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Technological Diversification and Strategic Alliances

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5 Technological diversification and strategic alliances

Paola Giuri, John Hagedoorn and Myriam Mariani

1 Introduction

Over the 1980s firms and industries have experienced a process of "technological convergence" or "technology fusion" (Rosenberg, 1976; Kodama, 1986, 1992). Due to the complexity and multi-technology nature of products, different firms and industries came to share similar and wider technological bases (Granstrand and Sjölander, 1990; Granstrand and Oskarsson, 1994; Granstrand *et al.*, 1997; Patel and Pavitt, 1997). In many cases these wider technological bases are achieved through firms' technological diversification.

Unlike technological diversification, product diversification decreased over time through the processes of restructuring and refocusing of large diversified firms (Scott, 1993; Hoskisson and Hitt, 1994; Markides, 1995a). Empirical work witnessed the difference between technological diversification and product diversification (Granstrand, 1997; Granstrand *et al.*, 1997) suggesting that while in principle multi-technology firms can develop a wide range of different products, there are severe limitations to the acquisitions of the downstream assets needed to produce and commercialise products in a high number of different markets (Gambardella and Torrisi, 1998).

One way to get access to competencies that firms lack internally is by developing linkages with other companies. During the past two decades a number of studies in the economic and managerial literature have focused on the extent, motivations and characteristics of strategic alliances (Kogut, 1988; Contractor and Lorange, 1988; Hagedoorn, 1993; Dunning, 1993, 1995). There is also empirical evidence showing that the increasing technological diversification of firms is frequently associated with the use of strategic alliances (Mowery *et al.*, 1998).

Based on these literature, our chapter explores empirically the relationship between firms' internal technological profile – *internal* technological diversification – and diversification through strategic alliances – *external* diversification – in Europe, the USA and Japan. It examines some stylised facts highlighted in the literature about technological diversification, market diversification and strategic alliances, and explores the relationship between diversification strategies and firms' performances. More specifically, this work looks at three issues.

It first describes the extent of firms' internal technological diversification versus external technological diversification. We believe that firms invest internally in developing a wider range of technological competencies compared to external agreements. This is because the internalisation of knowledge aims at both enhancing firms' core-competencies, and at creating absorptive capacities to acquire technologies developed by others.

Second, it shows that technological diversification is more pronounced than product and market diversification. Although firms develop competencies in several technological fields they may find it difficult to access production and commercialisation assets for entering different businesses.

Finally, the chapter studies the relationship between firms' economic performance, internal technological diversification and external technological diversification. Most of the literature focuses on the impact of related and unrelated product diversification on firm performance. The results indicate that related diversifiers outperform unrelated diversifiers (Robins and Wiersema, 1995; Berger and Ofek, 1995; Markides and Williamson, 1994; Varadarajan and Ramanujam, 1987; Dubofsky and Varadarajan, 1987), and that refocusing has a positive effect on firms' performance (Markides, 1995a; Comment and Jarrell, 1995). We expect technological diversification to be positively correlated with firms' performance in specific sectors like transportation equipment where product development requires the integration of a wider range of different technologies compared to sectors like the ICTs.

To analyse these issues we combine firm level data on technological diversification, strategic alliances and economic performance in 13 industrial sectors from 1990 to 1997. The empirical analysis is based on a worldwide sample of 219 industrial firms selected from the largest 500 companies (Fortune 500, 1998–1999). For each company we collected information about the internal technological profile (*internal diversification*) and external alliances (*external diversification*). We assume that internal technological competencies of firms are reflected in the relative number of patents granted in each sector. Therefore, patents granted to our 219 companies are used to define their internal technological configuration. Strategic alliances are used to trace their external strategies in technology and production related operations. Firm level data are drawn from three datasets.

USPTO patent data in the period 1990–1997 are used to measure firms' internal technological diversification (Techline, 1999). These patents are classified in 27 technological classes.

Data on strategic alliances are drawn from the SDC database (Securities Data Company). These data are used to measure technological diversification by external operations, and diversification in production and marketing activities. The SDC database on joint-ventures, strategic alliances and licensing provides information on about 115,000 agreements. We selected 12,342 alliances signed by our sample companies during the period 1990–1997, and collected information on several of the agreements. By using the SIC codes of the alliance we classified each operation by business sector. We then developed a concordance table between the 27 technological classes in which patents are classified and the SIC codes of the alliances in the manufacturing sectors. Alliances in the service sectors, with the exception of telecommunication (SIC 4800) and software (SIC 7370), are excluded from the analysis. According to their content, alliances were also classified as *technological alliances* and *production and marketing alliances.*

Finally, the Compustat database provides information on firms' economic performance.

The chapter is organised as follows. Section 2 presents the background literature on technological diversification and strategic alliances. It focuses on the issues that will be explored in the empirical sections. Section 3 describes the data. Section 4 compares internal and external technological diversification to the diversification through production and marketing alliances during 1990–1997. Section 5 develops a multiple correlation analysis to study the relationship between internal and external diversification, and economic performance. Section 6 concludes.

