Decomposing technological change at the twilight of the twentieth century: Evidence and lessons from the world's largest innovating firms

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Abstract

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Abstract

The present-day economy, characterised by a pattern of steady technological and organisational change, has its roots in the so-called information revolution of the late twentieth century. As this unique period of recent history recedes, the benefits of hindsight make it possible to deliver new perspectives on what really happened across industries facing rapidly mutating global competitive settings. This paper provides an analysis of the transformations that occurred in a collection of technological capabilities nurtured by industrial sectors as represented by nearly 500 of the world's largest industrial corporations during the 1980s and 1990s. Using structural decomposition analysis it shows how industries adapted under the strain of radical shifts in the technological context with varying degrees of success.

Keywords

Structural decomposition analysis; patent indicator; manufacturing sectors

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1. INTRODUCTION

The last decades of the twentieth century were turbulent for the capitalist economic system. These dramatic, hectic times were characterised by the twin phenomena of global competition and technological revolution. How industries reacted to, adapted to, and took advantage of these intertwined and unfolding transformation processes remains a poorly understood question.

This paper attempts to exploit the advantages of fresh hindsight to shed some light on the knowledge dynamics of broadly defined industries as characterised by the world's largest innovative companies over the course of the 1980s and 1990s. As time moves on and we gain distance from this defining period of recent history it becomes pertinent to uncover new insights into what really happened across industries in dynamic markets in the wake of rapidly mutating knowledge bases. To this end, we mobilise data pertaining to over half a million patents by 463 globally oriented and technologically active US, European and Japanese firms. To this raw material we apply a well known technique traditionally applied in the field of empirical international economics, but still largely under-utilised in the context of neo-Schumpeterian analysis of technological capabilities: structural decomposition analysis.

What we observe is evidence of a strongly stylised fact of contemporary industrial change that has been captured in a number of other investigations (e.g. Granstrand et al., 1997; Cantwell et al., 2004): the knowledge base of large manufacturing companies across industries has become more complex over time (Cantwell and Fai, 1999) and the management of innovation itself has become more complex. The sources of this complexity are attributed to the ever-increasing levels of technical sophistication in products (Brusoni et al., 2001), processes and the need to coordinate transnational networks of highly heterogeneous and dynamic component suppliers (Mendonça, 2005). Notwithstanding, what we begin to unveil are industry specific patterns of response to the new technological challenges. Using structural decomposition analysis (SDA) we are able to identify information and communication technologies (ICTs), New Materials, and Pharmaceutical & Biotechnology as the most subversive technologies to challenge the *a priori* industrial knowledge profiles. We are also able to assess the extent to which different industries facing this shifting technological landscape responded by internally nurturing those disruptive new technologies.

The next section sets the basic theoretical underpinnings upon which this research rests. Section 3 describes the data, section 4 the methodology, and section 5 discusses the results.

The novelty of paper consists in the application on the SDA method to unpacking the technology diversification phenomenon (subsection 5.1), and in the specific application of the method to the technology fields (subsection 5.2). Section 6 offers some concluding comments.

2. TECHNOLOGY STRATEGY FOR SCHUMPETERIAN SELECTIVE ENVIRONMENTS

Simply stated this paper sees the large global innovating industrial firm as a system of technologies evolving in different directions and at different rates. Building on Freeman's (1987) and Lundvall's (1992) systemic view of technical change, we assume that innovative business organisations may be regarded as open systems of innovation. For the strict purposes of this paper, a corporate innovation system will be understood as the intertwined set of activities and interactions that allow the organisation as a whole to develop new technologies, products, markets and new ways of conducting business.

This general framework is given empirical substance by a body of applied work which has denoted the major business organisations of the contemporary economy as multi-technological corporations. The key observation in this literature, pioneered by Granstrand and Sjölander (1990) and Patel and Pavitt (1994), is that modern industrial firms are characterised by internal variety in their technological capabilities, harbouring technologies that go well beyond those directly related to their major product lines. It follows that large, technologically competitive manufacturing firms typically develop an array of distributed competences, rather than concentrating exclusively on core competences as a source of advantage in international markets (Granstrand et al., 1997). Companies have maintained higher levels of technological diversity than product diversity in the past century (Gambardella and Torrisi, 1998; Andersen and Walsh, 2000; Piscitello, 2004), and this trend seems to have deepened under the impact of the technologies of the information age (Fai, 2003; Mendonça, 2006).

