# Working Paper

## Technological Competencies in the World's Largest Firms: Characteristics, Constraints and Scope for Managerial Choice

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# Preface

The research project on *Systems Analysis of Technological and Economic Dynamics* at IIASA is concerned with modeling technological and organisational change; the broader economic developments that are associated with technological change, both as cause and effect; the processes by which economic agents – first of all, business firms – acquire and develop the capabilities to generate, imitate and adopt technological and organisational innovations; and the aggregate dynamics – at the levels of single industries and whole economies – engendered by the interactions among agents which are heterogeneous in their innovative abilities, behavioural rules and expectations. The central purpose is to develop stronger theory and better modeling techniques. However, the basic philosophy is that such theoretical and modeling work is most fruitful when attention is paid to the known empirical details of the phenomena the work aims to address: therefore, a considerable effort is put into a better understanding of the 'stylized facts' concerning corporate organisation routines and strategy; industrial evolution and the 'demography' of firms; patterns of macroeconomic growth and trade.

From a modeling perspective, over the last decade considerable progress has been made on various techniques of dynamic modeling. Some of this work has employed ordinary differential and difference equations, and some of it stochastic equations. A number of efforts have taken advantage of the growing power of simulation techniques. Others have employed more traditional mathematics. As a result of this theoretical work, the toolkit for modeling technological and economic dynamics is significantly richer than it was a decade ago.

During the same period, there have been major advances in the empirical understanding. There are now many more detailed technological histories available. Much more is known about the similarities and differences of technical advance in different fields and industries and there is some understanding of the key variables that lie behind those differences. A number of studies have provided rich information about how industry structure co-evolves with technology. In addition to empirical work at the technology or sector level, the last decade has also seen a great deal of empirical research on productivity growth and measured technical advance at the level of whole economies. A considerable body of empirical research now exists on the facts that seem associated with different rates of productivity growth across the range of nations, with the dynamics of convergence and divergence in the levels and rates of growth of income, with the diverse national institutional arrangements in which technological change is embedded.

As a result of this recent empirical work, the questions that successful theory and useful modeling techniques ought to address now are much more clearly defined. The theoretical work has often been undertaken in appreciation of certain stylized facts that needed to be explained. The list of these 'facts' is indeed very long, ranging from the microeconomic evidence concerning for example dynamic increasing returns in learning activities or the persistence of particular sets of problem-solving routines within business firms; the industry-level evidence on entry, exit and size-distributions – approximately log-normal – all the way to the evidence regarding the time-series properties of major economic aggregates. However, the connection between the theoretical work and the empirical phenomena has so far not been very close. The philosophy of this project is that the chances of developing powerful new theory and useful new analytical techniques can be greatly enhanced by performing the work in an environment where scholars who understand the empirical phenomena provide questions and challenges for the theorists and their work.

In particular, the project is meant to pursue an 'evolutionary' interpretation of technological and economic dynamics modeling, first, the processes by which individual agents and organisations learn, search, adapt; second, the economic analogues of 'natural selection' by which interactive environments – often markets – winnow out a population whose members have different attributes and behavioural traits; and, third, the collective emergence of statistical patterns, regularities and higher-level structures as the aggregate outcomes of the two former processes.

Together with a group of researchers located permanently at IIASA, the project coordinates multiple research efforts undertaken in several institutions around the world, organises workshops and provides a venue of scientific discussion among scholars working on evolutionary modeling, computer simulation and non-linear dynamical systems.

The research focuses upon the following three major areas:

1. Learning Processes and Organisational Competence.
2. Technological and Industrial Dynamics
3. Innovation, Competition and Macrodynamics

## SUMMARY

Firm-specific technological competencies are major factors explaining why firms are different, how they change over time, and whether or not they are capable of remaining competitive. Systematic analysis of the technological activities of more than 400 of the world's largest firms shows that their technological competencies have the following characteristics.

- They are highly **diversified**. Large firms are typically **multi-technology**. The most pervasive competencies remain in mechanical, chemical and instrumentation engineering, and with an increasing spread of competencies in computers, materials and biotechnology.
- They are **highly stable** and **differentiated** in composition, with both the **technology mix** and the **directions** of localised search strongly influenced by the firm's **principal products**.
- The **rate** of search (as measured by the level and rate of increase of total innovative activities, and by the rate of entry into fast-growing technical sub-fields) is influenced by both the firm's **principal products**, and the conditions in its **home country**.
- However, **considerable unexplained variance** suggests **scope for managerial choice** in the overall commitment of resources to the accumulation of technological competencies, and in the vigour with which promising sub-fields are explored.

These findings:

1. confirm the importance of **complexity** and **path dependency** in the accumulation of firm-specific technological competencies;
2. demonstrate that technological competencies give a convincing empirical explanation of the boundaries (or – and perhaps better – the **core** activities) of firms.
3. **challenge** many of the standard taxonomies of technology strategies in large firms. In particular:
   - firms' technological diversity challenges notions of “focus”, “core competence”, “competence-destroying innovations”, and “technological leap-frogging”;
   - firms' differentiated competencies and path dependency put severe limits on the range of exploitable technological opportunities;
   - firms' stability in technology mix shows that technological accumulation and change are slow processes.
4. **confirm** the importance in technology strategy of integration (or “fusion”) of different fields of technological competence.
5. point towards the importance of complementary **managerial** competencies in organisational integration, methods of resource allocation, and learning.

# Technological Competencies in the World's Largest Firms: Characteristics, Constraints and Scope for Managerial Choice

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## 1 INTRODUCTION

### 1.1 Why Firm-Specific Technological Competencies are Important

The purpose of this paper is to throw empirical light on the nature and determinants of the technological competencies of the world's largest firms. The subject of "firm-specific competencies" is of increasing interest to practitioners, and to theorists – and particularly to those in the neo-Schumpeterian tradition, who are seeking to explain why firms provide different ranges of goods and services, why they change at different rates and in different directions over time, and what makes them competitive (Rumelt, 1974; Ramanujam and Varadarajan, 1989; Prahalad and Hamel, 1990; Dosi et al., 1992; Carlsson and Eliasson, 1991; Teece et al., 1992, Teece et al., 1993).

Our main data source is systematic information of US patenting by more than 400 of the world's largest technologically active firms, broken down by each firm's nationality (headquarters country) and principal product group, and by the technical field and by the country of origin of the inventor of each patent[1]. Similar data has been used by Hall and her colleagues (1986) to measure lags between R & D and patenting at the firm level, by Narin and his colleagues (1987, 1988) for corporate and competitor analysis, by Jaffe (1986, 1989) to identify and measure technological "spillovers", and by Cantwell (1991) to explain patterns of international production.

[1] These firms have been chosen from the list of world's largest firms published in the Fortune magazine in 1988. Only firms with more than 50 patents granted in the US in the period 1981-90 have been included. For a detailed description of the characteristics and method of compilation of the database see Patel and Pavitt (1991).

## 1.2 The Main Questions and their Answers

We concentrate here on systematic comparisons of the level, rates of change and composition (by technical field) of each firm's patenting activity, and on their characteristics and determinants. In this paper, our level of analysis is not detailed enough either to identify a specific company's distinctive competence within a product field, or to describe how it accumulates technology to gain competitive advantage[2]. Instead, we intend to answer two questions.

**First**: "What are the characteristics of technological competencies in large firms?" We shall show that they are:

- diversified (i.e. multi-technology) and evolving over time;
- heavily differentiated and stable in their composition and their directions of search, both as a function of the products that they make.

**Second:** "What are the constraints on the development of technological competencies in large firms, and what in consequence is the scope for managerial choice?" We shall show that:

- the rate of search is significantly influenced by both the firm's product mix and country of origin;
- there is considerable unexplained variance in the aggregate level of technological activity, and in the rate of entry into fast-growing technical sub-fields.

This suggests that, whilst **directions** of search are heavily constrained by accumulated competencies, considerable scope for managerial choice remains in fixing the **rate** of search.

## 1.3 The Framework of Explanation: Coping with Complexity

Both our questions and our answers are consistent with the neo-Schumpeterian framework of analysis, based on the pioneering work of Nelson and Winter (1982)[3]. Technological artefacts, and the organisational and economic worlds in which they are embedded, are *complex*: in other words, they each comprise so many variables and interactions that it is impossible fully to model, predict and control their behaviour through explicit and codified theories and guidelines. Certainty about the future, probabilistic risk and optimisation are therefore impossible. The best approach to problem-solving and the management of change is step-by-step experimentation, in which changes are made in one feature or component at a

[2] For a recent example of the latter, see Miyazaki (1994), who used bibliometrics and interviews to trace how a number of major companies assimilated opto-electronics technologies. She found cumulative paths of learning: directions of search were influenced by previously accumulated competencies; and over time search became more focused and applied.

[3] See also Rumelt et al., 1991.

time, and ends and means re-interpreted in the light of the subsequently observed changes. In addition to codified knowledge, experience and tacit knowledge improve the effectiveness of:

- the choices of the feature or component to vary at each stage;
- subsequent modifications in means and ends made after observation of the effects of variations in features or components.

This method is called "learning", or "experimentation", or "trial and error" (and many other things, including "suck it and see"). Essentially the same approach underlies Lindblom's prescriptions in public policy (1959), Quinn's in corporate strategy (1980), and Kline's in engineering design and development (1990). It explains our results, as follows:

- the complex and multivariate nature of technological artefacts requires the combination and application of advances in many fields of knowledge: hence large firms' competencies are typically *multi-technology*, and evolving over time;
- complexity also constrains firms to search and experiment in and around what they already know and produce: hence firms competencies are *differentiated*, *stable*, and closely related to their *product mix*;
- the rate and direction of a firm's search will be influenced by the opportunities and incentives that it faces. These will depend on its own accumulated competencies, and on its surrounding environment: hence the influence of both *principal product group*, and *home country* on firms' level of technological activities;
- but complexity means uncertainty, and the impossibility for a firm to identify all possible future states, let alone to predict what will happen. It also means difficulty and uncertainty in identifying the competitive competencies that the firm has at its disposal. Hence the *unexplained variance* in the level of technological activities and in the rate of entry in fast-growing sub-fields, reflecting the *scope for managerial choice*.