2 On technological diversification and strategic alliances.

A number of contributions explore firms' technological and business diversification. As far as technological diversification is concerned, these studies show that during the past decades the complexity and multi-technology nature of products and processes led firms to broaden their technological base in order to develop new products and processes (Granstrand and Sjölander, 1990; Patel and Pavitt, 1994; Granstrand and Oskarsson, 1994; Granstrand *et al.*, 1997). The literature suggests that firms might develop technologies that are different but highly interdependent with their distinctive capabilities. They can also invest in complementary fields in order to be able to adopt and integrate technologies developed by external suppliers. Moreover, firms may want to develop some knowledge in non-core technologies in order to have a window on emerging technological opportunities. Or, still, they can internalise some "general purpose technologies" which are used in different products and processes. Some authors, however, point out that firms' technological profiles are difficult to change. They tend to be stable over time and evolve in a path-dependent fashion according to strong inter-sectoral differences. Furthermore, firms that successfully diversify technologically maintain a certain coherence between existing and new fields (Patel and Pavitt, 1997; Teece *et al.*, 1994; Breschi *et al.*, 1998).

Unlike technological diversification, product diversification decreased over time due to the process of restructuring and refocusing of large diversified firms (Scott, 1993; Hoskisson and Hitt, 1994; Markides, 1995a). Hence, firms broaden their technological knowledge, but they do not use all their competence to enter new businesses. Empirical studies witness the difference between technological diversification and product diversification (Granstrand, 1997; Granstrand *et al.*, 1997). Some of them point out that while in principle multi-technology firms can develop a wide range of different products, there are severe limitations to the acquisitions of the downstream assets needed to produce and commercialise these products in many different markets (Gambardella and Torrisi, 1998). Other studies focus on the impact of related and unrelated product diversification on firm performance. The results indicate that related diversifiers outperform unrelated diversifiers (Robins and Wiersema, 1995; Berger and Ofek, 1995; Markides and Williamson, 1994; Varadarajan and Ramanujam, 1987; Dubofsky and Varadarajan, 1987), and that refocusing has a positive effect on firms' performance (Markides, 1995a; Comment and Jarrell, 1995).

A branch of the literature on technological diversification focuses on the strategies that firms adopt to build up technological competencies internally. The distribution of patents across technological classes is used to measure the extent to which firms diversify technologically. In-house R&D investment, however, is not the only means that firms can use to enlarge their technological base. External collaborations help acquire competencies that are more "exogenous" to the firm (Hagedoorn and Duysters, 2002). They are a means to strengthen firms' critical technological competencies, to acquire general-purpose technologies that companies do not develop internally, to get access to frontier technologies produced by firms in other sectors, and to expand knowledge in complementary or more marginal fields. Some contributions explore the trade-off between the internal development and the "outsourcing" of technologies. Richardson (1972) suggests that similar and complementary activities should be maintained within the firm, while activities that are complementary but dissimilar can be accessed externally. Prahalad and Hamel (1990) claim that firms should invest internally in related areas or in core technologies, and use external alliances to acquire technological competencies in unrelated areas or in non core technologies. In addition, firms can use strategic alliances to get access to new and complementary technologies (Teece, 1986), to speed up firms' learning processes, to share the costs and risks of R&D activities, to exploit economies of scale and scope in research, to access new markets or production facilities, or to monitor the evolution of non core technologies (Hagedoorn, 1993). These issues have been studied intensively during the past two decades, when there has been a steep increase in the use of collaborative agreements between domestic firms in related markets and foreign companies in global markets (von Tunzelmann, 1995; Freeman and Hagedoorn, 1995; Hagedoorn and Schakenraad, 1994; Chesnais, 1988).

This chapter focuses on strategic alliances as a means to exchange technological knowledge and other downstream assets. The "competence-based" theories of the firm provide a valid support to the study of this issue. The basic idea is that economic institutions have different abilities to support the acquisition and development of knowledge or other assets. These abilities are firm-specific, they are cumulative, and determine firms' competitive advantages. Inter-firm linkages can help combine these firm-specific assets that require time to build up and that are hard to reproduce. Moreover, since the shared assets can be accessed without separating them from the developer firm, the problem of tradability is also bypassed (see, for example, Richardson, 1972; Kogut and Zander, 1992).

