innovation expenditures, and by no means the largest:

Figure 2. - Composition of innovation expenditures by industry, all firms pooled, mean

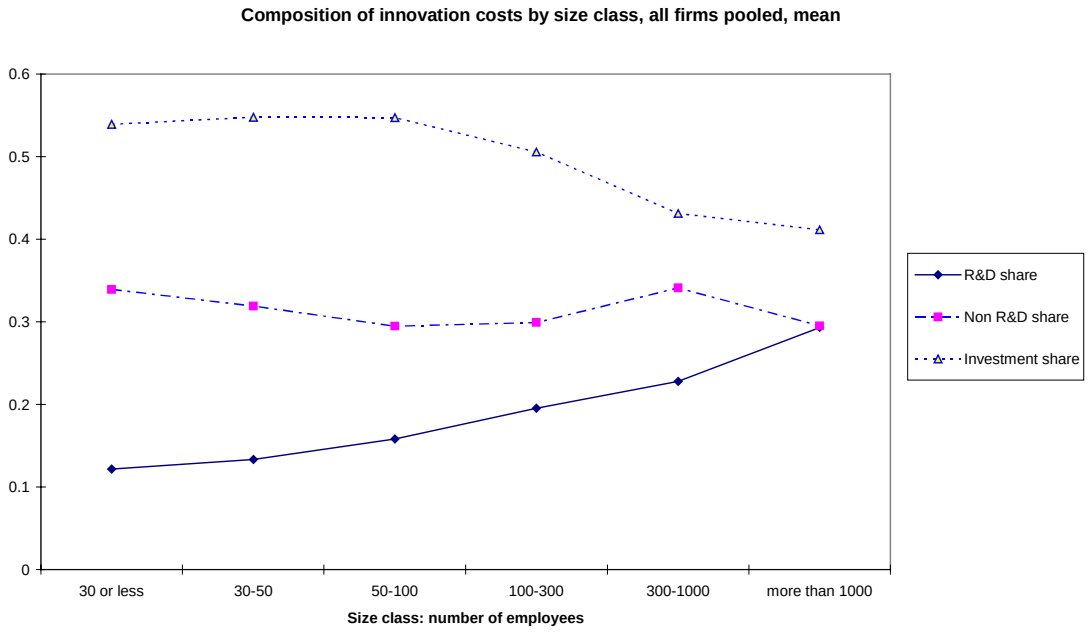


Source: Rinaldo Evangelista, Tore Sandven, Giorgio Sirilli and Keith Smith, **Innovation Expenditures in European Industry**, Report to the European Commission, DG-XIII-C, European Innovation Monitoring Initiative. p. 46

There is, as we would expect, variation in the share of R&D expenditures in total innovation expenditure across industries, with electrical, electronics, and chemicals (here including pharmaceuticals) having high shares; this is exactly what we would expect from the R&D statistics. To this variation across industries there roughly seems to correspond a variation in the opposite direction for the share of investment expenditures: firms that have relatively low R&D shares have higher investment shares. This in turn implies that non-R&D expenditures (design, training, market research etc) vary somewhat less across industries. The mean R&D share by industry varies between about 0.1 and 0.25, the mean non-R&D share is generally close to 0.3, while the mean investment share varies between about 0.4 and 0.6.

Figure 3 shows the composition of innovation expenditures by size class for all countries pooled.

Figure 3 - Composition of innovation expenditures by size class, all firms pooled, mean



Source: Rinaldo Evangelista, Tore Sandven, Giorgio Sirilli and Keith Smith, **Innovation Expenditures in European Industry**, Report to the European Commission, DG-XIII-C, European Innovation Monitoring Initiative. p. 47.

What we have here is, once again, a rather consistent non-R&D expenditures share, but on the other hand a clear relationship between firm size and the share of *R&D* expenditures, with this share increasing consistently with firm size. To this there seems to correspond, though less clearly, a decrease in the share of investment expenditures with firm size. The implication here is that small firms rely more on the acquisition of capital goods in innovation expenditures, so that knowledge structures in SMEs are likely to be more heavily dependent on embodied knowledge within capital equipment.

