

MANAGING DISTRIBUTED KNOWLEDGE BASES AND TECHNOLOGICAL UPGRADING IN LOW AND MEDIUM TECHNOLOGY INDUSTRIES

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Preferred Stream: 6 (Knowledge Management and Intellectual Capital)

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ABSTRACT

Low and medium technology industries, which account for more than ninety per cent of GDP in advanced economies, engage in relatively little intra-mural Research and Development activity. Nevertheless, they are often comparatively innovative because many low and medium technology firms are adept at drawing relevant new knowledge from other sectors. This knowledge is sometimes conceptual or abstract, but it is often embodied in equipment purchased by the firms or results from joint ventures or other forms of collaboration. Because the knowledge needed by these firms is so diverse and widely distributed, it raises crucial management issues. In this paper, we discuss these issues and present illustrations from the food sector.

Keywords: Knowledge transfer; Business innovation; Knowledge management research methods; Research and development; Inter-firm knowledge sharing; Knowledge-based view of the firm.

INTRODUCTION

The study 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, the focus of learning and knowledge generation has become broader as firms have embraced an increasingly wide range of sources when undertaking innovation. Although this tendency – which is sometimes associated with ‘open innovation’ – is not, in fact, new (Chesbrough, 2003; Christensen, 2006), it does provide a more balanced view of the creation and use of knowledge than was provided by older concepts according to which, through research and development activities, new science eventually inspired new technology which then helped to foster new products and processes, without any provision for significant feedback (Kline and Rosenberg 1986).

Our argument is that, when discussing innovative activity at the levels of firms, industries and public policy, it is necessary to reach beyond a focus on science based activities, high technology, and internally-generated knowledge to investigate the broader range of innovative activities that drive change in practice. We contend that in most sectors a ‘distributed knowledge base’, one that transcends internal sources to draw widely from other firms and institutions, forms the basis for innovation. Through diverse channels, both formal and informal, firms obtain information from many sources which they then actively combine through internal adjustments. As levels of R&D are very low in much of the economy, the use of distributed knowledge is, in fact, a major source of new ideas and techniques, especially in low- and medium-technology (LMT) firms.

At present, however, the diverse sources of knowledge that firms rely upon for their innovative activities are rarely charted. In order to increase the understanding that managers, policy makers and scholars have of the processes by which knowledge is collected and used, we propose that the sources of innovative knowledge should be mapped systematically to increase our appreciation of the richness of the innovation process. In this way it will be

possible to better guide future improvements in the use of knowledge. We illustrate our point with an informal mapping of several sectors in food production and processing.

DISTRIBUTED KNOWLEDGE BASES IN LMT INDUSTRIES

The creation, diffusion and use of knowledge have been modeled in several ways that are not always compatible. Much analysis of knowledge creation rests on R&D data, particularly intramural R&D carried out by firms. This is often measured indirectly, as Powell and Snellman (2004) have done, through the use of patent data. But while patents are a valuable indicator when used carefully (Patel and Pavitt, 1995; Griliches, 1991), it is mistaken to over-identify knowledge creation with intramural R&D and patenting, partly for conceptual and partly for practical reasons. Conceptually, R&D data tend 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) (Kline and Rosenberg, 1986). The linear model portrays innovation as a set of development stages originating in research, and this prior significance of research is used as a justification for using R&D as a key knowledge indicator.

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 (Schulz, 2001). Activities such as 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 in a range of ways, including 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. 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 of knowledge via a range of activities. In this framework R&D is important, but should be viewed as a problem-solving activity in the context of innovation processes, rather than an initiating act of discovery.

Thus the relevant knowledge base for many industries is not solely, or even principally, internal to the industry, but is distributed across a range of technologies, actors and industries.¹ A 'distributed knowledge base' is a set of knowledges, maintained across an economically and/or socially integrated set of agents and institutions. In general, enterprises do not depend on a single technology or on single sources of technological knowledge. They must blend knowledge that is distributed among various knowledge bases according to such factors as industrial source, geographical location, intellectual (scientific or technical) location, social location and chronology. Although the relative importance of these may vary from enterprise to enterprise and sector to sector,

innovation management in a dynamic environment consists largely of finding efficient ways of detecting, comprehending and mixing and integrating distributed knowledge to achieve outcomes that are economically efficient and lead to acceptable social outcomes both within enterprises and in broader societal and political contexts.

