LARGEST FIRMS' PATTERNS OF TECHNOLOGICAL AND BUSINESS DIVERSIFICATION. A COMPARISON BETWEEN EUROPEAN, US AND JAPANESE FIRMS

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ABSTRACT

The international literature has so far investigated many aspects of corporate diversification, with a recent particular emphasis upon firms' moves into new products (business diversification) and new technological fields (technological diversification). Indeed, it has recently been pointed out (e.g. Granstrand et al., 1997) that large firms are typically multi-technology as well as multi-product, and that therefore, careful attention needs to be devoted to the distinctions between products that the firm develops and produces, and the firm-specific technological knowledge that underlie its ability to do so (Pavitt, 1998) since the two follow different patterns. The purpose of the present paper is twofold: (i) it aims to investigate the largest firms' patterns of technological and product diversification over time, trying to highlight differences between European firms and their US and Japanese competitors, and (ii) it suggests a measure (based on the analytical framework developed in Teece et al., 1994) of the concordance between products and technologies which derives from and partly explains firms' diversification strategies. The data employed refer to a large cross-firm panel of technological and business activity of 248 large firms in the period 1977-1995.

1. Introduction

Diversification has long been studied as a broad topic. Nonetheless, despite recent reports to the contrary, corporate diversification remains a ubiquitous feature of the modern economic landscape (Montgomery, 1994). The economic and managerial literature has paid increasing attention to corporate diversification, emphasising the benefit from diversification in terms of lower costs and risk-spreading, as would arise from the exploitation of economies of scale and scope by firms. In particular, the literature has still largely focused upon the reasons for, and nature of, product diversification (Rumelt, 1974; Bigadikke, 1979; Didrichsen, 1982; Pavitt et al., 1989; Montgomery, 1994). Only recently, the framework based on the resource-based view of the firm (Penrose, 1959; Wernerfelt, 1984) which has been touted as particularly well suited to understanding diversification, has been extended to the concept of "technological competence" (e.g. Cantwell, 1994; Patel and Pavitt, 1994) and of corporate technological diversification (e.g. Granstrand and Sjolander, 1992; Granstrand et al., 1997; Pavitt, 1998) meant as the diversification of the firm's technological base.

In this context, it has recently been argued that greater care and attention needs to be devoted to the distinctions between the *artefacts* (products) that the firm develops and produces, and the firm-specific technological *knowledge* that underlies its ability to do so (von Tunzelmann, 1995; Pavitt, 1998). New opportunities emerging from scientific and technological advances have determined increasing systemic complexity characterising the interrelationship between technologies and products; products are becoming increasingly "multi-technology", and so are firms that produce them. Each specific body of technical knowledge cannot be associated uniquely with a single, specific class of product[1]. Products and related technologies co-evolve within firms, but their dynamics are different (Granstrand, 1982; Granstrand and Sjolander, 1990; Oskarsson, 1993; Gambardella and Torrisi, 1998; Pavitt, 1998).

Therefore, the aim of the present paper is twofold:

(1) to study the patterns through which large firms move in space of technologies and products over time, trying to highlight the differences in diversification patterns followed by European firms *vs.* their US and Japanese competitors;

(2) to attempt to develop a methodological framework, based on a matrix representation, for the analysis of the complex many-to-many relationship between technological competencies and products.

The empirical analysis makes use of a large panel of the largest European, US and Japanese firms over the period 1977-1995.

[1] As Pavitt (1998) observes, this a source of frustration for economists who would like to match statistics on inventions from technology-based patent classes with product-based trade and production statistics. See for example Scherer (1982) and Silvermann (1999).