Table 1 looks in more detail at these shares across both industries, for seven countries (Belgium, Denmark, Germany, Ireland, Italy, the Netherlands and Norway). We present the mean, standard deviation and coefficient of variation for each type of innovation expenditure and each industry. While there are inter-country differences in the basic data, nevertheless the variances tend to be low, suggesting that industry profiles do not vary significantly across the countries of Europe.

Table 1

Innovation expenditures: shares by industry

	R&D			Non-R&D			Capital exp.		
	Mean	St.dev.	Coeff. var.	Mean	St.dev.	Coeff. var.	Mean	St.dev.	Coeff. var.
Food, beverages, etc,	0.11	0.03	0.30	0.27	0.03	0.12	0.62	0.03	0.05
Textiles, clothing	0.12	0.03	0.23	0.37	0.02	0.06	0.51	0.03	0.05
Wood products	0.16	0.18	0.12	0.27	0.06	0.23	0.57	0.19	0.34
Pulp and paper	0.12	0.03	0.26	0.31	0.04	0.13	0.58	0.06	0.10
Chemicals	0.24	0.05	0.20	0.25	0.06	0.23	0.52	0.03	0.05
Mineral products	0.12	0.05	0.45	0.30	0.05	0.17	0.58	0.07	0.13
Basic metals	0.17	0.04	0.26	0.25	0.06	0.26	0.59	0.06	0.10
Metal products	0.13	0.05	0.39	0.32	0.04	0.11	0.55	0.03	0.05
Machinery	0.20	0.03	0.16	0.37	0.05	0.13	0.42	0.06	0.13
Transport equipment	0.15	0.07	0.47	0.36	0.07	0.19	0.49	0.04	0.09
Electrical, electronic etc	0.28	0.05	0.18	0.31	0.03	0.11	0.41	0.03	0.08
Other	0.08	0.03	0.31	0.34	0.04	0.12	0.57	0.04	0.07

This data suggests a strong case for not focusing simply on R&D when we consider expenditure by firms and industries on innovation and knowledge creation, and suggest also a need to look into the significance of other sources of knowledge. It seems particularly important to look at capital investment, which represents a very significant component of innovation expenditure: in fact is the largest single component in every industry. In this context it is important to note that capital expenditure is a key mode of 'embodied' knowledge spillover from the capital goods sector to using industries. Can we find a way of incorporating such embodied spillovers into our understanding of the knowledge intensity of the using industry by an empirical account of their knowledge contents?

THE ROLE OF KNOWLEDGE AND LEARNING IN INNOVATION ACROSS INDUSTRIES

How do capital investment, intermediate good acquisition and non-R&D expenditures relate to the structure of knowledge in an industry? Most analyses of learning have focused on analysing the characteristics of learning processes, or on the broad types of knowledge that are involved, rather than on the specific content and structure of industrial knowledge bases. So innovation theorists have tended to explore such aspects of learning as cumulativeness, tacitness, and interactivity, or such issues as the institutional structure of knowledge creation across economies. Others, such as Lundvall and Johnson, have explored the components of knowledge and firm-level competence – distinguishing between specific factual information, knowledge of

basic scientific principles, specific and selective social knowledge and practical skills and capabilities.[16] But these approaches do not focus on the actual content of the knowledge base of a firm or industry, or on how it is organized institutionally.