At the same time, research on technological diversification has stressed that the composition of corporate technological capabilities is complex but still is stable, and that the direction of search follows path-dependent dynamics demarcated by the fields of knowledge required by their primary product focus, i.e. chemical firms will tend to search in chemical technologies - industry matters (Patel and Pavitt, 1997). This strong association of core technologies with specific industries indicates path-dependency in the evolution of an industry's technological trajectory and has led to claims that creative accumulation prevails over creative destruction at the level of the firm, i.e., inside the organisation the emergence of new technological fields are linked to established ones in a complementary fashion and evolution in technological mastery takes a long time to establish (Granstrand, 1998; Pavitt, 1998).

However, our findings suggest that much more than conservative accumulation along given trajectories seems to be happening when business organisations face historically unique, technologically turbulent, and fast changing competitive environments. In fact, the technological profiles of industries may be idiosyncratic, but changes may be more dramatic than previously thought. There are indications that the scope of corporate technological diversification in the late twentieth century turned out to be significantly greater than earlier periods (Fai and von Tunzelmann, 2001a, 2001b). In particular, the rising tide of ICTs, biotechnologies and other new technologies may be said to have affected all industries, although to different degrees (Mendonça, 2004) being felt both in "high-tech" and "low-tech" sectors (Gambardella and Torrisi, 1998; von Tunzelmann 2003). In other words, whilst the broader technological environment faced by all industries was changing radically at the end of the twentieth century, firms too were internally changing their technological profiles.

This paper attempts to cast some light on how different industries reconfigured their knowledge profiles (measured by their patent portfolios) against, or in line with, the movement of structural change occurring in the broader technological environment. We broadly interpret the development of economically relevant technological knowledge through the resource-based or capability-perspective, but tentatively extrapolate from the firm to the industry level. Multi-technology studies have found (e.g. Patel and Pavitt, 1997) that large innovative firms in the same principal product areas seem to be characterised by similar technological profiles. Thus, in this exploratory industry level study we will broadly assume that individual firms in the industry tended to adapt themselves in roughly the same way to technological opportunities. Within firms, intangible idiosyncratic competitive assets emerge as a result of organizational processes that build on, and attempt to go beyond, previously accumulated cognitive capabilities (e.g. Teece et al., 1997; Winter, 2003). Within industries, we assert that intangible idiosyncratic industrial assets emerge as a result of inter-organizational and inter-institutional processes that build on, and attempt to go beyond, previously accumulated cognitive capabilities.

The phenomenon to be addressed is the evolution of industrial knowledge distribution and their adaptation in a fast moving knowledge landscape (shaken by a technological revolution). We wish to examine the evolution of industries in the context of a shifting knowledge landscape in which different technologies develop in different ways at different speeds. We would hypothesise that the distribution of the technology portfolios within corporations is being skewed by the attractiveness of certain fields such as ICT, Pharmaceutical and Biotech and New Materials, in spite of all the inertia that derives from the slow and localised learning processes that normally take place in firms and this is reflected at the industry level.

3. DATA

The following analysis is based on data extracted from the SPRU database using US Patent Office (USPTO) information. Our database reports accumulated patent counts for 463 of the world's largest manufacturing companies across 14 industries and 34 technology classes for the years 1981-85, 1985-90, and 1991-96. Patents were assigned to the primary class for which they were granted by the examiners. These were then allocated to one of 34 broader patent classes of the SPRU database (see Appendix 1).

Some patent classes were a simple process of aggregation i.e. where a USPTO class clearly fell into a single class within the broader SPRU classification scheme, e.g. patents registered under US Patent Class 435 Chemistry, Molecular Biology and Microbiology, were allocated to the SPRU category 7 Drugs and Bioengineering in their entirety. However, occasionally patents within a USPTO class were split and allocated to two or more broader SPRU categories, e.g. some of the patents registered under US Patent Class 424 Drug, Bio-Affecting and Body Treating Compositions were allocated to SPRU class 3 Agricultural Chemicals, and others were assigned to class 7 Drugs and Bioengineering, where appropriate.

The construction of the industry data involved a tremendous effort of consolidation of 4500 subsidiaries and divisions of firms: different assignee names, kept or bought by the 463 up to 1992, were identified using *Whom Owns Whom* of 1992 as a basis for allocation to their parent companies. The parent companies have then been allocated to one of SPRU's 14 industrial classes (see Appendix 2) according to their primary production output.