### 1.4 Limitations of our Analysis

Our paper has three sets of limitations. *First*, we measure only technological competence, and thereby neglect many others that are important. Dosi and Teece(1993) have distinguished organisational-economic competencies from technical competencies, and have argued that the latter derives from the former, and is therefore more fundamental to the firm[4]. Our empirical

[4] "Organisational/economic competence involves: (1) allocative competence - deciding what to produce and how to price it; (2) transactional competence - deciding whether to make or buy, and whether to do so alone or in partnership; and (3) administrative competence - how to design organisational structures and policies to enable efficient performance. Technical competence, on the other hand, includes the ability to develop and design products and processes, and to operate facilities effectively.....................A firm becomes superior in a

results suggest that this is only partly correct. A firm's organisational competence does influence its *level* of commitment to technological activities, and its *rate of entry* into fast-growing sub-fields. However, a firm's accumulated technological competence strongly constrains the *directions* in which it searches: even the brightest and the best organisational capabilities will find it difficult (impossible?) to convert a firm making Harris Tweed jackets, or Italian high-fashion shoes, into a world class firm in personal computers. The differentiated nature of technical competencies is one the most important factors explaining the coherence and the boundaries of the firm. And a recent survey of 100 Italian firms by Malerba and Marengo (1993), ranked technological competencies as of greater long term importance than competencies to respond to either market signals or competitors' strategic actions. The subject therefore deserves analytical and empirical attention, even if it does not cover – and cannot explain – everything[5].

The *second* limitation is that we measure technological competencies only imperfectly through patent data[6]. Nonetheless, patenting in the USA is a better measure than most, if not all, the alternatives given its relative homogeneity, detail, accuracy and (after recent advances in information technology) accessibility and cost: hence its increasing use by both analysts and practitioners[7]. However, in relation to the subject of this paper, three potential limitations of the US patenting measure must be mentioned:

1. Patents do not measure the extent of the firm's external technological linkages. However, many studies have shown (most notably, Cohen and Levinthal, 1989) that external technological linkages are in general complementary to internal competencies, and these we do measure.
2. Patents measure codified knowledge, whereas a high proportion of firm-specific competencies is non-codified (i.e. tacit) knowledge. We would argue that the two forms of knowledge are complementary, not substitutes. Other measures that embody tacit knowledge (such as R & D expenditure, judgements of technological peers) give results very similar to those using patenting (see Patel and Pavitt, 1987).

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particular technological domain because it has certain organisational capabilities: it allocates resources to more promising projects, it harnesses experience from prior projects, it hires and upgrades human resources, it integrates new findings from external sources, and it manages a set of problem-solving activities associated with that technology." (Dosi and Teece, 1993, pp. 6-7).

[5] In a similar manner (and using the jargon of another academic discipline), we are fully aware that technological competencies in large firms are "socially constructed (Hughes and Pinch, 1987). But we concentrate here on the important cognitive factors that shape the social construction of technology.

[6] The uses and abuses of patent data have been extensively discussed elsewhere, See, for example, Basberg, 1987; Pavitt, 1988; Grilliches, 1990; Patel and Pavitt, 1994a.

[7] In addition to Jaffe (1986, 1989) and Narin And Noma (1988) see - for example - Griliches (1984) and *Business Week*, (1993).

3. Patenting does not fully measure competencies in software technology, since copyright law is often used instead as the main means of protection against imitation (see Barton, 1993; Samuelson, 1993). We readily admit this to be the major empirical shortcoming of our analysis, and plead only that no-one has yet found a satisfactory, accessible and systematic measure of competencies in software technology that we could use[8]. And as we shall see in section 2 below, we have nonetheless been able to identify the growing importance of competencies in information technology.

The *third* limitation to our analysis is that we do not assess how differences in the rate and direction of technological accumulation affect firms' economic and competitive performance. Suffice to say that a growing number of studies confirm the competitive importance of technological competencies at the level of the firm[9], which should in principle heighten interest in studies like ours that attempt to describe and explain how they are acquired.

### 1.5 Structure

We shall now describe the key characteristics of large firms' technological competencies that emerge from our analysis: diversity in section 2, differentiation and stability in section 3, and the influence of sector, country and management in section 4. In section 5, we draw conclusions for practice and for theory.

## 2 TECHNOLOGICAL DIVERSITY: THE PREVALENCE OF THE "MULTI-TECHNOLOGY" FIRM

### 2.1 The Extent of Technological Diversity

The most striking feature of the technological competencies of large firms is the *diversity* of technological fields in which they are active. This is shown most simply in Table 1, which gives the distribution of US patenting of our large firms, in each of the 16 principal product groups, across four major technological families: chemical, electrical–electronic, non-electrical machinery and transport, as well as a residual category labelled 'other'[10]. Firms have substantial technological competencies outside what would appear to be their core areas. Thus, both electrical and chemical firms have about two-thirds of their competencies in their obvious core areas, but each has 15% or more in non-electrical machinery: and automobile

[8] Recent research by Jacobsson and Oskarsson (1994) uses very interesting data on the technical field of specialisation of Swedish engineers working in Swedish firms. Unfortunately, this method cannot easily be reproduced in other countries, because of lack of data.

[9] See, for example, Cantwell (1989), Franko (1989), Geroski et al., (1993), Oskarsson (1993).

[10] The method for distributing firms' technological activities amongst four technological families is described more fully in Patel and Pavitt (1994b). Briefly stated we re-classified the US Patent Classes and sub-Classes into 34 technical fields, and 91 sub-fields. On the basis of the 91 sub-fields, we re-combined patenting into the four technological families shown in Table 1. The "Other" category includes traditional manufacturing (e.g. textiles) and non-manufacturing (e.g. construction, medicine, agriculture).

firms have less than a third of their competencies in transport technologies, but more than 45% in non-electrical machinery. Only firms principally in pharmaceuticals have less than 10% on average of their technological competencies in non-electrical machinery.

**Table 1. The Distribution of Large Firms' Technological Activities in Five Broad Technological Fields, according to their Principal Product Group: 1981–90.**

| Principal Product Group (PPG) | Percentage share of the PPG's patents in technology field: Chemical | Non-Electrical Machinery | Electrical | Transport | Other | Total |
|---|---|---|---|---|---|---|
| Chemicals | 71.0 | 16.9 | 8.9 | 0.6 | 2.6 | 100.0 |
| Pharmaceuticals | 80.2 | 8.0 | 2.1 | 0.0 | 9.7 | 100.0 |
| Mining & Petroleum | 57.1 | 34.2 | 6.7 | 0.9 | 1.1 | 100.0 |
| Textiles etc. | 52.9 | 31.7 | 9.5 | 0.6 | 5.3 | 100.0 |
| Rubber & Plastics | 43.2 | 29.3 | 4.7 | 20.1 | 2.7 | 100.0 |
| Paper & Wood | 25.4 | 47.1 | 12.4 | 0.4 | 14.6 | 100.0 |
| Food | 70.6 | 21.9 | 3.0 | 0.1 | 4.3 | 100.0 |
| Drink & Tobacco | 40.8 | 50.3 | 4.6 | 0.3 | 3.9 | 100.0 |
| Building Materials | 30.5 | 51.3 | 10.0 | 0.9 | 7.3 | 100.0 |
| Metals | 26.8 | 54.9 | 13.9 | 2.1 | 2.2 | 100.0 |
| Machinery | 7.6 | 64.9 | 13.9 | 10.2 | 3.3 | 100.0 |
| Electrical | 7.6 | 21.2 | 67.0 | 1.3 | 2.8 | 100.0 |
| Computers | 5.2 | 16.3 | 77.3 | 0.2 | 1.0 | 100.0 |
| Instruments | 14.3 | 18.3 | 64.2 | 0.1 | 3.0 | 100.0 |
| Motor Vehicles | 3.8 | 44.8 | 20.7 | 28.8 | 1.9 | 100.0 |
| Aircraft | 8.1 | 48.5 | 31.2 | 8.3 | 3.9 | 100.0 |
| All 440 Large Firms | 28.8 | 27.9 | 35.7 | 4.4 | 3.1 | 100.0 |

Source: Calculated from data supplied to SPRU by the US Patent and Trademark Office.

Another measure of technological diversity is the number of technical fields – out of the total of 34 used in our analysis[11] – in which our firms have been granted a patent and are therefore technically competent. Table 2 confirms this diversity: only 4% of our firms were active sometime in the 1980s in 10 or fewer of these technical fields, whist 52% were active in between 10 and 20, and 44% in more than 20 – hence the term "multi-technology" firm (See Archibugi, 1988; and Granstrand and Sjolander, 1990)[12].

[11] See Table 5 for the name of each of the technical fields.

[12] The distribution of our firms amongst the different degrees of technological diversity shown in Table 2 is sensitive to the measure of technological competence chosen. Thus, when it is increased from one to ten patents in the 1980s, the proportion of firms active in more than 10 technical fields declines from more than 95% to just over 30%. However, as we shall show in section 3, apparently low-level technological activity is an important and permanent feature of firm-specific technological competencies. And other measures confirm large firms' technological diversity. For example, 90% of total technological activity is concentrated in five or fewer technical fields in 14 % of our firms, whilst 64% reach this threshold at between 6 and 10 fields, and 20% with more than 10 fields.