So how can the knowledge content of an industry be understood and described? We can distinguish between three areas of production-relevant knowledge, namely firm-specific knowledge, sector or product-field specific knowledge, and generally applicable knowledge.[17] At the firm level, the knowledge bases of particular firms are highly localised, and specific to very specialised product characteristics, either in firms with one or a few technologies which they understand well and which form the basis of their competitive position, or in multi-technology firms. Secondly there are knowledge bases at the level of the industry or product-field. At this level, modern innovation analysis emphasises the fact that industries often share particular scientific and technological parameters; there are shared intellectual understandings concerning the technical functions, performance characteristics, use of materials and so on of products.[18] This part of the industrial knowledge base is public (not in the sense that it is produced by the public sector, but public in the sense that it is accessible knowledge which in principle available to all firms): it is a body of knowledge and practice, which shapes the performance of all firms in an industry. Of course this knowledge base does not exist in a vacuum. It is developed, maintained and disseminated by institutions of various kinds, and it requires resources (often on a large scale). Finally, there are widely applicable knowledge bases, of which the most important technically is the general scientific knowledge base. This is itself highly differentiated internally and of widely varying relevance for industrial production; but some fields - such as molecular biology, solid-state physics, genetics or inorganic chemistry - have close connections with major industrial sectors.

Distributed knowledge bases

The examples given above suggest that the relevant knowledge base for many industries is not internal to the industry, but is distributed across a range of technologies, actors and industries. What does it mean to speak of a 'distributed knowledge base'? A distributed knowledge base is a systemically coherent set of knowledge, maintained across an economically and /or socially integrated set of agents and institutions.

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[16] B. Lundvall and B.Johnson, "The learning economy", **Journal of Industry Studies**, Vol 1 No 2, 1994, pp.23-42.

[17] This kind of differentiation goes back quite a long way in economics, but has been significantly developed in recent years (for an early account, see W. Salter, **Productivity and Technical Change**, (Cambridge:CUP) 1969, pp.13-16.)

The problem is not so much definition as empirical analysis of content. How can we describe the content of these knowledges across particular industries, and how are they integrated? We turn now to an empirical illustration of this question, looking at two major industries. We seek to 'map' these knowledge bases in terms of their empirical content. The main issue is the forms of knowledge involved in an industry, the articulation of these knowledges and their flow across industries. The examples are drawn from empirical analysis in Norway.

These inter-agent or inter-industry flows conventionally take two basic forms, 'embodied' and 'disembodied'. Embodied flows involve knowledge incorporated in to machinery and equipment. Disembodied flows involve the use of knowledge, transmitted through scientific and technical literature, consultancy, education systems, movement of personnel and so on.

The basis of embodied flows is the fact that most research-intensive industries (such as the advanced materials sector, the chemicals sector, or the ICT complex) develop products that are used within other industries. Such products enter as capital or intermediate inputs into the production processes of other firms and industries: that is, as machines and equipment, or as components and materials. When this happens, performance improvements generated in one firm or industry therefore show up as productivity or quality improvements in another. The point here is that technological competition leads rather directly to the inter-industry diffusion of technologies, and therefore to the inter-industry use of the knowledge which is "embodied" in these technologies. The receiving industry must of course develop the skills and competences to use these advanced knowledge-based technologies. Competitiveness within 'receiving' industries depends heavily on the ability to access and use such technologies.

As examples, consider fishing and fish farming, both of which are apparently low technology sectors in terms of internal R&D. This is a large industry worldwide, with aquaculture growling particularly strongly; this is moreover an important growth sector for developing countries. Examples of embodied flows in fishing include use of new materials and design concepts in ships, satellite communications, global positioning systems, safety systems, sonar technologies (linked to winch, trawl and ship management systems), optical technologies for sorting fish, computer systems for real-time monitoring and weighing of catches, and so on. Within fish farming, these high-technology inputs include pond technologies (based on advanced materials and incorporating complex design knowledges), computer imaging and pattern recognition technologies for monitoring (including 3D measurement systems), nutrition technologies (often based on biotechnology and genetic research), sonars, robotics (in feeding systems), and so on. These examples are not untypical of 'low-technology' sectors – on the contrary, most such

[18] Richard Nelson call this the 'generic' level of a technology. Nelson, R., **Understanding Technological Change as an Evolutionary Process** (North Holland: Amsterdam), 1987, p.75.

sectors can not only be characterised by such advanced inputs, but are also arguably drivers of change in the sectors that produce such inputs.