The empirical evidence suggests that various factors influence the choice between different types of external agreements, such as the pace of technological change, the complexity and the objectives of the transaction. Pisano (1991) and Teece (1992) demonstrate that when technological change proceeds fast, companies prefer flexible forms of organisation – i.e. strategic alliances versus mergers and acquisitions. Other contributions show that in industries characterised by rapid technological change, the scope for learning, the organisational change and the quick strategic response require flexible forms of organisation (Hagedoorn, 1993; Eisenhardt and Schoonhoven, 1996). By contrast, when transactions are complex, hierarchical organisations have superior monitoring and incentive aligning properties. Some contributions also show that the larger the number of partners, the broader the product and/or technology scope, and the wider the functional activities covered by an alliance, the higher the likelihood of the alliance being a joint venture or, more generally, an equity arrangement (Pisano, 1989; Garcia Canal, 1996; Oxley, 1997). Even though the empirical evidence on the relationship between the technological content and the organisational form of the alliances are mixed (Osborn and Baughn, 1990; Gulati, 1995) the preference for more hierarchical arrangements is more likely also when firms develop or transfer tacit know-how.

To conclude, in recent years there has been a trend towards the increasing technological diversification of firms and the intensification in the use of strategic technological alliances. Although the relationship between technological diversification and firms' performances deserves further attention, so far the empirical results suggest that there is a positive correlation between the two. The same positive relationship holds for strategic technological alliances and firms' performances, although the results are not clear across sectors (Hagedoorn and Schakenraad, 1994). By contrast, firms' performances are positively affected by the process of refocusing and restructuring of production and marketing activities (among others Markides, 1995a, 1995b; Montgomery and Wernerfelt, 1988; Amit and Livnat, 1988; Hitt and Ireland, 1986).

This work adds empirical evidence to some of these issues. It investigates the relationship between *internal* technological diversification and diversification through strategic alliances, and highlights differences across countries and sectors. It also explores the relationship between internal and external technological diversification and firms' economic performances. More specifically, we explore the following issues.

First, the chapter compares firms' *internal technological diversification* with *external technological diversification*. We expect the former to be more pronounced than the latter. Firms develop in-house critical technologies and try to maintain a frontier position in these fields. However, the multi-technology nature of products and processes leads companies to internalise knowledge in a wider range of technological fields. Competencies developed internally are also needed to evaluate, understand and assimilate outside technologies (Cohen and Levinthal, 1989, 1990; Rosenberg, 1990), and allow firms to guide the evolution of external collaborations by avoiding that the partners entirely shape the scope of the relationships.

Second, this work compares firms' *internal technological diversification* with *external market diversification* (see also Granstrand, 1997; Patel and Pavitt, 1994, 1997; Granstrand *et al.*, 1997). The expectation is that internal technological diversification is more pronounced than external market diversification. Although firms develop competencies in several technological fields, they may find it difficult to get access to production and commercialisation assets for entering different markets (Gambardella and Torrisi, 1998). The internalisation of a wide range of technologies does not imply the presence in "all potential" markets in which these technologies can be applied. Entry in different markets requires investments in downstream assets, some of which are extremely specific.

Third, by means of multiple correlation analysis, this chapter describes the relationship between firms' performances, internal technological diversification, and diversification through strategic alliances. We expect the results to be sector-specific, with some sectors like transportation equipment displaying a positive correlation between firms' performances and technological diversification. This is because, compared to industries like the ICTs, the transportation equipment sector requires the integration of a wider range of different technologies to develop the products.

3 Data

The empirical analysis focuses on a sample of 219 manufacturing firms. We drew 265 industrial firms from the Fortune Global 500 (1998–1999). From this sample we selected the 219 firms for which we have information on patents and alliances. Fifty firms are European, 121 are American, 48 are Japanese, four are from South Korea and two from Canada. We used the company primary SIC code (Standard Industrial Classification) to classify each firm in one of the 13 industrial sectors as shown in the Appendix (Table 5.A1).

For each company we collected information about the internal technological profile – *internal diversification* – and external alliances – *external diversification*. We assume that internal technological competencies of firms are reflected in the relative number of patents granted in different sectors.[1] Therefore, patents granted to our sample companies are used to define their internal technological configuration. We use strategic alliances to trace their external strategies in technology and production related operations.[2]

The empirical analysis is based on three sources of data.

Patent data are drawn from the Techline database that provides data on patents issued by the American Patent Office in 1990–1999. The total number of patents issued to our 219 sample companies from 1990 to 1997 is 309,574. The distribution of patents by region and sector is shown in the Appendix (Table 5.A2). The technologies in which firms' patent are classified according to 27 technological classes are described in Table 5.A3 of the Appendix.

Data on strategic alliances are drawn from the SDC database (Securities Data Company, 1999). The SDC database on joint-ventures, strategic alliances and licensing provides information on about 115,000 agreements. We selected 12,342 agreements signed by our sample companies from 1990 to 1997, and collected information about the primary SIC code of the participants, the activity developed within the alliance, the location of the participants, the technological content of the alliance, the direction of the technology flow, and all SIC codes in which the alliance is classified. By using the SIC codes of the alliance we also classified each operation by industrial sector and by one of the 27 technological classes in which patents are codified. The Appendix (Table 5.A3) shows the concordance table between technological fields – in which patents are classified – and the SIC codes of the alliances in the manufacturing sectors, as indicated by the SDC database. Alliances in the service sectors, with the exception of telecommunications (SIC 4800) and software (SIC 7370) are excluded from the analysis.