**Table 2. Number of Technical Fields (out of 34) in which Firms have one Patent or more in 1981–90: Percentage Distribution.**

| Product Group | Number of firms | Less than or equal to 10 | Greater than 10 but less than or equal to 20 | Greater than 20 but less than or equal to 30 | Greater than 30 | Total |
|---|---|---|---|---|---|---|
| Chemicals | 66 | 4.5 | 39.4 | 50.0 | 6.1 | 100.00 |
| Pharmaceuticals | 25 | 12.0 | 56.0 | 32.0 | 0.0 | 100.00 |
| Mining & Petroleum | 31 | 0.0 | 48.4 | 38.7 | 12.9 | 100.00 |
| Textiles etc. | 10 | 10.0 | 80.0 | 10.0 | 0.0 | 100.00 |
| Rubber & Plastics | 9 | 0.0 | 77.8 | 22.2 | 0.0 | 100.00 |
| Paper & Wood | 18 | 5.6 | 83.3 | 11.1 | 0.0 | 100.00 |
| Food | 14 | 42.9 | 42.9 | 14.3 | 0.0 | 100.00 |
| Drink & Tobacco | 8 | 0.0 | 100.0 | 0.0 | 0.0 | 100.00 |
| Building Materials | 16 | 0.0 | 56.3 | 43.8 | 0.0 | 100.00 |
| Metals | 38 | 0.0 | 57.9 | 42.1 | 0.0 | 100.00 |
| Machinery | 58 | 1.7 | 67.2 | 31.0 | 0.0 | 100.00 |
| Electrical | 56 | 0.0 | 37.5 | 48.2 | 14.3 | 100.00 |
| Computers | 17 | 11.8 | 58.8 | 29.4 | 0.0 | 100.00 |
| Instruments | 21 | 4.8 | 38.1 | 57.1 | 0.0 | 100.00 |
| Motor Vehicles | 35 | 2.9 | 48.6 | 48.6 | 0.0 | 100.00 |
| Aircraft | 18 | 0.0 | 22.2 | 77.8 | 0.0 | 100.00 |
| All Sectors | 440 | 4.3 | 52.0 | 40.0 | 3.6 | 100.00 |

Source: Calculated from data supplied to SPRU by the US Patent and Trademark Office.

### 2.2 The Determinants of Technological Diversity

We have suggested elsewhere (Pavitt, 1984; Patel and Pavitt, 1992) that two factors influence the degree of diversity of large firms' technological activities:

1. *Firm Size* will be positively associated with technologically diversity, both as a *consequence* of successful product diversification in science-based technologies (chemicals and electrical–electronics), and as an *incentive* to the application of production-based technologies in order to exploit economies of scale. We would therefore expect a positive association between firm size and technological diversity, measured as the number of technological fields in which the firm is active.

2. *Technology Intensity* will also influence a firm's technological diversity. Increased intensity – measured as patenting per unit sales – will be positively associated with the of fields of competence, reflecting the results of more energetic technological search.

3. *Home country characteristics* are also said to influence firms' degree of technological diversity. For example, it is argued that the competitive and institutional framework

for Japanese firms leads them towards greater technological diversity than in other countries (see, for example, Kodama, 1986; and Oskarsson 1993).

4. Finally, it can be argued that *industry characteristics* influence the number of fields in which the firm is active through the range of competencies required to develop and produce a given class of products.

In Table 3, we present the results of our regressions testing the above explanations. The dependent variable is each firm's number of active fields of competence (out of a total of 34) in the 1980s; the independent variables are each firm's sales, patent intensity, country of origin and industry. The results show that the coefficients on size and technology intensity have the expected sign and are significant at the 5% level. On the other hand firms' countries of origin have no significant effects on the diversity of technological competencies, since the country dummy variables are not significant at the 5% level. Industries (i.e. product groups made) do matter, with food firms showing the least technological diversity and aircraft firms the most.

**Table 3. Determinants of Technological Diversification**

*Dependent Variable: Number of Technical Fields (out of 34) of Patenting (81–90)*

| | Coeff. | Std Error | Coeff. | Std Error |
|---|---|---|---|---|
| Constant | 16.11* | 0.34 | 15.16* | 1.33 |
| Sales (1988) | 0.25* | 0.02 | 0.25* | 0.02 |
| Patent Intensity (1988) | 0.02* | 0.00 | 0.02* | 0.00 |
| Dummy Japan | | | –0.95 | 0.55 |
| Dummy USA | | | 0.45 | 0.48 |
| Dummy Chemicals | | | 2.98* | 1.39 |
| Dummy Pharmaceuticals | | | –1.46 | 1.54 |
| Dummy Mining & Petroleum | | | 1.98 | 1.51 |
| Dummy Rubber & Plastics | | | 0.21 | 1.87 |
| Dummy Paper & Wood | | | –1.89 | 1.61 |
| Dummy Food | | | –3.91* | 1.70 |
| Dummy Drink & Tobacco | | | –1.22 | 1.94 |
| Dummy Building Materials | | | 1.71 | 1.65 |
| Dummy Metals | | | 1.84 | 1.45 |
| Dummy Machinery | | | 1.06 | 1.40 |
| Dummy Electrical | | | 2.62 | 1.42 |
| Dummy Computers | | | –1.26 | 1.63 |
| Dummy Instruments | | | –1.61 | 1.68 |
| Dummy Motor Vehicles | | | –0.56 | 1.49 |
| Dummy Aircraft | | | 4.37* | 1.62 |
| R Sq (adj) | 0.35 | | 0.49 | |
| F | 121.3* | | 21.1* | |
| N | 440 | | 440 | |

* Indicates that the coefficient is significantly different from zero at the 5% level.

### 2.3 Changing Technological Diversity over Time

Not only are large firms technologically diverse, but their diversity has been changing over time. This is confirmed in Table 4, which shows the numbers of firms (from Europe, Japan and the USA) whose technological diversity increased, decreased and remained stable over this period. It emerges clearly that firms differ markedly according to their country of origin, with most Japanese firms increasing the technological diversity of their patenting activities, and a majority of European firms doing likewise, whilst most US firms decreased the diversity of their patenting. At the sectoral level, technological diversity increased in US firms in pharmaceuticals, computers and drink and tobacco, and in European firms in chemical and machinery related sectors.

**Table 4. Changes in Firms' Technological Diversity by Product Group and Region: 1969–74 to 1985–90.**

*Number of Firms*

| | USA | | | Europe | | | Japan | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dec | Stab | Inc | Dec | Stab | Inc | Dec | Stab | Inc | Dec | Stab | Inc |
| Chemicals | 23 | 0 | 3 | 3 | 2 | 10 | 0 | 1 | 23 | 26 | 3 | 36 |
| Pharmaceuticals | 3 | 3 | 8 | 2 | 0 | 5 | 0 | 0 | 4 | 5 | 3 | 17 |
| Mining & Petroleum | 10 | 1 | 5 | 2 | 1 | 8 | 0 | 1 | 3 | 12 | 3 | 16 |
| Textiles etc. | 3 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 4 | 4 | 3 | 6 |
| Rubber & Plastics | 5 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 8 | 0 | 2 |
| Paper & Wood | 7 | 1 | 5 | 1 | 0 | 2 | 0 | 0 | 1 | 8 | 1 | 8 |
| Food | 8 | 2 | 2 | 0 | 0 | 1 | 0 | 1 | 2 | 8 | 3 | 5 |
| Drink & Tobacco | 2 | 2 | 3 | 1 | 0 | 2 | 0 | 0 | 1 | 3 | 2 | 6 |
| Building Materials | 7 | 1 | 1 | 3 | 0 | 1 | 0 | 0 | 4 | 10 | 1 | 6 |
| Metals | 8 | 3 | 4 | 7 | 3 | 9 | 0 | 0 | 10 | 15 | 6 | 23 |
| Machinery | 20 | 2 | 8 | 7 | 1 | 12 | 1 | 0 | 11 | 28 | 3 | 31 |
| Electrical | 16 | 4 | 7 | 5 | 3 | 4 | 0 | 0 | 17 | 21 | 7 | 28 |
| Computers | 5 | 0 | 5 | 1 | 1 | 2 | 0 | 0 | 2 | 6 | 1 | 9 |
| Instruments | 6 | 2 | 3 | 0 | 1 | 0 | 2 | 0 | 5 | 8 | 3 | 8 |
| Motor Vehicles | 6 | 0 | 4 | 5 | 1 | 9 | 0 | 0 | 12 | 11 | 1 | 25 |
| Aircraft | 10 | 0 | 2 | 2 | 0 | 5 | 0 | 0 | 0 | 12 | 0 | 7 |
| All Product Groups | 139 | 23 | 61 | 43 | 14 | 72 | 3 | 3 | 101 | 185 | 40 | 234 |

Dec: Firms where there has been a decrease in the number of technical fields (out of 34) of activity.
Stab: Firms where there has been no change in the number of technical fields (out of 34) of activity.
Inc: Firms where there has been an increase in the number of technical fields (out of 34) of activity.

The meaning of these trends is ambiguous. It is tempting to conclude that the declining technological diversity of US firms reflects their declining technological competitiveness, compared to firms from Japan and Europe[13]. However, the data for US firms reflect domestic patenting, the scope of which is sensitive to its cost; whilst the data for European and Japanese firms also reflect international patenting, the scope of which reflects international

[13] Since the late 1960s, business-funded R & D has increased more rapidly in Japan than in Europe, and more rapidly in Europe than in the USA. See Patel and Pavitt, 1994a.

technological competitiveness and business strategy. The trends could therefore simply reflect increases in the cost of US patenting (influencing US firms), and the processes of technological catch-up (influencing European and Japanese firms). Suffice to say that, by the 1980s, our US firms were in aggregate still slightly more diversified (according to the same measure as in Table 2) than the European and Japanese firms.