Although some authors (Coombs and Metcalfe, 2000; Coombs, et al., 2003) concentrate on distributed activity that is formally structured – through joint ventures, strategic alliances, conscious outsourcing, and other well-defined organizational forms – we contend that distributed knowledge bases are often inchoate in important ways. As we discuss below, because of uncertainty and uneven distributions of knowledge, it is often difficult to know where to look for appropriate knowledge, if indeed there is any reason to suppose that such knowledge currently exists. The chains through which knowledge is conveyed may have several links, and not all chains are interconnected. Even when knowledge is ‘in the air’, a particular firm may not be breathing in the right spot to inhale it.

Distributed Knowledge Sources of LMT Industries

The management of distributed knowledge in established low- and medium-technology industries presents distinct challenges, but it is vital. Because the sources of knowledge may be widespread, however, a first stage towards managing them is to trace where firms in individual industries gain their knowledge, weigh the importance of the various sources, and map them to determine which sources are most important and under which circumstances. Theorising and modeling in isolation are likely to generate empty boxes if they are not grounded in detailed empirical findings.

Established LMT industries comprise 97 per cent or more of GDP and are similarly dominant in employment and investment (Robertson and Patel, 2007). The importance of high technology is primarily exerted through its influence on productivity in LMT industries rather than directly. Because research and development activities as traditionally defined are only minor contributors to change in many established industries, technological upgrading often involves incorporating new technologies based on knowledge that originates outside the enterprise² into complex existing frameworks (Hirsch-Kreinsen, et al., 2006; Kodama, 1992). Firms in established LMT industries, even those among the very oldest, need to manage distributed knowledge bases effectively in order to maintain domestic and international competitiveness. Unless they innovate, these firms risk being overtaken by rivals that implement new product or process technologies or manage change in other parts of their supply chains more successfully. This is often a complicated task, however, that requires commitments of substantial financial and intellectual resources.

Differentiation of knowledge and its communication within organizations is well-known (Schulz, 2001). Porter’s diamond also discusses the value to firms (and to national economies) of having widespread sources of external knowledge through ‘Related and Supporting Industries’ that allow relatively inexpensive and quick access to new knowledge (Porter, 1990). Porter’s main emphasis is on clusters or industrial districts in which highly specialized firms in close physical

proximity are able to develop and diffuse information efficiently using mechanism similar to the horizontal and vertical channels discussed by Schulz (2001). Although there is no doubt that industrial districts may be effective in promoting innovation in some cases (and quite ineffective in others) (Robertson, et al., forthcoming), for many firms much information comes from further afield.

For example, firms may find it relatively simple to acquire the fruits of new knowledge from other sectors because it is embodied in equipment (Pavitt, 1984) or other inputs that the firms can purchase. In other cases, however, firms may not be able to outsource knowledge acquisition because outsiders do not understand their problems and opportunities as well as the firms themselves. As a result, in dynamic environments firms need to develop absorptive capacity to access knowledge directly (as well as to increase their 'receptive capacity' (Robertson, et at, 2003) by acquiring a range of other capabilities needed for successful implementation of change). As new knowledge may come from widely distributed sources, this is a difficult problem to manage because, in order to contain costs, firms are forced to gamble on which sources will turn out to be most profitable.

LMT firms may also face problems in trying to mix different vintages of technology (Kodama, 1992). Both products and processes tend to evolve over time as incremental improvements are fitted into existing patterns and procedures. Where there is conscious modularity and design rules have been laid down (Sanchez and Mahoney, 1996; Baldwin and Clark, 2000), some changes may be effected through an easy substitution of new components for older ones, but such seamlessness is not always possible. This forces managers to rethink existing practices in order to make the best use of new developments. Knock-on effects from small changes may, as a result, be significant. Moreover, when potential improvements of several kinds become available almost simultaneously but have been developed in different environments that are not subject to the same sets of design rules, managers may be forced to choose among them because of incompatibility.

In addition, the uncertainties imposed by widely distributed knowledge generate opportunities for strategic initiatives as managers look for niches in which some types of innovation are especially sought after while others offer less advantage. Specialisation in knowledge acquisition is therefore possible, but carries a risk of generating technological inflexibility if neglected areas turn out subsequently to be competitively vital.