Alliances are then distinguished into:

- ***production and marketing alliances***: alliances aimed at obtaining downstream assets in marketing and production activities – i.e. Joint Marketing and Joint Manufacturing operations. The total number of market alliances is 5,840.
- ***technological alliances***: alliances in which some technological knowledge is exchanged trough technology transfer or joint innovative projects – i.e. Licensing Agreements and Joint Research Agreements. The number of technological alliances is 6,502. Technological alliances are divided into alliances through which firms acquire technological

knowledge and alliances through which firms transfer their knowledge to third parties. To differentiate between these two types of alliances we use the information on the direction of the technological flow involved in the alliance. The analysis below will focus only on the alliances used to acquire knowledge.

The distribution of technological and production alliances is shown in Tables 5.A4 and 5.A5 in the Appendix.

One problem in comparing firms' internal and external diversification concerns the use of different measures for the two strategies. We use patents to measure internal technological diversification, and strategic alliances to describe external technological and market diversification. The problem is that these two proxies measure different "objects", and that one patent is something smaller and technologically more specific than one alliance. Symmetrically, an alliance includes a wider range of activities and technologies compared to a patent. This means that the comparison between the number of sectors in which firms patent and the number of sectors in which they develop alliances could be biased because we are not comparing similar objects as it could be by comparing the patents produced by in-house R&D, and those generated by developing technological alliances. In other words, one would need data on the number and classes of patents developed internally, and the number and classes of patents developed by using external agreements. Unfortunately, these data are not available.

To mitigate this problem, a possible solution is to use the information provided by SDC on all technologies and sectors involved in each alliance. For each operation we have the number and the sectoral classification of the different technological "components". By using the SIC codes of these "components" we disaggregate each operation in different technologies, from 1 to 11 sectoral classes. This allows us to compare the number and classes of patents with the number and classes of alliances of the 219 companies in the sample.

4 Technological diversification and alliances

This section compares firms' internal technological profile with their propensity to engage in external alliances. We use Herfindhal indexes as indicators of diversification. The internal technological diversification (ITD) is proxied by the Herfindhal index of the number of patents of each firm in the 27 technological classes shown in the Appendix (Table 5.A3). The external technological diversification (ETD) is measured by the Herfindhal index of the number of technological alliances in the same 27 technological classes. Finally, the external diversification in production and marketing activities (EPMD) is measured by the Herfindhal index of the number of production and marketing alliances in the 27 classes. The index ranges between 0 and 1. A value close to 1 indicates that firms concentrate patents or alliances in few technological classes or only in one technological class when the index is equal to 1. The lower the index, the higher the degree of diversification.

Table 5.1 shows the average Herfindhal indexes by sector for the period 1990–1997.[3] On average, firms are less diversified externally than internally. The Herfindhal index for ITD is 0.24 compared to 0.46 and 0.50 for ETD and EPMD. In other words, firms produce patents in a wider range of sectors than those in which they develop external technological and production and marketing agreements. We will explore further the relationship between internal and external diversification later in this section. There are cross-sectoral differences in the level of diversification. Firms in the ICTs and chemical and pharmaceutical industries are more focused internally (ITD) than companies in the transportation equipment, metal, machinery and electrical equipment sectors. The same applies for ETD. As far as EPMD is concerned, chemical and pharmaceutical firms are more diversified than the sample average, while firms in the transportation equipment sector are more focused than the average.

Table 5.2 shows the Herfindhal indexes by macro-regions. The differences across regions are less marked than those across sectors. Japanese firms are more diversified technologically (ITD and ETD) than the European and the American ones, while European and Japanese firms are more diversified in production and marketing alliances (EPMD) than American firms. However, these patterns may reflect sectoral differences. The multiple correlation analysis performed in section 5 will better highlight sectoral and country differences.

We now turn to the relationship between firms' internal and external technological diversification (ITD and ETD). Table 5.3 shows the Pearson correlation coefficients among the three indexes of diversification calculated at the firm level. They are all positive and significant, suggesting that firms that diversify technologically, also diversify in marketing and production activities, and that internal technological diversification is associated with external technological diversification at the firm level.

