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(eds.)

Low-tech Innovation in the Knowledge Economy



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Low and Medium Technology Industries in the Knowledge Economy: The Analytical Issues

1. Introduction

There has been an over-emphasis in both academic and policy contexts on the differences between so-called "high-tech" and "low-tech" industries. While it is clear that new sectors or sub-sectors do grow rapidly on the basis of the application of new technologies, these new technologies frequently diffuse to "old" sectors and sub-sectors. In some cases the old, traditional, industries grow more rapidly, or more consistently, over a longer period, than the new sectors. In addition, while not the results of research and development (R&D), there are innovations in low-tech industries that, where they occur, enhance the competitiveness of those industries on international markets. An internationally competitive traditional sector may contribute more to a small economy's prosperity than a new sector that burns brightly but briefly, transferring any innovations to more advanced, larger economies closer to core markets. The aim of this chapter is to explore some of these issues and to underline the main aspects that have been focussed upon in the PILOT project.

We begin the chapter with consideration of why so much academic and policy attention has been paid, in our view disproportionately, to high-tech industries. In the second section we turn to the 'knowledge society', a concept to some extent consequent upon the focus on science and high-tech industries as the sources of economic success. Here we raise the question as to whether non-science-intensive industries have relocated out of Western Europe. A cause and consequence of the definitional problems is the way technology is measured. We focus on this issue in the third section of the chapter.

Next, in the fourth and fifth sections of the chapter, we examine knowledge itself, first showing that there are different types of knowledge, and then pointing out the complexity in the relationships between science, knowledge and innovation. The following section focuses in on innovation in low-tech industries specifically. This leads into a consideration of the importance of regional factors in the success of low-tech industries. We end with a brief conclusion that raises issues considered elsewhere in the book.

2. Why the focus on high tech?

It is our view that a disproportionate amount of importance is attributed to a small number of relatively research-intensive industries. In this section we consider the origins and development of the academic and policy focus on

¹ This chapter is a reorganization, summary and selection from Hirsch-Kreinsen et al, 2003.

high-tech industries. We argue that the interest in science-based industrial and technological development – which is what the high-tech discourse is essentially about – originates in four partly related forces:

- the Vannevar Bush model for science and growth;
- the long-run development of corporate capitalism
- the cold war
- perceptions of Triadic competition.

As regards the first, we consider that the Vannevar Bush (1945/1980) report to President Roosevelt on *Science – the Endless Frontier* laid the ground for a new paradigm which may be called the 'linear model' (Stokes, 1997). The linear model is an ideological construct, a policy-related conception of the process of technological change. It rests on the usually unexamined idea that the knowledge underlying industrial production is defined by principles which are essentially scientific, that is, principles which have in some sense been transferred from scientific research. The process rests on a prior condition, which is an act of search and discovery; via R&D, new scientific or technological principles are elucidated, and the innovation process is seen as one in which the opportunities provided by this discovery are realised. The 'translation' process is basically sequential – from discovery, to engineering development, to new product creation and then to diffusion or spread (see Laestadius: Innovation, in this volume).

Bush's report, which foreshadowed the establishment of the National Science Foundation, in effect presented just such a science-based account of competitiveness. Its fundamental claim was that:

Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science. ... A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill (Bush, 1980: 19).

This kind of view about the role of science became quite widespread in documents related to science funding issues. But it is also sometimes expressed by more or less influential science policy-makers, either in the terms seen here, or as a more general statement about the nature of modern technology and its dependence on a science base. For example, Jerome Weisner, Dean of the Science School at MIT, and Presidential Science Advisor during the Kennedy administration, suggested that:

This is the nature of modern, scientifically-based technology. The first requirement is the existence of a body of scientific knowledge. Then the technologist must have a thorough understanding of the underlying science to use it as the basis for an invention in the solution of a specific problem. Also, more likely than not, he will find that the scientists who first explored the field that he is exploiting left large areas of ignorance which must be filled before his task can be completed. This can only be done by further fundamental research (Weisner, 1965: 33).

Although it had only weak support from theory or empirical studies, this linear model gained strong de facto support within parts of academia as well as in policy units. This type of view is by no means a thing of the past, or something which is not present in current policy discussions.