**Table 5. Changes in the Number of firms that are Active in 34 Technical Fields, by Region: 1969–74 to 1985–90.**

*Sorted by total change*

| | 1985–90 | | | | Change Since 1969–74 | | | |
|---|---|---|---|---|---|---|---|---|
| | WE | JP | US | Total | WE | JP | US | Total |
| Calculators & Computers, etc. | 74 | 69 | 142 | 285 | 14 | 34 | 22 | 70 |
| Drugs & Bioengineering | 54 | 54 | 96 | 204 | 18 | 27 | 0 | 45 |
| Materials (inc glass & ceramics) | 91 | 94 | 177 | 362 | 7 | 28 | 6 | 41 |
| Plastic & rubber products | 80 | 79 | 128 | 287 | 10 | 37 | –11 | 36 |
| General Electrical Ind. Apparatus | 105 | 90 | 172 | 367 | 6 | 38 | –8 | 36 |
| Instruments & controls | 120 | 95 | 192 | 407 | 8 | 31 | –5 | 34 |
| Metallurgical & Metal Treatment proc. | 72 | 68 | 130 | 270 | 0 | 29 | 3 | 32 |
| Dentistry & Surgery | 56 | 47 | 70 | 173 | 17 | 34 | –21 | 30 |
| Miscellaneous metal products | 110 | 75 | 195 | 380 | 5 | 26 | –2 | 29 |
| Other – (Ammunitions & weapons, etc.) | 97 | 65 | 175 | 337 | 4 | 26 | –7 | 23 |
| Image & sound equipment | 59 | 65 | 107 | 231 | 6 | 33 | –17 | 22 |
| Chemical Processes | 113 | 96 | 204 | 413 | 4 | 18 | –1 | 21 |
| Mining & wells: mach. & proc. | 42 | 20 | 75 | 137 | 12 | 15 | –7 | 20 |
| Hydrocarbons, mineral oils, fuels etc. | 44 | 36 | 72 | 152 | 14 | 5 | –2 | 17 |
| General Non-electrical Ind. Equip. | 112 | 78 | 187 | 377 | 2 | 18 | –6 | 14 |
| Agricultural Chemicals | 31 | 29 | 48 | 108 | 5 | 17 | –10 | 12 |
| Semiconductors | 35 | 49 | 82 | 166 | 3 | 23 | –14 | 12 |
| Photography & photocopy | 27 | 58 | 62 | 147 | –1 | 39 | –28 | 10 |
| App. for chemicals, food, glass etc. | 106 | 92 | 195 | 393 | –4 | 23 | –10 | 9 |
| Assembling & material handling app. | 86 | 67 | 166 | 319 | –2 | 21 | –10 | 9 |
| Road vehicles & engines | 49 | 32 | 61 | 142 | 6 | 11 | –9 | 8 |
| Electrical devices & systems | 76 | 56 | 135 | 267 | 5 | 22 | –19 | 8 |
| Organic Chemicals | 72 | 73 | 139 | 284 | 8 | 14 | –19 | 3 |
| Non-electrical specialized ind. equip. | 116 | 85 | 193 | 394 | –2 | 17 | –12 | 3 |
| Power Plants | 47 | 29 | 62 | 138 | –2 | 19 | –14 | 3 |
| Inorganic Chemicals | 50 | 48 | 85 | 183 | –2 | 14 | –10 | 2 |
| Aircraft | 24 | 6 | 43 | 73 | 5 | 3 | –6 | 2 |
| Metallurgical & metal working equip. | 108 | 79 | 179 | 366 | –1 | 21 | –20 | 0 |
| Telecommunications | 68 | 50 | 134 | 252 | –2 | 15 | –14 | –1 |
| Bleaching Dyeing & Disinfecting | 34 | 28 | 48 | 110 | 2 | 13 | –18 | –3 |
| Other transport equip. (exc. aircraft) | 67 | 39 | 100 | 206 | –4 | 15 | –16 | –5 |
| Food & Tobacco (proc. & prod.) | 33 | 25 | 61 | 119 | 4 | 9 | –21 | –8 |
| Induced Nuclear Reactions | 8 | 6 | 16 | 30 | –7 | 3 | –14 | –18 |
| Textile, clothing, leather, wood products | 30 | 16 | 48 | 94 | –2 | 11 | –34 | –25 |

WE denotes European Firms.

Stronger conclusions can be reached about the technical fields into (and out of) which firms are moving over time. Table 5 shows the total number of large firms that have been active in each of our 34 technical fields in 1985–90 and the changes therein since 1969–74. It thereby compares the degree of pervasiveness of technological competencies in different fields, and how this has changed over time. The technological fields are sorted according to the last column, namely, the change in the number of active firms between the two periods. It emerges that:

- for firms from Japan, Europe and the USA, the most pervasive competencies are the same: instrumentation and control, production machinery and chemical processes, in all of which the overwhelming majority of our firms was technologically active;
- the least pervasive competencies were in nuclear energy, aircraft and textiles;
- over time, the sectors in which the number of firms with competencies increased most rapidly were computing, drugs and bio-engineering, and materials;
- the patterns and trends were similar in all three regions, except for a particularly sharp decline in US firms with competencies in image and sound, and in photography and photocopy.

### 2.4 Some Implications of "Multi-technology" Firms

Our results are consistent with the conclusions of research by Ove Granstrand and his colleagues at Chalmers in Sweden[14]. In particular, large firms and the products they make depend on many fields of technological competence, the number of which is changing over time with the widening range of technological opportunities emerging from improvement in computing and other science-based technologies. In order to assimilate this range of emerging technologies, large firms simultaneously increase their internal competencies, form alliances with external sources, and increase their overall R & D expenditures.

At the same time, the striking technological diversity of our large firms casts some doubt on the feasibility of a "focused" technological – as distinct from product market – strategy (Porter, 1985), given that the products that they make are multi-technology (see Freeman, 1982). Similarly, the notion of "core competencies" (see Prahalad and Hamel, 1990) in technological strategy is not entirely clear, when large firms are typically active so many technical fields.

[14] See, in particular, Granstrand and Sjolander, 1990; Granstrand et al., 1992; Jacobsson and Oskarsson (1994); Oskarsson, 1993.

In this context, it is worth noting that business practitioners often have a more elaborate classification of firms' technological competencies. According to those in large firms that are members of the European Industrial Research Management Association (EIRMA):

> "In order to consider explicitly the technological resources needed to implement a strategic plan, it is essential to know the precise technological position of the company (or the business unit), in relation to that of its major competitors......This can.......be considered in terms of three types of technologies which show differing potential for competitive impact.
> + *Basic technologies* – Widely available; low risk low reward.
> + *Key technologies* – Proprietary; essential to maintain in-house; medium risk, medium reward.
> + *Pacing technologies* – These can produce a breakthrough for the company: normally achieved by in-house effort over a long time; high risk, high reward."
>
> (EIRMA, 1986, p.19)

# 3 FROM FIRM-SPECIFIC COMPETENCIES TO PROFILES

In this context, we shall now show that large firms have *profiles* of competencies, with levels of commitment and advantage that vary amongst technological fields. We shall also show that these profiles are highly stable, differentiated and strongly related to the product base.

## 3.1 Defining and Measuring Firms' Technological Profiles

Our definition of a firm's technological profile reflects both the experience of practitioners (see quote from EIRMA above) and the nature of our data base, as well as earlier contributions to the subject. We distinguish two interrelated dimensions of technological competencies.

1. **Core vs. Niche Competence** reflects the relative importance of the field in the firm's total portfolio. It is measured as the share of the firm's patenting in each of our 34 technical fields **(PS)**. Relatively high shares will measure what we call a *core competence*, and relatively low shares a *niche competence*.

2. **Distinctive vs. Background Competence** reflects the degree to which the firm has an advantage in the field compared to other firms. It is measured as the firm's share of total patenting in the field, divided by the firm's aggregate share in all fields. Elsewhere, we have called this the *Revealed Technology Advantage* (**RTA**) of the firm in each field. A high RTA will measure what we call a *distinctive competence*, and a low RTA what we call a *background competence*.

We represent the full classification in Figure 1 below, showing that firms can have four categories of technological competence (in addition to having no competence of any kind in some fields). The following properties are of particular importance.

- Some categories are more important than others – in particular, *core-distinctive* is more important than *niche-background.*
- Given their definition, the measures along the two axes are correlated, and the correlation would be perfect, if there were an equal volume of total patenting in all 34 technical fields.
- However, there are technical fields with relatively low levels of total patenting activity, where firms may develop a *niche-distinctive* competence.
- There are also technical fields with relatively high levels of patenting activity, where many firms have a *core-background* competence that is very similar to what European practitioners call *basic technologies*[15]. Our own earlier analysis shows that large firms find it necessary to maintain some in-house competence in basic (background) technologies, that are often related to production techniques and located in fields of mechanical, chemical and instrumentation engineering (Patel and Pavitt, 1994b. See also Table 5 above).
- The positioning of the axes on Figure 1 is (inevitably) arbitrary. We have placed the line between *core* and *niche* at the share that would allow equal distribution across all fields: 100/34 = 3%. We have defined the difference between *distinctive* and *background* (and the cut-off for the latter) more pragmatically, after examining the profiles of a number of firms.