2. Data

The large cross-firm panel employed to analyse corporate diversification[2] derives from the intersection of the two following datasets:

(a) A dataset on product diversification, which has been developed at Politecnico di Milano, and which relates to the sales of the *Fortune* largest firms over the period 1978-1993. Specifically, firms included in the dataset have been selected from *Fortune 1987*'s largest firms, but taking into account sectoral and geographical issues, *i.e.* stratifying the sample to make sure that firms from the whole sectoral and geographical spectrum are represented. The dataset then consists of the 300 largest European, American and Japanese firms, which are assigned to 20 primary manufacturing lines of business on the basis of where they obtain their greatest shares of sales.[3] Data on the breakdown of each firm's sales among 42 sectors (26 manufacturing and 16 service sectors) have been gathered for three years, namely 1978, 1987 and 1993. A detailed description of the 42 sectors considered, and their concordance with the SIC 4-digit classification, is reported in Annex 1. The primary lines of business utilized are set out in Annex 2.

(b) A dataset on technological diversification, which has been developed at the University of Reading, and which relates to the patenting activity in the USA of the largest US, European and Japanese firms over the period 1901-1995. The firms included in the dataset were identified in one of three ways. The first group consisted of those firms which have accounted for the highest level of US patenting after 1969; the second group comprised other US, German or British firms which were historically among the largest 200 industrial corporations in each of these countries (Chandler, 1990); and the third group was made up of other companies which featured prominently in the US patent records of earlier years. In each case, patents were counted as belonging to a common corporate group where they were assigned to affiliates of a parent company.[4]

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[2] Large multi-divisional firms are the largest single source of the new technological knowledge; they perform most of the R&D activities, employ most of the qualified research scientists and engineers, perform and publish most of the corporate basic research, and maintain the closest links with academic research (Pavitt, 1998). They also contribute to the development of knowledge and products for their suppliers of production equipment, components and software (Rosenberg, 1963; Patel and Pavitt, 1994).

[3] For Japanese firms we often used the *Japan Company Handbook* (1979, 1988, 1994) and therefore we had to adapt its classification to the one adopted in the present study.

[4] It is worth noting that the company to which a patent has been assigned, and the name and location of the inventor responsible for the underlying invention, are both recorded separately in the US Patent Office

Patents from each US Patent Office class or sub-class have been allocated to one of 56 technological fields (see Annex 3).

It is worth emphasising that this technological classification of patents is distinguished from the line of business classification of the company to which the patents are granted. Most large companies have engaged in at least some development in most of the general spheres of technological activity, irrespective of the industry in which they operate (for instance, chemical firms develop many mechanical technologies, including chemical machinery and equipment). In all, the historical path of US patenting activity was traced from the beginning of the century for 857 companies or affiliates that together comprise 283 corporate groups.[5] It is perhaps worth observing that there are some potential limitations of the US patenting measure, mainly related to the fact that patents measure codified knowledge, whereas a high proportion of firm-specific competence is tacit (*i.e.* non-codified) knowledge. However, patent data has been increasingly used as an indicator of corporate technological capabilities in management research (Jaffe, 1986; Patel and Pavitt, 1991, 1994; Mowery et al., 1996, 1997) and the most recent studies (*e.g.* Patel and Pavitt, 1997) have shown that other measures that embody tacit knowledge (such as R&D expenditure, the judgement of technological peers) give results very similar to those obtained using patenting.[6]

From the intersection of the two datasets considered, a sample of 248 European, American and Japanese of the world's largest firms was selected. In particular, those firms:

(i) are allocated to 18 manufacturing lines of business;[7]

(ii) are diversified into 42 manufacturing and service sectors, for the three years specified above (1978, 1987 and 1993);

data. Where patents have been assigned to firms, the inventor is normally an employee of the company or is directly associated with it in some way, but occasionally independent individual inventors do choose to assign their patents to firms (Schmookler, 1966). Normally the typical assignor was a prominent member of a corporate research laboratory, or some other similar in-house company facility. The geographical location of both assignor and company are recorded in the dataset, but are not our primary concern in this paper.

[5] Births, deaths, mergers and acquisitions, as well as the occasional movement of firms between industries (sometimes associated with historical change in ownership), have been taken into account.

[6] The pros and cons of using US patents as an indicator of technological activity are well covered in the literature (*e.g.* Schmookler, 1966; Basberg 1983, 1987; Griliches, 1984, 1990; Pavitt, 1985, 1988; Jaffe, 1986; Archibugi, 1992).

