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Localised Technological Search and Multi-technology Companies

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Summary

Two 'stylized facts' that have emerged from much recent work in innovation studies are that learning at the firm level is 'localised' and idiosyncratic, and that firms have to command a wide range of technologies to progress. At first sight, these two inferences seem contradictory. The paper uses patent statistics and concentration indices to examine whether companies have diversified or specialised in terms of technological fields since the end of the 1960s. For the electronics companies investigated, it is found that there has been some reduction in diversification, occurring mainly in the middle 1980s. Changes in the corporate structure of companies including takeovers and demergers, have amplified this degree of specialisation. In food processing, diversification has increased at the company-wide level (except for European companies) but on balanced demand at the level of the companies; lines of business. It is suggested that technologies are becoming so complex that trade-offs are being sought between localisation and extent of technological search. We may be entering a phase in which a wider range of advanced technologies are being outsourced from user companies.

1 Introduction

The basic argument of this paper is that there is an inherent conflict between the pressures towards localisation of learning, as outlined here and in other papers in this special issue,[1] and the underlying tendencies of technological change in recent times. The latter are driving the structure of technological requirements towards greater complexity, representing an acceleration of a longer-term historical pattern. This complexity is reflected in the growing need to command a multiplicity of technologies (Patel and Pavitt 1995). It is firms that find themselves trying to reconcile this enhanced technological complexity with the enhanced pressures towards localised learning. The consequences have been displayed in several ways, and in this paper we shall concentrate upon the consequences for organisation of firms and industries.

"Technological complexity" could be defined in a number of ways, and the definition is rather critical to the argument of the paper. Here technological complexity is taken to be the diversity of technologies required to produce or further develop the product range of the firm. This can be illustrated by the experience of one of the industries considered explicitly in this paper, that of food processing. This industry was dominated through most of its historical development in the industrial era by two main technological fields: machinery and chemicals (the latter often working through machinery, eg, in refrigeration). Over the past two decades, these fields have been added to in significant ways by newer technological fields, including advanced instrumentation (lasers, etc), electronics, biotechnology, pharmaceuticals, advanced materials (especially in packaging), and so on. It is this addition of new technological fields, together with the extension of the more traditional technologies, which is being thought of in this paper as indicating greater technological complexity.

[1]This paper has been drafted for a special issue of *Economics of Innovation and New Technology* on localised learning, to be edited by Professor C Antonelli.

An alternative interpretation of technological complexity would consider its depth rather than its breadth, ie the extent of basic scientific and technological knowledge required in each particular area. It is evident that this, too, has been increasing and probably accelerating in modern times. To an extent this has been subsumed into the breadth-oriented definition used here, by talking about "advanced" levels of each technological field. There is however an argument for conceptually distinguishing the two. It is this latter depth-oriented perspective which is exacerbating the demands for localisation of learning. In essence, the progress of technological knowledge in many of these fields is becoming so difficult that firms and institutions are being compelled to narrow their focus. It may be that there are "diminishing returns" to R&D inputs, with greater and greater amounts of resources being required to achieve equivalent payoffs to those attained when the scientific and technological requirements were less demanding. Or it may be that the payoffs themselves are rising, though perhaps partly masked by competitive pressures (many firms are engaged in the race). Whatever the situation, it seems likely that the cognitive and resource requirements are increasing, and that this lies behind the localisation of learning.

It is equally obvious that firms which observe the logic of localisation may be "missing the bus" so far as the breadth-oriented expansion of technology is concerned. Small firms may decide to localise regardless, and content themselves with niche strategies of development. There is much evidence that this has been happening and that it constitutes an important part of the story at the level of the industry. In this paper, however, we are concerned primarily with large firms, which aim at market dominance and participate in oligopolistic rivalry with other large firms. How will they be able to reconcile greater depth and greater breadth without escalating R&D or similar costs?

In studying this issue, we take two broad industries as exemplars: electronics and food processing. The former, aside from its importance as the predominant new "paradigm" of the modern era, is mostly an upstream industry, driven above all by technological advance and supply factors. The latter is a downstream industry, which has taken longer to be radically reshaped by modern technologies, and which is for the most part driven by demand-side factors emanating from market developments. These differences appear to underlie the differences in corporate response that will be noted in this paper. The industries will be examined through case studies of some of the large firms and their corporate development.

2 Methodology

The main indicator we shall use to examine technological breadth and depth is patent statistics, specifically patenting in the USA. This indicator has been much used in recent studies, and its advantages and disadvantages for those studies repeatedly debated (eg, Pavitt 1988). Many of the disadvantages adduced for such earlier studies are not very relevant to the present analysis. We are not here using patents as indicators of company technological strength overall. Our concern is instead with the composition of patents - the technological fields in which they are located. This composition of technologies as revealed in the patents of each corporation is assessed at differing levels of aggregation. Those considered here are described as the one-digit and three-digit levels of disaggregation, for reasons described below. In principle, the data permit taking disaggregation as far as the "nine-digit" level, though few patterns remain at such an intensive level of disaggregation.

Some of the problems discussed in regard to patent studies do, however, affect our results. The composition of technologies as assessed through patent statistics may be biased by differing propensities to patent in particular fields or by particular companies. Given the measures adopted in this paper, each of these will constitute a source of bias only to the extent of contamination by the other factor. For instance, the differences in patentability of various technological fields have been much remarked upon. In recent years, the main concern has been in regard to software, which for long was effectively unpatentable; though now more frequently patented, one can hardly feel comfortable that the patents that have been granted are a fair guide to the technological development of the software industry. It is clear that this will affect the electronics industry especially in our sample. The breadth of technologies will be underestimated by largely overlooking one of the most rapidly growing fields involved. The results of comparing firms will, however, be affected only to the extent that these less patentable activities are undertaken to different degrees in the firms being analysed - the neglect of software is thus taken to a first degree of approximation as affecting all the cases analysed in parallel ways. The same goes for other areas where patent propensities are believed to differ. Equivalently, the differences across companies in their propensity to patent - which again have been widely recognised - will matter only to the extent that they may influence the particular composition of each company's patents. For example, if Pepsico patents its new varieties of soft drink while Coca-Cola Co. chooses not to, a bias may be introduced; but if neither patents such things, the bias can be ignored.

