PILOT

Policy and Innovation in Low-Tech

New wine in old bottles

–technological diffusion in developed economies –

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Contribution to the conference

Low-Tech as Misnomer:
The Role of Non-Research-Intensive Industries
in the Knowledge Economy

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As new and old technologies generally co-exist in the complex production methods that characterise major sectors of modern developed economies, it is important for policy makers to analyse them together in order to take full advantage of complementarities and optimise outcomes for entire economies rather than for individual industries. In this paper, we look at the interrelationships between technologies of different vintages from three perspectives. Firstly, we develop a short theoretical model to demonstrate the reciprocal connections between industries that are generally described as being "high technology" with the other sectors that rely more heavily on "non-high tech" methods. Through the use of patent data, we then show that long-established industries that are not generally thought of as being high tech often employ cutting-edge knowledge in their own research and development and, by extension, in their other activities. Finally, we use sectoral case studies to show how so-called high tech knowledge is used in specific long-established industries. Our conclusion is that relationships between high tech and non-high tech sectors are highly symbiotic and that the health of high tech firms and industries depends heavily on their ability to sell their outputs to other sectors in developed economies.

I. Introduction

The relationships between various vintages of technology in a modern economy are complex. Although much of the impetus for growth and development in mature economies may be traced ultimately to a limited number of radical innovations in any particular period, the actual impact from those innovations is generally conveyed through improvements, often subtle, in many other industries. To take an obvious and on-going example, advances in land, sea and air transport have resulted in countless changes transmitted through individual sectors that have benefited from an ability to serve ever larger markets. In some cases, these changes have represented simple reductions in transport costs which have been passed on to consumers, but other changes have been deeper. For instance, as Chandler (1977) has noted for the USA after 1870, railroadisation broadened markets for individual producers and therefore made it more feasible for them to adopt equipment that provided substantial economies of scale. Thus the radical innovation in transport led directly to substantial changes in the technologies of a wide range of sectors. Other new technologies such as steel, electrification and (more recently) improvements in Information and Communications Technologies (ICT) have had similarly widespread effects. The benefits have not been confined to process innovations, however, but have led to an enormous diversification in the varieties of final products available: Steel, which eased the construction of bridges and railways, was also incorporated in automobiles, while electrical motors were not only used in machinery but also in domestic appliances. Similarly, ICT now affects the operations of many other sectors through the use of electronic control equipment in manufacturing and service industries but is also a useful marketing tool, allowing even small firms to provide 24/7 global information to customers through individual web pages.

Our argument is that any sensible analysis of the place of innovation and technological change in developed economies must examine all sectors because, with few exceptions, radical technological change has broad impacts that cut across economic activities. Not only do many innovations eventually diffuse to multiple sectors, but low and medium technology sectors (LMT)[1] are often the best customers of high-tech producers. Furthermore, research and development activities are rarely confined to high-tech sectors. Countries that invest heavily in high-tech R&D also tend to invest heavily in R&D in all sectors. As a result, analysis has to look not only at how technological change is generated but also at its use because it is clear that the amounts invested in R&D depend on the size of the markets that will subsequently evolve and that dominant shares of these markets will frequently be outside high-tech areas.

Thus our paper situates LMT sectors within their wider economic and technological environments, in the process also illuminating the experiences of high-tech areas as well as those of the older LMT sectors that are normally the focus of the PILOT project. We examine a selection of relevant issues by considering three aspects of the relationship between high-tech and non-high-tech sectors. In Sections II and III, we develop a simple model to show how and why the continued health of LMT sectors is crucial to the prosperity and growth of high-tech industries. Statistical analyses of the high tech/LMT nexus at the sector level and the level of national economies are presented in Section IV. Section V looks at recent innovations in two frequently discussed LMT sectors, food processing and textiles, to show that producers are becoming increasingly sophisticated in their use of technology, with interesting but mixed effects on international patterns of production and trade. Finally, we present some tentative policy suggestions in Section VI.

II. Technological Diffusion and Economic Development

For at least a century, economists have assigned technological innovation an important role in stimulating economic growth and structural change. Innovation is not a uniform process, however, and its effects have differed depending on the characteristics of the economy or sector under consideration. While "new" technologies have had demonstrably powerful effects in many circumstances, the meaning of "new" is not always clear. Products and processes that originated in particular industries or countries may reappear many years later to provide significant stimulation under very different conditions. Thus, innovation should not be viewed as a one-off process but as a string of changes that wend their way throughout economies, following paths that may be impossible to predict in advance (Rosenberg, 1976). Moreover, the most important effects of change may not be felt in innovative or "high-tech" sectors but may arise from the diffusion of innovations in diverse guises to other sectors that are usually thought of as traditional, mature and low or medium tech. As Hall (2005, 460) has recently argued,

> [Diffusion is] an intrinsic part of the innovation process, as learning, imitation, and feedback effects which arise during the spread of a new technology enhance the original innovation. … For entities which are "catching up," such as developing economies, backward regions, or technologically laggard firms, diffusion can be the most important part of the innovative process.