Although patents have become a hugely popular innovation indicator, their proper use remains a non-trivial matter. The problems of this indicator are significant, but will not be discussed here. The concerned reader is directed to the methodologically oriented literature, now quite mature and extensive (Pavitt, 1985; Narin and Olivastro, 1988; Griliches, 1990; Smith, 2005).

Following the multi-technology literature we know that large industrial firms are technologically active (i.e. they claim patentable knowledge at the frontier of given knowledge fields) even outside their core domains traditionally linked to the generation of their industrial output. Table 1 illustrates the correspondence between industrial sector and core and non-core technological fields within the SPRU patent database. The final column of the table 1 shows the proportion of patents registered by firms in each industry in technological fields outside of those identified as core to each industry. For instance, whilst ICTs related technologies are core technical fields for the Computer and Electrical/Electronics industries, 25.1% and 39.3% of patents are taken out in other technologies such as drugs and bioengineering by firms in these two sectors, respectively. Thus, we have a way to measure the extent and dynamics of the technological diversification behaviour.

Table 1. Correspondence between industrial sector and core technological field.

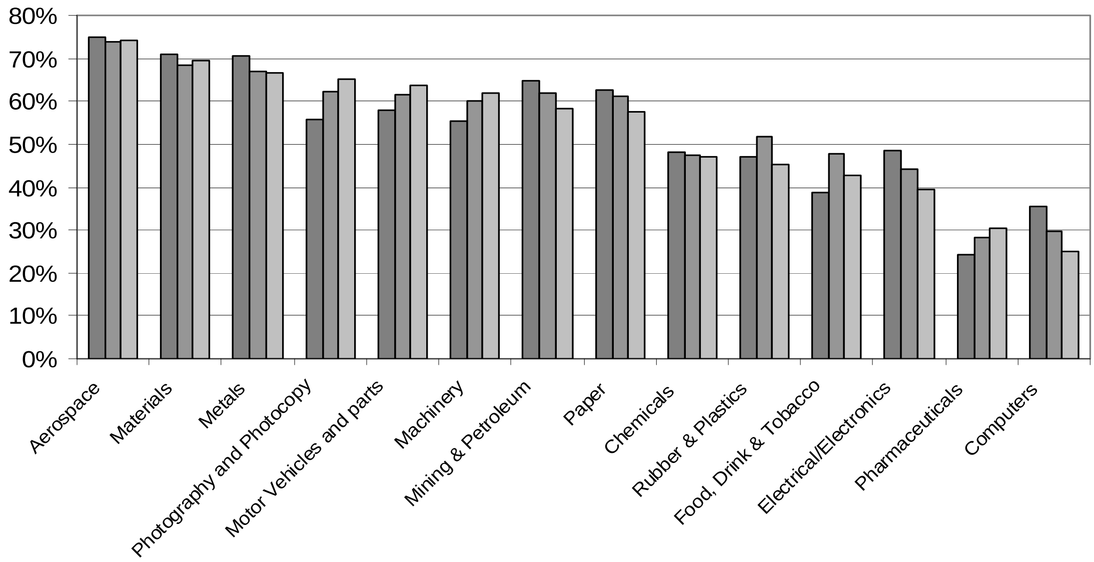
Industry	***Core Technical Fields (CTFs)***	***Patents outside CTFs*** *(1991/96)*
Aerospace	Aircraft, General Non-electrical Industrial Equipment, Power Plants	74.0%
Chemicals	Organic Chemicals, Agricultural Chemicals, Drugs & Bioengineering	47.0%
Computers	Computers, Semiconductors,	25.1%

	Telecommunications, Image & Sound Equipment	
Electrical/Electronics	Telecommunications, Semiconductors, Electrical Devices, Computers, Image & Sound Equipment	39.3%
Food, Drink & Tobacco	Food & Tobacco, Chemical Processes, Drugs & Bioengineering	42.6%
Machinery	General Non-electrical Industrial Equipment, Metallurgical & Metal Working Equipment, Chemical Apparatus, Vehicles Engineering, Mining Machinery	62.0%
Materials	Materials	69.5%
Metals	Metallurgical & Metal Treatment Processes, Materials, Metallurgical & Metal Working Equipment	66.5%
Mining & Petroleum	Organic Chemicals, Inorganic Chemicals, Mining Machinery	58.3%
Motor Vehicles & Parts	Vehicles Engineering, General Non-electrical Industrial Equipment, Other transport Equipment	63.6%
Paper	Materials, Specialised Machinery	57.7%
Pharmaceuticals	Organic Chemicals, Drugs & Bioengineering	30.2%
Photography & Photocopy	Photography & Photocopy, Instruments & Controls	65.3%
Rubber & Plastics	Plastics & Rubber Products, Materials	45.1%
All industries	Core technical fields	48.3%