For the purposes of this paper, we shall adopt measures of concentration as our guide to technological focus. Such measures have not usually been applied in this area, but serve our needs reasonably satisfactorily. It has been pointed out in the literature on industrial concentration that different measures of inequality and concentration rest on differing conceptual foundations (Hannah and Kay 1977). Here we take both Herfindahl indices and Concentration Ratios as indicators of technological diversity. For the most part the results come out similarly (some cases where they do not will be noted), though they quite often differ in degree.[2]

The "one-digit" level of disaggregation is a means for classifying the technological fields into more or less standard industrial categories. There are about 20 of these categories adopted for each of the two industries considered, as set out in Table 1, so the term "one-digit" is something of a misnomer. Since the categories are effectively confined to manufacturing activities, the level is much more disaggregated than the one- or two-digit ISIC classification, which collapses all manufacturing into one one-digit or nine two-digit classes. The main point to be made is that there is no one-to-one correspondence between these classes for

[2]The CRs are mostly used here to indicate cases where the composition of technologies has changed. This can be roughly seen by comparing the CR for particular periods with the CR for the company in all periods taken together.

Table 1 List of Technological Fields, by industry

Electronics companies		Food-processing companies	
One-digit field	No 3-digit	One-digit field	No 3-digit
Telecommunications	6	Food	4
Other Communications	3	Agriculture	6
Semiconductors	6	Tobacco	1
Computing	8	Packaging	5
Image	8	Biotechnology	4
Sound	3	Chemicals	47
Electrical Devices	12	Drugs	3
Electrical Equipment	27	Materials	21
Power	2	Metals	43
Instruments	34	Instruments	30
Machinery	49	Machinery	52
Metals	44	Refrigeration	1
Materials	23	Printing	8
Printing	11	Electrical	24
Food	1	Electronic	26
Biotechnology	2	Vehicles-Fuels	21
Chemicals-Drugs	34	Textiles	17
Vehicles-Fuels	19	Others	19
Construction	5		
Weapons	3		
Miscellaneous	6		
Total	**307**		**332**

Note: Figures in second and fourth columns are the numbers of 3-digit fields actually encountered in the considered firms, 1986-94 for electronics and 1969-94 for food.

patent fields, and product-oriented classifications such as the ISIC or SITC, and on the basis of the arguments made in this paper there should not be. The US Patent Office classes aim to classify patents according to technological fields, in contrast to the product-based classifications of the latter kinds. As technological complexity increases, the number of technologies associated with each particular product class increases, and conversely the number of products associated with each technological field increases as well - this is how technological complexity is being defined. The technological and product types of classification are thus linked by a matrix, which is becoming less and less sparse as complexity rises. Attempts which many have made to develop a linear concordance between patent classes and industry or trade classes therefore have to be treated with care. However it has to be recognised that neither set of classifications is purely one or the other - in practice the patent classifications do include quite a number of product classes, and equivalently the trade classifications include some technological classes. "Industries", in this perspective, have boundaries that are defined by overlapping technological-product linkages, and so have some characteristics of both. It then follows that the boundaries between industries are becoming fuzzier as a result of growing technological complexity, and this accords with what we observe in the advanced industrial world today.

The "two-digit" level of disaggregation relates to a more intensive subdivision of the US patent classes, originally proposed by Giovanni Dosi and subsequently refined by Pari Patel. Here there are about 98 categories (the number varies slightly according to the version adopted), so the "two-digit" appellation is appropriate, though again the disaggregation is much more extensive than the corresponding industry-trade classifications. This is little used in what follows. The bulk of the work here that is not at the one-digit level is at the "three-digit" level. This is based on the Patent Office's own three-digit numbering, which spans about 400 categories. The ordering of the patent fields is fairly random, and these categories have to be extensively reordered to aggregate up to two-digit or one-digit levels. Our three-digit classification is somewhat larger than the Patent Office's, because some of their individual three-digit classes are broken up on the basis of their six-digit breakdown, where the classes appear to cover more than one "industry". Thus, for an extreme instance, class 436 is subdivided into chemicals, food, instruments and machinery classifications, according to the six-digit numbering. In analysing firms in the electronics industry from 1986 below, some 307 of these three-digit classes were found, and in the food industry over a longer period of years (1969 onwards) there were 332 (see Table 1).

At the industry level, therefore, we cannot appropriately talk of "localised" search. Naturally each industry has a relative specialisation in the fields with which its technologies are most associated, but the overall diversity is extensive. Analysis of the electronics companies examined in this paper shows little trend over time at the two-digit level in the number of fields spanned from 1970 to 1990, but a marked reduction in 1990 as measured at the three-digit level. In the food processing companies, the reduction (at three-digit level) comes in the mid-1970s, and thereafter the number of fields covered is roughly constant.

If there is localisation of technological search, at least as reflected in patent statistics, it therefore would arise at the firm rather than the industry level, and the bulk of this paper is thus devoted to the analysis of firms.

3 Technological concentration in electronics

The products of the electronics industry have been extensively studied for the modern era. A persuasive argument is that electronics constitutes a new "techno-economic paradigm" for the current state of industrial development (Freeman and Perez 1988). The main issues analysed here have been the growth of the industry itself and the impact on user industries. These in turn are derived in large part from the dynamics of technological development within the electronics industry, which are considered in the present paper.