Figures 5.1 to 5.3 show the position of each firm in terms of ITD, ETD and EMPD. Figure 5.1 shows the scatter diagram of internal and external technological diversification of firms. With the exception of a few companies, most firms are located below the diagonal of the graph, meaning that the Herfindhal indexes for patents (ITD) are lower than the Herfindhal indexes for technological alliances (ETD). This suggests that large firms have, on average, a more diversified internal than external technological profile. This is consistent with the multi-technology view of products and processes that leads firms to internalise knowledge in different fields in order to develop new products and processes. It is also consistent with the idea that firms invest internally to improve knowledge in different fields, both "core" and marginal ones, and to absorb technologies acquired externally. The few firms above the diagonal in Figure 5.1

Table 5.1 Herfindhal indexes by sector, 1990–1997

	ITD: Herfindhal index – average by sector	*No. of firms*	*ETD: Herfindhal index – average by sector*	*No. of firms*	*EPMD: Herfindhal index – average by sector*	*No. of firms*
Chemicals and Pharmaceuticals	0.26 (0.09)	50	0.51 (0.23)	49	0.44 (0.19)	50
Electrical Equipment	0.18 (0.12)	11	0.39 (0.31)	11	0.27 (0.14)	11
Electronics	0.22 (0.13)	28	0.41 (0.23)	27	0.43 (0.26)	26
ICT	0.39 (0.19)	41	0.58 (0.20)	39	0.68 (0.22)	37
Machinery	0.17 (0.06)	17	0.45 (0.22)	12	0.46 (0.24)	16
Metal	0.13 (0.04)	17	0.33 (0.14)	15	0.33 (0.22)	17
Other Manufacturing	0.24 (0.12)	18	0.57 (0.26)	15	0.71 (0.25)	17
Transport	0.19 (0.10)	37	0.33 (0.20)	35	0.51 (0.28)	37
Total	*0.24 (0.14)*	*21*	*0.46 (0.24)*	*20*	*0.50 (0.26)*	*21*
		9		*3*		*1*

Source: Techline (1999) and SDC (1999).

Note
*Standard deviations in parenthesis.

Table 5.2 Herfindhal indexes by country, 1990–1997

	ITD: Herfindhal index – average by region	*No. of firms*	*ETD: Herfindhal index – average by region*	*No. of firms*	*EPMD: Herfindhal index – average by region*	*No. of firms*
Canada	0.25 (0.00)	2	0.45 (0.00)	1	0.65 (0.00)	1
EU	0.22 (0.10)	50	0.43 (0.22)	46	0.40 (0.22)	49
Japan	0.20 (0.09)	42	0.38 (0.24)	41	0.42 (0.24)	41
Korea (South)	0.18 (0.01)	4	0.51 (0.38)	4	0.33 (0.16)	3
The United States	0.27 (0.17)	121	0.50 (0.23)	111	0.57 (0.26)	117
Total	0.24 (0.14)	*219*	0.46 (0.24)	*203*	0.50 (0.26)	*211*

Source: Techline (1999) and SDC (1999).

Note
*Standard deviations in parenthesis.

Table 5.3 Pearson correlation of Herfindhal indexes (firm-level elaborations), 1990–1997

	ITD	*ETD*	*EMPD*
ITD	1.000 (219)		
ETD	0.338 (203)	1.000 (203)	
EMPD	0.434 (211)	0.472 (198)	1.000 (219)

Source: Techline (1999) and SDC (1999).

Note
*Correlation is significant at the 0.01 level (2-tailed). Number of observations in parenthesis.