Source: SPRU database, own calculations
Note: Correspondence between industries and "core technical fields" drawn from Patel (1999)

Figure 1 presents the same data with an inter-temporal perspective. The Computer and Electrical/Electronics sectors, appear to be registering fewer patents in technologies outside of their core fields, or equivalently, are focusing more on their core technological competencies, over time. In contrast, Photography and Photocopy demonstrate a sharp increase in the patents granted outside its core technical fields. We interpret this as a transition towards a richer ensemble of technological activities and hence a broadening of the knowledge base of this industry. Other industries displaying similar tendencies include: Motor Vehicles & Parts, Machinery, Pharmaceuticals, and to a more limited extent, Food, Drink & Tobacco.

Figure 1. Firms patenting outside their "Core Technical Fields", 14 different industries (1981-85, 1986-90, 1991-96)



Source: SPRU database, own calculations.
Note: for the three periods data refers to the weight of "non-core" patents obtained in the total technology portfolio

Despite cross-industry variability in the level and rhythms of technological diversification, almost half of the patents generated by our population are generated outside each industry's core domain of technological expertise (Mendonça, 2003).

4. METHOD

The patent data are analysed using structural decomposition analysis (SDA). SDA is derived from constant market share analysis as used in empirical studies of trade (Tyszynski, 1951; Fagerberg and Sollie, 1987; Laursen 1999). Tyszynski (1951) looked at change in the export performance of a nation in terms of its market shares at the end of the period compared to that at the start. He broke this down into two elements. He calculated what the nation's market share of exports would have been at the end of the period if the nation's initial shares across the basket of commodities did not change over time (i.e. using Laspeyres weighted indices). The difference between the initial share and this hypothetical end share is the *structural effect* because it reflected the changes in a nation's share of trade that was attributable to structural changes in its trading environment. The residual, or remaining difference between the hypothetical end share and the actual end share (i.e. Paasche weighted index) he put down to a *competitiveness effect* because it reflected changes in a nation's share of trade that was attributable to the nation's changing competitive strength.
Fagerberg and Sollie (1987) strengthen Tyszynski's basic analysis and demonstrate that by using initial weight (Laspeyres) indices throughout their methodology, the residual effect

which Tyszynski attributed entirely to the competitiveness effect can actually be broken up in to two separate effects: the reported *competitiveness effect*, but also a *commodity adaptation effect*. In other words, this third effect allows for the possibility that a nation's export performance might improve overtime because it can alter the composition of its "basket" of export commodities so as to adapt with any changes in the broader composition of commodities in world export markets. Laursen (1999) borrows this methodology and applies it not only to export markets but also to sectors of technological opportunity. This paper in turn borrows from Laursen's (1999) application of the methodology to technological opportunity but brings it down to an industry-level analysis. The logic of the methodology is given below.

i = a technological field (1…34)
j = an industry (1…14)
t-1, t = subscripts for initial year and final year of the period under consideration

Let
M = industry j's share of all patents
a = industry j's share of all patents in technology i
b = technology i's share of all patents

M can be written as the inner product of the vector a and vector b:

M = ab or,

$$M = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ \ldots \\ M_j \end{bmatrix} = a \otimes b = \begin{bmatrix} a_{11} & . & . & . & . & . & a_{1i} \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ a_{j1} & . & . & . & . & . & a_{ji} \end{bmatrix} \otimes \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ \ldots \\ b_i \end{bmatrix}$$

The change in industry j's share of patents in an industry over time is:

$$
\begin{aligned}
\Delta M &= M_t - M_{t-1} \\
&= a_t b_t - a_{t-1} b_{t-1} \\
&= (a_t - a_{t-1}) b_t + a_{t-1} b_t - (a_t - a_{t-1}) b_{t-1} + a_t b_{t-1} - 2a_{t-1} b_{t-1} \\
&= (a_t - a_{t-1}) b_{t-1} + a_{t-1}(b_t - b_{t-1}) + (a_t - a_{t-1})(b_t - b_{t-1}) \\
&= \Delta M_a + \Delta M_b + \Delta M_{ab}
\end{aligned}
$$

where the third term in the final line indicates the degree to which an industry has succeeded in adapting its own technological profile to the changes in the broader technological environment in which it operates. It is the *technology adaptation effect.*