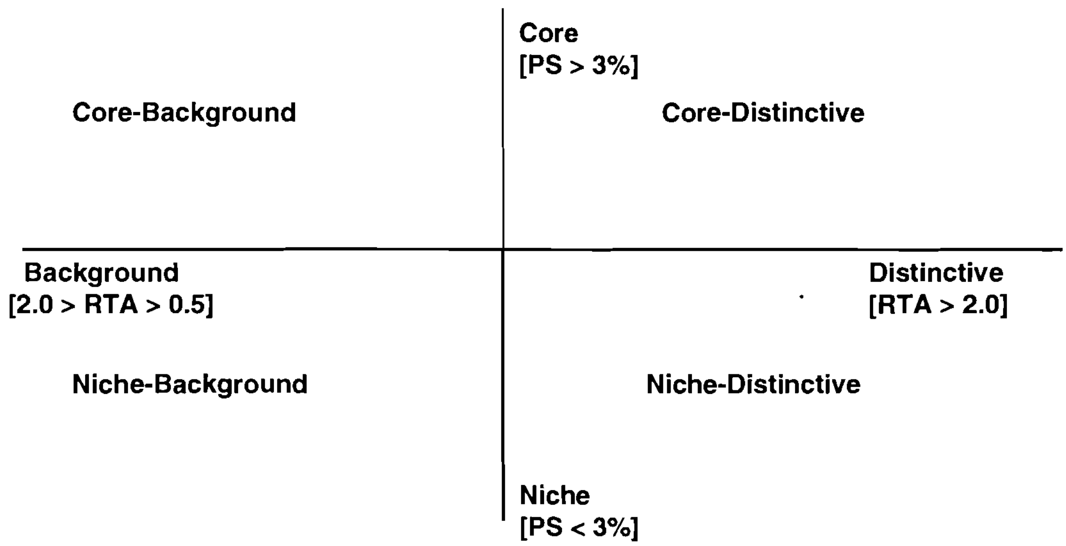


**Figure 1: A Classification for Firms' Technological Profiles**

[15] Available not only within large firms, but also in smaller, specialised firms to whom large firms sometimes "spin-off' their innovations (Rosenberg, 1976; von Hippel, 1988).

In Figure 2 below, we reproduce the technological profiles of three large (and well-known) firms, from the chemical electrical and automobiles industries[16]. A number of features of firms' profiles emerge from Figure 2.

- A relatively large number of technological fields combine to define each firm's technological profile: 11 in chemicals, 18 in electrical, and 20 in automobiles.
- In all three firms, these sectors account for more than 90% of the firms' patenting.
- The *core distinctive* competencies are very different:
  - *chemicals*: organic and agricultural chemicals, pharmaceuticals and photography;
  - *electrical*: computers, semiconductors, and image and sound;
  - *automobiles*: vehicles, engines and other transport.
- All three firms have at least one *niche-distinctive* competence;
- The chemical firm has just one *core-background* competence (chemical processes) accounting for 7% of all its patenting.
- The electrical and automobile firms are very different, with respectively 8 and 10 *core background* competencies, accounting for 47% of all patenting in the electrical firm, and 64% in the automobile firm. In both cases, instrumentation accounted for about 15% of all patenting activities.

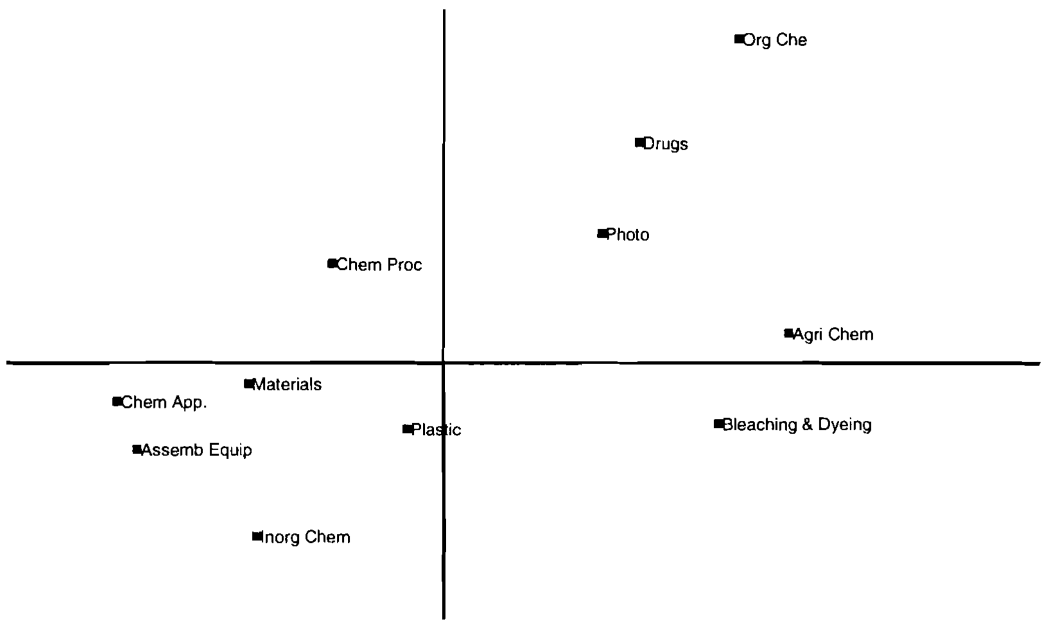


**Figure 2a. Technological Profile of a Chemical Company**

[16] Since we are (amongst other things) interested in illustrating differences amongst firms from different industries, the RTAs are calculated on the basis of patenting by firms from all sectors. For competitor analysis, they should probably be calculated on the basis of competitor firms only.

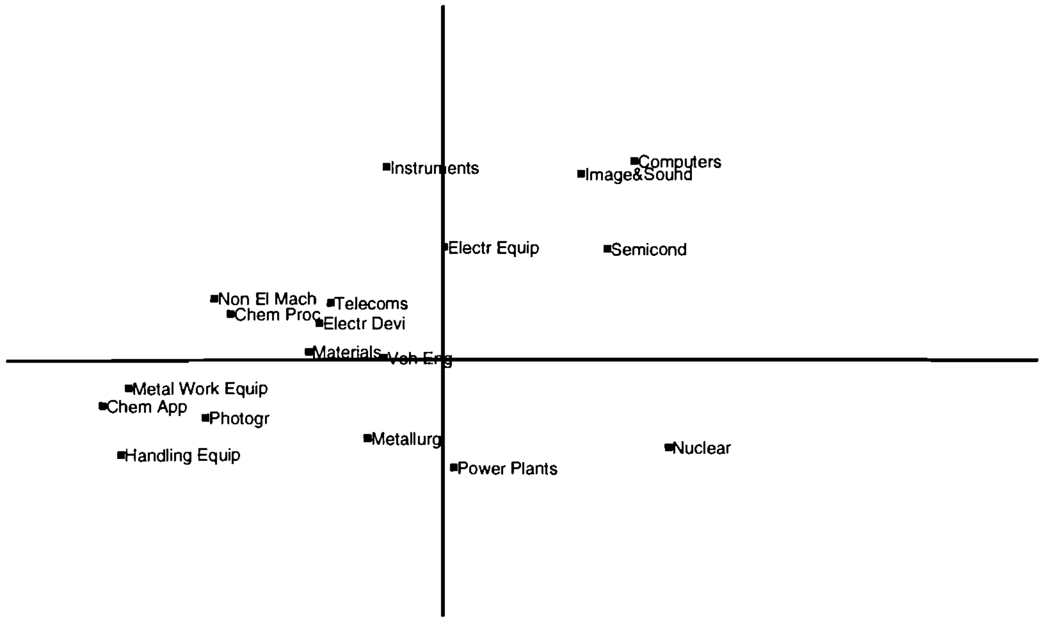


**Figure 2b. Technological Profile of an Electrical Company**

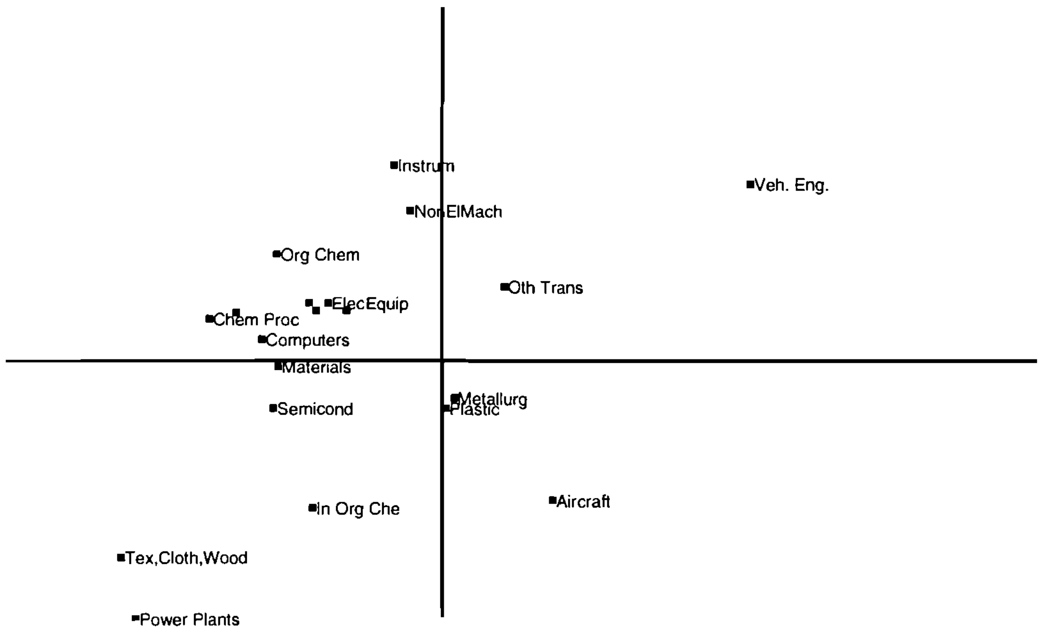


**Figure 2c. Technological Profile of an Automobile Company**

On the basis of these examples, we may provisionally conclude that the classification of technological profiles proposed in Figure 1 has three potential strengths.

1. It encompasses the wide variety of technological competencies accumulated within large firms.

2. It distinguishes the differing contributions of each field of competence.
3. It highlights the importance of the *core background* competencies that are often neglected or ignored in conventional analysis.

We shall now show that large firm's technological profiles have two other characteristics: they are both highly stable and highly differentiated.

### 3.2 The Strong Stability of Firms' Technological Profiles and Directions of Search

For nearly all our firms, these technological profiles are remarkably stable over time. For each firm, we correlated both the patent shares (PS) and the RTAs for the periods 1969–74 and 1985-90. Table 6 shows that according to both measures, the overwhelming majority (more than 90%) of firms have profiles of technological competence that are statistically similar between 1969–74 and 1985–90, at the 1% level of significance[17]. Large firms clearly do not shift around rapidly in their fields of technological competence[18].