(iii) patent in 56 technological fields (where the data refer to cumulated stocks of patents for 1977, 1986 and 1995).

Sectoral and geographical characteristics of the sample are reported in Table 1, which also reports characteristics of the *Fortune 500* firms[8], in order to assess the balance of the sample. It emerges that, as far as the sectoral breakdown is concerned, sectors like Coal and petroleum (-4.9 percentage points), Food (-3.5) and Motor vehicles (-2.3) are under-represented, while firms from Pharmaceuticals (+3.9), Aircraft (+2.5) and Textiles and clothing (+1.8) are slightly over-represented in our sample relative to the *Fortune 500*. Likewise, in relation to the geographical breakdown, while Japanese firms are under-represented (-6.0 percentage points), US firms (+11.3) are over-represented.

3. Large firms' pattern of diversification in products and technologies: a comparison between EU, US and Japanese firms

Large manufacturing firms typically operate in many markets, so they are highly diversified in product terms. The diversification patterns have been measured both by counting the number of businesses in which each firm was active, and by calculating an index based on the Herfindhal concentration index (*i.e.* DIV = 1-H). Table 2 provides the frequency distribution describing the number of businesses for the 248 firms in our sample in the three periods considered, subdivided by geographical area (EU, US and Japan). Interestingly, it emerges that US firms change their product diversification although without a sharp trend (their presence changes in several classes unsistematically) while European and Japanese firms seem to generally focus their activities upon 2, 3, 4, 5-sector classes. However the patterns become clearer when crossing the geographical dimension with the sectoral one (and using the Herfindhal-based index), the perspective becomes more precise and clearer. Indeed, Figures 1, 2 and 3 show business diversification of each primary sector in the three periods considered for EU, US and Japanese respectively. At a first glance, it immediately emerges that US firms are the most diversified although recording a noteworthy decreasing trend in all the sectors considered (the only exception being represented by

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[7] The number of industries (or sectors) has been reduced to 18 from 20, since firms from industry 12 (Other transport and equipment) and industry 20 (Other manufacturing) have been re-allocated, as they would not be numerically significant if taken on their own.

[8] The year considered for the Fortune list of firms is 1993.

Professional and Scientific Instruments). Different behaviour are instead generally recorded for EU and even more for Japanese firms. In fact, EU firms in Office equipment, Aircraft, Food, Chemicals, Rubber and Plastic products and Mechanical engineering show an increasing business diversification, as well as Japanese firms in Electrical equipment, Textiles and clothing, Chemicals, metals, Motor vehicles, Paper and Rubber and plastic products, Mechanical engineering and Professional and scientific instruments.

Large firms are also multi-technology. Again, two different indicator for diversification have been considered. First, we considered the number of technological fields in which the firms are active; secondly, an index based on the variation coefficient (*i.e.* TECHDIV = 1/CV) has been calculated[9]. Table 3 provides the frequency distribution describing the number of technological fields for the 248 firms in our sample in the three years considered, for the three geographical areas considered. The table shows that large firms typically spread their technological activity over a large number of fields, and that this holds over time although with some shifts among classes. In other words, the largest firms remain highly diversified (Montgomery, 1994). Specifically, when considering differences among countries it is possible to observe that in the first period, European and US firms were the most technologically diversified, while in the two following periods, this tendency characterises more the Japanese firms (Kodama, 1992, 1995).

Again, when crossing the geographical dimension with the sectoral one (and considering the index TECHDIV), the patterns become clearer. Figures 4, 5 and 6 show technological diversification of each primary sector in the three periods considered, for EU, US and Japanese firms respectively. Figures confirm that Japanese firms increase their technological diversification more rapidly, while EU and US firms seem instead to generally decrease it. In particular, looking at single sectors, it emerges that J, EU and US pharmaceutical firms record a similar technological diversification although recently

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[9] The CV measure has often been used as well in the analysis of business concentration across firms within an industry, as opposed to concentration or dispersion across sectors within a firm (see Hart and Prais, 1956). It is worth noticing that alternative measures could be used (*e.g.* the Herfindhal index) but that for a given number of firms or sectors (N), there is a strict relationship between the Herfindahl index (H) and the coefficient of variation (CV) (Hart, 1971). The relationship is: $H=(CV^2+1)/N$.

increasing only for EU firms. Additionally, Europe performs better also in Chemicals and Coal (where Japanese firms record increasing diversification too).