Mapping Distributed Knowledge Sources

The production of detailed maps entails tracing as many of the technological influences operating in a sector as possible and assessing their relative importance. Such maps are essential for good firm management as well as for formulating sound public policies because, in the course of studying complex knowledge flows, they can identify strengths and weaknesses. In particular, structural holes (Burt, 1992) affecting whole sectors and regions as well as particular firms can be located. Short-cuts in existing lengthy flows can be found and entirely new routes opened. But knowledge bases are often diverse and it may be hard to define their characteristics across several dimensions. Which of the contributing sciences and technologies are the most important, and what

criteria are used in making a determination? Is a specific category of knowledge (new or old) needed in-house and, if so, how much expertise is really needed? Does a specific type of new knowledge come to a firm in an embodied or disembodied form? What sorts of organisational relationships are needed to deal successfully with outside sources of knowledge? These and similar questions are empirical issues and are likely to vary across knowledge categories and from firm to firm and sector to sector. In a complex environment, both managers and policy makers must be able to answer these questions accurately for specific cases rather than relying on broad *a priori* models.

A number of different types of maps can be generated. For example, to capture knowledge transmission through formal channels, maps of alliances and networks or modular chains are useful. Informal networks such as communities of practice may also be important in charting distributed knowledge flows. However, any single map is unlikely to capture all of the important dimensions in a distributed knowledge base. Restricting the investigation to formal channels of knowledge transmission could miss important flows travelling through informal channels. Looking at knowledge as ideas and concepts overlooks embodied flows. Using only regional or sectoral frameworks is likewise inadequate – or at least it may be, since the relative importance of each type of channel can differ depending on a firm's particular situation. Furthermore, investigation should take in potential as well as actual channels since important improvements may be secured by removing existing barriers to knowledge transmission.

Network overlap may also be identified. Carlsson (2006) lists four major sets of institutional structures within which innovation occurs: National Innovation Systems, Technological Systems, Regional Innovation Systems, and Sectoral Innovation Systems. Of these, National Innovation Systems have been extensively explored for nearly twenty years (Lundvall, 1992; Nelson, 1993) but have proved hard to operationalise at the level of the firm. Technological Systems (Carlsson and Stankiewicz, 1995) centre on the role of techno-economic relationships in the innovation process. Many of the underlying concepts of Regional Systems of Innovation can be traced back to Marshall (1920 and earlier editions). More recently, the study of regional systems has gained popularity through surveys of Silicon Valley (Saxenian, 1994) and broader conceptual statements (Storper, 1997). Finally, studies of Sectoral Systems of Innovation have gained momentum in recent years (e.g. Malerba, 2004, 2005). All of these have been attempts to codify activities that have been evident for decades if not centuries. Moreover, all four of these sets of studies lead to results that are messy in the sense that individual experiences vary considerably no matter what dimension is under scrutiny.³ Analysts must therefore carefully compare maps in order to achieve as much reconciliation as possible.

EMPIRICAL EVIDENCE

Practical difficulties arise in the empirical analysis of content. How can we describe the content of various knowledges across particular industries, and how are they integrated? Although there is insufficient space for full-scale studies, we turn now to an illustration of this question by

looking at the innovative experiences of a major sector whose knowledge base we seek to map. The main issue is the forms of knowledge involved in a sector or industry, the articulation of these knowledges and their flow across industries.

Embodied and Disembodied Flows of Technology

Inter-agent or inter-industry flows conventionally take two basic forms, 'embodied' and 'disembodied'. Embodied flows involve knowledge incorporated in 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. Pavitt (1984) indicates that embodied transfers of knowledge are especially characteristic of LMT sectors in which there is little intra-mural R&D.

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.⁴ When this happens, performance improvements generated in one firm or industry therefore show up as productivity or quality improvements in another. Thus technological competition leads 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 in turn 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.⁵

Shifting Bases of Internal R&D

The range of technologies used by firms in established sectors has increased substantially in recent decades (Granstrand et al., 1997). Table 1 is based on the U.S. patenting activities of more than 500 of the technologically most active firms in the world.⁶ It shows clearly that patenting by these firms, which was already diverse, tended to shift even further away from core technologies between 1981 and 2000.⁷ Not surprisingly, the fields that gained the most were in the fast developing areas of drugs and biotechnology and electronics, even among firms whose core businesses were in neither of these areas. To cope with this increasing reliance on distributed knowledge, firms in many industries have had to broaden their technological activities to deal extensively with areas that were previously of comparatively little importance.