We contend that all levels of technology, from the newest to the most traditional, are inextricably linked in a modern developed economy and that they feed off each other by being mixed in various combinations in different sectors.

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[1] As used here, low and medium technology sectors comprise all sectors that would not normally be designated as high technology. Although definitions vary (see Laestadius, *et al.*, 2005), LMT sectors account for perhaps 97 per cent of output in modern developed economies.

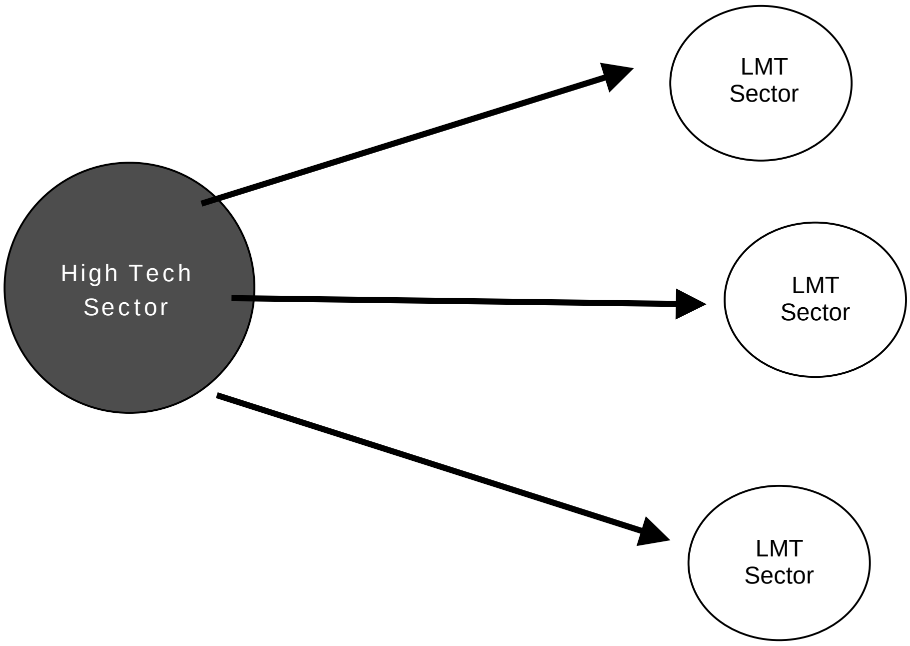
This interrelated, in fact symbiotic, relationship between sectors using different types of technology came eventually to be well recognised by development economists, although theoretical positions on sectoral patterns of growth underwent several major shifts in the middle years of the twentieth century. While Rosenstein-Rodan (1943) had used the opening of a single shoe factory in an otherwise undeveloped country as an example of how development might be spurred, Nurkse (1953) pointed out that highly concentrated investment could lead to a "vicious circle" because, for instance, much of the extra income received by the workers at the factory would be devoted to items aside from shoes. How, then, in a closed economy could enough demand be found to purchase the total production of the new plant? As a remedy, Nurkse (1953) recommended that investment should take place simultaneously in a variety of sectors in order to bring about "balanced growth", allowing the additional income generated by modernisation and increased productivity to stimulate many areas at once. Nurkse's concerns were shared by Lewis (1954) and others who warned against the creation of "dual economies" in which modern and traditional sectors coexist without the newer activities providing substantial stimulation for development in the older ones. Although Lewis (1954) originally referred to labour markets in developing counties, the concept of dualism (Myint, 1985) was later expanded to embrace "financial dualism", "sociological dualism", "organizational dualism" and – the issue of most interested to us here – "technological dualism".

In its turn, the value of balanced growth was challenged from the late 1950s onwards as development experts such as Rostow (1960a, 1960b) and Hirschman (1958) argued that growth could be triggered most effectively through investment targeted at a few especially promising sectors. In contrast to Rosenstein-Rodan, however, Rostow and Hirschman specified mechanisms through which growth could spread from these sectors to the economy as a whole. Hirschman (1958, ch. 6) developed the idea of "linkages" to show how the growth of a single industry, perhaps steel, would generate demand from suppliers in other sectors and create pecuniary externalities (Scitovsky, 1954) that could stimulate producers of intermediate goods and final customers. Rostow used a similar mechanism to support his argument that expansion based on "leading sectors" would have wide-spread ramifications for a developing economy and lead eventually to a widely-based "take-off into sustained growth". Rostow (1960b, 52) contended that "[p]rimary growth sectors, where possibilities for innovation or for the exploitation of newly profitable or hitherto unexplored resources, yield a high growth rate and set in motion expansionary forces elsewhere in the economy." The primary growth sectors are supported by "[s]upplementary growth sectors, where rapid advance occurs in direct response to—or as a requirement of—advance in the primary growth sector." Although Rostow's immediate focus was on the Industrial Revolution in eighteenth-century Britain, he also argued that the process repeated itself as new primary growth sectors arose periodically in already developed economies to take the place of earlier ones whose benefits had been eroded, encouraging a new group of secondary growth sectors and reigniting economic expansion (Rostow, 1960b).