The second force relates to the development of corporate and managerial capitalism. This was observed already by Berle and Means (1932) and Burnham (1941) but attracted new interest in the 1960s (cf. e.g. Baran and Sweezy, 1966 and Galbraith, 1967). Alfred Chandler's (1977; 1990) work in recent decades has been seminal. Hand in hand with the growth of big industrial corporations, the innovation processes underwent transformation, as did the analysis of them. This is clear in the writing of Schumpeter which shifted its analytical focus from the "heroic entrepreneur" (Schumpeter, 1911/34) to the R&D department of the big corporations (Schumpeter, 1943/81). The argument was that innovation simultaneously became science-based and institutionalised in the formal R&D departments of large firms. Starting in the German chemical industry in late 19th century this phenomenon of institutionalised and large scale organised innovation rapidly diffused to American firms during the first half of the 20th century (Schmookler, 1957; Freeman, 1974; Mowery and Rosenberg, 1998). Around 1960 innovations were something that had to be *managed* in the R&D units (cf. Burns and Stalker, 1959/61). Despite the fact that many question whether it makes sense to describe either the German or America economies from the late 19th century as "science-based" this connection between large industrial corporate capitalism and R&D-based innovation has become an influential background notion in our time.

The third force was the intensive discussion following the launch of the Soviet Sputnik in 1957. What Nelson called "orbiting evidence of un-American scientific activity" caused a general panic in Western countries about the alleged neglect of science and technology – in policy as well as in the traditional growth models (Nelson in NBER, 1962). This led to a general increase in public-sector support in leading OECD economies in such fields as telecommunications, aerospace, and computing.

The growing rivalry between Western countries during the 60s – after two decades of recovery from the second world war – may be looked upon as a fourth force although it also had a clear relation to the growth of big corporations (cf. eg. Servan-Schreiber, 1967). So-called Triadic competition (Japan, Europe, USA) has since then been a continuous focus of attention by those who believe in the high tech race (cf. Dertouzos et al, 1989; Scherer, 1992; Heiduk and Yamamura, 1990).

Together these forces created the context for the emerging interest within the OECD (cf. OECD, 1971; OECD, 1981) and the European Union (cf. FAST, 1984; EUR, 1994) for the role of science and technology in relation to growth. It may even be argued that this process as a whole constitutes the cultural context for the development of innovation theory or economics of innovation (cf. eg. Freeman, 1974; Dosi et al, 1988; Grupp, 1998).

3. The 'Knowledge Society', globalization and de-industrialization

Among the consequences of the focus on science-based high-tech industries has been the idea that ongoing societal change in modern societies can be characterised as an emerging 'Knowledge Society' (cf. Drucker, 1994; Stehr, 1994; Willke, 1998; David and Foray, 2003) or 'Learning Economy' (cf. Lundvall and Borrás, 1997). These writers and others share the idea that modern organisations and societies are undergoing a fundamental change process, resting on an enhanced significance of knowledge as a productive force and asset. Continual innovation is seen as a decisive determinant of economic and social development, accompanied by a restructuring of work processes and organisation. In this process the generation, diffusion and utilisation of knowledge has become a core characteristic of firms and economic activity as a whole. These discourses on the emerging knowledge society describe – beyond any doubt – important tendencies of economic and social development but they can be misleading.

We share the view that knowledge is an increasingly important resource, but we dispute much of the conventional wisdom about how the knowledge economy is structured, and its implications for economic trends and hence policy measures. On the one hand, the knowledge economy is usually identified with a very small number of research-based or science-based activities, especially information and communications technologies (ICT), and biotechnology. On the other hand, it is often argued that as a consequence of increased knowledge intensity the economies of industrialised countries in Europe and elsewhere are going through at least two great changes (Carson, 1998):

- Significant elements of industrial production are moving from their traditional sites to developing countries. A classic example is the exodus of textiles from the rich world over the past three decades. This applies particularly to labour-intensive 'mature' industries: quite soon, it is argued, many big western firms in such industries will have more employees and even customers in developing countries than in developed ones.
- The second change is that, in many industrialised countries, the balance of economic activity is swinging from manufacturing to services. Even in Germany and Japan, which rebuilt so many factories after 1945, manufacturing's general share of jobs of the whole economy is declining very fast, in favour of high tech manufacturing and services.

Particularly in Western countries, these alleged trends have caused a debate about an ongoing process of "de-industrialisation", begun as early as the 1970s (cf. Fröbel et al, 1977). By the end of the 1980s, many American and European experts had come to believe that their countries' industries were being "hollowed out" as many basic activities moved to other areas (see especially Dertouzos et al, 1989). At its most extreme, the argument was that only high technology, knowledge intensive activities would survive in the rich countries. Facilitated by globalization, multinationals would be able to

undertake knowledge intensive parts of their processes in the rich countries, and labour intensive activities in low-wage, poor countries.