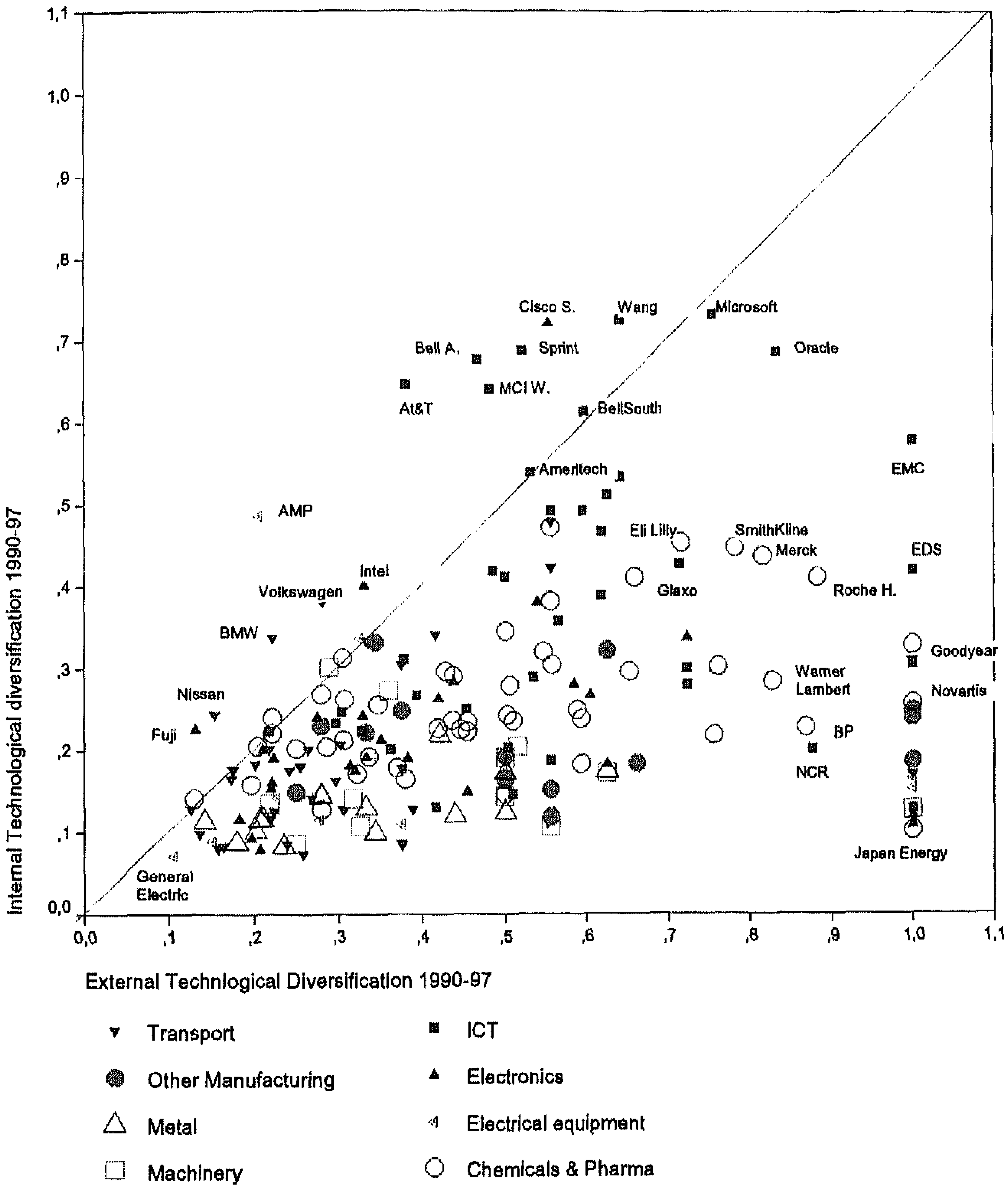

Figure 5.1 ITD vs ETD, 1990–1997.

are less diversified internally than externally. Some of them, like AT&T, Bell Atlantic, MCI WorldCom, Cisco System in the ICT and electronic sectors are very focused internally and much more diversified in terms of technological alliances. Finally, the Herfindhal index for ETD is 1 for a small group of firms. However, since the total number of alliances of these firms ranges between 1 and 8, the value of the Herfindhal does not necessarily reflect a strategy of technology focusing. Some of these firms are also very diversified internally.

Figure 5.1 also highlights the cross-sectoral differences shown in Table 5.1. The less diversified firms, both internally and externally, are in the ICT sectors and in the software industry (e.g. Microsoft and Oracle). In the chemical and pharmaceutical sectors there are both diversified and focused companies. Specifically, pharmaceutical companies are less diversified than those in chemicals and petrochemicals. The most diversified firms are in the electrical equipment sector (e.g. General Electric) and in the transportation equipment, metal and machinery industries.

Figure 5.2 confirms that internal technological diversification is more pronounced than external market diversification. The difference between the Herfindhal index for patents and the Herfindhal index for production and market alliances is almost always negative. This suggests that large companies are, on average, more diversified in developing internal technological competencies than in engaging in external market alliances. The sectoral differences are less marked.

Figure 5.3 compares firms' diversification in technological alliances and market alliances. It confirms the positive correlation between the two Herfindhal indexes as many companies are located around the diagonal. There are, however, cross-sectoral differences. Pharmaceutical and petrochemical companies diversify in production and marketing alliances more than in technological alliances. Firms in the ICTs and in the automotive and aerospace sectors are more diversified in developing technological alliances than in market alliances. Since strategic alliances might be a strategy to integrate or strengthen firms' internal competencies, these large firms broaden their technological competencies more than they do with their business portfolio. This is consistent with the idea that, even though a multi-technology firm might develop a wide range of products, it would find it extremely difficult to acquire the downstream competencies needed to enter different markets. Gambardella and Torrisi (1998) reach similar results in the electronics industry. They find that technological convergence in the computer, telecommunications, electronic and electrical equipment industries is not followed by a similar degree of diversification in downstream activities.