III. Reciprocal Relationships between High-Tech and LMT Sectors in Developed Economies

Thus Rostow and Hirschman emphasised the role of diffusion in economic growth by showing that the performance of existing and initially dominant sectors can be stimulated by the introduction of new technologies. Furthermore, while some of the benefits may be pecuniary externalities, they may also derive from actual technological updating in established industries, a progression that can be slow and complicated as knowledge spreads and adaptations to extant systems are made to accommodate new techniques (David, 1991; Denison, 1967). The development of complementary activities, assets and institutions is vital (Rosenberg, 1976) and, through attempts to eliminate bottlenecks or "reverse salients", can lead to further innovation to reinforce diffusion (Hughes, 1992; Rosenberg, 1976). On the other hand, failure to overcome obstacles quickly may stifle or delay innovation (Dahmén, 1989; Robertson, *et al.*, 2003a).

Figure 1: The Diffusion of High Technology through the Economy

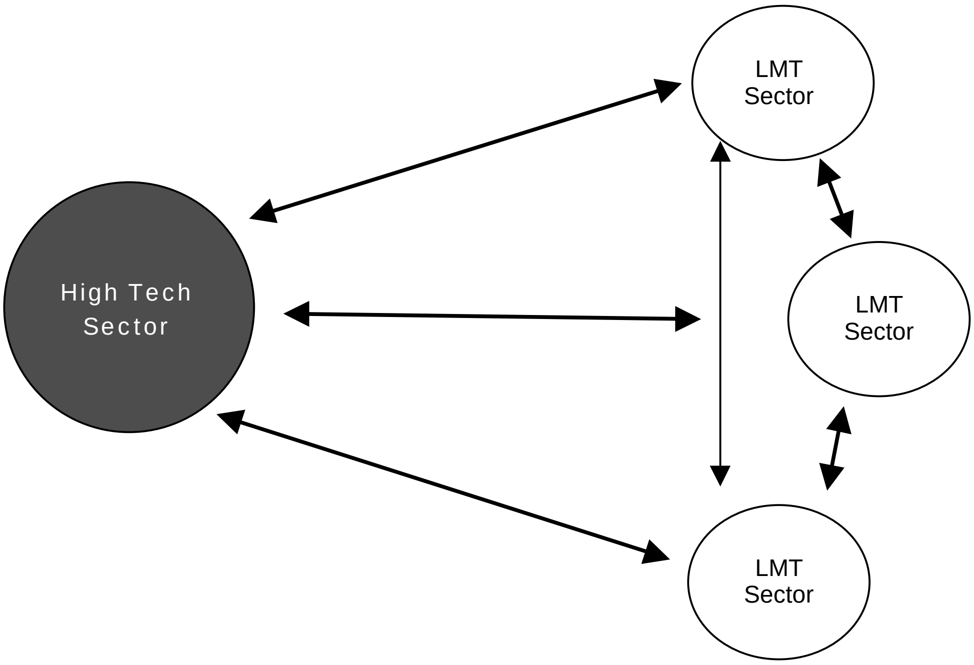


Because established sectors constitute by the far the largest part of an economy at any time,[2] technological updating in these industries has played an important role in overall economic growth from the Industrial Revolution (Bruland, 2004) to the present (Nordland, 2001). In the case of innovations of potentially wide applicability, however, lags can be substantial. This can be the result of obstacles to diffusion. When an innovation is radical, and especially when it originates in a sector that is not normally monitored by other parts of the economy, decades may pass before its full potential becomes clear. Even when the news has spread, there can be many other barriers. One, discussed by Rosenberg (1976) and Hughes (1992), is the need to fit an innovation into an existing technological configuration in a particular industry. When the innovation can be treated as a piece of peripheral equipment that can be tacked on to an existing technology, as has often been true of microcomputers, then widespread adoption may occur even if immediate benefits seem to be modest. But when bottlenecks arise from incompatibility between old and new technologies, the scope of development needed to adopt an innovation can be extensive and costly. When, as sometimes happens, the initial performance advantage of an innovation over existing technologies is small (Utterback, 1994), potential adopters may resist making large scale new investments to fit the innovation into their current production processes. "Gateway technologies" (David and

[2] According to Nordhaus, (2001) for example, even on a generous definition , in 1998 the "new economy" sectors of machinery, electrical equipment, telephone and telegraph, and software accounted for only about 9 per cent of GDP in the USA, arguably the country with the highest concentration of high-tech sectors.

Bunn, 1990) that create compatibility between previously clashing technologies can help to ease adjustment problems, but (as is argued below) other forms of encouragement may be useful to achieve optimal results in other cases.

Figure 2: Reciprocal Relationships between High Technology Sectors and Other Sectors



But flows do not move only from new and higher-technology sectors to older and, on balance, lower-technology sectors. In many cases the viability of high-tech sectors and the levels of resources devoted to research and development are directly related to the rate of diffusion because the main customers for high-tech products are in the established sectors, and therefore the rates of return to R&D in high-tech areas are also a direct function of rates of diffusion.[3]

These propositions are illustrated in Figures 1-3. Figure 1 presents a simple, uni-directional model of change in which innovations from a high-tech sector diffuse to a number of LMT sectors, leading to pecuniary externalities in established industries and/or allowing these older areas to produce better products (i.e. those of higher quality in the sense of being fitter for use). In established sectors, the incorporation of new technologies into existing products can confer a competitive advantage on the adopting firm and may even lead to increased demand ("rejuvenation") if potential customers find that the usefulness of the product of the established sector has been substantially improved.