In our view these forecasts have not been realised. Traditional sectors have undergone change, but not simply destructive change. Rather the industrial sectors of many countries are reorganising themselves in a new economic environment. The result is that many allegedly threatened mature or traditional or low-tech industries are not only still located in their former home countries, but they are also very competitive and successful on world markets.

It is true that the main feature of the current change process is intensified innovation activities of many companies, based on the growing importance and utilisation of knowledge and knowledge work. This change has important implications for corporate strategies and behaviour (see Lazonick 2004, for an account of this). To mobilise knowledge and skills, companies have to introduce and finance specific innovation strategies. These strategies are mainly aimed at changing their traditional organisational and personnel structures as well as their conventional styles of utilising technologies. What Lazonick calls "organizational integration" is key for development and implementation of innovation strategies. On the level of work organisation, this requires more indirect forms of co-ordination are necessary alongside the conventional forms of hierarchical control and co-ordination. This increases the importance of the employees' commitment, motivation and initiative, especially in new forms of work organisation. The participative use of information technologies, the greater importance of organisational culture and the increased impact of inter-organisational production networks are also central elements both in changes in industrial organisation and structure.

These phenomena are by no means specific to high-technology activities. They hold true also for industrial sectors that can be termed "low-tech", producing mature products like furniture, clothing or light bulbs (cf. The Economist, 1998; Maskell, 1998; Palmberg, 2001). In the public discourse on the emerging knowledge society there is a firm belief that the high-potential and growth sectors are to be found among the industrial sectors that are engaged in new activities, innovative technologies and intensive research and development. The dominant view, in other words, is that such "high-tech" industries hold the key to the future. Such industries are identified with knowledge-intensive sectors, whereas the low- and medium-tech (LMT) sectors are usually regarded as based on low levels of knowledge, without a real future in many industrialised countries. Only the high-tech sectors offer prospects for development, and therefore, so the argument continues, it makes sense that economic and science-technology policymakers should favour them.

This argument simply overlooks a key fact: that in all industrialised countries there is a large sector of LMT industries, in manufacturing as well as in service sectors. Let us take, as an example, a traditional, so-called low-tech industry, that has many of the characteristics of industries that on the basis of the usual de-industrialization and re-location arguments we would expect to decline in

Western Europe and grow in less industrialized countries. This industry, the furniture industry, has in fact not only survived, it is one of the most important industries in Europe; it has 65,000 firms, with nearly half a million employees, and an annual growth rate of 4.5 percent (which is faster than the growth of European GNP). Over the 30-year period 1961-1990, furniture was the second-fastest growing product group in OECD manufacturing trade, surpassed only by computers and peripherals. This is despite a significant increase in international competition in furniture, from Mexico, Eastern Europe and Taiwan (Smith, 2003).

To some extent, the industry has been reshaped by integration and economies of scale, with firms like IKEA and Habitat reaching mass markets. But European competitiveness has been based on rapid product and process innovation, and the transformation of furniture into a flexible, design-based and knowledge-based production system. Recent research has shown that learning in furniture rests on local innovation systems, characterised by inter-firm collaboration, good quality regional infrastructures, access to high-grade design resources, and highly skilled labour forces. Complex patterns of specialization make this an innovative and growing industry in Europe (see Lorenzen, 1998 for a major detailed study).

Thus far we have argued that there is a tendency to focus on high-tech industries, and that while R&D and science-based knowledge are important, the significance of traditional, so-called low-tech industries is underestimated or, worse, ignored. How technology is measured emphasises the problem.

4. Measuring the level of technology

The standard OECD classification of industries, in terms of level of technology, is based mainly on R&D data. The *Frascati Manual*, developed in the early 1960s, provided – and still provides, in its sixth edition (OECD, 2002) – a basis for collecting and comparing data on R&D. This led to the classification of manufacturing sectors according to R&D intensity (the percentage of total revenue allocated to R&D) (OECD 1986). There was originally a three-position taxonomy: high-, medium- and low-tech industries. High-tech industries were those (such as ICT and pharmaceuticals) spending more than four percent of turnover on R&D, medium-tech those (such as vehicles and chemicals) spending less than four but more than one percent of turnover on R&D, and low-tech those (such as textiles and food) spending less than one percent of turnover on R&D. The contribution of high-tech, even in the most advanced economies, is small as it is shown by Kaloudis et al (in this volume).