[Place Table 1 around here]

Food Processing

While it is not possible to present a full analysis in the limited space available, the food processing sector offers excellent case studies of the growing importance of distributed knowledge in an LMT sector. For centuries, technological change has been common along the many links in the food processing value chain. Table 2 gives an overall indication of changing technological activities

of large food manufacturing firms based in the USA, Japan and Europe using patent statistics. Not only did the volume of US patents increase by over 80 per cent from 1981-1990 to 1991-2000, but (in common with the other sectors in Table 1) the fields in which patenting activity took place changed substantially. The share of patents related to food processing and products dropped from 38 per cent of the total to 29.2 per cent, and the share of patents related to chemicals and chemical processes also declined – although in all cases absolute numbers of patents granted actually increased. The major change was in patents within the ‘drugs and bioengineering’ class, which nearly quadrupled from one decade to the next, thereby increasing their share from 13.6 per cent to 29.3 per cent. Given the recent growth in relevance of bioengineering for agriculture and food processing, this is not surprising, but it does mark a major acquisition of new scientific and technical skills in a sector that is evolving rapidly despite its long history.

[Place Table 2 around here]

If anything, these figures probably understate the penetration of new technologies into food and related industries, and in particular into food processing, as such technologies are also being imported as embodied technology from firms in other industries, for example from manufacturers of packaging products and processing equipment. Food processing is only part of a long chain of production, all aspects of which are subject to improvements in quality and customer satisfaction (Peri, 2005). The span of issues covered is formidable because, as was pointed in the first issue of the journal *Innovative Food Science and Emerging Technologies*,

Food science and technology by nature are multidisciplinary. Many publications cover two or more of a range of disciplines, such as nutrition, microbiology, structure, physics (high pressure, ultrasound), electrical engineering (pulsing electric fields, radiofrequency heating), protein and lipid chemistry and membrane technology (Lelieveld, 2000).

Case Study 1: Fishing and Fish Farming and Meat Processing

Based on extensive research undertaken by the STEP⁸ (Science Technology Economic Policy) group in Oslo, more detailed, if still preliminary, maps may be extracted from segments of the food processing sector. Consider fishing and fish farming in Norway, both of which are apparently low technology sectors in terms of internal R&D. This is a large industry worldwide, with aquaculture growing 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 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 rely 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.

A similar breadth of scientific and technological fields underpins innovation in the very old industry of meat processing. The abstracts of papers presented at the 52nd International Congress of Meat Science and Technology testify to the wide range of fields that now contribute to innovation (Troy, et al., 2006). Extended sessions were devoted to 'Meat Quality – Genomics and Biotechnology' (17 papers) and 'Meat Quality – Muscle Biology and Biochemistry' (28 papers). 'Hot Topics' included 'Polarimetric Ohmic Probes for the Assessment of Meat Aging'; 'Investigating the Behavioural Properties of Adipose Tissues using Confocal Laser Scanning Microscopy', and 'Influence of Pelvic Suspension and RN⁻ Genotype on Shear Force and Sensory Quality in Pork Loin'.

Case Study 2: Improvements in Packaging

The extent to which both the meat and fish sectors have been affected by changes in the field of packaging give a taste of the breadth of current developments in the industry. Food packaging presents major challenges and opportunities for food processors, as reflected in the many papers on packaging and preservation reported by Troy, et al. (2006). The current use of non-biodegradable polymers such as polyvinyl chloride leads to major disposal problems and vulnerability to increases in petroleum prices (Bucci et al., 2005). In addition, alternative forms of packaging may increase the shelf-life of products, reducing the importance of speed in transportation. Potentially, prolonged shelf-life can also lead to a broadening of markets and may therefore further increase the trend to global supply that was begun in the nineteenth century, as well as offering the prospect of enhanced economies of scale. If, for instance, improved packaging could make it possible to sell refrigerated, rather than frozen, Norwegian or New Zealand fish in distant markets, this would, at least in theory, lead to greater demand and higher prices for producers in Norway and New Zealand (and to

overlapping markets and the generation of new types of competition among suppliers that were formerly confined to discrete markets).

A number of different ways of improving packaging, using different scientific and technological bases, are under consideration. For instance, a recent study (Cannarsi et al., 2005) compared the use of two biodegradable films for wrapping freshly cut beef steaks with the results obtained from polyvinyl chloride, the plastic that is currently used. After extensive tests designed to simulate normal storage conditions, the outcomes from the three films were compared. The authors concluded that there was no substantial difference in the performance of the three products and therefore that a switch to biodegradable films is desirable on environmental grounds. Del-Valle et al. (2005) have reported on a development with a similar outcome (longer shelf-life with reduced use of non-biodegradable packaging) but one that is being pursued from a different scientific base. By creating a mucilage-based coating derived from prickly pear cacti, scientists have been able to create an edible coating for strawberries that also offers the possibility of reducing losses during handling and transport.