Fagerberg and Sollie caution that a zero technology adaptation effect does not indicate that no adaptation occurred, but that the rate of the industry's adaptation is exactly the same as the rate at which the broader environment's technological profile is changing. Thus a positive adaptation effect suggests the industry is adapting well relative to the pace of change in the environment and a negative adaptation effect suggest it is not adapting well. However, following Laursen (1999), the *reason* for a positive value of the adaptation effect has two bases: the industry appears to be adapting well because it is entering areas of growing technological opportunity, or because it is leaving areas of stagnating opportunity. Laursen therefore breaks up the third term – technology adaptation effect, into two parts: the technological growth adaptation effect which is positive if the industry moves into technological areas providing more opportunities for growth and the technological stagnation adaptation effect which is positive if the industry moves out of areas of declining opportunities. Thus following on from above, the full equation for the structural decomposition model is given by:

$$
\begin{aligned}
\Delta M &= \Delta M_a + \Delta M_b + \Delta M_{ab} \\
&= \Delta a b_{t-1} + a_{t-1}\Delta b + \Delta a \Delta b \\
&= \Delta a b_{t-1} + a_{t-1}\Delta b + \Delta a(\Delta b + \frac{|\Delta b|}{2} - \frac{|\Delta b|}{2}) \\
&= \Delta a b_{t-1} + a_{t-1}\Delta b + \Delta a(\frac{\Delta b + |\Delta b|}{2}) + \Delta a(\frac{\Delta b - |\Delta b|}{2}) \\
&= TS + ST + GA + SA
\end{aligned}
$$

Thus, the change in a firm's patent share consists of four elements:

(TS) the technology share effect isolates the extent to which an industry has gained or lost shares of total patents through its endogenous patent growth into new areas, assuming a fixed technological structure at the broader technological level across the period.

(ST) the structural technology effect isolates the extent to which an industry has gained or lost shares of total patents because the technological structure of the broader environment has shifted to more closely or less closely resemble the balance of the industry's own technological composition as it was at the start of the period.

(GA) the technology Growth Adaptation measures the extent to which an industry has gained shares of total patents through the movement into the 'right' or more influential technological fields (positive sign), or equivalently, out of the 'right' technological fields (represented with a negative sign);

(SA) the technology Stagnation Adaptation effect isolates the extent to which an industry has benefited from moving out of the 'wrong' or stagnating technological fields (positive sign), or equivalently, into stagnating technological fields (negative sign).

We examine the evolution of each industrial group of firms with respect to the changes in the technologies produced (patents obtained) by the entire group of 463 firms. Thus, this study takes technological development in this population of 463 firms as an approximation of the relevant technological landscape. We acknowledge that the entire technological landscape extends well beyond the horizon provided by these organisations alone to include contributions by small high-tech firms, innovation consortia, public and private research institutions, universities, etc. Similarly, the variable propensity to patent across industries means that our reliance on patent data as a proxy provides, at best, a limited picture of the technological landscape. These constitute limitations of the present analysis, nevertheless, studies have shown that the correlation between inventions and patents is stronger for large firms than small firms (Acs and Audretsch, 1988) and that whilst patent protection is a limited motivation for the introduction of a commercial invention, corporations from all industries nevertheless utilise the patent system extensively for patentable inventions (Mansfield, 1986). Moreover, Cohen et al (2000) found that patents maybe relied upon more heavily by large firms in the late twentieth century than they were in the 1980s, which corresponds with our period of analysis. As such, we utilise patent data of the 463 firms here as a proxy for the technological developments at the industry level, albeit with caution and acknowledging its shortcomings.

5. RESULTS AND DISCUSSION

Today it is well recognised that something revolutionary happened in the world economy in the last two decades of the twentieth century. Several authors describe this moment as the third industrial revolution, the information revolution (Freeman and Louçã, 2001), setting the stage for an ICT paradigm (Freeman, 2007), an era of informational capitalism (Castells, 2000). In this new age it is argued that the factors for competitiveness have become more dynamic and ever more dependent on knowledge and intangibles. What matters, are those capabilities that explore new knowledge and which gather, recombine and exploit, old knowledge.