In response to this fact, the three-position model was replaced by a four-position model (OECD, 1994):

high-tech industries	R&D/Turnover > 5%
medium high-tech industries	5% > R&D/Turnover > 3%
medium low-tech industries	3% > R&D/Turnover > 0.9%
low-tech industries	0.9% > R&D/Turnover > 0%

Nevertheless, even with this new classification, even if new EU members are included, and even if more recent years are examined, the shapes of the graphs remain roughly the same, more or less flat since the mid-1980s. Employment in high-tech is actually declining.

Innovation is much more than R&D. But even what must be included in R&D is debatable. Design, for example, though explicitly excluded by the *Frascati Manual*, is a fundamental part of the development of a product. The original OECD discussion of the classification was careful to point out that direct R&D is but one indicator of knowledge content. However, in practice, the classification has without this qualification had enormous influence, especially on policy. The EU and its member countries, for example, have turned the aggregate R&D/GDP ratio into a quantitative target for science and technology policy as a whole. This is open to two important objections. First, R&D 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.

From the data presented by Sandven et al (in this volume) and from such examples as the furniture industry, we can borrow a concept from Kaldor (1985) and argue that the stylised facts of the EU industrial experience indicate that high-tech industries are not nearly as important for industrial and economic change as the dominant science and technology discourse assumes. Consequently there are strong arguments for analysing the mechanisms behind industrial and technical change in those parts of the economy in which these mechanisms have been ignored in recent decades. Central among these are LMT activities, which include major activities across the whole of the economic structure, in mining and extraction, in agriculture, in manufacturing, and in both private and public services. As to why these industries are underestimated, at the heart of the problem is a whole set of assumptions about the nature of knowledge and its relationship to the level of technology.

Knowledge and level of technology

Knowledge-intensive, and science-based, have become almost interchangeable epithets in describing industries. This encourages the perception that advanced, science-based industries, and in particular information and communication technologies (ICT) and biotechnology industries (BTI), are the only ones that incorporate knowledge, in any serious sense. The focus shifts, as a result, to the need for high levels of education, training and skill acquisition for these industries but not for any others. This kind of perception by both policy makers and the media can have the paradoxical consequence of reducing the demand by students for certain high technology courses. This occurred when there was a radical downturn in applicants to third level computer courses in Ireland in 2003. Seeing a recession in the computer industry and the associated reduction in employment in that sector, students, encouraged by their parents, opted for other courses in colleges and

universities. They turned to arts, humanities and business studies. This was based on the false premise that the only industry in which computer skills are required, is the computer industry.

There are other consequences of this focus on science-based knowledge. First, it supports the emphasis on R&D – and particularly research – as the basis for industrial growth and economic prosperity. However, if we understand innovation in the broadest sense as “the processes by which firms master and get into practice product designs and manufacturing processes that are new to them, whether or not they are new to the universe, or even to the nation” (Nelson, 1992), then it is clear that many firms without formal R&D are innovative. R&D is only one aspect of the system of innovation. The system of innovation can also be defined broadly, “as a set of actors such as firms, other organisations, and institutions that interact in the generation, diffusion and use of new – and economically useful – knowledge in the production process” (Fischer, 2001). Such knowledge also includes knowledge about new or altered products, about ways of organising, as well as about production processes themselves. Accepting a system of innovation approach implies a rejection of the simple form of the OECD definition; “a too narrow focus on R&D overlooks the importance of other types of innovative efforts in the business sectors and, thus, the innovative performance of low-tech sectors in the economy” (Fischer, 2001). That systems of innovation include non-R&D-based innovation is often ignored. An example is a report of the Irish Science Technology and Innovation Advisory Council (1995); even though the report – *Making Knowledge Work for Us* – espouses the national system of innovation as a basis for the development of policy, its main focus is on science and advanced technology, to be achieved through increasing R&D.