As technologies enter into the food processing supply chain at different points as well as from different sources, the possibilities for change are manifold. In the early stages of the chain, for example, new processes such as fish farming and new products (or modified versions of existing products) can lead to cost reductions that then force changes in subsequent stages such as distribution, and the same applies to changes in other links that then reverberate throughout the chain. Taken together, these pose considerable challenges for firms that need to coordinate responses to change. Mapping increases the awareness of food processors to developments in food production, packaging and transportation as well as in the technologies that their own firms develop internally and use directly.

CONCLUSION

Firms in established industries must often operate in unstable and uncertain environments that require them to manage a diverse and changing array of knowledge bases. The message that emerges from the varied experiences that we have discussed is not that the problem is too complex to be analysed, but that the place to begin is with detailed empirical mappings of the management of distributed knowledge bases in order to determine which are the most important and under which circumstances.

The pervasiveness of distributed knowledge bases accounts for much of the diversity that the maps reveal since different firms belong to different, if overlapping, networks as a result of many factors including different social connections, perhaps derived from using different suppliers and catering for different customers. The outlooks and training of owners and managers also vary across

firms in the same sector or region and among firms using similar technologies and drawing on similar scientific bases.

It is naïve to believe that the study of any particular dimension or network structure can adequately capture how knowledge bases are managed in respect to innovation.⁹ Any firm operates in a region or regions, belongs to a sector or sectors, and employs one or more technologies. And conditions will often vary across firms because of their own internal characteristics. A global firm will probably be differently placed in many of these types of networks than a highly localised firm would be (which is not to deny that even one plant SMEs can also be embedded in international networks in important way). Similarly, multi product and single product firms may have access to different knowledge bases, although this can be altered to some extent by investments in absorptive capacity.

Moreover, the possibility of diminishing returns must be recognised since search costs would surely put the detailed mapping and analysis of knowledge flows for all firms beyond the capacity not only of firms but of governments. Sampling strategies need to be developed in order to maximise the value of mapping exercises. In the end, it is likely that only a very limited number of firms and sectors could be explored in depth. The information gathered, however, could be used together with the results of the broader, but necessarily more shallow, innovation surveys that many governments have conducted in recent years. This would also enable analysts to generate a far richer picture of how distributed knowledge bases are currently managed as well as offering better insights into how management could be improved in certain cases.

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Table 1. Changing Technological competencies of 500 large firms: 1981 to 2000 (percentage shares).

Product Groups	<i>Chemicals</i>		<i>Drugs & Biotechnology</i>		<i>Electrical & Electronics</i>		<i>Machinery & Process</i>		<i>Transport</i>	
	<i>81-90</i>	<i>91-00</i>	<i>81-90</i>	<i>91-00</i>	<i>81-90</i>	<i>91-00</i>	<i>81-90</i>	<i>91-00</i>	<i>81-90</i>	<i>91-00</i>
Aerospace & Defence	10.7	9.8	0.3	0.5	32.0	33.2	47.6	46.0	7.2	8.3
Chemicals	47.0	45.6	14.3	16.2	8.0	8.2	26.7	25.7	0.2	0.7
Electrical/Electronics	6.6	5.5	0.1	0.2	61.7	67.4	28.5	24.3	1.1	1.2
Food, Drink & Tobacco	8.1	8.6	10.7	25.9	2.6	2.1	30.2	24.7	0.1	0.1
Instruments	2.2	3.0	0.6	2.9	47.4	42.4	47.9	49.7	0.7	0.7
IT Related	1.9	1.4	0.0	0.0	74.2	83.2	20.8	14.4	1.2	0.5
Machinery	5.0	4.6	0.3	0.5	21.1	22.7	54.5	52.8	5.4	5.5
Materials	50.5	48.9	2.2	2.9	9.0	11.9	31.3	31.1	0.3	0.6
Metals	21.7	22.1	1.5	3.1	11.9	16.8	56.9	49.5	2.3	3.1
Mining & Petroleum	42.9	45.7	3.2	3.0	5.5	5.3	45.8	44.4	0.9	0.5
Motor Vehicles & parts	3.3	3.3	0.0	0.1	21.2	26.3	45.3	43.2	25.2	22.9
Paper	19.1	25.1	1.9	2.0	12.3	7.5	38.6	37.2	0.3	0.2
Pharmaceuticals	33.7	23.2	46.0	60.1	2.7	1.7	15.1	13.0	0.0	0.0
Photography & Photocopy	11.0	8.5	1.6	0.9	63.3	67.6	22.8	21.5	0.0	0.0
Rubber & Plastics	50.0	54.0	3.2	2.1	6.1	5.0	32.8	31.5	2.0	2.0
Telecommunications	5.2	1.8	0.1	0.1	72.2	82.9	21.2	14.4	0.4	0.3

Source: Robertson and Patel, 2007.