3.1. A brief note on business diversification towards service sectors

In observing the dynamics of the sectors, one can look at the overall (1978/1993) changes of firm presence in each sector, as in Table 4. This reveals that the highest positive values were for Electronics (+16), Rubber and plastic products (+16), Scientific instruments (+12), Motor vehicles and components (+8), Aircraft (+5), Office equipment (4) and Other goods (4). By contrast, Leisure products (-6), Wood products and paper (-4), Cosmetics and detergents (-4), Petroleum (-3) and Drink (-2) decrease in both sub-periods. Similarly, the overall changes in service sectors show the highest positive values in Finance (+11), Insurance (+6), Telecommunications (+5) and Informatics (+4), whilst Distribution (-8), Estate (-5), Transport (-4) and Catering and hotels (-3) show the highest negative changes. Overall this conforms with expectations about sectoral changes over this period. Note that, on average, the changes are positive between 1978 and 1987, but mixed and often negative between 1987 and 1993.

The average number of firms active per sector rises from 17.9 in 1978 to 18.8 in 1987, before falling fractionally to 1993. This implies that the 'average firm' in the sample was active in 3.03 sectors in 1978 and 3.17 in 1993.

The patterns in service sectors especially are important. Indeed, business diversification reveals an increasing trend towards service sectors. Therefore, in order to analyse the different behaviour of European vs. US and Japanese firms, as well as their dynamics, Figures 7, 8 and 9 report the share of sales in services for EU, US and Japanese firms in each primary sector in the three periods considered, respectively. Looking at the three figures, it is possible to immediately observe the general increase in the share of service industries, particularly for European and even more for US firms. In 1978, EU firms resulted the most diversified all over the primary sectors (especially in Mechanicals engineering, Electrical equipment, Food and Motor vehicles), while in the second and in the third period, US firms increase their diversification towards service sectors too. Interestingly, in the latest periods firms in Office equipment, Professional and scientific instruments and Electrical equipment are the most diversified in services. Similarly, although less significantly, Paper products, Food and Aircraft result diversified to service sectors too.

4. The many-to-many relationship between technological competencies and products

The increasing interrelatedness among technologies, and the consequent need for an increasingly broad knowledge base for the development of more complex products and production processes (Granstrand and Sjolander, 1990, 1992; Kodama, 1992, 1995; Granstrand et al., 1992), the scientific and technological complexity of each individual product has been rising, and at the same time pervasive technologies have been installed in an ever-widening range of products. Products are thereby becoming increasingly "multi-technology" and so are firms that produce them. In other words, as technological complexity increases, the number of technologies associated with each particular product increases, and conversely the number of products associated with each technological field increases as well[10]. Each specific body of technical knowledge cannot be associated uniquely with a single specific product, and the technology-product connection is not one-to-one but many-to-many (von Tunzelmann, 1995; Pavitt, 1998). Several studies have already highlighted the crucial relationship between products and technologies, basically through two fundamental approaches:

(i) by focusing on the importance of technology as playing a primary role within the firm's *resource base* thus representing a main source of opportunities for firms to diversify into new and related product markets (Rumelt, 1974; Bigadikke, 1979; Didrichsen, 1982; Pavitt et al., 1989);

(ii) by emphasising the temporal and causal relationship between product and technological diversification, both stating that diversification into new product fields pushes firms to increase diversification of technological capabilities (e.g. Granstrand and Sjolander, 1992) along a distinctive path established by the technological trajectory (Dosi, 1982), and *viceversa*, that most often

[10] As observed in von Tunzelmann (1998) and von Tunzelmann and Wang (1999), technological complexity could be defines either with reference to its breadth, *i.e.* to the diversity of technologies required to produce or further develop the product range of the firm, or to its depth, *i.e.* the extent of basic scientific and technological knowledge required in each particular area.

technological diversification anticipates product diversification, since technological exploration in a wide range of technologies is a prerequisite for production (Pavitt, 1998).