**Table 6. Stability of Technological Profiles Across 34 Technical Fields: 1969–74 to 1985–90.**

| | | Patent Shares | | | Revealed Technology Advantage | | |
|---|---|---|---|---|---|---|---|
| | No. of Firms | Not Sig at 5% | Sig at 5% | Sig at 1% | Not Sig at 5% | Not Sig at 5% | Not Sig at 1% |
| 1 Chemicals | 65 | 1 | 1 | 63 | 5 | 7 | 53 |
| 2 Pharmaceuticals | 25 | 2 | 3 | 20 | 0 | 0 | 25 |
| 3 Mining & Petroleum | 31 | 7 | 7 | 17 | 5 | 5 | 21 |
| 4 Textiles etc. | 13 | 4 | 6 | 3 | 5 | 6 | 2 |
| 5 Rubber & Plastics | 10 | 0 | 0 | 10 | 1 | 1 | 8 |
| 6 Paper & Wood | 17 | 1 | 3 | 13 | 4 | 4 | 9 |
| 7 Food | 16 | 0 | 1 | 15 | 1 | 2 | 13 |
| 8 Drink & Tobacco | 11 | 0 | 1 | 10 | 0 | 2 | 9 |
| 9 Building Materials | 17 | 0 | 0 | 17 | 0 | 0 | 17 |
| 10 Metals | 44 | 4 | 6 | 34 | 5 | 7 | 32 |
| 11 Machinery | 63 | 2 | 5 | 56 | 5 | 10 | 48 |
| 12 Electrical | 56 | 4 | 5 | 47 | 5 | 8 | 43 |
| 13 Computers | 16 | 0 | 0 | 16 | 0 | 1 | 15 |
| 14 Instruments | 19 | 0 | 0 | 19 | 2 | 3 | 14 |
| 15 Motor Vehicles | 37 | 0 | 0 | 37 | 2 | 2 | 33 |
| 16 Aircraft | 19 | 0 | 0 | 19 | 1 | 1 | 17 |
| All Sectors | 459 | 25 | 38 | 396 | 41 | 59 | 359 |

[17] No systematic differences in stability can be detected between firms in different sectors and countries.

[18] Given our method of compiling data of firm-level patenting, we cannot measure any changes in our firms' technological profiles resulting from acquisitions and divestments. On the basis of data for large Swedish firms, Oskarsson (1993) has concluded that acquisitions and divestments have had little influence on the shape of their technological profiles.

This stability over time in firms' technological profiles is defined by relatively broad technological fields, and does not reflect the more detailed processes of search that firms undertake. For this reason, we have identified in US patenting activities the 1,000 (out of a total of around 100,000) technological sub-classes of the highest technological opportunity, as measured by their absolute increase in patenting from the 1960s to the late 1980s. In aggregate, their share increased steeply from 3 to 18% of total US patenting. A relatively high proportion of fast growing fields (FGFs) are to be found in electronics and chemical technologies[19].

In Table 7, we show that firms are in fact heavily constrained by their prior competencies in the directions in which they accumulate competencies in these fast-growing fields. Their shares of total fast-growing patenting in 1985–90 within the five broad fields of technology used in Table 1 – chemicals, mechanical, electrical–electronic, transport and "other" – are strongly and positively correlated with their prior shares of total patenting in these same fields over the period 1969–84. In other words, firms' capacities to exploit fields of high technological opportunity are strongly constrained by their prior competencies.

**Table 7. Correlations of Past (1969–84) Shares of Total Patenting on Shares of Patenting in Fast-Growing Areas in 1985–90.**

| | Shares of Patenting in Fast-Growing Areas in 85–90 | | | | |
|---|---|---|---|---|---|
| | Chemicals | Mechanical | Electrical | Transport | Other |
| Share of Total Chem 69–84 | 0.91* | –0.41* | –0.61* | –0.26* | 0.00 |
| Share of Total Mech 69–84 | –0.41* | 0.68* | –0.10* | 0.14* | 0.09* |
| Share of Total Elec 69–84 | –0.58* | –0.12* | 0.87* | –0.17* | –0.17* |
| Share of Total Trans 69–84 | –0.34* | 0.18* | –0.13* | 0.85* | –0.04 |
| Share of Total Othe 69–84 | 0.06 | –0.12* | –0.18* | –0.07 | 0.55* |

* Denotes a coefficient significantly different from zero at the 5% level.

### 3.3 The Differentiation of Industries' Technological Competencies

In addition to being very stable, our data also show that large firms' technological competencies are highly differentiated. To begin with, average patent shares and RTAs for each of our sixteen industries (i.e. aggregate data based on our firms) are in general very different. For patent shares, 23% of the cross-industry correlations are positive and significant[20]; and for RTAs the share is reduced to 5%. In both cases, there are essentially three clusters:

[19] For this reason, we find significant correlations between firms' share of total patenting in fast-growing fields, on the one hand, and their R & D intensity and share of total patenting in science based technologies, on the other.

[20] At the 5% level.

- the chemical and chemical-related industries (the first eight listed in Table 1);
- machinery and vehicles;
- electrical and computers.

There is also one significantly negative correlation that is important: between the RTAs of firms in chemicals and in electrical products. Although both are often lumped together as "high technology" or "science- based" firms, they are clearly based on very different mixes of technological competence.

The statistical similarities and (above all) differences described above reflect similarities and differences in core and distinctive competencies amongst firms in different sectors. These are set out systematically in Table 8 which describes the contribution of competencies in our 34 technical fields to firms in each of the 16 sectors according to the four-fold classification shown in Figure 1.

From Table 8 it emerges that technical fields vary greatly in the nature and extent of their contributions to firm-specific competencies:

- organic chemicals and materials are *core distinctive* competencies in five industries; drugs, non-electrical machinery, and image and sound in three each; instruments (in spite of its overall importance) in only one; and five fields in none at all;
- as can be anticipated from Table 5, *core background* competencies are located mainly in chemical processes, machinery, instrumentation, and organic chemicals;
- *niche distinctive* competencies are restricted to relatively few fields such as plastics, dyestuffs, nuclear energy and power plant;
- the most prevalent of *niche-background* technologies are assembly and materials handling, plastic and rubber, and metallurgical processes;
- in spite of its spread amongst an increasing number of companies, computer competence is so far identifiable beyond the usual "high-tech" industries only in machinery and vehicles.

It also emerges from Table 8 that profiles of competencies vary greatly amongst firms in the different sectors:

- the number of technical fields involved varies from 7 in pharmaceuticals to 24 in aircraft;
- in only four sectors (chemicals, pharmaceuticals, petroleum and mining and electrical products) do the number of *core distinctive* technological fields outnumber the number of *core background* fields;

**Table 8. Firms' Technical Profile According to their Principal Product Group: 1981–90.**

| | Principal Product Group | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Chem | Phar | Mini | Text | Rubb | Pape | Food | Drin | Buil | Meta | Mach | Elec | Comp | Inst | Moto | Airc |
| InOrChem | *** | | **** | | | | | | * | **** | * | | | | | * |
| OrgCh | **** | **** | **** | **** | **** | ** | ** | ** | ** | ** | | | | ** | | ** |
| AgrCh | **** | *** | | | | | * | | * | | | | | | | |
| ChePro | **** | ** | ** | ** | ** | ** | **** | ** | ** | ** | ** | ** | ** | ** | | ** |
| Hydroc | * | | **** | | * | * | | | | * | | | | | | *** |
| Bleach | *** | *** | * | **** | | * | *** | | | * | | | | | | |
| Drugs | **** | **** | * | ** | | | **** | ** | | | | | | | | |
| Plastic | *** | | * | *** | **** | *** | * | * | *** | * | * | * | | | * | * |
| Materials | ** | | * | **** | **** | **** | * | * | **** | **** | * | * | | ** | | ** |
| Food&T | * | * | | * | | * | **** | **** | * | | | | | | | |
| Metallu Pro | * | | * | * | | | | | * | **** | * | * | | | * | *** |
| ChemApp | ** | | **** | ** | ** | ** | ** | ** | ** | ** | ** | | | * | | * |
| NonElMach | | | ** | | | | * | ** | ** | ** | **** | ** | | | **** | **** |
| ElEqup | | | | | | ** | * | | ** | ** | ** | ** | ** | * | ** | * |
| SpecMach | | | | ** | * | **** | ** | ** | ** | ** | **** | | ** | | * | |
| MetalWEq | | | | | ** | * | | | ** | **** | **** | * | | | ** | ** |
| AssHandApp | | | | * | * | * | * | ** | * | * | ** | | * | * | | * |
| Nuclear | | | | | | | | | | | *** | *** | | | | |
| PowerP | | | | | | | | | | | * | * | | | *** | **** |
| VehiEngi | | | | | | | | | | | **** | | | | **** | * |
| OthTran | | | | | * | | | | | * | ** | | | | **** | * |
| Aircraft | | | | | *** | | | | | | | | | | | **** |
| Mining | | | **** | | | | | | * | * | **** | | | | | * |
| Telecoms | | | | | | | | | | | | **** | ** | | | ** |
| Semicond | | | | | | | | | | | | **** | **** | * | | * |
| ElectrDevi | | | | * | | | | | | | | **** | ** | | ** | ** |
| Computers | | | | | | | | | | | * | **** | **** | ** | ** | ** |
| Image&Sou | | | | | | | | | | | | **** | **** | **** | | * |
| Photog&C | ** | | | * | | ** | | | | | | * | * | **** | | |
| Instrumen | | | ** | ** | ** | | | ** | ** | ** | ** | ** | ** | **** | ** | ** |
| MiscMetProd | | | | ** | ** | **** | ** | ** | ** | | ** | | | | ** | ** |
| TextWoodetc | | | | * | | * | * | | | | | | | | | |
| Medical | | **** | | | | ** | | | | | | | | * | | |

**** Core-Distinctive *** Niche-Distinctive ** Core-Background * Niche-Background

- in at least six sectors, *core background* fields account for more than 50% of all technological competencies.