A prominent view over the past decade or more has been that electronics technologies and products are "converging", in the sense that digitalisation, based on the development and diffusion of semiconductor technologies, is becoming the common means of advancing the basic technological architectures. The precise meaning attributed to this notion of "convergence" does, however, vary among those expressing such views - in particular, whether it is the technologies or the products that are converging most rapidly in practice. Empirical studies by ourselves and others have cast some doubt on the nature and extent of this alleged convergence (Soete and von Tunzelmann 1987; Duysters 1995). Irrespective of these empirical investigations, the convergence phenomenon has had major impacts upon corporate behaviour. In the 1980s, this took the form principally of attempts to form strategic alliances, merge or conduct takeovers between telecommunications and computing companies, with the initiatives coming from both sides (eg, by AT&T, Ericsson, IBM, STC). Here the presumption was that telecoms switches were becoming more like computers, while computing increasingly involved networking and communications linkages, so the common denominator of chip technology was expected to generate economies of scope at the technology level. In actuality the market differences faced by the respective participants were too great, the R&D and developmental costs too high, and the technological and organisational synergies too limited, to warrant such organisational restructuring, and most of these arrangements soon collapsed (Soete and von Tunzelmann 1987). In the 1990s there has been another spurt of enthusiasm for "convergence", but this time based to a greater extent on the product rather than the technological level, eg, towards multimedia. At the time of writing there are signs that this, too, may have underestimated the difficulties, and especially those lying beyond the immediate technological problems.

If convergence of the technological kind was taking place within companies - a broadening range of technologies to produce given products - we would expect to see a diversification in the technological composition of particular corporations, with computing companies developing communications technologies and vice versa. Convergence of the product kind - the given technologies producing a wider range of products - is less straightforward to track from technological data alone, but we should reasonably expect a broader diversification of the corporation's technological portfolio; as complementary technologies from other areas of electronics or from non-electronic fields (eg, advanced instrumentation) become called upon.

The notion of convergence in such senses is thus to be understood as applying not just to the technologies and products, but to their development within firms. Accordingly, the data are analysed on the firm level. The list of firms included in the present study is given in Table 2. The list is a small subset of a larger sample of about 115 multinational electronics firms whose patenting we have studied between 1969 and 1986 (von Tunzelmann, Patel and Pavitt 1993). The subset is not by any means a random sample, but has been selected to examine

Table 2 Electronics companies analyised

Company	Country	Acquisitions, etc*	Date
CGE/Alcatel	France	Part of ITT	1987
		National Telecoms	1989
		Telettra	1990
		Divisionalisation	ca 1990
GEC	UK	Picker	1980
		Plessey	1987/8
		Ferranti	1990
		JV with Alsthom	1988
Olivetti	Italy	Triumph-Adler	1986
		JV with AT&T	1983/9
Racal	UK	Demerger	1988/91
STC	UK	ICL	1984/90
		Nortel (takeover)	1990
Siemens	Germany	Plessey	1988
		Nixdorf	1990
		Divisionalisation	ca 1988
Thomson	France	CGR div'tmt	1987
		RCA	1987
		Semiconductor div'tmt	1987
SGS-Thomson	Italy/France	Formation	1987
		Mostek	1986
		Inmos	1989
AT&T	USAS	NCR	1990

*Large changes only

some of the largest corporate upheavals in the industry in the later 1980s, as briefly detailed in the Table. Over the period 1969-1986, the internal composition of firms in the industry was fairly stable, despite the meteoric growth of some of its branches. Corporations did engage in takeovers, divestments, and other such manoeuvres, but for the most part not on a dramatic scale. The position altered sharply in the mid-1980s, when major restructuring of some of the largest firms took place, involving such things as takeover of other large companies, proliferation of strategic alliances, and inter-corporate exchanges of whole large divisions or affiliates.

This raises certain problems for the analysis, in that the companies which emerged from this round of corporate change were often difficult to compare, technologically and otherwise, with the firms of the same name who had earlier entered into the fray. Patenting at the US Patent Office is conducted by institutional units which may or may not correspond with the parent company. At one extreme, IBM submits the great majority of its patents in its parent-company name, so it has only a small number of patenting units in its fold. Japanese companies behave similarly. At another extreme, the French company CGE, later Alcatel (after the 1987 reconstruction), has almost 300 such patenting units within its embrace, and a number of other leading European companies come close to 100 (Siemens, Philips, etc). The diversity of this latter group is an obstacle to compiling a corporate-level database, but at the same time, once it is compiled it makes it easier to trace the impact of acquisitions, etc, since these tend to linger on among the active patenting units long after they are annexed.

Following the convention of such studies, this paper aggregates the patenting units into corporations on the basis of the structure of the firms at a particular point in time. The larger electronics database referred to above used end-1986 as its basis for company composition, and this is continued for the earlier years (1970/86 and 1970/90) of this present study. Any acquisition made after 1969 but before end-1986 is treated as if belonging to the company throughout. This means that the annual data do not actually count the numbers of patents the company and its various affiliates took out in each year, but the number that would have been taken out had the structure been that of the terminal year. Elsewhere we have examined the contribution of acquisitions, etc between 1969 and 1986 (von Tunzelmann *et al* 1993), but the exercise is not repeated here. For the more recent years, specifically for patents from January 1986 to August 1994, a different basis for company aggregation has been chosen: one based on the companies as they were structured at end-1992. This second aggregation thus considers the situation after the most rapid period of reconstruction had died down.

Summary indications of the pattern of technological composition and diversification, incorporating the patents of all of the firms studied, appear in panels of Figure 1. A crude assessment can be obtained from the share of electronics in the total of annual patenting, as shown in the Figure. The top curve covers 1970 to 1990, and shows that electronics patents generally constituted just over half the total taken out by these companies, with that share rising to almost 60% in 1987. An interesting and perhaps significant feature of this diagram is that the rising share of electronics patents preceded the corporate restructuring, which as we shall see was directed towards a focus on "core competencies". The lower line of the figure shows equivalent data for the recent period, 1986 to 1994, using the 1992 basis of aggregation. The electronics share is here slightly lower, averaging about 50% and generally stable. These data thus suggest a moderate increase in broad specialisation.