Statistical evidence of the economic significance of this revolution is usually sought in the changing industrial composition of the economy. For instance, evidence of this stylised fact can be found in the rise of ICT-based firms in the top two hundred US firms of the Fortune magazine in the 1970s and 1980s (Louçã and Mendonça, 2002). However, the process of adjustment taking place within industries (or firms) themselves is a form of structural change which occurs 'under the radar' and for which evidence in the extant literature is less abundant. The following analysis tries to fill this gap.

5.1 Industry analysis

Table 2 reports the result of the SDA described earlier and orders the industries according to growth in patent share over the period 1981/85 to 1991/96. It confirms that the fastest growing industries are Computers, Photography & Photocopy and Electrical/Electronics and the slowest are Mining and Petroleum, Chemicals and Materials. Strikingly, every industry outside the top three suffers falling patent growth if their existing technological profiles are held constant in the face of a changing technological environment (ST effect is negative).

Table 2. Structural decomposition analysis across industries 1981/85 to 1991/96 (Change in pattern change)

Industry	TS	ST	GA	SA	ΔMj
Computers	1.68	2.62	0.46	-0.06	4.69

Photography and Photocopy	2.61	1.18	0.55	-0.23	4.10
Electrical/Electronics	-2.18	4.15	-0.67	0.12	1.43
Machinery	1.03	-0.62	0.02	-0.24	0.19
Food, Drink and Tobacco	0.39	-0.26	0.01	-0.08	0.05
Paper	-0.12	-0.08	-0.02	0.02	-0.21
Rubber & Plastics	-0.12	-0.14	-0.01	0.02	-0.25
Metals	-0.32	-0.48	0.04	0.09	-0.67
Aerospace	-0.49	-0.20	-0.16	0.04	-0.80
Pharmaceuticals	-0.70	-0.29	0.01	0.15	-0.83
Motor Vehicles and Parts	0.16	-1.04	-0.03	-0.02	-0.93
Materials	-0.98	-0.19	-0.04	0.15	-1.06
Chemicals	0.54	-2.77	-0.04	-0.17	-2.44
Mining & Petroleum	-1.51	-1.87	-0.12	0.23	-3.27

Source: SPRU database, own calculations

Among the top three industries, the TS effect indicates that Computers and Photography & Photocopy both would have experienced internal growth in patent shares in the absence of any change in their technological environment, suggesting that their core technological areas (as indicated in Table 1) provided them with many opportunities for growth. All three of the industries with the greatest technological growth benefited from a favourable change in the technological environment (the ST effect) i.e. the environment altered to provide these industries with more opportunities for growth. We can also see from the combined GA and SA effects that Computers, Photography & Photocopy grew in areas of technological opportunity (positive GA), whilst Electrical/Electronics benefited for a different reason, moving out of the technological areas offering fewer opportunities (positive SA); notably out of the more mature field of electrical devices.

At the opposite end, whilst the core technologies in the chemical industry continue to offer some opportunities for growth (TS=0.54) it suffers because the general technological environment does not favour it (negative ST). Similarly, the environment does not favour Materials nor Mining & Petroleum, but they suffer also because their own internal growth is negative. All three have negative GA effects suggesting they failed to move into, or worse, moved out of the more influential technological fields of this period, although Materials and Mining & Petroleum do also move out of stagnating technological fields to some degree (positive SA).

5.2 Technological field analysis

For this part of the analysis we apply the SD analysis to the technological fields in our database. It now traces how the technological fields themselves performed across industries in the face of a changing industrial structure rather than vice versa as above. In particular, we are interested in how the non-core technological fields in each industry performed, as a proportion of industrial shares of patents. However, being non-core technologies, changes in their industrial distribution can be quite small, therefore we have aggregated the 34 technologies of the SPRU dataset (based directly on the USPTO original patent classes) into 9 broader technological groupings (constructed on the basis of technological proximity) to give movements greater visibility in our findings (such aggregation procedures are often crude but can yield very interesting results, e.g. Robertson and Patel, 2007). Table 3 illustrates our aggregation of the technological fields, into broader technological groups according to technological similarity. For instance, under the ICT label we cluster technological areas that have been strongly underpinned by the advent of the microchip and that incorporate a strong digital element (for more details on this re-grouping see Mendonça, 2003).