A second, related, consequence of the focus on science-based knowledge is a view that formal, codified knowledge is most important for the “knowledge economy”. Formal and codified can be contrasted with informal and tacit, where the latter implies that the knowledge is derived from experience rather than formal study, and is passed on through inter-personal interaction in the work process, rather than through specific training or education. (For a more detailed definition, see Lam, 2000.) Codified knowledge is associated with high-tech, and tacit with low-tech. The reality is much more complex than this. LMT industries in fact do use codified knowledge, employ engineers – and in some cases even undertake R&D. In general, however, this use of educated, trained and skilled people, sophisticated machinery, and advanced knowledge about organising, about logistics and about design, is all ignored or relegated because of low levels of R&D. Thus firms like IKEA, Habitat, Benetton and Zara, are in the low-tech category despite their innovativeness.

This not to say that tacit knowledge is unimportant in LMTs. The importance of tacit knowledge, moreover, is closely related to the systems perspective, and to the evolutionary economic theory that underlies it. Most tacit knowledge is obtained through learning-by-doing. It is often based on work practices (routines) and rules that are not necessarily person-bound; they are rather

norms accepted collectively by the employees or the community in question. This leads directly to the collective dimension of knowledge. Collectiveness concerns knowledge stored in the rules, procedures, routines and shared norms of work processes, problem-solving activities and patterns of interaction among individuals. In this sense, the collective side of knowledge is rather to be found between than within individuals. It can be more or less than the sum of the individuals' knowledge, depending on the mechanisms that translate individual into collective knowledge (cf. Lam, 2000). The arguments by Teece (2002) are similar and link this to competitiveness: the ability to translate (individual) resources to (firm) capabilities is what constitutes firms' competitiveness. Tacitness of knowledge is not the only defining characteristic of low-tech activities, but it is clear that this concept points us towards important problems in knowledge creation and learning. Moreover, there is nothing in this discussion that excludes tacit knowledge from low-tech activities in high-tech firms.

It should be noted that knowledge gained through the specific work experience may include both tacit and codified knowledge. If we consider the situation in which people work, as in aircraft maintenance, at least formally on the basis of a manual. Through working with others and their own experience of the work itself, workers learn (obtain tacit knowledge about) how to implement what is written in the formal manual. However, in addition there are changes in the formal manual, some that have had to be implemented in order to do the job properly, others that facilitate 'short cuts'. The resultant informal manual, though informal in the sense that it has not been approved, is nevertheless codified in the sense that it is written down. If and when the changes become officially accepted, then the knowledge becomes both codified and formal. The combination of tacit knowledge and informal codified knowledge can be called "practical" knowledge.

Another problem in the definition of knowledge is the difference between knowledge and competence – with a science focus emphasising the former. A recent study on the dynamics and characteristics of firms' relations to external repositories of knowledge (Hales, 2001), demonstrates that a distinction between knowledge as furnished by external repositories or 'knowledge bases' and the productive competence² underpinning firm-level innovation and behaviour is essential for understanding the 'learning processes' of innovating firms. Rather than 'knowledge intensity', this implies that the relevant driver is 'competence intensity'. Although formulated somewhat differently this perspective is present in several discourses on knowledge formation and creation of firm capabilities. Cohen and Levinthal (1990) for example use the concept "absorptive capacity" and Teece et al (1997) and Zollo and Winter

² Hales (2001) defines competence broadly as something that determines a firm's competitiveness. It includes people, and capital and equipment; characteristics that qualify a firm to be in an industry, or those that enable it to lead or innovate; and competences are seen both as resources and assets.

(2002) use "dynamic capability" to address these issues. The competences and capacities are not necessarily R&D-based, and may involve many non-technological dimensions.

Organisations with high levels of competence do not necessarily have high levels of knowledge, and vice versa. Firms with high levels of R&D are clearly knowledge intensive. They may not be competitive in their industries and may therefore have low competence intensity. Firms that have a core competence in simple assembly functions may not be knowledge intensive but, if they are competitive in their industry, they are by definition competence intensive. In the extension of this family of arguments we face the complexity of knowledge formation in agglomerations, in networks, and in supply chains. The dynamics and synergies within these structures and collaborative relations are far from easy to capture and locate to specific actors/industries.

5. Science, knowledge and innovation

It follows from the above that there are other types of knowledge than that which arises from scientific research. In comparison to what is suggested by the Bush report and the linear model, this suggests a greater complexity in the relationships between science, innovation and industry (more in line with the earlier work of scholars like Whitehead, 1925 and Schmookler, 1950).