The disembodied flows and spillovers are also significant. Underlying the technologies for fishing and fish farming mentioned above are advanced research-based knowledges. Ship development and management relies on fluid mechanics, hydrodynamics, cybernetic systems, and so on. Sonar systems rely on complex acoustic research. Computer systems and the wide range of IT applications in fisheries rest on computer architectures, programming research and development, and ultimately on research in solid-state physics. Even fishponds rest on wave analysis, CAD/CAM design systems, etc. Within fish-farming the fish themselves can potentially be transgenic (resting ultimately on research in genetics and molecular biology), and feeding and health systems have complex biotechnology and pharmaceutical inputs. In other words a wide range of background knowledges, often developed in the university sector, flows into fishing: mathematical algorithms for optimal control, molecular biology, and a wide range of sub-disciplines in physics for example.

MAPPING THE KNOWLEDGE BASE OF AN ACTIVITY

In what follows, we draw on earlier empirical research carried out in Norway, seeking to give empirical content to the notion of an industry-level knowledge base. An empirical approach is developed, and then applied to the food processing industry. The research sought to map knowledge bases by identifying and describing the following basic aspects of industrial production:

- First, the key activities in the industry in terms of technical phases of production. What are the main technical components of production activity within the sector concerned? What must a firm do to be a viable operator in the industry?
- Second, the key techniques - meaning capital inputs, equipment, instruments and production routines - being utilised to perform these activities. What are the techniques, which the firm must master in order to be able to undertake the activities, described above?
- Third, the knowledge bases - in terms of engineering and scientific knowledges - supporting these techniques. What are the codified knowledges with which the technical operations are designed, analysed, and produced?
- Fourth, the institutional framework. What are the organisational forms - in terms of companies, research institutes, universities and so on - through which these

knowledges are produced and disseminated? Concretely, who develops the relevant knowledge inputs, and on what resource basis?

KNOWLEDGE BASE OF FOOD PROCESSING IN AN ADVANCED ECONOMY

Food processing is one of the largest manufacturing industries in all OECD economies, and certainly is one of the largest industries in Europe. In order to map the technology knowledge base of the food processing industry we follow the method outlined above, seeking to identify the specific activities of this industry, then to identify the knowledge content of those activities and finally to map the producers and suppliers of that knowledge. An overview is presented in Figure3.

When identifying activities the criterion has been that they were specific to this industry, and common to all companies of the industry. On the basis of this criterion nine categories of activities were identified. Four of them describe different stages in the process of transforming the raw product:

- *Selection and preparation of raw materials* including activities as washing, sorting, selecting, filtering etc.
- *Processing*. Because of the wide range of products in this industry, the activities related to processing are very diverse. This category includes a wide range of processing functions, from cooking to pasteurisation.
- *Preservation and storing* is a very important area in the food processing industry; the activity includes chemical, biological and technical preservation methods.
- *Packing/wrapping and coating* is another important area which is related to preservation and storing, but also relates to issues of food safety and environment, besides marketing and advertising the product.

Two of the nine activities have to do with the actual product - raw products as well as end products:

- *Hygiene and food safety* includes keeping products clean and free of bacteria and other kinds of food pollution by maintaining cleanliness in the production environment and selecting harmless equipment and materials (e.g. non-toxic lubricants, detergents and wrappings).

- *Food quality and nutrition* concerns of course nutritional elements of the products, but also colour, texture and taste.

The last three categories includes activities supporting the actual products and production process, namely:

- *Quality control and documentation* which has to do with control of both raw products, end products and the production process in relation to hygiene, food safety, food quality and nutrition. It has also to do with documentation of quality standards vis-à-vis authorities and customers.
- *Transport and distribution* might not seem industry specific, but because of the short durability of the products and the long distances between suppliers of the raw products (primary sector) and producers, and between producers and customers and consumers, logistics is very important to the food processing industry.[19]
- *Trading/marketing/sales* does likewise not seem industry specific except for the special conditions for trade and competition and current developments in those areas.