But it would be wrong to concentrate our analysis only on forward linkages from high-tech sectors to their customers in LMT sectors, because technological diffusion vitally affects all of the sectors involved. Perhaps the most important backward linkage from LMT to high-tech industries comes simply from the revenue that sales provide, which helps to cover the substantial fixed costs that arise out of the innovation process and engenders economies of scale. In innovative situations, lumpiness and resulting non-convexities affect several areas including gearing up for production and the expenses associated with R&D itself. Diffusion can be crucial at this stage because the larger the number of LMT industries that adopt an innovation, the quicker the rate of amortisation of

[3] Much of the material that follows is based on Robertson *et al.* (2003).

development costs will be. These economies of scale can then be translated into lower prices of innovative products for the LMT industries (greater pecuniary externalities), further economies of scale for the high-technology industries, and the generation of what Nurske (1953) has termed a “beneficent circle” (Figure 2).

This proposition can be easily demonstrated. The level of investment in R&D is a function of expectations of profitability,

$$I_{R\&D} = F[PV(EB)],$$

where PV(EB) is the present value of the expected stream of profits. As these expectations are heavily influenced by past experience ($I_{R\&D(n)}$ depends on $I_{R\&D(n-1)}$), increasing the extent of diffusion in one period will increase profitability from investment in R&D and therefore, *ceteris paribus*, lead through feedback loops to greater expenditures on R&D in the next period (Figure 3). As overall economic performance is also a function of investment in R&D and higher GDP eases the provision of funds for future research,[4] the effects of improving the extent of diffusion can be doubly beneficial. Finally, because investment depends on present value calculations from a stream of income, increasing the *rate* of diffusion can contribute to both increased investment in R&D and improved economic performance in general.

Figure 3: Feedbacks to Investment in R&D from High Rates of Return and Economic Growth

The implications for policy are straight-forward. In a modern economy, the levels of performance of both high-tech and LMT sectors are heavily interdependent. Much of the improved efficiency of LMT sectors may derive from high-tech improvements, but the health of the high-tech sectors depends on being able to serve the needs of LMT industries. The economy must be viewed as a whole, in which these connections are explicitly nurtured. Therefore, promoting the health of the 90%+ of modern economies that are not high-tech but which do provide the vast bulk of employment, incomes and assets also promotes the welfare of the high-technology sectors because diffusion leads to innovation. As Nurske (1953, 6), paraphrasing Adam Smith, reminds us, “The inducement to invest is limited by the size of the market.” Moreover, for an economy to thrive, the *rate* of diffusion must be high to ensure that payback for investment in R&D is achieved quickly. This is especially important when rates of technological change are high in order to avoid innovations becoming obsolete before investment in the R&D that led to their development is fully amortised.

[4] This follows from the New Growth Theory (NGT) which posits that technological change is endogenous to an economy. For an introduction see Romer (1986, 1990, 1994). There are, of course, other ways that new technologies may come to be used in established sectors, but the NGT concentrates on factors that encourage investment in R&D.

IV. Innovation in LMT Sectors

We have argued above that in modern developed economies there is a great deal of interdependence between industrial sectors classified according to their levels of technology. In particular we contend that a large part of the economic benefits of innovations generated in high-technology sectors is realised when such innovations diffuse into industrial sectors with various different levels of technology. In this section we discuss empirical evidence regarding two related issues. The first is that firms in many so-called LMT industries are getting increasingly involved in knowledge creating activities in high-technology fields. The second is that there are strong complementarities in national innovation performance in sectors classified according their levels of technology. In other words countries with strong innovation performance in high-technology industries also perform strongly in LMT industries.

Technological competencies of Non-high-tech firms

One of us has argued in previous work (Granstrand, Patel and Pavitt, 1997) that large firms are heavily diversified in their product mix as well as in their technological competencies. Moreover the level of diversification of technological competencies is increasing over time as a consequence of new opportunities emerging from general advances in science and technology. Thus products are multi-technology (and becoming more so over time) and technological fields can have applications in a number of different product areas. Here we want to extend this argument by showing that firms that are active in the so-called traditional industries have been accumulating technological competencies in high-technology areas such as biotechnology and IT.

We assess technological competencies on the basis of firm-level patenting data. It is well-known that patenting activity is an imperfect indicator of technological status or performance (Laestadius, *et al.*, 2005),[5] but our intention is different. Our purpose is to show that many long-established LMT sectors are aware of and use recent high-technology knowledge. We argue, therefore, that patenting in a particular field (especially repeated patenting) demonstrates knowledge of the current state of technology in that field – that these LMT sectors are not caught in a technological time warp but are assimilating new knowledge on a substantial scale while continuing to maintain their traditional knowledge bases. The granting of a patent reflects the judgement of a patent examiner that the applicant has the competence to improve technology in a given field, even though it may be difficult to foresee its degree of usefulness at the time. Thus patent data 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.