The Bush report gave birth to the concept of basic research – independent of all practical ends – and assigned it the role of pacemaker of technological progress. This was followed by a conclusion on the necessity for nations to establish basic research to obtain a "competitive position in world trade" (Bush, 1980, p. 13). A further review of the basic research concept may lead us too far from our ambitions; but here it is enough to conclude that the linear model which emerged out of this reasoning – although frequently questioned – has become attractive for science and technology policy makers in many countries. The basic science on which innovation allegedly rests has been identified as a public good, with low appropriability, as well as non-rivalry and hence positive externalities, and is thus well suited for publicly financed science policy (cf. Arrow, 1962).

It may be argued that the linear model, as it is deployed in the Bush report, obscures the importance of at least three classes of (partly related) problems: a) the duration problem; b) the independence of engineering and crafts and c) the endogeneity of science.

The duration problem is, quite simply, the fact that there is in many cases a long period between the relevant scientific discoveries and inventions on the one hand and successful innovations on the other. For the inkjet printer, for example, the period between the first reported scientific results on influencing liquid droplets and a commercial printer was as long as 200 years and certainly more than 100 years (Laestadius, 1996). The gap between the discovery of the scientific principles of the laser by Einstein and the first practical applications was about sixty years. Gaps of decades or even centuries at the very least suggest the need for science and technology

policies to reconsider the idea that economic success is directly dependent on research. Production capability involves the integration or articulation of many different modes of knowledge, skills, and competences. These do not develop automatically and may well require the solution of problems that are far more complex than an initial scientific insight.

This leads us to the second problem, the status of engineering knowledge. The problem is whether engineering should be understood as applied science or whether it has an epistemology and procedures of its own, and is thus independent from natural science – though subject to the same natural laws. This problem has attracted researchers on engineering knowledge formation for decades (cf. eg. Layton, 1976 and 1988; Vincenti, 1990; Downey and Lucena, 1995). In some cases engineering and science may be intertwined, as in the obviously science-based biotechnology field (Narin and Noma, 1985). However even in modern technological breakthroughs, like the transistor, it can be shown that the technological paths were far from given by the achievements of science (Gibbons and Johnston, 1982). According to Rosenberg (1969), technological problems solved are just a fraction of those we are capable of handling, thus leaving technological development more or less undetermined by the scientific frontier and more dependent upon imbalances and focusing processes created in the technological system itself.

One conclusion, out of many, which may be drawn from the conjecture of the relative independence of engineering, is that the influence between science and engineering may run in both directions. This topic, here labelled as the endogeneity of science, relates to the fact that throughout history science has developed on the shoulders of instruments and artefacts constructed by craftsmen and engineers (Rosenberg, 1992; Stokes, 1997; Mowery and Rosenberg, 1998; Jardine, 1999; Joerges and Shinn, 2001). Technology – and its artefacts – often create the foundation for science, and scientists sometimes explain how and why existing things work rather than laying the foundation for inventing them. It is often the case that technologies or production processes generate problems that lead to major scientific breakthroughs – Pasteur's successful solution to the spoilage problems of the Bordeaux wine industry, or Penzias' and Wilson's solutions to ATT's background noise problems, each involved major scientific breakthroughs.

Questioning science-based innovation models, and the scientification of technology more generally, leads us to a set of empirical problems. These include how innovations in practice occur: what is the role of science, of engineering, of craftsmanship, of design and other forms of knowledge processes, of market reactions, and how do these practices differ between technologies and industries? The Kline-Rosenberg (1986) highly interactive model is one way to handle the problem of complexity, and there are others as well. The Kline-Rosenberg model in effect sees R&D not as the foundation of innovation, but as the problem-solving activity of last resort – it is what firms do in an innovation project when they cannot solve problems with their existing sets of knowledge and skills. Stepping away from the linear model thus opens

up how we can think about innovation, but perhaps more importantly it opens up how we can think about an innovating industry, and from that leads to new territory in thinking about economic growth.

6. Low-tech and innovation

Among the clear consequences of the arguments above is the necessity to examine in much greater detail than is the case in the dominant discourse, innovation in low-tech industries. Each of the different types of knowledge is important in low-tech, and innovation occurs as knowledge accumulates. Let us consider again the example of practical knowledge raised above. As suggested, practical knowledge is often the precondition for systematic work rules or engineering and technological findings, prototypes and other products. In other words, practical knowledge is in reality closely connected with codified knowledge. In this sense, practical knowledge shows high potential for development with its bearers proving to be very capable of learning. An instructive example, described by Laestadius (1995), is the absorption of external R&D results in a company producing anchor cables. It concerns the adjustment of given material parameters to the actual requirements of a forging process whose course is hard to calculate. Obviously, this requires a high degree of practical experience in employees.