The overall map looks as follows:

[19] One reason, presumably, why the Pentagon has reportedly sent staff to study the state-of-the-art logistics of Walmart.

Figure 4. Activities, technology/knowledge areas and knowledge networks in the Norwegian food processing industry

Activity	Technology/Knowledge-area	Knowledge suppliers
Selection and preparation of raw materials	Filtering-, centrifugal-, washing technology; steaming (thermic treatment); sensorics; molecular biology and micro biology; chemistry and biochemistry	Matforsk, Norconserv, NLH, NVH
Processing	Process lines (engineering); IT and informatics; logistics; heating and refrigerating technology; sensorics; molecular biology, micro-biology, bacteriology; chemistry, biochemistry, analytical chemistry; gastronomical skills	Norconserv, Matforsk., NLH, NVH, NTNU (kkt); SINTEF, Norske Meierier, Potetindustriens Laboratorium
Preservation and storing	Cooling/freezing technology; vacuum; hermetics and modified atmostfere packing; sterilisation; pasteurisation and homogeinisation; biological preservation (f.ex. fermentation); bio-technology; bio-chemistry; bacteriology and micro-biology; analytical chemistry	NLH, NVH (ins. fmn), Matforsk (avd. pros.), Norconserv, SINTEF (knt), NTNU (kkt), Norsk Kjøtt, NTH (ins. kt)
Packing/wrapping and coating	Disposal technology and environmental issues; materials technology; process lines (engineering, informatics); design; consumer preferences and merketing; micro-biology and bacteriology; bio-chemistry and analytical chemistry; cooling/freezing technology; vacuum; hermetics and modified atmosfere packing	NVH (ins. fmn; ins.bfe), Norske Meierier, Matforsk (avd.kval.), Norconserv, NLH
Hygiene and safety	Micro-biology; bacteriology; bio-chemistry; analytical chemistry	Norsk Kjøtt, Norske Meierier, Potetindustriens Laboratorium, NVH (ins. fmn), Matforsk (avd.kval.), NLH, SSF
Quality and nutrition	Chemistry; micro-biology; additives; texture; sensoric analysis and evaluation	Matforsk, Norconserv, NLH, UiO NVH (ins. fmn; ins.bfe), Norsk Kjøtt, Norske Meierier, Fisk.dir. Ernær.inst.
Quality control and quality documentation	Testing/measurement technology; spectroscopology; sensorics; micro-biology and bacteriology; bio-chemistry and analytical chemistry	Norske Meierier, Kontroll inst. f. meieriprodukter; Norconserv; NVH (ins. fmn; ins.bfe),NLH, Matforsk (avd. kval.)
Transport and distribution	Logistics; IT and informatics; general transport technology; cooling/freezing technology; micro-biology and bacteriology; bio-chemistry and analytical chemistry	SINTEF (knt), NTNU (kkt), NLH, Matforsk, NVH (ins. fmn), UiO (informatics and logistics)
Trading/marketing/ sales	Sociology (consumer preferences and trends); economy (price elasticities etc.)	BI, NLH, SIFO

Source: Trine Bendix Knudsen, Arne Isaksen and Keith Smith, 'Innovation and Knowledge Bases in the Norwegian Food Processing Industry' in O.J. Borch (ed) **The Food Industry: between business and politics** (Oslo: Tano Aschehoug), p. 196 [in Norwegian]; Thor Egil Braadland and Johan Hauknes, **Innovation in the Norwegian Food Cluster**, STEP Group, Oslo, 2000.