To sum up, there is a positive correlation between internal and external technological diversification, and between technological diversification and diversification in production and marketing activities. However, some questions remain unanswered on the goals that firms pursue when they

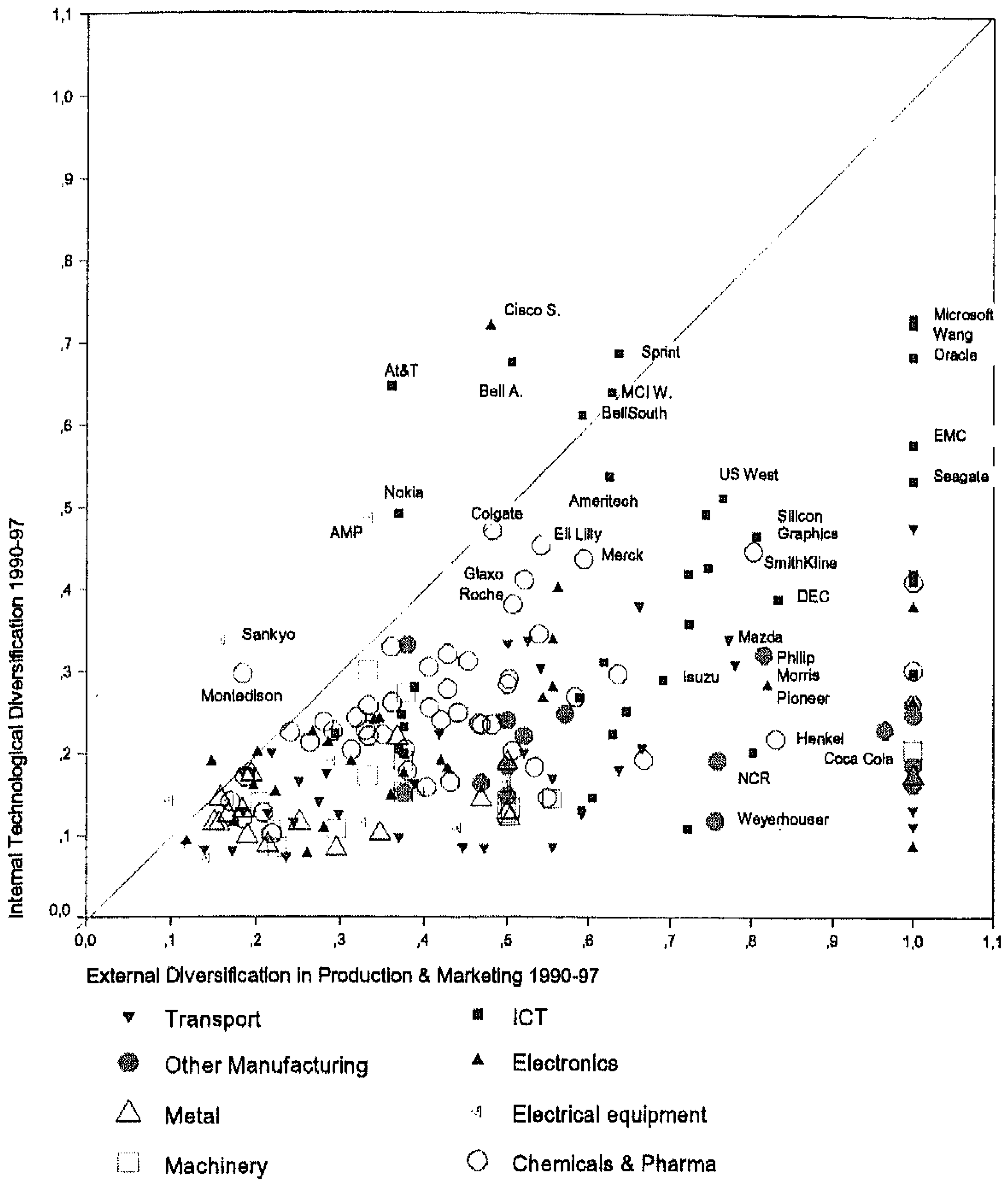

Figure 5.2 ITD vs EPMD, 1990–1997.

engage in external collaborations. For example, do firms invest externally in complementary or "non core" technologies that are not developed internally? Do firms invest internally in building up the absorptive capacity for acquiring technologies through external agreements? Do firms invest both internally and externally in critical technologies? In which sectors do firms use alliances for accessing production and marketing assets?

A deeper inspection in our data, and specifically a look into the set of technologies in which each firm patents and develops alliances helps answer these questions. For each company in the sample we identified the technological class with the largest number of patents, technological alliances and production and marketing alliances. We then computed the correlation coefficient among these top classes in the two sub-periods 1990–1993 and 1994–1997.