The convergence argument requires us to look first at patterns within electronics. The next two panels give Herfindahl concentration indices for the fields that are here defined as making up "electronics". The middle panel shows the two-digit Herfindahl index from 1970 to 1990, exhibiting a steady fall within electronics until the early 1980s, then the sharp rise at the time when the overall electronics share was also rising - again, before the corporate restructuring.[3] The data for principal companies shows a less marked fall in concentration before 1982 but a more pronounced rise thereafter. The more abundant data for the years 1986/94 in the bottom panel of Figure 1 show a short decline in Herfindahls (one-digit and three-digit) following the mid-1980s peak, and then stability or small rise.

It should be noted in passing that the Herfindahl indices are influenced by the number of units whose concentration is being analysed. A rough estimate suggests that the change from a

[3]At this level of disaggregation within electronics, the one-digit and two-digit levels are practically the same. The three-digit level is not yet available for these years.

Figure 1

1986 basis of aggregation to that of 1992 would lower the index within electronics fields by about 2.8% in the early 1970s, rising to 6.5% by the mid-80s, as the result of the takeovers, etc.

These data for all firms however do not engage with the issue of the degree of specialisation within individual firms. Similar indices of the Herfindahl type, and Concentration Ratios for various levels of concentration (CR5, CR20, etc), have been computed for the individual firms and for the major patenting units within them, where they can be separately identified and analysed. As before, three-digit indices are compiled only for the post-1986 period. An attempt to summarise verbally the many results derived is contained in Table 3. In this Table, the findings cover not only the patterns for the corporations as a whole, but the impact of major takeovers or demergers on the patenting profile. Here we seek to assess whether the corporations' principal manoeuvres may have widened the range of their competencies or instead aimed at consolidating them.

Reading across the Table first, and looking at the columns entitled "average" for H1, the one-digit Herfindahl index, we see that the H1 in 1986/94 was generally higher than for the earlier period 1970/91. Some part of this may be explained by the larger number of patents that were in most cases granted in the longer early period, but it is unlikely that this can account for most of the observed differences. At the foot of the Table, it can be seen that the weighted average of all the included parent companies rises from 0.1085 to 0.1421. Exceptions to the general rule are provided by Alcatel Cables, Racal Security, Nixdorf and Inmos, all of which had relatively few patents.

A second indicator of a trend towards increasing concentration is provided by the columns headed "change", which show the absolute difference between the last and the first sub-period in each case. The weighted average at the foot of the table gives an increase of 0.0236 for the H1 in 1970/91 (specifically, a rise from 0.1039 in 1970/4 to 0.1275 in 1987/91), and one of 0.0170 in the much shorter period of 1986/94 (specifically, from 0.1365 in 1986/8 to 0.1536

Table 3 Herfindahl Indexes by Company and Structure

Company	Structure	H1, 70/91 *average*	H1, 70/91 *change*	H1, 86/94 *average*	H1, 86/94 *change*	H3, 86/94 *average*	H3, 86/94 *change*
CGE/Alcatel	Overall	.0868	-.0018	.1061	.0137	.0296	-.0010
	Divisions	.1256	.0537	.1690	.0059	.0608	.0186
-- Alc Telecom	Overall	.1799	.0658	.1958	.0118	.0472	.0209
	less Acqns	.1837	.0646	.1957	.0154	.0476	0.216
	Divisions			.2163	.0070	.0568	.0170
-- Cable	Overall	.2022	.0066	.1763	-.0264	.1025	-.0298
-- Alsthom	Overall	.1042	-.0077	.1450	.0060	.0681	.0054
	Divisions			.2484	.0264	.1600	.0315
	less Acqns			.1856	.0436	.0574	.0395
GEC	Overall	.1480	.0523	.1619	-.0221	.0259	-.0043
	less Acqns Lg	.1094	.0154	.1051	-.0033	.0198	.0035
	and JV			.1025	-.0083	.0184	.0027
	less Div'mts	.1110	.1047				
	less Acqns Sm	.1104	.0168	.1291	.0032	.0282	.0083
-- Plessey	and GEC			.1439	-.0097	.0218	-.0008
	less Acqns Lg	.0132	.0163	.1047	-.0040	.0187	.0036
	less Acqns Sm			.1186	-.0045	.0221	.0066
	Plessey only	.1360	-.0208	.1496	.0699	.0348	.0472
Olivetti	Overall	.1628	.0862	.2909	.1099	.1868	-.0160
	less Acqns Am			.3076	.0471	.2325	.1088
	less Acqns Eur	.1312	.0521	.2317	.2049	.1251	.0294
	less both			.2423	.1477	.1599	.2230
	less Acqns Ital			.2606	.2447	.1799	.3104
	less Subs Ital			.2720	.4800	.1969	.5437
-- AT&T	Overall	.1145	.0629				
	and Olivetti	.1071	.0526				
	NCR only	.1044	-.0012				
	and NCR	.1011	.0316				
Racal	Overall	.1290	.0928	.1896	.0518	.0623	.0166
	less Vodafone	.1295	.0955	.1836	.0504	.0634	.0272
	less Security	.1452	.1479	.2481	.0791	.0910	.0296
	Security only	.2873	.0473	.2444	.0068	.0778	.1406
STC/ICL	STC only			.1822	.0668	.0566	.0230
	STC/ITT-UK	.1249	.0625				
	and ICL	.1077	.0659	.1588	.0946	.0484	.0610
	ICL only	.1777	.2307	.3347	.3756	.1672	.1961
-- Nortel	Overall	.1402	-.0021	.1660	.0876	.0423	.0127
	and STC	.1277	.0319	.1635	.0787	.0397	.0133