[5] The strengths and weaknesses of using patent statistics to track developments in technology have been discussed elsewhere (Patel and Pavitt, 1995). For our purposes the main strengths are that they enable us to identify detailed areas of technology over a long period of time and provide information by named firms. The main weakness is the potential bias due to the differing propensities to patent in the technology classes identified.

Table 1 is based on a systematic analysis of patenting activities in the USA of over 500 of the technologically most active companies in the world. We have classified the firms according to their principal product group and aggregated the US patent classes within which they are active into five broad areas of technology. (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.) The distribution of patenting is presented for two separate decades, 1981-90 and 1991-2000. The main message to emerge from this analysis is that firms from a number of different product groups are becoming increasingly involved in knowledge creating activities in two of the five broad groups of technologies: *drugs and bioengineering* and *electrical and electronics*. More detailed results show that many of the technical fields of increasing activity are related to *biotechnology* and *IT*.

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

Product Groups	***Chemicals***		***Drugs & Biotechnology***		***Electrical & Electronics***		***Machinery & Process***		***Transport***	
	81-90	*91-00*	*81-90*	*91-00*	*81-90*	*91-00*	*81-90*	*91-00*	*81-90*	*91-00*
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

In the context of this paper three main points emerge from the data in Table 1. Firstly firms whose principal activity is in *food, drink and tobacco* have increased their competencies in *drugs and biotechnology*. The technological trends in the food sector are discussed in more detail in Section V. Secondly firms from three other LMT sectors, namely *motor vehicles, machinery,* and *metals* have increased their patenting in *electronics* technologies. In the case of the first two industries between a fifth and a quarter of all their patenting is in these technologies. Finally, the assimilation of new technologies increased substantially in all of these categories in the 1990s in comparison to the 1980s.

In our previous work (Granstrand, *et al.*, 1997), we have argued that increasing technology diversification in companies is the result of multiple factors. Firstly, commercial opportunities emerging from major scientific and technological breakthroughs give firms the opportunity to introduce new technologies into products and systems for improved performance and new functionalities. This process can best be described as *technology fusion*, whereby firms with an existing portfolio of competencies explore and experiment with new technologies for possible deployment both now and in the future. As discussed in the next section, this occurs in a range of different industries, many of which may be described as traditional or LMT. Secondly increased technological diversification arises from the need to co-ordinate innovation and change in core products with complementary changes in the production system and supply chain. This is especially the case in complex products and production processes, where there are strong technical interdependencies between what firms develop and make themselves, and what they require from their suppliers of machinery, components, software and materials. The effective use and improvement of outside components, sub-systems and machinery requires a matching in-house capability to choose, integrate, learn, and to co-ordinate and manage systemic change.

National innovation performance in different sectors characterised by R&D Intensity

In recent years there has been an upsurge of interest in assessing the innovation performance of countries (and regions). However very few such assessments take into account the sectoral make-up of the economy, which can have an important bearing on overall innovation performance. Here we report the results of a recent study undertaken for the Trend Chart project (funded by DG Enterprise) which took a sectoral approach.[6] The aim was to analyse the innovation performance of EU countries on the basis of the characterisation of sectors according to R&D intensity proposed by the OECD. This aggregates all manufacturing industries into four different categories based on the average R&D intensity across a range of OECD countries: High-, Medium-High, Medium-Low, and Low technology.[7] Innovation performance in each of these sector groupings was measured on the basis of 10 different indicators gathered from the OECD STAN and CIS III databases and included patent based indicators (see Table 2).

Table 2. Indicators and Data Sources for Measuring National Innovation Performance

	Indicator	Data Source
1.1	Business R&D over Value Added (%)	OECD-STAN
1.2a	EPO Patent per Employee	MERIT
1.2b	USPTO Patent per Employee	MERIT
2.1	SMEs innovating in-house (%)	EUROSTAT CIS III
2.2	SMEs innovation co-operation (%)	EUROSTAT CIS III
2.3	Innovation expenditures (%)	EUROSTAT CIS III
2.4	Investment Per Employee (KEuro)	OECD-STAN
3.1	Value Added per Employee (KEuro)	EUROSTAT SBS
3.2	Sales new to firm and to market (% of total turnover)	EUROSTAT CIS III
3.3	Sales new to firm, not to market (% of total turnover)	EUROSTAT CIS III

[6] *Sectoral Innovation Scoreboard*, 2003 European Innovation Scoreboard, Technical Paper No 4 (2003). http://trendchart.cordis.lu/scoreboards/scoreboard2003/pdf/eis_2003_tp4_sectoral_innovation.pdf.

[7] The latter three of which are aggregated as “LMT” in this paper.