The approach followed in the present study relies upon the view echoed by research about "technological competencies", which embraces the idea that a firm can be viewed as composed of one set of businesses (or product/market combinations) constituting its *business base*, and one set of resources, constituting its *resource base*, and a many-to-many correspondence between resources and businesses, subjected to environmental changes, management and organisation behaviour (Granstrand, 1998).

The more recent line of research has focused upon technological diversification, with the ultimate goal to link it to product diversification (Breschi et al., 1998), thus highlighting evidence of stable and highly specific areas of corporate technological strength (Pavitt et al., 1989; Cantwell and Andersen, 1996; Patel and Pavitt, 1997), and high correlation between the primary business in which a firm operates and the set of technological areas in which it patents, particularly in high technology and technology based industries (Patel and Pavitt, 1991, 1994). In particular, in order to test this latter point, a correlation analysis among largest firms' profiles of technological activities has been run and it is reported in Table 5. As expected, firms operating in high tech primary sectors show the most similar technological profile (e.g. Office equipment, Professional and scientific instruments, Chemicals, Pharmaceuticals, Aircraft). However, it is interesting to observe that in the period considered the correlation increases only for some sectors (Mechanical Engineering, Aircraft, Motor vehicles, Electrical equipment) while for others (e.g. Chemicals and Pharmaceuticals) it seems to decrease over time, meaning perhaps that the primary sector influences less the firms patterns of technological diversification. Nonetheless, this represents only a first simple analysis of the correspondence between sectors/products and technologies, and as such, it does not take into account the whole set of information available (especially that on product diversification). To a further effort in this direction is devoted the remaining part of the paper.

4.1. Methodological Framework

In order to represent the relationship between technological competencies and products, the most intuitive way is to adopt a matrix representation which takes into account the firm's contextual presence in many technological fields and the production of several different products[11].

The approach suggested is based on the survivor principle (originally proposed in Stigler, 1961, and already employed in a similar context by Teece et al., 1994) starting from the assumption that the more efficient combinations are those more likely to survive. Therefore, products and technological competencies more highly interrelated would be more frequently combined with the same firm[12]. Specifically, following the analytical methodology proposed in Teece et al. (1994), we define:

A_{ik} = 1, if firm k is active in sector i, and 0 otherwise;

P_{jk} = 1, if firm k patents in technological field j, and 0 otherwise.

Thus, the number of firms active in sector i, is:

$a_k = \Sigma_i A_{ik}$

and likewise the number of firms patenting in technological field j is:

$p_j = \Sigma_k P_{jk}$

Then, the number N_{ij} of firms which are active in sector i and at the same time patent in technological field j, is:

$N_{ij} = \Sigma_k A_{ik} P_{jk}$

Assuming the random hypothesis as being operationalised by a hypergeometric distribution of firms Xij, active in sector i and patenting at the same time in technological field j, it is:

$$m_{ij} = E(X_{ij}) = \frac{a_i p_j}{K}$$

and

[11] It is indeed worth noting that previous attempts to capture the relationship between product and technologies simply relied on the information about the firm's principal technological field and its principal product (see for example, Cantwell and Colombo, 1997).

[12] In other words, if firms which are active in product/sector A almost always also patent in technological field B, we would conclude that sector A and technological field are highly related.

$$s_{ij}^{2} = m_{ij}\left(1-\frac{a_i}{K}\right)\left(\frac{K-p_j}{K-1}\right)$$

Therefore, if the actual number of N_{ij} of joint occurrences observed exceeds the expected number μ_{ij}, than product/sector i and technological field j are strictly close each other. Accordingly, the measure of concordance between sector i and technology j is taken to be:

$$t_{ij} = \frac{N_{ij} - m_{ij}}{s_{ij}}$$

which measures the degree to which the observed co-presence of firms in product/sector i and technology j exceeds that which would be expected in case of random occurrences.