Company	Structure	H1, 70/91		H1, 86/94		H3, 86/94	
		average	*change*	*average*	*change*	*average*	*change*
Siemens	Overall	.0980	.0177	.1263	.0077	.0162	.0029
	less Acqns			.1259	.0106	.0162	.0033
	less JVs	.0985	.0194	.1288	.0120	.0162	.0037
	less Subs Local			.1292	.0116	.0163	.0036
	less Divns (HQ)	.0981	.0177	.1360	.0166	.0182	.0017
-- Nixdorf	Overall	.1352	-.0861	.1244	-.0205	.0352	-.0088
	and Siem HQ	.0980	.0189	.1341	.0161	.0178	.0013
-- Plessey	Overall	.1360	-.0208	.1496	.0699	.0348	.0372
	and Siem HQ	.0962	.0217	.1335	.0162	.0178	.0021
Thomson	Overall	.0967	-.0075	.1098	.0434	.0305	.0208
	less SCs	.0979	-.0054	.1136	.0553	.0322	.0257
	less Div'mts			.1175	.0538	.0339	.0243
	Divisions			.1894	.0639	.0705	.0366
-- CGR	CGR only	.4319	-.3857	.4415	-.0020	.1763	.0579
	and Thom	.1028	-.0085	.1166	.0448	.0298	.0211
-- RCA	RCA only	.1311	.0614	.2222	.1818	.0934	-.0893
	and Thom	.1124	.0110	.1442	.0084	.0481	-.0026
SGS-Thomson	Overall	.2570	.0733	.2996	-.0092	.0875	-.0044
	SGS-Ates	.2869	.1148	.3454	.0025	.0947	.0028
	Thomson-SC	.1767	-.3105	.2305	-.3004	.0757	-.0826
-- Mostek	Mostek only	.3260	-.3357	.3273	.0085	.1147	-.0219
	and Thom	.2481	-.1972	.2803	-.0609	.0916	-.0390
-- Inmos	and SGS-Th	.2602	.0684	.2899	-.0005	.0844	-.0053
	Inmos only	.4216	.4404	.3657	-.1964	.1226	-.0775
Weighted Av	Parents	1.085	.0236	.1421	.0170	.0318	.0058

Key: average = for whole period; change = differenece between last and first sub-periods; Acqns = Acquisitions; Lg - Large; Sm = Small; Am = American; Eur = European; Ital = Italian; Subs = Subsidiaries; JV = Joint Venture; Div'mts = Divestments; SC = Semiconductors.

Note: Figures for Divisions are weighted averages of major company divisions.

in 1992/4).[4] These figures, too, therefore show a pattern of increasing concentration, thus reinforcing the point that changes in composition, etc are far from the whole explanation for the increasing specialisation. Exceptions to the generalisation are shown by results reading as

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[4]The weights are the shares in total patents of this sample of companies in the respective periods or sub-periods. Alternative time contrasts were tried, to see whether the choice of period affected the results, but in practice the differences were small. Comparing 1970/80 with 1981/91 gave a rise of 0.0170.

minus values; there are evidently many more exceptions than to the first indicator. Some large companies showed stability or even deconcentration within one or other of the broad periods, though not in both periods.

For the three-digit Herfindahl, only the second indicator is at present available, though the first could be compiled. This also shows a trend towards increasing specialisation, in terms of the weighted average. Though the increase from 1986/8 to 1992/4 is smaller in absolute terms than for the H1 (0.0058), it is larger relative to the average (about 18% of the average as opposed to 12% for the H1). But the number of exceptions is also more significant, with some deconcentration witnessed in CGE/Alcatel (slight), GEC, Olivetti, RCA (while it lasted) and SGS-Thomson. It seems reasonable to conclude that the evidence for increasing specialisation at the three-digit level is more ambivalent than at the one-digit level. We can tentatively conclude that companies as a whole were focusing to a greater extent on their major technological competencies, broadly defined, but exhibiting a greater variety of behaviour in regard to their competencies when narrowly defined. That is, they were sometimes becoming more multi-technology within their heartland areas of technological competence. It should be noted that the main branches of electronics (telecoms, semiconductors, computing, etc) are treated as separate areas (one-digit level) for these purposes (see Table 1), so deconcentration of this kind does not imply "convergence" of the type described above.

In terms of organisational response, some idea can be obtained by reading down the columns of Table 3. It is more difficult to give an adequate summary measure, partly because the proportional changes that arise are strongly influenced by the relative numbers of patents affected (ie not just by the absolute numbers affected). If we look first at cases where company patent portfolios were effectively enlarged, by taking over another firm, entering into a major strategic alliance, etc, we generally find that the concentration ratio fell. Some of these examples of deconcentration were relatively large, like ICL's takeover by STC, NCR's takeover by AT&T, or Olivetti's strategic alliance with AT&T - in each of these cases, the

Herfindahl index for the combined operation is appreciably lower than that for either of the constituent firms. The cases mentioned are, of course, examples of the attempt to force the pace of technological "convergence" between computing and telecoms, in ways referred to above; they are also cases where the combined operation has subsequently fallen apart. STC's subsequent takeover by Northern Telecom reflects a much closer matching of technological resources.

In other cases, the Herfindahls for the merger lie between those for the constituent companies, and it is not easy to use the data to see whether the manoeuvre has narrowed or broadened the company's focus. Detailed consideration of individual companies is being undertaken in a companion paper; it may suffice here (in order to avoid getting bogged down in detail) to declare that the outcome is in favour of greater focus.

Finally, there are yet other cases where the data are unilluminating, because of a very large difference in absolute numbers involved. This is the case with Siemens' takeovers of Nixdorf and perhaps Plessey (the latter shared with GEC). No clear verdict can be reached in such cases.

The picture with regard to smaller-scale acquisitions is also somewhat varied. Our earlier finding, based on the 115 electronics multinationals, was that acquisitions considerably strengthened rather than diversified the foci of the companies at large (von Tunzelmann *et al* 1993). The findings for the much smaller group of companies in the present study are more ambiguous. Generally, the H-index (H1 or H3) is higher for the company without its acquisitions than with them. This suggests that the acquisition itself caused some diversification.[5] At first blush there seem to be some substantial counter-examples, but these generally evaporate on closer examination (as the companion paper argues).