Practical knowledge, as we have shown, can pass into officially codified knowledge, in a process of knowledge conversion between practical and theoretical knowledge; this appears to be common practice in many companies. These conversion processes can be considered as a central prerequisite for innovations, since in this way new knowledge is created. This may also be a way of transforming disembodied knowledge into embodied (cf. Laestadius, 1998). Nevertheless, these processes are not unproblematic, as shown in particular by Nonaka (1994), and complex requirements often have to be met.³ Nevertheless, this is a major process of knowledge creation which is unrecorded by available indicators and much innovation analysis, yet of vital importance for understanding the knowledge dimensions of low-tech industries.

In analysing the role of LMT sectors in the knowledge economy, we can start from the hypothesis that in industries with low R&D intensity we will find a type of knowledge which comes very close to the outlined features of practical knowledge in a special way. A characteristic feature of the production processes of significant segments of the LMT sector is their reliance on knowledge that is on the one hand created and reproduced through learning-by-doing as well as using, empirical trial-and-error, and limited systematic training. On the other hand LMT firms are characterised by a certain absorptive capacity, i.e. the ability to integrate and utilise codified and scientifically produced elements of knowledge from different, often external

³ See also in detail Nonaka and Takeuchi (1995).

sources (Cohen and Levinthal, 1990). In other words, the LMT knowledge base is complex, deep and systemic.

Apart from innovation in production in LMT industries, innovation in organisation is also important. The effective use of practical knowledge requires sophisticated enterprise organisation. In relation to how low-tech companies mobilise their specific practical knowledge, a broad spectrum of reorganisation and innovation strategies have been identified in case studies of German companies (see Hirsch-Kreinsen and Schmierl in this volume). They range from a far-reaching technical-organisational restructuring of the entire production process to partial and gradual steps of reorganising certain functions. The organisation must make it possible to continuously use the practical knowledge available and to develop and adjust it in response to new requirements. For low-tech companies, this often means a break with inherited "Taylorist" structures characterised by a strictly-defined division of labour, highly repetitive tasks and the use of mostly semi-skilled or even unskilled workers. As shown by Schmierl (2000) but also Hamngren et al (1995) advanced reorganisations of industries have led to mobilisation of creativity and knowledge which, in many cases, have contributed to significant productivity increases and higher quality performance. It may be argued that the reorganisation of industrial work (i.e. knowledge management) so as to mobilise the hitherto hidden competencies in the staff, challenges our traditional understanding of the concept "innovation". If routine production is mechanised and (virtually) all employees work creatively, the distinction between innovative and non-innovative activities will be blurred.

The aforementioned case studies (cf. Hamngren et al, 1995; Hirsch-Kreinsen, 2000; Schmierl, 2000) show that the effective reorganisation strategies of low-tech companies depend heavily on the utilisation of external conditions and supportive factors. Establishing relations with other companies, organisations and institutions is an activity even low-tech industries cannot do without. External collaboration helps in overcoming the limitations of a firm's own resources and know-how in developing new production and innovation potential. So we turn to regional perspective next.

7. Networks, industrial agglomerations, clusters

Among the clearest examples of groups of low-tech firms that became competitive and sustained that competitiveness over long periods, are the industrial districts of the Third Italy. Most of the industrial districts are in traditional sectors like clothing, textiles, footwear, furniture and ceramic tiles. There has clearly been something about the combination of place, culture and proximity that has contributed to the success of these industrial districts. Other agglomerations, like that in Silicon Valley, are high-tech; successful agglomerations are not synonymous with low-tech. The literature on clusters and industrial districts is now vast and too well-known to require summary here.⁴

⁴ See, for example, Jacobson et al (2002) and Jacobson and Mottiar (1999).