### 3.4 Do Firms' Technological Profiles match Product Groups?

One drawback in our analysis so far is that it neglects the possibility of diversity in the profile of technological competencies of firms *within* each industrial sector. For this reason, we summarise in Tables 9 and 10 of our systematic examination of the similarities and differences in profiles of technological competencies individually for all our large firms. Each table shows the percentage of firms' technological profiles, for the period 1981–90, that are similar (that is – positively correlated at the 5 % level) to firms inside the same product group, and to those in the other product groups; Table 9 does this for patent shares, and Table 10 for Revealed Technology Advantage. The main patterns that emerge are as follows.

- Firms have significantly different profiles of technological competence to most others: 19 % are similar in patent shares (i.e. core competencies), and 11% in RTAs (i.e. distinctive competencies).
- More generally, firms are more similar (or less dissimilar) to each other in their core than their distinctive competencies.
- In all sectors, firms have a higher probability of finding others with similar technological profiles within their sector than outside: from three times as high for machinery firms (according to RTAs), to more than fourteen times as high for pharmaceutical firms.
- The frequency of technological proximity between firms in different sectors is not evenly spread or random, but reveals distinct groupings, many of which have been anticipated earlier in Table 8: in particular, those with competencies in organic chemicals, in electronics, and in production machinery.
- These sectoral similarities and differences amongst firms in the sources and directions of technological accumulation are broadly consistent with a sectoral taxonomy of technical change proposed earlier by one of us (Pavitt, 1984):
  - two distinct science-based sectors centred on organic chemistry (chemicals, pharmaceuticals, petro-chemicals), and on physics-based technology (electrical, computers);
  - machinery suppliers with areas of specialisation influenced by major users;
  - a range of scale intensive sectors with production technologies dependent on improvements in chemical processes, instrumentation and production machinery.

**Table 9. Correlations of Firms' Shares across 34 Technical Fields, by Principal Product Group: 1981-90.**

*Percentage of the total that are Positive and Significant at 5% level.*

| | Own PPG | All Other PPG's | Phar | Mini | Text | Rubb | Pape | Food | Drin | Buil | Meta | Mach | Elec | Comp | Inst | Moto | Airc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemicals | 78.6 | 19.1 | 60.3 | 61.8 | 53.6 | 49.0 | 17.8 | 39.0 | 9.8 | 24.9 | 19.1 | 4.5 | 1.7 | 0.0 | 8.7 | 2.4 | 1.9 |
| Pharmaceuticals | 94.3 | 15.8 | | 28.3 | 30.8 | 18.7 | 6.4 | 38.3 | 12.5 | 4.5 | 4.1 | 1.1 | 0.1 | 0.0 | 8.2 | 0.1 | 0.0 |
| Mining & Petroleum | 69.0 | 19.3 | | | 39.0 | 34.4 | 15.9 | 22.1 | 3.6 | 17.5 | 17.7 | 7.0 | 1.3 | 0.2 | 5.5 | 4.8 | 3.4 |
| Textiles etc. | 55.6 | 24.7 | | | | 35.6 | 45.0 | 25.0 | 17.5 | 45.6 | 15.3 | 14.8 | 10.5 | 5.9 | 13.3 | 4.6 | 10.0 |
| Rubber & Plastics | 72.2 | 16.9 | | | | | 14.8 | 14.3 | 4.2 | 18.1 | 8.5 | 7.3 | 5.4 | 1.3 | 6.3 | 2.2 | 5.6 |
| Paper & Wood | 58.2 | 13.3 | | | | | | 17.1 | 26.4 | 34.0 | 9.6 | 23.9 | 5.4 | 2.6 | 6.3 | 4.9 | 3.4 |
| Food | 67.0 | 14.1 | | | | | | | 54.5 | 14.3 | 4.3 | 5.2 | 0.8 | 0.4 | 3.4 | 1.0 | 1.2 |
| Drink & Tobacco | 50.0 | 11.4 | | | | | | | | 18.0 | 5.9 | 20.9 | 3.3 | 1.5 | 4.8 | 7.9 | 10.4 |
| Building Materials | 48.3 | 15.5 | | | | | | | | | 25.7 | 17.1 | 5.7 | 0.7 | 6.5 | 6.4 | 15.3 |
| Metals | 72.8 | 12.7 | | | | | | | | | | 23.0 | 11.1 | 4.2 | 5.9 | 7.2 | 18.4 |
| Machinery | 45.0 | 12.8 | | | | | | | | | | | 12.7 | 5.9 | 7.6 | 44.3 | 30.1 |
| Electrical | 61.6 | 10.4 | | | | | | | | | | | | 59.3 | 30.9 | 13.7 | 41.4 |
| Computers | 100.0 | 12.7 | | | | | | | | | | | | | 34.2 | 5.9 | 38.9 |
| Instruments | 55.2 | 12.2 | | | | | | | | | | | | | | 11.6 | 30.4 |
| Motor Vehicles | 85.7 | 12.0 | | | | | | | | | | | | | | | 36.8 |
| Aircraft | 72.5 | 18.5 | | | | | | | | | | | | | | | |
| All Sectors | 67.3 | 14.5 | | | | | | | | | | | | | | | |

**Table 10. Correlations of Firms' RTA's across 34 Technical Fields, by Principal Product Group: 1981-90.**

*Percentage of the total that are Positive and Significant at 5% level.*

| | Own PPG | All Other PPG's | Phar | Mini | Text | Rubb | Pape | Food | Drin | Buil | Meta | Mach | Elec | Comp | Inst | Moto | Airc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemicals | 48.7 | 9.6 | 26.1 | 25.2 | 33.6 | 26.6 | 12.0 | 6.4 | 2.7 | 19.1 | 14.5 | 3.8 | 1.3 | 0.0 | 2.5 | 0.8 | 0.9 |
| Pharmaceuticals | 86.7 | 6.2 | | 3.1 | 16.8 | 0.9 | 3.8 | 20.6 | 13.0 | 0.5 | 0.0 | 0.5 | 0.1 | 0.0 | 4.2 | 0.0 | 0.0 |
| Mining & Petroleum | 72.9 | 7.4 | | | 4.2 | 7.5 | 9.7 | 0.2 | 0.0 | 4.6 | 14.2 | 3.6 | 0.6 | 0.0 | 1.1 | 1.8 | 2.9 |
| Textiles etc. | 46.7 | 12.4 | | | | 33.3 | 23.3 | 10.0 | 10.0 | 38.1 | 10.8 | 4.5 | 4.8 | 0.0 | 3.3 | 0.3 | 0.0 |
| Rubber & Plastics | 86.1 | 9.0 | | | | | 17.3 | 0.0 | 11.1 | 18.1 | 1.5 | 9.0 | 2.0 | 0.0 | 0.5 | 0.0 | 9.3 |
| Paper & Wood | 37.3 | 7.9 | | | | | | 11.9 | 22.2 | 29.9 | 1.6 | 9.2 | 2.8 | 0.7 | 6.3 | 1.4 | 0.0 |
| Food | 100.0 | 5.2 | | | | | | | 87.5 | 6.3 | 0.8 | 1.8 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Drink & Tobacco | 82.1 | 6.9 | | | | | | | | 10.2 | 2.0 | 5.8 | 1.1 | 0.0 | 0.0 | 1.1 | 0.0 |
| Building Materials | 52.5 | 9.6 | | | | | | | | | 10.5 | 10.0 | 3.9 | 0.0 | 6.0 | 2.1 | 1.0 |
| Metals | 77.8 | 7.2 | | | | | | | | | | 11.4 | 5.1 | 0.0 | 0.9 | 3.8 | 3.2 |
| Machinery | 21.3 | 7.4 | | | | | | | | | | | 5.8 | 2.0 | 3.1 | 27.1 | 7.6 |
| Electrical | 45.5 | 5.7 | | | | | | | | | | | | 47.4 | 15.3 | 3.6 | 5.5 |
| Computers | 99.3 | 7.6 | | | | | | | | | | | | | 16.5 | 0.0 | 3.9 |
| Instruments | 38.1 | 4.9 | | | | | | | | | | | | | | 1.8 | 3.7 |
| Motor Vehicles | 75.6 | 5.7 | | | | | | | | | | | | | | | 8.6 |
| Aircraft | 76.5 | 3.7 | | | | | | | | | | | | | | | |
| All Sectors | 51.5 | 7.2 | | | | | | | | | | | | | | | |

# 4 COMPETENCIES AND MANAGERIAL CHOICE: THE EFFECTS OF PRODUCT MIX AND HOME COUNTRY

It is already clear from the above analysis that managerial choice is constrained by firm's size and product mix. In particular, we have shown that:

- large firms are generally technologically *diversified*, and slowly changing over time , as the range of technological opportunities increases;
- however, each firm's *profile* of technological competencies remains very stable, and is strongly constrained by the products it makes;
- similarly, each firm's *direction* of technological search (and accumulation of competence) is strongly constrained by its prior competencies.

In other words, a firm's existing product mix and associated competencies strongly constrain the *directions* in which it seeks to exploit technological opportunities and acquire competence. We shall now extend these analyses to explore the determinants, not of the direction, but of the *rate* of the firm's technological search activities. We suggest that three factors will influence the rate of search.