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[5]However small changes might be due to the sheer numbers effect, as described above.

The two cases of Joint Ventures summarised in the Table both indicate the JV being used for diversification. An interesting case has been Siemens' use of a JV with Bendix to move into what for Siemens was a new product field, that of automotive electronics, in the mid-1980s. After a short period, Siemens set up its own division in the field, which quickly usurped most of the patenting of the JV. Thus these results suggest JVs being used productively to maintain or obtain footholds in more peripheral technologies, as indeed much of the recent outpouring of literature on strategic alliances has suggested. However the number of cases analysed here is small, partly because in general JVs do little patenting, and other results from broader datasets are less encouraging to such a hypothesis (eg, Duysters 1995).

The results on divisionalisation are more novel. With considerable consistency, the data here suggest that large companies are partly or wholly breaking up into smaller units, which are becoming active in patenting. An example of partial break-up is that of Siemens, in ways just hinted at. In the later 1980s, Siemens decided to establish a largish number of product divisions to replace the older technology-based divisions, which were thought to be unduly bureaucratic and insufficiently market-oriented. Much of Siemens' patenting is still done through the HQ, but an increasing amount is being done through the specified divisions, while some of the old divisions based on much earlier annexations have withered away. The very diversified old CGE in France has not only renamed itself as from 1987, but since about 1990 effectively split into three main units, built around telecoms switching, telecoms transmission (Cables), and heavy electricals, etc (Alsthom). These in turn seem to be devolving into divisional sub-units, eg, Alcatel Business Systems. In each case, the technological concentration in units or sub-units is substantially greater than in the parent conglomerates. In a few cases, the company has split into separate ownership units, like Racal in this dataset. The demerger is attributed to market pressures and the need for product concentration, but the effect has also been to concentrate in technological areas.

Creation of subsidiaries has similar effects to divisionalisation, and no doubt is explained by similar factors. Finally, the divestments noted in this Table have increased concentration in their wake - that is, the parent companies have sold off parts of the company that are comparatively unrelated to the core competencies of the company at large.

The picture that emerges from the study of the electronics companies is thus one of growing technological devolution within companies, growing technological concentration within the companies as a whole, and perhaps some resort to external manoeuvres to maintain or enlarge the requisite multi-technology characteristics.

4 Technological concentration in food processing

Food-processing firms confront a very different industrial environment. As a downstream industry, food manufacturing (here including drink and tobacco) has traditionally been driven by market forces and product characteristics to a greater extent than electronics. Until recent times, the industry was regarded as one of a jumble of oligopolies, each firm of which would be competing for market share, using brand loyalty rather than product innovation as its main competitive weapon. With very stable products, technological development was oriented towards cost-cutting, mainly through mechanisation and through substitution between materials. In more recent years, food manufacturing has come to feel some of the effects of technological revolutions occurring in some upstream industries, and as noted earlier is now receiving the impact of a whole range of new technologies, including advanced instruments, electronics, smart materials, biotechnology and pharmaceuticals. Underlying these technological changes have been major shifts in consumer demand, including the effects of:

- i) globalisation of tastes (hamburgers, soft drinks, etc);
- ii) rising incomes and mobility (consumption of ethnic foods, etc);
- iii) rising female employment (purchase of ready meals, spread of once-weekly shopping);
- iv) increased stress (resort to "grazing");
- v) older age distributions (rising consumption of health and functional foods);
- vi) growing environmental concerns (about packaging, pesticides, etc).

Thus product changes and associated process innovation have characterised the recent state of the industry.

Not only are the technologies of the industry demand-driven, but its organisation also reflects its downstream and market orientation. Large firms in the industry typically amalgamate several lines of business linked by a supposed market affinity, but often with little or no apparent technological connection. The technological structure of large firms is therefore more differentiated than in branches of electronics.[6] The firms included in our database may have another core competence in textiles (Sara Lee), energy and construction (Hanson), toys (Quaker Oats), electricals (Ralston Purina), chemicals (Procter and Gamble, Unilever), and so on.

The differentiation is unfortunately difficult to observe from the technological concentration indices, because these depend on how the technologies are clustered. There are only two major Patent Office codes for food (127, for sugars, and 426, for most of the rest), so even at the three-digit level the industry appears unduly concentrated alongside electronics firms. From consideration of the structure of the industry, we would expect to see several nodes of concentration of patenting. The object is therefore to see whether this concentration pattern has changed, and in particular whether the advent of new technologies has led to some deconcentration and reorientation. Following that investigation, we can trace the organisational implications, or absence of them.

The data for the industry are based on a list of the largest firms in the industry as of 1988.[7] Some of them were absorbed by other companies between 1988 and 1992, the date of our ownership data. A few were observed to have no patents at all between 1969 and 1994; omitting them leaves a total of 106 firms with ascribed patents (38 North American, 43

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[6]There are a few cases of firms in electronics which were linked by product rather than technological relationships, of which the best-known was ITT under its CEO, Harold Geneen (Fransman 1995). This ITT - with operations in hotels and insurance as well as telecommunications - has recently broken up.

[7]This part of the work is being jointly with Dr Ruth Rama of CSIC, Madrid, who has been responsible for the list of firms.

European, 22 Japanese and 3 Australian). Of these, 23 with a relatively large number of patents have been selected for further study (14 American, 7 European and 2 Japanese). The bulk of these selected firms had more than one main line of business. To analyse these, the overall companies were divided up into major "businesses". These are analogous to the divisions of the electronics companies, but differ in the lack of any obvious technological relationship and organisational integration.