Table 3. Broad technology groups

Chemicals	Fine Chem	Pharm & Bio	Materials	Mechanical	Transport	ICT	Electrical & Instruments	Other
InOrChem AgrCh Hydroc Bleach Plastic ChemApp	OrgCh ChePro	Drugs	Materials	NonElMach SpecMach MetalWEq AssHandApp Mining	VehiEngi OthTran Aircraft	Telecoms Semicond Computers Image&Sou	Instrumen Photog&C ElectrDevi ElEqup	Medical MiscMetProd Metallu Pro Nuclear PowerP Food&T TextWoodetc Other(weap.etc)

Tables 4 and 5 apply the SD analysis to the aggregated technology groups in our database. Previous work has observed that the last two decades of the twentieth century were marked by an explosively uneven change in technological opportunity across the spectrum of patent classes (Mendonça, 2006). The last column in both Tables shows how these broad technological groups grew in the total portfolio of all industries from the 1980s into the early 1990s and confirms these findings. Although with some variability over time, we observe that ICTs, New Materials and Pharmaceuticals & Biotech grew in importance over the entire period[3]. The same cannot be said about the other technologies. Moreover, given our focus on only patents registered in non-core technical fields, this strongly signals that these

[3] The aggregated technology classification used here does not distinguish between Pharmaceutical and Biotechnology. Had a lower level of technological classification been employed, a more significant growth in biotechnology is likely to have been detected. We thank the anonymous reviewer for bringing this point to our attention.

technologies were offering the most vibrant technological prospects for all industries, not just the sectors having the new technologies as their core technologies.

Table 4. Diversified technologies' structural decomposition analysis, 1981/85 to 1986/90

Technologies	TS	ST	GA	SA	∆Mj
ICT	2,37	1,54	0,51	-0,11	4,31
Other	1,33	0,13	0,04	-0,04	1,46
Materials	0,97	0,10	0,08	-0,09	1,07
Elect & Inst	0,38	0,22	-0,08	-0,05	0,47
Transport	0,02	-0,01	0,00	0,01	0,01
Pharmaceutical & Biotech	0,04	0,02	-0,05	-0,03	-0,02
Mechanical	-0,96	-0,01	-0,08	0,06	-1,00
Chemicals	-1,89	-1,15	-0,09	0,16	-2,97
Fine Chem	-2,25	-0,84	-0,31	0,08	-3,32

Source: SPRU database, own calculations

Table 5. Diversified technologies' structural decomposition analysis, 1986/90 to 1991/96

Technologies	TS	ST	GA	SA	∆Mj
ICT	1,22	1,96	0,09	-0,06	3,21
Fine Chem	1,44	-0,34	0,05	-0,16	1,00
Materials	0,38	0,29	-0,07	-0,02	0,58
Pharmaceutical & Biotech	0,22	-0,03	0,01	-0,02	0,18
Transport	0,00	-0,09	-0,01	-0,01	-0,10
Chemicals	0,04	-0,56	-0,01	-0,03	-0,56
Elect & Inst	-0,22	-0,62	-0,03	0,01	-0,87
Other	-1,25	-0,22	-0,03	0,12	-1,38
Mechanical	-1,82	-0,40	0,00	0,17	-2,05

Source: SPRU database, own calculations

The SDA confirms that industries other than the industries in which the new technologies originated and emerged, also aggressively pursued the cluster of revolutionary new technologies. To illustrate, in the 1980s whilst the TS effect dominates, the ST effect in the technologies associated with the third technological revolution (ICT, Materials and Pharmaceutical & Biotech) also has a positive influence. In other words, even in 1981/5 to 1986/90 we see that these technologies are also being picked up by other industries outside of those with which they would be most closely associated. These technologies extend their reach beyond the boundaries of their industrial origin. Furthermore, with the exception of Pharmaceuticals & Biotech, this influence grows stronger in the later period (Table 4), where the ST effects are greater in magnitude than the earlier period. This phenomenon shows the pervasiveness of the technologies of the third technological revolution across industrial boundaries from their industries of origin to the industries of use (Scherer, 1982).

6. CONCLUSIONS

This paper focused on how new technologies are modifying the profile of technological competencies of industries as represented by large US, European and Japanese manufacturing firms. Inter-sectoral structural change is commonly acknowledged as an important phenomenon in face of technological shifts, as industries rise and fall in terms of relative dynamism. But we still do not understand many things about the internal aspects, namely the intra-sectoral dimensions, of technological evolution. By using a structural decomposition approach, we have made an attempt to reveal some of the dynamics of endogenous knowledge diversification when technologies are of uneven attractiveness and when some technologies (ICT, Pharmaceuticals and Biotech, new Materials) offer more opportunities for creative accumulation than others, by being combined with pre-existing competences.