In the final column, the acronyms represent major publicly supported research institutions that form the knowledge infrastructure for this activity. Clearly many different kinds of skills, scientific disciplines and knowledge areas are involved in the functions and activities in the food processing industry. The point here is that Norwegian food processing as a total activity consists of

- 9 major activity areas
- 12 major technological fields
- approximately 20 'knowledge fields'

- 5 scientific disciplines
- 16 supporting research institutes
- 4 research-peforming universities/colleges

Despite the overall complexity most of this knowledge can be categorised into two main knowledge areas, namely food science and food technology. The Institute of Food Science & Technology (UK) defines these terms as follows:[20]

> … food science integrates the application to food of several contributory sciences. It involves knowledge of the chemical composition of food materials (for all food consists entirely of chemical substances); their physical, biological and biochemical behaviour; human nutritional requirements and the nutritional factors in food materials; the nature and behaviour of enzymes; the microbiology of foods; the interaction of food components with each other, with atmospheric oxygen, with additives and contaminants, and with packaging materials; pharmacology and toxicology of food materials, additives and contaminants; the effects of various manufacturing operations, processes and storage conditions; and the use of statistics for designing experimental work and evaluating the results.
>
> Likewise, food technology draws on, and integrates the application to food of, other technologies such as those of steel, tinplate, glass, aluminium, plastics, engineering, instrumentation, electronics, agriculture and biotechnology."

To sum up: despite the fact that this is an industry with relatively low levels of internal R&D, it might well be claimed that this is one of the most knowledge-intensive sectors of the entire economy. Presumably this is not unrelated to the fact that many of the sub-sectors of the industry are rapidly growing.

ICT IN THE DISTRIBUTED KNOWLEDGE BASE

How important is ICT in the knowledge base described above? It seems plain that ICT plays – as its proponents claim – a pervasive role. In instrumentation, communications, simulation, testing and monitoring functions, it is an omnipresent tool in these activities. But two points should be made about this.

First, ICT is not the only key technological input in these activities, nor is the knowledge behind ICT in any way the dominant knowledge input. Rather it is one input among a complex array of

[20] Source: Internet: http://www.blacksci.co.uk/products/journals/ijfst.htm.

inputs. It might be argued that ICT is a core technology in the sense that it is a technique that enables other knowledges to be brought to bear on production. These knowledge bases and technologies hang together, and it does not seem to me to make sense to single one of them out and label it as a decisive or 'leading' technology – rather these knowledges are mutually dependent and interacting within technology systems.

Second, it seems very problematic to argue that ICT is in some sense 'driving' innovation in these industries. Of course the technological opportunities offered by ICT play a role in shaping search processes, and in the heuristics that determine how problems are tackled. But if we look closely at the actual innovations that occur in these systems, it is rarely possible to say that ICT is a 'driver'. Let me give an example (again, I think, one which could be multiplied). Between 1987 and 1995 the second-fast growing manufacturing sector in Europe was 'Other Food Products'.[21] This category covers prepared fresh foods, an area of vigorous new product development in recent years. These innovations rest on advances in logistics, packaging, preservation techniques, food preparation and – not least – market research. ICT is there, if we look very closely, but it is no sense determining the trajectory of this high growth activity.

The point here is not to deny the importance of ICT. Rather it is a methodological issue of explanatory order. The omnipresence of ICT should not lead us to an excessive emphasis on its role as a generator of change. We might argue to the contrary in fact: a neglected problem is that of explaining why ICT plays such a key role in innovative search in out time.[22]

THE DISTRIBUTED KNOWLEDGE BASE AND THE KNOWLEDGE ECONOMY

A key point of the empirical analysis presented above is that if we accept the idea that modern economies are in some sense more knowledge-intensive, this does not necessarily mean that only some sectors or technologies are the bearers of the new knowledge economy. On the contrary, the knowledge bases of mature industries are cognitively deep and complex, and are moreover institutionally distributed: they are generated via 'knowledge systems', in the sense described by David and Foray.[23]

[21] See European Commission/Eurostat, **Panorama of European Industry**, Vol 1 (EC:Luxembourg) 1997, figure 7, p.9.
[22] The only person to address this issue in a systematic way, to my knowledge, is James Beniger: **The Control Revolution** (Cambridge: Belknap) 1984.
[23] David, P. and Foray, D., "Accessing and Expanding the Science and Technology Knowledge Base", **STI Review**, 16, 1996.