Table 4 presents data at the country level. The separate panels show that the share of food in total company patenting is fairly similar across the three main regions, but in other fields the regional structures are very different. The share of biological and chemical patents in Japanese firms is about twice as high as in the other two main regions, and accounts for nearly two-thirds of those Japanese patents. This is a quite striking result, in that the other two regions have companies which have their main competence in chemicals and with large numbers of patents (Procter & Gamble and Unilever), whereas Japan in this dataset has no such firm. This suggests that what are regarded as upstream technologies in America and Europe are being developed to a proportionately greater extent by downstream companies in Japan. This accords with accepted opinion that companies like Kirin Brewery are significant for developing biotechnology, etc in Japan. Regrettably the corporate structure of patenting in Japanese companies is not revealed in these data, because nearly all US patents are granted to the head office of Japanese corporations (the same is true in electronics).

Within each region, the pattern of shares according to technological field is generally very stable, despite the considerable difference across regions. There is thus little "convergence" in the patent portfolios between the regions. Overall the most evident change shown in the fourth panel, summarising all 106 included companies, is the rising share of tobacco patents, which in turn is attributable to certain American companies. This would seem to be a defensive response to declining markets for tobacco products. A more comprehensive examination at the one-digit level shows that the combined share of four fields that might be expected to link fairly closely to new technologies - biotechnology, pharmaceuticals,

Table 4 Country patenting portfolios, 1969/74 to 1990/4, percentages

Years	Food & Agricult	Tobacco	Packaging & Material	Biological & Chemical	Instruments & Machinery	Others	Nos
1 American Companies							
1969/74	32.42	3.02	13.70	29.16	16.79	4.91	2912
1975/9	30.23	2.37	11.16	33.25	17.41	5.58	2114
1980/4	28.16	5.05	10.92	32.16	17.56	6.15	1822
1985/9	30.89	7.21	10.72	23.81	21.40	5.98	2276
1990/4	24.68	9.81	12.99	23.26	21.15	8.12	2549
Total	**29.37**	**5.52**	**12.07**	**28.04**	**18.87**	**6.13**	**11673**
2 European Companies							
1969/74	24.14	0.80	14.63	28.46	23.90	8.07	1251
1975/9	27.14	0.40	14.27	37.49	15.88	4.82	995
1980/4	28.45	0.48	13.57	35.89	14.65	6.96	833
1985/9	26.02	0.76	15.10	38.18	13.58	6.36	1053
1990/4	23.92	0.38	16.46	39.69	14.23	5.31	1300
Total	**25.66**	**0.57**	**14.93**	**35.82**	**16.70**	**6.31**	**5432**
3 Japanese Companies							
1969/74	18.94	0.00	4.85	71.37	3.52	1.32	227
1975/9	24.71	0.00	2.28	66.92	4.94	1.14	263
1980.4	24.62	0.38	5.68	62.88	4.55	1.89	264
1985/9	25.34	0.00	5.22	57.45	9.67	2.32	517
1990/4	15.81	0.00	3.83	71.88	7.65	0.83	601
Total	**21.31**	**0.05**	**4.38**	**65.87**	**6.89**	**1.50**	**1872**
4 All Companies							
1969/74	29.08	2.26	13.70	30.98	18.30	5.78	4391
1975/9	28.58	1.65	11.22	37.34	16.08	5.21	3374
1980/4	27.89	3.32	11.15	35.98	15.67	5.99	2920
1985/9	28.59	4.51	11.25	32.28	17.91	5.48	3850
1990/4	22.98	5.51	12.73	35.21	17.34	6.23	4456
Total	**27.51**	**3.56**	**12.14**	**34.01**	**17.06**	**5.69**	**18991**

instruments and electronics - rose from 13.3% of all patents in 1969/74 to 20.6% by 1990/4. But most of the increase came from pharmaceuticals, especially in the Japanese companies; in total these more than doubled their share and their total numbers. Among the principal companies, much the largest proportional increase in drugs came in Procter and Gamble which, Japanese companies aside, already had much the largest proportionate share of drugs in its patent portfolio. The number of biotechnology patents in both American and European companies actually fell over this period. Examination of the data for individual companies suggests that there were few new entrants into biotechnology patenting over these years - companies that were relatively significant in the field in the 1990s were those that already had a considerable presence in the 1970s, even for the Japanese companies.

These comments put into perspective the changes in concentration in the principal companies and their businesses, as detailed in Table 5. The first impression is one of substantial differences across regions and among companies; there are also differences that arise out of the degree of disaggregation, despite the limited breakdown of some of the leading technological fields between one-digit and three-digit indicators. The lower panels of the Table show an overall decline in technological concentration at the one-digit level, stemming from the American and Japanese companies, but approximate stability at the three-digit level, where the Japanese decline is offset by the European increase.

The inference to be drawn from reading down the columns of the Table is that the individual businesses were generally much more concentrated than the corporation as a whole. This demonstrates the point made verbally above - that the larger firms typically consist of a number of businesses with little evident technological interconnection.[8] The effect is naturally less evident in cases where the largest business undertakes most of the whole company's patenting - this is indicated by the figure for patent numbers of the largest business in the second column of the Table. In general, the changes registered for the businesses show a greater trend towards concentration than those for the whole company, thus reinforcing the trend towards localisation of learning.

Examination of the data for individual companies, and especially the apparent exceptions to the generalisations just made, allows a surmise that even the cases of deconcentration do not

[8]Hanson announced that it was breaking up into its core businesses on the day that this paper was submitted for publication (30 January 1996).