One of the issues addressed in the Trend Chart project relates to the possibility that a country that performs badly in high technology sectors may perform better in low-technology sectors. Innovation performance was measured by constructing a composite indicator, based on the 10 indicators shown in Table 2, for each country in each of the four technology groupings.[8] Table 3 reports the ranks of the 14 countries in our sample within each technology grouping. The main question addressed in our analysis was whether there was any consistency in the country ranks in innovative performance across the four industry groups. To answer this question, we correlated the ranks of the 14 countries in each of the four industry groupings.[9] The results of this correlation analysis show that country rankings are similar across most industry classes. Figure 4 illustrates the results of comparing country rankings in high-tech and low-tech industries.

Table 3. Country rank orders in national innovation performance by technology group

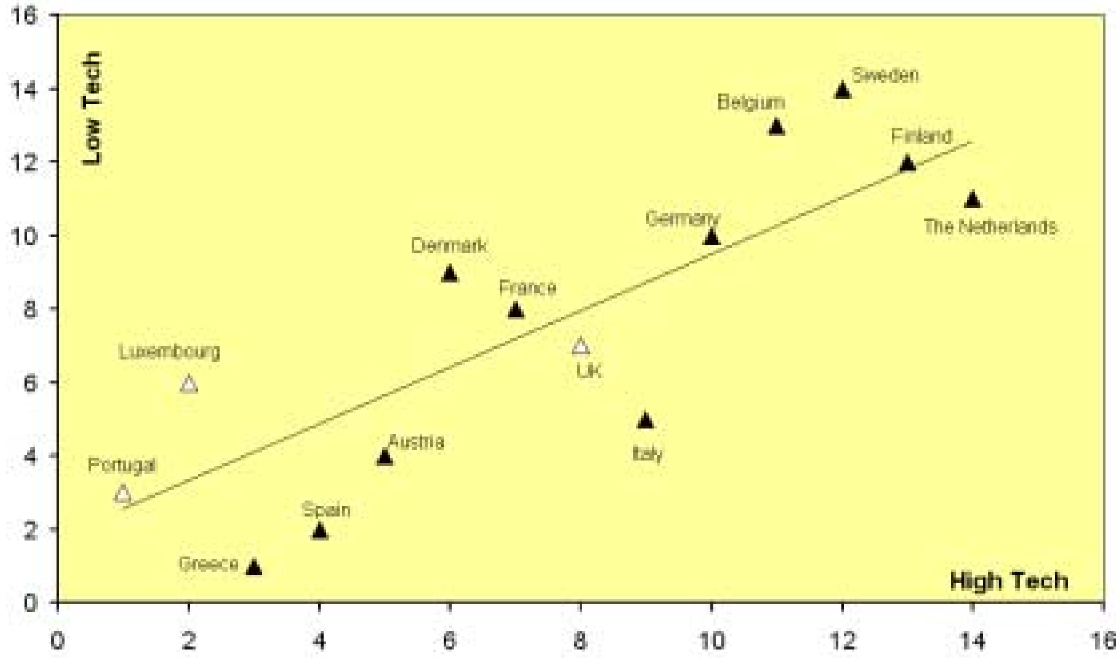
Rank	High	Medium-high	Medium-low	Low
14	NL	NL	FIN	S
13	FIN	S	B	B
12	S	F	S	FIN
11	B	D	AT	NL
10	D	B	D	D
9	IT	AT	NL	DK
8	UK	FIN	IT	F
7	F	UK	F	UK
6	DK	DK	DK	LU
5	AT	LU	UK	IT
4	E	IT	LU	AT
3	GR	E	P	P
2	LU	GR	GR	E
1	P	P	E	GR

At a general level, our analysis shows that a country with a high ranking in high technology industries is also likely to have a high ranking in medium-high, medium-low, and low technology industries. Thus Finland is ranked 2nd amongst the EU countries in high technology and 1st in medium-low technology industries, and 3rd in low-technology. A similar pattern occurs for the Netherlands. Both these countries have a significant lead in Europe in 3 out of the 4 industry groupings. Other countries that have above average performance in all sectors are Sweden, Germany, and Belgium. The countries that lag behind most EU countries in all four industry groupings are Greece, Spain and Portugal. This suggests, among other things, that variations in R&D intensity are not solely a function of whether a sector is classed as high tech or as LMT, but are heavily influenced by other factors that manifest themselves at different and broader levels of aggregation. In particular, approaches to learning and technological assimilation may be strongly affected by national institutional factors that transcend sectoral influences. Thus the fact that a particular industry is established and LMT may have relatively little effect *per se* on knowledge generation or technological upgrading.

[8] *Sectoral Innovation Scoreboard*, 2003 European Innovation Scoreboard, Technical Paper No 4 (2003). http://trendchart.cordis.lu/scoreboards/scoreboard2003/pdf/eis_2003_tp4_sectoral_innovation.pdf.

[9] Here the top rank is 14 (best performing country) and the bottom rank is 1 (worst performing country).