This is important both for developed and developing economies. For the developed economies it might be argued that the growth trajectories rest as much or even more on such sectors as engineering, food, wood products, vehicles and so on, as on radically new sectors as ICT or biotech. ICT has of course grown rapidly, but from a very low base, and with a very low share of output. Growth within the less glamorous sectors is certainly innovation-based, and moreover it rests on deep knowledge bases, which from time to time are subject to discontinuous change. One suggestion which emerges from all this is that growth is based not just on the creation of new sectors but on the internal transformation of sectors which already exist, that is, on continuous technological upgrading. This internal transformative capacity rests, in turn, on complex innovation systems that create, distribute and maintain advanced (often basic scientific) knowledge.[24] We can suggest that many so-called low-tech sectors are intensive in their use of scientific knowledge – industries such as food production, machinery, printing and publishing, wood products, and a range of services, have significant indirect science inputs. The depth and complexity of industry knowledge bases are not linked to their direct R&D performance, and indicators or industrial classifications based on this are misleading.

These types of industries are based on knowledge distributed across agents, institutions and knowledge fields. Many of the relevant knowledge fields lie in the sciences. These science inputs are supported by little-explored, indirect links with universities, research institutes and supplier companies. Thus 'low tech' industries are knowledge intensive, and are frequently part of 'high-tech' systems, and both scholars and policy-makers should be aware of their significance for growth. If the term ‘knowledge economy’ is to have any real significance then it must take such processes and activities into account, not only as bearers and users of knowledge, but also as drivers of change. This recognition takes us towards new problems. If we reject the implicit technological determinism of many ‘high-tech’ approaches to the relationship between innovation and growth, then we must face more squarely the question of the sources and determinants of innovation. On the one hand, we need to analyse the innovation decisions of firms in such sectors: under what circumstances can they muster the resources to invest in the complex of physical and intangible assets that make up a knowledge-intensive approach to production. Why are some firms in these industries far more successful than others in learning and innovation? This is primarily an issue in corporate strategy and control.[25] On the

[24] See M. Gibbons et al, **The New Production of Knowledge. The dynamics of science and research in contemporary societies**, London: Sage, 1994 for arguments on the ways in which this has affected scientific research.

[25] See Lazonick, W., and O’Sullivan, M., ‘Organization, Finance and International Competition’, **Industrial and Corporate Change** Vol 5 No 1, 1996, pp.1-49, and O’Sullivan, M., **Contests for Corporate Control. Corporate Governance and Economic performance in the United States and Germany** (Oxford: OUP), 2000.

other hand, we need a theory of the knowledge system which helps us understand how and under what circumstances knowledge-creating institutions actually generate and sustain cognitive flows, between themselves and into the production system.[26]

These issues have significant policy implications. Certainly within Europe, policy-makers remain heavily focused on ICT issues (both in innovation and diffusion-oriented policies) to the exclusion of most of the areas of knowledge that are in fact producing disruptive and discontinuous change across the major industries of the European economy. This may or may not be a problem, depending on whether or not ICT investment crowds out investment that would find better uses in other fields of knowledge and technology. But there does seem to be, on the face of it, a problem of analytical awareness. There seem to be real asymmetries in the policy attention given to arenas of relevant knowledge advance that are reshaping not the economy of tomorrow but the economy we have actually got.

For developing countries the point here is that growth rests as much on the technological upgrading of low technology 'traditional' industries as it does on the creation of high technology sectors. A key difference between developed and developing economies lies not in the structure of activities but in their technological levels. For many industries the technological level rests in turn on the extent to which the industry is supported by knowledge infrastructures that enable and support distributed knowledge bases and the flow of knowledge into activities that may be unglamorous, yet vital to growth.

[26] Some of the important issues here are discussed by Paula Stephan, 'The Economics of Science', **Journal of Economic Literature**, Vol XXIV, No 3, 1996, pp. 1199-1262.

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