It is worth pointing out, however, that there is a close relationship between the literature on industrial districts – both in the Third Italy and elsewhere – and work on learning and innovation. Systems of innovation theories, for example, attributing a critical role to technological, organisational and institutional learning in the process of innovation, stress that learning is an interactive and socially embedded process (Lundvall, 1992; Fischer, 2001). Industrial districts, in which inter-firm co-operation is facilitated by spatial proximity, provide support for the idea that spatial proximity is important in promoting interactive learning, innovation and the development of competitive advantage. Lorenzen (2002) takes this idea further, providing theoretical arguments for ascribed trust being at the heart of the way in which a kind of shared understanding develops in networks of firms. Some of this can be codified, especially in relation to 'hard' information such as business data on revenue and profits. This does not particularly require proximity. In addition, even exchange of "complex, tacit, and 'embodied' information" – though requiring trust, and "frequent face-to-face interactions", and though helped to some extent by proximity – is "not severely inhibited by geographical distance". However, to derive benefit from high levels of social trust, sharing in local culture, being part of a community and its rich social capital, does require close proximity. The "social learning processes that create social codebooks... are constrained by geography", Lorenzen argues, and "hence 'cultures' arise locally – for example in industrial clusters". All these are highly tacit, the costs of their development appear nowhere (and certainly not under R&D expenditure), and yet they contribute substantially to the innovativeness of what Lorenzen calls industrial clusters. His contribution to the development of theory in this area provides a basis for relating the social and cultural to the economic, in a way particularly relevant to LMT industries.

Organisational proximity is of a non-material and non-market nature (Burmeister and Colletis-Wahl, 1997), and it "presupposes the existence of shared knowledge and representations of the environment within which the firm exists" (Hudson, 1999). Through interactions in intra-industry relations, co-operation and collective learning processes, organisational proximity creates a capacity to assemble fragmented information, tacit knowledge and other non-material and non-standardised resources. Information originating outside the network is received in a qualitatively better way, due to organisational proximity among the actors. The existence of organisational proximity – formal and/or informal networks – enhances absorptive capacity. Organisational proximity is viewed as a prerequisite for collective learning processes, and for co-operation among different organisations in the creation of new resources and innovation. While organisational proximity is a necessary condition for creating innovations and resources through processes of collective learning, it is also simultaneously a product of the process of collective learning.

Heanue and Jacobson (2002) provide empirical evidence of organisational proximity in the case of a dispersed network of three firms in the furniture industry in Ireland. They show that these firms share values, meanings,

understandings and tacit knowledge and a common set of institutions through which these features are produced. The most important mediating institution in this case was the Irish industrial development agency, Enterprise Ireland. The individual involvement of each of the firms over time in various industry initiatives with Enterprise Ireland not only contributed to the development of a shared "worldview", but it also enabled the firms and institution together to identify suitable partners for the current network.

The empirical focus of this work was a geographically dispersed formal network. In contrast, Dahl and Pedersen (2003) examine the case of regionally clustered informal networks. The theoretical context of their work is the recent importance attached to the role of informal networks in the development of regional clusters. In particular, informal contact between employees in different firms is argued to be one of the main carriers of knowledge between firms in a cluster. They empirically examine the role of informal contacts in a specific cluster. The analysis, based on a questionnaire sent to a sample of engineers in a regional cluster of wireless communication firms in Northern Denmark, shows that the engineers acquire and share valuable knowledge through informal networks. The authors argue that this shows that informal contacts are important channels of knowledge diffusion. Again it must be emphasised that firms gaining from this diffusion of knowledge do so without any specific R&D effort; in this case the firm gains without any explicit effort at all. Clustering and knowledge exchange of these types appear to be a pervasive feature of LMT industries (Isaksen, 2001), and it is this that links the innovation and growth potential of LMT industries to important regional issues in Europe.

8. Conclusion

In this chapter we have selected and summarised reviews from a number of literatures that formed the backdrop to the initiation of the PILOT project. There is at least one result that seems beyond dispute; it is clear that even in industries that have relatively low or even no R&D, innovation can and does take place. No studies have yet provided evidence of a deep understanding of the nature of innovation processes in so-called low-tech industries. The case studies undertaken in the context of the PILOT project have begun to provide this deeper understanding as the following chapters in this book will show.

Some of the other conclusions of this chapter are more contentious. It may be that many academics and policy makers will disagree with our argument that the attention, policy focus, and perhaps even share of funding, that goes to high-tech, science-based research, is disproportionately high. We should emphasise that we do not argue that research in such areas as ICTs and BTIs is inappropriate. Rather, our argument is that LMTs are more important than is usually considered to be the case, and that research on and support for innovation in those industries should therefore be increased.

Even more fundamental than the argument over the relative importance of "high-tech" and "low-tech" industries, we have raised the problems of definition. It is likely that if we arrive at agreed definitions and taxonomies, this

will clarify and even reduce the points of contention. Measurement and taxonomy are the focus of the next chapter.

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