Figure 4. The relationship between High-Tech and Low-Tech Country rankings in national innovation performance



V. *Technological Upgrading in Established Industries – Sectoral Case Studies*

Although rates of productivity growth clearly vary across industries, “old” and “technologically stagnant” are not necessarily correlated. It is clear that many venerable industries are constantly updating their technologies even though the public perception of their activities remains much the same. Newsagencies and many other shops, for example, now both use and sell electronic devices. They electronically scan even relatively unchanged items such as newspapers for price, use personal computers and software packages to keep track of accounts, and send data online when selling lottery tickets. The effects on complex industries have been even more striking. Ships and shipbuilding techniques have co-evolved over thousands of years, in the process passing through a number of distinct stages. In the mid nineteenth century, wooden sailing vessels were replaced with iron and later steel ships powered by steam and eventually by petroleum-fuelled engines (Pollard and Roberson, 1979). In the same period, a number of other, smaller, innovations were introduced, many of which, including plumbing and electricity, were from other sectors. Shipbuilding changed in step with improvements to ships as a wide range of new equipment was introduced to deal with new materials and heavier components, and the marine engineering industry was created to design and manufacture propulsion systems. This pattern of change has continued, with the introduction of a stream of new types of vessels and new construction techniques that have raised the productivity of both shipping and shipbuilding, while lower costs have been passed on to customers, leading to a general stimulus to world trade.

In general, it is fair to say that virtually no industry relies almost exclusively on a single vintage of technology. For one thing, new techniques often rely heavily on imaginative reuses of existing techniques as well as on ideas and artefacts that are more strictly “new”.

Even an industry such as the manufacture of micro computers can involve patterns that are similar to cottage industries in pre-modern Europe, with sophisticated components assembled by hand using reasonably primitive tools and organisational techniques.

These trends are evident in the evolution of technology in two large industries of importance to the European Union. Food processing and clothing and textile manufacturing are quintessential traditional industries, with histories extending back for millennia. Both are undergoing substantial technological change, but their histories and probable fates are diverging. As a result, their recent histories help to illuminate the importance of developing technologies in LMT industries.

Technological Upgrading in Food Processing

For centuries, technological change has been common along the many links in the food processing value chain. Many episodes were the result of trial and error involving techniques developed especially to deal with animals or plants, but science has also played an important role since Liebig's discovery of the uses of nitrogen in fertilizer in the first half of the nineteenth century. Selective breeding of domestic animals – horses, cattle, sheep, pigs and dogs – has been common for centuries, producing better performance characteristics. Fruits, vegetables and grain have also been selectively bred to produce better characteristics in terms of yield, appropriateness for various climates, and suitability for other factors such as mechanical picking.[10]

In terms of processing proper, improvements have been made to reduce disease (for example, pasteurisation) as well as to increase longevity and thereby allow wider distribution. Tinning, developed in the early years of the nineteenth century, was followed by refrigeration and freezing later in the century. These innovations then hooked up with transportation improvements, in shipping and railways, to allow the world map in food production to be redrawn as extensive agriculture to serve European markets was now possible in North and South America, Africa and the antipodes. In addition to permitting traditional European meats to be sold more cheaply, refrigeration also allowed fresh tropical fruit including bananas to be sold in Europe on a large scale for the first time.

In the past couple of decades, these technological trends have continued, with the possibility of further changes to international exchanges in food products. Table 4 (Changing Technological Competencies of Large Firms in Food: 1981-2000) gives an overall indication of changing R&D activities in the field. Not only did the volume of US patents increase by over 80 per cent from 1981-1990 to 1991-2000, but the fields in which patenting activity took place changed substantially. As a share of total US patents in food, patents related to processing and products within the sector 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 fell – 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 and increased their share of total patenting in the sector 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 roots.

[10] For a detailed account of the factors surrounding the development of one important fruit, see Harvey *et al.* (2002).

Table 4. Changing Technological competencies of Large Firms in Food: 1981 to 2000

	1981-1990		1991-2000	
Technical field	**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

If anything, these figures probably understate the penetration of new technology into food and related industries, and in particular into food processing because new technologies are also being imported 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).

A few examples from 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. 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.

Technological Upgrading in Textiles, Clothing and Textile Machinery

The cluster of textile, clothing and textile machinery manufacture represents another major area of continued improvement despite the comparative antiquity of much of the sector. As is well-known, the locus of the industry is shifting rapidly from traditional producers in Europe and North America to other regions. Although this movement was slowed for a couple of decades by the quantitative restrictions imposed by the Multi-Fibre Agreements, it has now gained momentum as a result of the end of quotas negotiated under the aegis of the World Trade Organisation. Areas of Eastern Europe, Asia (especially China) and Latin America are now major suppliers of clothing. This has been accompanied by a shift in textile production to the regions that are gaining dominance in clothing manufacturing. As a result, since the mid-1990s world exports in clothing have continued to expand rapidly, but exports of textiles have levelled off (OECD, 2004).