This framework thus provided a matrix representation of the complex relationship between products and technologies. Specifically, three matrixes (one for each period), sized 42 (product/sector) x 56 (technologies) have been built, the characteristics of which will allow us to discern the closest linkages as well as their temporal changes. To these analyses is dedicated the next section.

4.2. The concordance between products and technologies, and its changes over time

The empirical results giving the concordance values for each couple product/technology have been re-elaborated and reported in Table 6, which shows the average values of the indices τ_{ij} over the whole period considered, thus highlighting the strongest linkages among products and technologies (shaded cells contain indeed values greater than average, at $p<.05$). It is remarked that the average value of the index over the whole period is 0.31 (derived from values of 0.26, 0.42 and 0.31, respectively in the three sub-periods observed), its standard deviation is 1.69 and it ranges from a minimum value of –4.79 to a maximum of 9.10.

Specifically, it emerges that in Electronics (sector 36) many technologies (15 to be precise) show a value significantly above the average, as also in Chemicals (12), Aircraft (12), Mechanical machinery (11), Scientific instruments (9), Office equipment (9), Motor vehicles and components (6), Pharmaceuticals (6), and Cosmetics and detergents (5). These results seem eminently reasonable when considering the upstream and pervasive nature of electronic and chemical technologies. Similar results have been found in studies of the supply and use of innovations.[13] Other details can be easily read off the table for each product/technology couple.

In order to identify more precisely pervasive technologies, Table 7 reports for each technology considered, the number of sectors which present a positive concordance ($\tau ij>0$). According to Patel (1999), the table highlights the pervasive nature of technologies like Chemical processes, Chemical and allied equipment, Electrical devices and systems, General electrical equipment, Metal products, Specialised machinery, Office equipment and data processing, amongst the others and throughout the whole period considered. Other technologies seem to perform pervasiveness only in some of the sub-periods considered (*e.g.* Metal working equipment, paper making apparatus and building material processing equipment seem to perform pervasiveness only more recently).

Likewise, in order to analyse the multi-technological character of sectors, Table 8 reports the number of technologies related which each sector ($\tau ij>0$). In particular, Electronics, Scientific intruments, Motor vehicles and components, Office equipment, Mechanicals machinery, Metal manufacturing and Rubber and plastic products show a multi-technological character throughout the period considered. As far as services are concerned, Telecommunications and Finance show the same multi-technological pattern, while Construction and Insurance have only recently become so.

Additionally, detailed tables (Tables 9 and 10) were prepared for the sub-period changes which highlight the dynamics of the concordance values. In the first sub-period (Table 9), the greatest changes clearly occurred within the service sectors, which on average become more multi-technology in character at this time, though with some significant declines as well. Additionally, among the manufacturing sectors, it is worth noting that sector 44 (Office equipment) shows the greatest number of significant positive and negative changes. Few of the changes in manufacturing as distinct from

[13] Pavitt *et al.*, 1989, and references therein.

services sectors are statistically significant, supporting the usual belief in the strong path-dependency of technological development in manufacturing.

The shifts in the second sub-period (Table 10) again confirm the noteworthy patterns of the service sectors, which show a great number of negative and positive significant changes in the interrelatedness with several of the technologies. As far as manufacturing sectors are concerned, a more detailed analysis would demonstrate the already recognised interdependence between firms' product and technological profiles, due to (a) technical interdependence between changes in the complex products produced by large firms, and the complementary changes required from suppliers of materials, components and production machinery, and (b) emerging technical opportunities (Granstrand *et al.*, 1997; Patel and Pavitt, 1997). The results so far obtained would allow to draw some "indirect" conclusions about firms' diversification vs. specialisation strategies both with reference to products and technologies. In particular, by correlating the average concordance with the changes within each sub-period, it would be possible to discern increases in specialisation (whenever they are positively correlated) or conversely (if the correlations were negative), both for technologies and products.