Table 5 Concentration in Food-Processing Companies, 1969/94

Company	No Patents (Largest)	H1 average	H1 change	H3 average	H3 change
1 American Companies					
American Brands	387	.1640	-.0516	.0515	.0005
Businesses	184	.2890	.0303	.1504	.0464
Anheuser-Busch	122	.2446	.0891	.1162	.1533
Businesses	107	.2636	.0656	.1264	.1296
Borden	370	.2465	.1529	.1139	.1273
Coca-Cola	417	.2534	.1536	.0867	-.2148
Businesses	382	.2579	.1744	.1007	.1043
Conagra	376	.1868	-.0187	.1300	-.0047
Businesses	263	.1966	-.0314	.1391	-.0223
CPC International	377	.2397	.0474	.1282	.0874
General Mills	450	.2697	.0763	.2061	.1169
Pepisco	247	.2195	-.0126	.1621	.0684
Businesses	124	.2687	-.1092	.1839	-.1007
Philip Morris	2266	.2787	-.1239	.2366	-.1204
Businesses	1375	.4303	-.0210	.3783	-.0171
Proctor & Gamble	3479	.2280	-.1269	.0888	.0180
Businesses	2916	.2481	-.0686	.1144	.0241
Quaker Oats	398	.2135	.0004	.1494	-.0209
Ralston Purina	343	.3049	-.3145	.2518	-.2810
Businesses	250	.5306	-.3589	.4325	-.3616
RJR-Nabisco	1018	.2175	.1279	.1908	.1482
Businesses	540	.4153	.2514	.3685	.2771
Sara Lee	296	.1066	.0061	.0314	.0165
Businesses	170	.1719	.0237	.0694	.0258
2 European Companies					
Allied-Lyons	96	.3001	.3113	.1923	.4313
Businesses	71	.3146	.3733	.2146	.4794
Grand Metropolitan	315	.3389	.0893	.2508	.1517
Businesses	280	.3437	.0993	.2605	.1595
Hanson	681	.1251	.0160	.0193	.0281
Tate & Lyle	348	.2208	.0970	.0978	.0473
Businesses	280	.2250	.1289	.1073	.0664
Unilever	2341	.2744	-.0045	.1071	.0193
Businesses	1443	.3557	.0731	.1713	.0994
Nestlé	944	.2221	-.0640	.1676	-.0753
Businesses	660	.3058	-.0247	.2323	-.0604

Company	No Patents (Largest)	H1 average	H1 change	H3 average	H3 change
3 Japanese Companies					
Ajinomoto	611	.2812	-.1271	.1282	-.0689
Meiji Seika	215	.3064	-.0040	.1312	.0981
4 Weighted Averages					
American	10546	.2459	-.0539	.1435	.0000
European	4725	.2433	.0096	.1172	.0303
Japanese	826	.2878	-.0969	.1290	-.0276
All Companies	16097	.2473	-.0372	.1350	.0067
5 Whole Dataset					
American	11672	.1436	-.0457	.0815	-.0066
European	5432	.1564	.0150	.0680	.0211
Other	1885	.1940	-.0672	.0918	-0.181
All Companies	18989	.1444	-.0319	.0723	-.0019

Key: See Table 3 and text

Note: Figure for number of patents of "Businesses" in Column 2 is for the largest Business (usually the core company).

reflect any great shift towards incorporating new technologies. Sometimes this has been brought about by direct acquisition of companies specialising in research-intensive fields, as for instance Ralston Purina's purchase of Protein Technologies. But this strategy still seems to be uncommon. The most common strategy seems instead to be that the development of new technologies, and new generations of older technologies, is moving out of these firms. Specialist suppliers are seemingly becoming more usual, not just in the traditional arena of machinery but in these R&D-intensive activities like biotechnology and advanced instrumentation. In other words, the growth of technological complexity seems to be being met in the meantime by industrial fragmentation. For this, there are strong historical parallels, as noted in the Conclusion below. We also have to allow for the rather different pattern in Japan, which may be partly due to the lack of technologically strong upstream suppliers in that region.

5 Conclusions

The problem posed at the beginning of the paper can now be appraised, in the light of the experience of these two industries. How has it been possible to reconcile the pressures towards localisation of learning that derive from bounded rationality and increasing technological difficulty and those towards greater technological complexity, in the sense of the need to integrate wider ranges of technologies and some relatively new technological fields?

The results first of all indicate a much longer time period for the incorporation of new technological paradigms than the conventional wisdom implies. Diversifying learning continues to trouble companies - a point that has already been established in other industries, exemplified by the problems that pharmaceutical companies have had in trying to move into recent-generation biotechnology (Sharp and Galimberti 1993). The electronics industry tried to solve this problem in the 1980s by merger and takeover, but such efforts have for the most part failed. In the 1990s, there appears to have been a change in strategy, towards diversification through devolution. The complementary technologies are being hived off to more autonomous divisions. It is far from clear that this solves the underlying problems of running multi-technology companies. Studies of progressive individual firms indicate a shift towards flexible groups that self-organise to develop new technology-product mixes, as for instance Beckman and Mowery (1995) have shown at Hewlett-Packard.

The strategy adopted in the food-processing industry has been quite different. Individual lines of business continue to maintain existing strengths, often with little technological link to other businesses in the company. The companies are instead held together by demand-side product market interlinkages. These are of varying degrees of strength, and the reorganisations of the 1990s, which to date have been much more modest than in the mid-1980s, seem to have involved some decline in technological conglomeration. Confronted by a world of growing technological complexity, the food manufacturers are either buying up research-oriented businesses or, more often, outsourcing the technological developments to independent firms.

Thus a new phase of the "Rosenberg model" of vertical dis-integration combined with technological spillovers may well be being witnessed. In the Rosenberg case (Rosenberg 1963), machinery manufacture and later machine-tool manufacture split off upstream, to permit technological focus on specific processes and their spread to new ranges of users.[9] Similar patterns seem to be emerging for some of the new research-intensive upstream industries, like biotechnology, in the modern era; though the Japanese companies appear to be heading in a different direction.

In summary, it can thus be argued that the underlying problem has been met by flurries of corporate reorganisation, whose dominant characteristic has changed from period to period and differs according to industry, but the basic issue has probably not yet been solved - it may even prove insoluble.

[9]Rosenberg refers to the spillover of technologies into new product areas as "technological convergence", but obviously the meaning is different from the way the term is used in this paper.

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