Table 2. Changing Technological competencies of Large Firms in Food: 1981 to 2000

Technical field	1981-1990		1991-2000	
	Number of US Patents	%	Number of US Patents	%
Drugs and Bioengineering	356	13.6	1399	29.3
Food and Tobacco (processes and products)	997	38.0	1392	29.2
Chemical Processes	391	14.9	586	12.3
Organic Chemicals	261	10.0	331	6.9
Non-electrical specialized industrial equipment	151	5.8	293	6.1
Miscellaneous metal products	62	2.4	121	2.5
Dentistry and Surgery	32	1.2	119	2.5
Apparatus for chemicals, food, glass etc.	80	3.0	111	2.3
Other	47	1.8	65	1.4
Assembling and material handling apparatus	33	1.3	42	0.9
Bleaching Dyeing and Disinfecting	25	1.0	40	0.8
General Non-electrical Industrial Equipment	24	0.9	40	0.8
General Electrical Industrial Apparatus	32	1.2	39	0.8
Instruments and controls	40	1.5	37	0.8
Metallurgical and metal working equipment	19	0.7	33	0.7
Materials (inc glass and ceramics)	20	0.8	23	0.5
Image and sound equipment	4	0.2	19	0.4
Plastic and rubber products	13	0.5	17	0.4
Textile, clothing, leather, wood products	9	0.3	14	0.3
Inorganic Chemicals	7	0.3	13	0.3
Agricultural Chemicals	5	0.2	12	0.3
Total	2623	100	4769	100.0

Source: Robertson and Patel, 2007.

¹ The use of the word ‘distributed’ has become popular in recent years to describe something that has multiple sources of inputs. The types of activity that are distributed are diverse and include purchasing and marketing as well as production, but on further analysis most sooner or later involve information and knowledge. See Coombs, et al. (2003) and Coombs and Metcalfe, (2000). For a recent treatment that advocates wider distribution of R&D and other technological activities, see Chesbrough (2003).

² This is also true of many small and medium-sized enterprises (SMEs) that are too small to be able to afford R&D activity as conventionally classed. The main exception, of course, is the small but important number of SMEs set up explicitly to exploit new knowledge. Some firms of this type are highly specialised in knowledge creation but lack other capabilities needed to produce and market the fruits of their research (Dahmén, 1989; Robertson, et al., 2003).

³ For example, Malerba (2004, 2005) notes the high degree of variations among the sectors that he and his colleagues have mapped..

⁴ Embodied knowledge cannot necessarily be slotted into an existing framework on a turn-key basis. On the contrary, for both product and process technologies, embodied knowledge may lead users to make substantial adjustments that involve significant development (and sometimes scientific research) activities on their part.

⁵ ‘Sending’ industries also face problems in locating the full range of customers who might be interested in their products. If they fail to attract the notice of enough customers, this may substantially lower the rate of return on innovative activity (Robertson, 1998; Robertson, et al., 2003).

⁶ A patent is granted when a patent examiner believes that the applicant has the competence to improve technology in a given field, despite the fact that it may be difficult to foresee its degree of usefulness at the time. Patent data therefore reflect corporate capacity to generate change and improvement in a given area of technology. In this respect, their main drawback is that - until recently - they did not cover software inventions, and that firms sometimes use other methods than patenting to protect their technological lead. As a result, our findings should be taken as an *understatement* of the importance of new technologies to LMT sectors because they may fail to catch many other aspect of technological upgrading.

⁷ There is a residual category containing all the patents that are not in these five categories. Consequently, the percentages within each product group reported in Table 1 do not add up to 100.

⁸ Now NIFU-STEP.

⁹ Groenewegen and van der Steen (2006) discuss layering within each type of innovation system. This suggests that another of the challenges of mapping is to relate layers within a network to similar layers in parallel and overlapping networks.