Tables 11 and 12 show the results of the correlation analysis for technologies and products, respectively[14]. Additionally, in order to make a comparison, the t-values estimated from simple OLS regressions, limited to one particular technology/product at a time are also given.[15] As is common in such estimations, the t-values from the simple regressions (one technology or product at a time) are generally higher than from the panel data, notwithstanding the much greater number of degrees of freedom in the latter. The coefficients of determination (R-bar squareds) estimated for the panel data in both Tables confirm that the overall fit for products (Table 12) is much higher than for technologies (Table 11). This might be thought of as suggesting that products provided

[14] It is worth observing that we also tried to model the average technology/product couplings rather than considering them separately, and also investigated two-way technology/product changes. Nonetheless, results were less clear-cut and therefore we preferred to report just the results from the one-way panel analyses, in which all technologies or products are included as dummy variables. Therefore, the values for the coefficients and t-values are obtained by substituting the dummy coefficients into those estimated for the base sector.

[15] The actual coefficients for these simple regressions (effectively obtained by correlating each row/column of Table 6 with its counterparts in terms of changes) are not reported here. However, it is worth noting that they are generally similar to those from the panel data. The full results are obtainable from the author.

a stronger focus for change than technologies, which indeed is possible. However when we look more carefully, we can see that the higher R-bar squareds for products are due entirely to the service sectors included in products (italicised in the table).[16] Few of the goods as opposed to services provide significant correlations in the panel data for products (Table 12). Thus technology structure also acted to direct firms' activities, alongside the push into or out of services. In this sense, firms had to consider relatedness in both the technology and the product space.

As previously noted, the correlations are fairly consistently positive in the first sub-period and often negative in the second period[17]. Thus for the mid/late 1970s to the mid-1980s, the higher the level of coupling to products for a particular technology (or converse for a product), the greater the coupling was likely to increase; hence over this period firms were intensifying their bi-dimensional relatedness. In the second period from the mid-80s to the mid-90s the reverse applied. In the first sub-period, the strengthening of technological specializations was greatest (statistically most significant) in many of the 'older' areas of industrial products and equipment, and with the reversal these were often those that showed the greatest decline in specialization in the later sub-period (see Table 11). In product terms, the results are slightly different - the declines in the second sub-period are again usually in older products like leather goods, but the rises in the first sub-period are significant in some more high-tech activities such as office equipment or aircraft (perhaps reflecting the more pervasive impact of radical technological realignment in the later years).

Importantly, there is some indication here of the growing importance of service sectors for shaping the direction of diversification, and indeed of technological trends. While there has been considerable path-dependency in manufacturing, together with some incorporation of new technologies in recent years, the service sectors do appear to be leading many of the more clearcut changes in the overall pattern. This may be coming about partly because of the growing overlap between service activities and manufacturing activities (Soete, 1987; Petit and Soete, 1998), according to which many

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[16] Indeed, the individual results for technologies are rather better than for products excluding services.

[17] Thus a faster growth in specialization in a particular technology/product coupling in the first sub-period was likely to be associated with a faster decline in that specialization in the second sub-period. It might be thought that random events in the middle of the overall period were helping to bring this about, but the coefficients for both sub-periods in both Tables show marked sectoral patterns. This suggests to us that the phenomena observed are real and not the consequence of random data variability.

newer areas of business such as IT take on both manufacturing and service characteristics, and indeed the new technologies themselves assist this 'convergence' between services and manufacturing[18]. In particular, the analysis seems to confirm the view expresses in von Tunzelmann (1998) that there has been upstream diversification, reflected in he patterns of technological diversification, coupled with “downstream” specialisation, reflected in the product specialisation.

5. Conclusions

In a context characterised by increasing complexity, by the recently recognised many-to-many relationships between products and technologies, and by the consequent difficulties in corporate diversification choices, the present paper has pursued two main objectives: (i) to analyse largest firms’ patterns of diversification into new spaces of products and technologies, and (ii) to model the complex relationship between products and technologies through a matrix representation.