The first part of our analysis allowed us to demonstrate that the industries of Computers, Photography & Photocopy and Electrical/Electronics were among the fastest growing at the edge of the 21st century. This appeared to leave the other industries behind, revealing them as laggards, taken unawares of the technological fate that was to befall them. However, the second part of our analysis demonstrated how the technological groups themselves were distributed across industrial sectors. This showed that even in the early 1980's, as the new technologies were in their infancy, some of their influence was already being felt in industries beyond the ones of their birth. Non-specialist industries were taking advantage of the potential enhancing effects of ICT, Materials and Pharmaceutical & Biotech technologies for their development, enabling the creation of more complex products.

In this industry level study we found indications that something revolutionary challenged the cognitive inertia of firms across many industries, rather than just a few rapidly changing ones and the locally-bound nature of technological search. Our findings suggest that large firms from all industries started to patent in the new promising areas of the technological revolution and, in doing so, extended the lifecycle and scope of application of their own previously established technological profiles. Technological revolutions can be embraced as a means to extend the life of more mature corporations and industries rather than rejected as a threat to the status quo. To be aware of major new, potentially revolutionary technological developments, and to find a way to bring them into organisational practices can sometimes be of benefit to all.

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Appendix 1. *The SPRU Database Patent Classes*

1 Inorganic Chemicals
2 Organic Chemicals
3 Agricultural Chemicals
4 Chemical Processes
5 Hydrocarbons, mineral oils, fuels and igniting devices
6 Bleaching Dyeing and Disinfecting
7 Drugs and Bioengineering
8 Plastic and rubber products
9 Materials (inc glass and ceramics)
10 Food and Tobacco (processes and products)
11 Metallurgical and Metal Treatment processes
12 Apparatus for chemicals, food, glass, etc.
13 General Non-electrical Industrial Equipment
14 General Electrical Industrial Apparatus
15 Non-electrical specialized industrial equipment
16 Metallurgical and metal working equipment
17 Assembling and material handling apparatus
18 Induced Nuclear Reactions: systems and elements
19 Power Plants
20 Road vehicles and engines
21 Other transport equipment (exc. aircraft)
22 Aircraft
23 Mining and wells machinery and processes
24 Telecommunications
25 Semiconductors
26 Electrical devices and systems
27 Calculators, computers, and other office equipment
28 Image and sound equipment
29 Photography and photocopy
30 Instruments and controls
31 Miscellaneous metal products
32 Textile, clothing, leather, wood products
33 Dentistry and Surgery
34 Other - (Ammunitions and weapons, etc.)

Appendix 2. *The SPRU Database Industries*

Principal Product Group	*Number of firms*	*Examples of firms in the database*
Aerospace	16	Boeing, Lockheed, BAE, Societé Nationale Industrielle Aerospatiale
Chemicals	69	BASF, Hoescht, Dow Chemical, ICI, Sumitomo Chemical
Computers	15	Apple, Bull, Fujitsu, HP, IBM, Olivetti, Toshiba
Electrical/Electronics	74	Fuji Electric, GE, Hitachi, Phillips, Raytheon, Sharp, Westinghouse
Food, Drink & Tobacco	18	Ajinomoto, Borden, General Mills, Nestlé, Quaker Oats, Pepsico
Machinery	72	Ahlstrom, Black & Decker, Deere, Dragerwerk, Schindler, Komatsu
Materials	15	Asahi Glass, Corning, Lafarge, Saint-Gobain, Toray, Ube, Unitika
Metals	39	Alcan Aluminum, Bethlehem Steel, Kobe Steel, Metallgesellschaft
Mining & Petroleum	25	Amoco, ENI, Exxon, Petrofina, Shell, Total
Motor Vehicles & Parts	47	Dana, Ford, Honda, Mazda, Navistar, Pegeut, Toyota
Paper	16	Kimberly-Clark, Svenska Cellulosa Aktiebolaget, Weyerhauser
Pharmaceuticals	34	Abbot, Merck, Novo Nordisk, Pfizer, Roche, Tanabe Seiyaku
Photography & Photocopy	14	Canon, Carl Zeiss Stiftung, Essilor, Konica, Ricoh, Olympus
Rubber & Plastics	9	Bridgestone, Continental, Goodyear, Michelin, Pirelli