This has not been simply a move to low wage areas, however, because developing economies such as China have also adopted the latest technologies from Europe and North America. Moreover, productivity increases in fields such as spinning may be accelerating in comparison to their long-term trend. New technologies are also being introduced at the various stages of the clothing production process, although in many cases they have not yet been perfected. For example, at the design stage, CAD systems have substantially increased the productivity of designers at the *haute couture* end of the market, although they are still not able to simulate how all materials will drape a body. Computer systems are also being applied to most other stages including pattern making, grading and nesting and marking. By contrast, totally automated processes have been slower to be adopted in cutting and sewing, where dependence on skilled labour remains high despite attempts to develop CAM machinery. Although many firms in the sector are small, the possibility remains of outsourcing some of the higher-technology functions to specialist firms or to small firms cooperating in the use of expensive equipment. These trends can be reinforced by improvements in telecommunications that will make it easier to gather data from decentralised sources (OECD, 2004, Annex4.A2).

The geographical shift of textile and clothing manufacturing has also affected the performance of textile machinery firms, although not uniformly. The OECD (2004) contends, for example, that the market base of German sewing machine manufacturers has been eroded by the shift of clothing and textile production because it has broken the close nexus that the machinery firms used to have with their customers. This has not affected the market for German needles, on the other hand, because interaction with users is less important than for more complex products.

VI. Conclusion

Our argument has three prongs, all of which support the importance of technological improvements in LMT sectors for high level macroeconomic performance. In Sections II and III, we have presented a cluster of related arguments to show that, not only is the relationship between high-technology and LMT sectors reciprocal, but that the future of high-technology sectors depends heavily on the continued health of other parts of the economy because the LMT sectors that dominate modern industrial economies in terms of investment, output and employment provide the bulk of the markets for high-tech products and encourage further investment in R&D. In the absence of substantial technological updating in established LMT sectors, the demand for high-technology products would plummet, R&D activities would no longer be as profitable, and overall economic performance would deteriorate.

Through the use of patent data, the argument is extended in Sections IV and V to show that new areas of science and technology have already been embraced by a number of mature industries, including several of the largest sectors in the European Union. For example, substantial and growing levels of research in biotechnology now characterise the age-old food sector to the point where it is dubious to think of it in LMT terms despite obvious retentions of mature vintages of technologies in some fields. Even products that seem very traditional, such as fruits and vegetables, may be changing greatly as a result of applied scientific knowledge. Furthermore, substantial though they are, results based on patent data *understate* the amount of change in these industries as they are also adopting new technologies developed in other industries, for example packaging. Finally, however, as the recent history of the textiles and clothing sector shows, long-term dominance in technologically-advanced fields is no longer necessarily a prerogative of firms in developed economies. As in the textile and clothing sector in China, new technologies may be transferred almost immediately to developing economies, giving them an advantage in wage costs without any compensating penalty in productivity.

These arguments point to the importance of both the generation and diffusion of knowledge throughout modern economies. Individual technological breakthroughs are not enough in themselves to bring about sustained increases in welfare. Where appropriate, they must also spread as quickly as possible through the breadth of the economy. In general, this means that *knowledge* must diffuse quickly, sometimes embodied in equipment but often in more abstract forms. This knowledge can be divided into three classes: (1) original scientific and technological discoveries of the sort that is often termed “high tech”; (2) knowledge of the state of technology available elsewhere in the economy, that is absorptive capacity; and (3) knowledge of how to adapt technologies developed in other firms and other sectors to a firm’s own circumstances.

The sources and uses of knowledge are thus highly varied, requiring government policies of similar diversity. In addition to common objections based on the impossibility of picking winners, the limits to targeting specific growth sectors may soon be reached because productivity-enhancing knowledge is generated so widely in modern developed economies. Promoting a widespread awareness of new technological possibilities may be every bit as important as developing new technologies. As we have shown, accelerating the rate of diffusion increases incentives for investment in R&D as well as leading to pecuniary externalities and other benefits for the adopting firms and sectors. Equally significantly, incremental changes originating in LMT sectors are themselves important in producing increases in productivity and in stimulating the development of new types of good and services.

From this it follows that government policies should emphasize diffusion as well as innovation and that they should be aimed squarely at traditional LMT sectors as well as at high-tech areas. However, as the most important decisions are ultimately made by managers in individual firms, people who face diverse environments and have varied goals, we would argue against a proliferation of policies which offer narrow choices that, individually and collectively, overlook the needs of substantial sectors. In order to be successful, policies that support technological diffusion must seem plausible to the managers who are charged with adopting them (Robertson, *et al.*, 2003b). They must also allow for flexibility so that firms can follow their own strategic paths and adapt freely to changing circumstances.

Thus policies should be facilitating rather than commanding or even indicative. Governments need to concentrate on making access to new technological knowledge quick, inexpensive and not tied up in red tape that discourages potential users from tapping into government-sponsored channels. The specification of detailed procedures is beyond the scope of this paper, but our findings point to the need for general mechanisms. The first requirement is to provide convenient access to learning institutions throughout the careers of technologists, managers and workers in general. Secondly firms in all sectors should be encouraged to search out and implement technological improvements as well as to generate change internally, a process of great complexity given the wide range of needs and attitudes in a modern economy (Robertson, *et al.*, 2003b). Above all, these policies must not be restricted to high-tech sectors or even to high technology (however defined). Instead, they must also promote the smooth upgrading of technologies in LMT sectors.

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