As far as the first issue is concerned, the statistical analysis supports the emerging belief that large firms grow by diversifying their technological competencies (*e.g.* Granstrand *et al.*, 1997; Pavitt, 1998) although the average number of firms per field fell. One explanation could be that they were becoming more focused in particular technologies, although they were not completely deserting other fields. Overall, and contrary to the prevailing literature, there is some evidence here that firms diversify both on the technological and on the product side, and that any 'return to the core' on the part of the largest firms, their downsizing, refocusing and specialisation, is being abandoned. In other words, 'creative accumulation' in technologies seems to be associated with a similar creativity in products, thus revealing some kind of virtuous circle between them. The degree to which this is compatible with the usually asserted benefits of specialisation and focus remains to be more fully assessed.

As far as the second issue is concerned, the analytical representation of the relationship between products and technological competencies has been empirically conducted on the basis of the survivor principle which led to a matrix representation of the concordance between products and technologies. Alongside the evidence for the impact

[18] Globalisation of finance is a well-known area in which service demands have led technological capacities.

of *specific* new pervasive technologies, our findings indicate a growing pervasiveness of technologies *in general*, represented through the many-to-many interrelationships demonstrated. In particular, we have drawn attention to the growing overlap between manufacturing and services. It seems plausible to assert that this is closely related to the view that some services (at least) are increasingly becoming spearheads of growth, jointly with or perhaps even in lieu of traditional manufacturing. However our main stress lies on their interrelationships rather than any competition between them.

Finally, it is worth observing that the perspective outlined in this paper renders inadequate the traditional definition of industries or sectors and calls for a new bi-dimensional one. Industries are customarily defined by overlapping technological-product linkages, thus having characteristics of both. In some industries technological linkages seem to underlie conventional notions of the boundaries of the industry; in other industries it is product rather than technology linkages which underpin the conventional boundaries, as in many downstream industries that use a large variety of technologies. As the number of technologies and products, and especially their interlinkages, continues to rise in most industries, the conventional boundaries become increasingly fuzzy. This has major implications not only for the ways in which industry statistics etc. are compiled and analysed and interpreted, but for competition and industrial change in general, and for management and governance.

With our bi-dimensional perspective, industries could instead be defined not just as homogeneous clusters of products sharing similar technological profiles, or alternatively as clusters of technologies which pertain to the same products, but more consistently as bi-dimensional clusters, *i.e.* product/technology couplings. In other words, rather than the hotchpotch categories of conventional definitions such as those employed by the OECD, which jump erratically between either technology-based or product-based notions, it should be explicitly recognised that industries are potentially useful entities which have varying composites of both technologies and products.

We believe that this will not only facilitate analyses of industrial change, along the lines already set out in this section, but it will carry important implications for the management and governance of industry.

The idea of a matrix relationship between products and technologies suggests the existence of more complex linkages that management has to allow for. To an extent this has long been recognised in the advocacy and sporadic adoption of matrix management systems, in which the matrix is similar in form to that suggested here. Such systems have had a bad reputation for exacerbating bureaucracy and restricting rather than extending inter-communication, e.g. between departments. It will need to be recognised that each unit, and arguably each individual, in a firm has a dual role in the dimensions of both technology and product. In our many-to-many perspective, it is not a matter of boxing off units and individuals but of recognising that each has to maintain multiple links.

In a dynamic context of increasing complexity of linkages, this becomes all the more important. By establishing new sets of linkages, whether by choice of new markets to serve or new technological fields to be present in, the management sets in motion new directions for the development of the firm's set of complementarities and competencies. In particular, although it is necessary to take into account that corporate policies that apply to products/markets do not equally apply to technologies, it is also worth observing that they are always interrelated, especially in relation to the recent changes characterising the evolution of large firms, *i.e.* the increasing diversification into new product markets and new technologies, and the increasing internationalisation leading to division of labour and organisational decentralisation.

In respect of external governance, it follows that firms have to allow for the possibility of 'lateral' new entry into their product areas, developed through a quite different set of technologies[19]. Similarly, government policies aimed at stimulating competition, such as antitrust, may have increasing difficulty in defining what is or is not a monopoly, on account of the difficulty of defining where one industry or product ends and the next begins.

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