1. The firm's *home country* will influence its rate of technological accumulation through the nationally-based supply and demand-side inducement mechanisms described by Porter (1990). These are likely to remain strong since, globalisation of markets and other things notwithstanding, large firms continue to perform the overwhelming proportion of their R & D activities (~90%) in their home countries (Patel and Pavitt, 1991; Patel, 1994).
2. The firm's *sector* of activity will influence its rate of technological accumulation. Given that the firm's competencies and directions of search are determined in large part by what it produces, and that technological opportunities are unequal across fields, firms will have varying capacities to exploit opportunities, and thereby varying rates of accumulation (Malerba, 1992).
3. *Firm-specific* factors will also influence the rate of technological accumulation. Given uncertainties, different managements will make different bets. Also, the professional background of managers, and their associated "rules of thumb" and professional loyalties, may influence the propensity to encourage technological accumulation[21].

In Table 11, we present the results of our analysis of the effects of home country conditions and of product mix (both measured through the appropriate aggregate indicators from our

[21] See, for example, Scherer and Huh (1992) and Bosworth and Wilson (1992), who have shown that, in the USA and the UK, the level of firms' allocation of resources to technological activities is positively associated with the presence of graduate scientists and engineers in top management.

large firm database) on various measures of the rate of accumulation of technological competencies in firms. From this it emerges that:

- both home country and product mix have a statistically significant influence on the rate of technological accumulation, whether measured in terms of patent per unit of sales, growth in patent share, or share of total patenting in fast-growing fields;
- the unexplained variance amongst firms nonetheless remains considerable – 56–80% of the total, which suggests that company-specific factors – and particularly those influencing the volume of resources allocated to technological accumulation – remain important[22].

**Table 11. Factors Influencing Firms' Rate of Technological Accumulation.**

| | Patent Intensity: 1985–90 | | Change in Patent Share: 1969–74 to 1985–90 | | Share of Patents in F–G: 1985–90 | |
|---|---|---|---|---|---|---|
| Dependent Variable | Coeff. | Std Error | Coeff. | Std Error | Coeff. | Std Error |
| Constant | –32.08* | 10.90 | 0.83 | 0.52 | –6.71* | 1.69 |
| Industry Average | 1.03* | 0.07 | 1.88* | 0.42 | 0.82* | 0.05 |
| Country Average | 0.62* | 0.16 | 0.68* | 0.07 | 0.38* | 0.07 |
| | | | | | | |
| R Sq (adj) | 0.33 | | 0.20 | | 0.44 | |
| F | 113.3* | | 57.1* | | 172.7* | |
| N | 462 | | 462 | | 447 | |

* Denotes Coefficient Significantly Different from zero at the 5% level.

## 5 CONCLUSIONS

The substantive findings of our paper are summarised at its beginning. We shall now explore their implications for policy, theory and the agenda for future research.

### 5.1 For Corporate Policy

Our results confirm and sometimes clarify some prescriptions on technology strategy in large firms, whilst casting doubt on others.

**The Strong Constraints on Feasible Choice.** Perhaps most important, we have identified a number of important constraints on the strategies for technological competence-building in large firms.

[22] Since all three dependent variables are based on patenting, part of the unexplained variance may reflect inter-firm differences in the propensity to patent the results of R & D and related technological activities. However, this is less likely to operate in shares of total patenting in fast-growing fields, where more than 55% of inter-firm variance still remains to be explained.

- Their technological strategies can only rarely be "focused", since the products they develop and make require the integration of knowledge from a range of technological fields (see also Freeman, 1982).
- Their competence to exploit specific technological opportunities is highly differentiated, and heavily dependent on past competencies accumulated through making specific classes of products.
- Their capacity to modify their profiles of technological competence is limited, and takes a long time (see also Rosenbloom and Cusumano, 1987).
- In addition to these constraints on the *directions* of technological accumulation, both home-country and industry characteristics have a significant influence on the firm's *rate* of competence accumulation, although the unexplained variance suggests considerable scope for managerial discretion.

**The Nature of Competencies.** We have also shown that the simple concept of "core competence" cannot encompass the range and variety of technology profiles found in large firms. Our four-fold classification shows that large firms also accumulate *background* – and manly production-related – competencies, the importance of which can sometimes outweigh *distinctive* competencies. This variety of inputs into large firms' competencies has other important consequences that we shall now explore.

**Technology Fusion.** The growing spread of firms' technological competencies in computing, biotech and materials must be seen in the context of the widespread and continuing importance of competencies in mechanical, chemical and instrumentation engineering. As Kodama (1986) has pointed out, effective innovation often requires the combined development of well-established and new technological fields, and takes considerable time, which is why firms' technological profiles change only slowly, and why the implementation of corporate technology strategy requires the effective integration of firm-specific-knowledge across a range of fields (see, for example, Henderson and Cockburn, 1993).

**Competence-Destroying Innovations?** It is also why "competence-destroying" innovations are less likely in large firms with diversified competencies and R & D programmes (Cooper and Schendel, 1976; Tushman and Anderson, 1987; Utterback and Suarez,1993). Although radical breakthroughs may destroy one part of such a firm's competence, it is unlikely to destroy them all. This can be seen in the new biotechnology, where – in spite of a slow start – established chemical and pharmaceutical firms have succeeded in combining the radical breakthroughs with their established fields of competence (Arora and Gambardella, 1992; Galimberti, 1993).

**"Technological Leap-frogging"?** Similarly, the multi-technology nature of many products reduces possibilities for "technological leap-frogging" by developing countries. Perez and Soete (1988) have suggested that radical new technologies open opportunities for late-comer countries and companies to by-pass (or "leapfrog") earlier paths of technological accumulation, and to enter new product areas with greater dynamism than more advanced countries and companies more firmly embedded in older paths of technological development. However, when new technologies must be combined or "fused" with older ones, the earlier paths of technological accumulation cannot be avoided. This remains the case in many sectors of central importance to economic development, including the electronics sector in East Asia, which depends heavily on technological competence in production engineering (Bell, 1984; Hobday, 1993).

**External Strategic Alliances as Complements to In-house Competence-Building.** Finally, we should note that the technological fields where firms have been acquiring an in-house capability most vigorously since the early 1970s – computers, biotechnology and pharmaceuticals, and materials (see Table 5) – are also those where firms have increased most vigorously their external alliances for technological exchanges and joint developments (see Mowery, 1988; Hagedoorn and Schakenraad, 1992). This suggests – as Granstrand and his colleagues have noted in micro-studies (1992) – that external alliances are complements to internal learning, and not substitutes.

### 5.2 For Theory

**Complexity and Path-dependency.** The variety, stability and differentiation of large firms' technological competencies, their close links to the products that they make, and the localised nature of their technological search, all confirm the importance of technological (and other) complexity in:

- constraining firms' processes of technological search (see, for example, David, 1975);
- allowing firms to differentiate themselves to explore and master different zones of technological complexity;
- explaining why the assimilation of radical new technology takes a long time.

**Technological Relatedness rather than Economies of Scope.** They also suggest the need for a more refined notion of "economies of scope" that allows them to be partial rather than complete. For example, our analysis in Table 7 shows virtually no competence-based economies of scope between chemicals and computers, but a much higher probability of their existence between chemicals and pharmaceutical products. A chemical firm would therefore have partial economies of scope, ( in that it would probably still need to invest in certain complementary fields of competence in order to enter pharmaceuticals) whereas in computers it would be starting from scratch. In fact, the earlier concept of "technological relatedness" (Rumelt, 1974) is analytically and operationally more useful, especially now that it can be measured directly.

**Explaining the *Core* – rather than the *Boundaries* – of the Firm.** Our analysis suggests that notions of firm-specific dynamic competencies provide a convincing empirical – and competence-based – explanation of the *core* (not the boundaries) of the firm (Dosi et al., 1992). In particular, our results in Tables 8 and 9 suggest that we are able to claim the following: "Show us a firms' profile of technological competencies, and we shall *probably* be able to predict the range of products it makes, and almost certainly be able to predict what it does *not* make".

**What Type of Variety?** "Variety" is an often used term in evolutionary economics[23]. Our analysis shows various possible definitions of the term, each of which should be carefully distinguished in any general scheme of things:

Variety *within* firms in the technological competencies that they embody;

- Variety *between* firms in their mix (or profile) of technological competencies, largely defined by the products they develop and make.
- Once given their profile of competencies and product mix, *lack* of variety in managerial decisions about their *directions* of search, but considerable variety in decisions about their *rate* of search.

### 5.3 For Future Research

**Technology and Firm Performance.** Continuing improvements in information technology and firm-level data bases are opening considerable possibilities for econometric explorations of the influence of technological activities on the performance of individual firms. Beyond standard cross-sectional studies, attention should be paid to:

- the effects of the level and field of education of management and the work force. These could influence both the nature of decisions about the allocation of resources to technology made under uncertainly, and the speed of learning (Bosworth and Wilson, 1992; Scherer and Huh, 1992; Prais, 1993; Pavitt and Patel, 1988)
- the dynamic interactions between technological activities, product diversification and performance.

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[23] See, for example, Metcalfe and Gibbons (1989).

**Corporate Strategy and Technology Management.** Qualitative studies (historical and case-based) will also be necessary to understand the dynamics of competence building and exploitation in large firms. In particular:

- the dynamic interactions in competence-accumulation amongst technologies, components, sub-systems and products (see, for example, Abernathy and Clark, 1985; Miyazaki, 1994);
- the organisational implications of different technologies and types of innovation (see, for example, Coombs and Richards, 1991; Tidd, 1993);
- the problems of corporate technology strategy in the firm that is multi-product, multi-divisional, and multi-technology (see, for example, Chandler, 1991, 1992);
- the problems of defining corporate competencies *ex ante* rather than *ex post.*

**A Red Herring.** We should also avoid trying to answer unanswerable questions, such as why particular firms choose to combine particular technologies in particular ways to make particular products, from amongst the (almost) infinity of mathematical possibilities that do exist. As in nature, firms evolve in a complex and path dependent world, where history matters. If Darwin and DNA cannot model and predict the emergence and existence of the elephant and the mouse, we should not be expected to do the equivalent in explaining why industries are what they are and not something else.

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