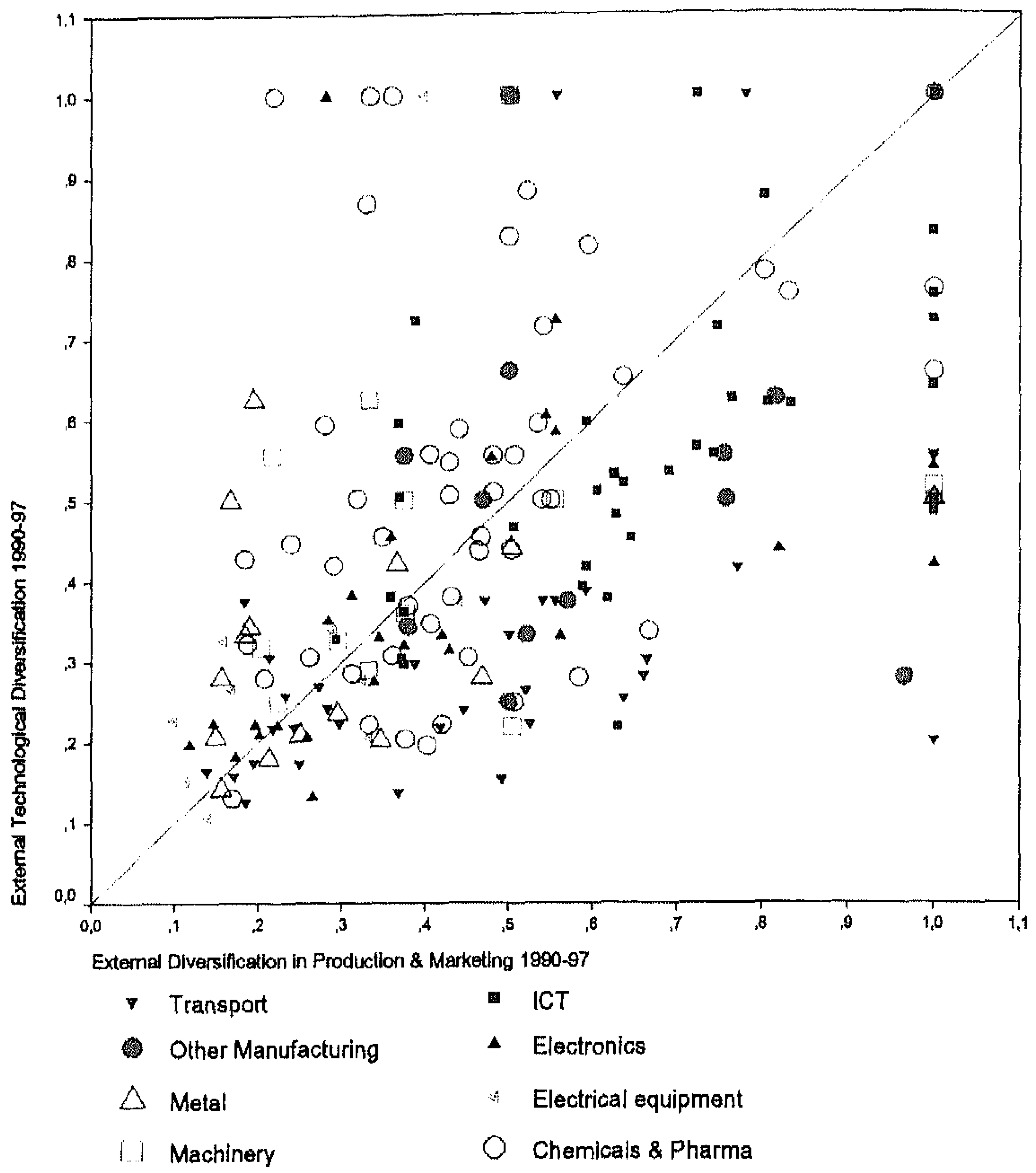

Figure 5.3 ETD vs. EPMD, 1990–1997.

The correlation coefficients between the top technological classes in which the 219 companies produce patents and engage in external collaborations are all positive and significant, suggesting that in many cases large firms concentrate patents and alliances in the same technological classes. However, these correlation coefficients decrease substantially from 1990–1993 to 1994–1997. While in 1990–1993 firms engaged in technological alliances in the same fields in which they patented, in 1994–1997 firms developed technological alliances in more diversified and complementary technologies compared to their core technologies.

There are, however, cross-sectoral differences. In the aerospace, electrical equipment, machinery, metal and petrochemical sectors, the top classes in which firms patent are the same as those in which they engage in alliances in a lower number of cases compared to firms in the chemical, pharmaceutical, computer and telecommunications sectors.

Table 5.4 Spearman correlation between top technological classes in ITD, ETD, EMPD (firm-level elaboration), 1990–1993 and 1994–1997

	ITD	*ETD*	*EMPD*
1990–1993			
ITD	1.000 (219)		
ETD	0.831 (219)	1.000 (219)	
EMPD	0.626 (190)	0.597 (190)	1.000 (190)
1994–1997			
ITD	1.000 (219)		
ETD	0.583 (192)	1.000 (192)	
EMPD	0.680 (201)	0.620 (179)	1.000 (201)

Source: Techline (1999) and SDC (1999).

Note
*Correlation is significant at the 0.01 level (2-tailed). Number of observations in parenthesis.

We can go a step forward in this analysis by comparing the top three technological classes in which each firm patents and develops technological alliances. In the ICT and electronic sectors – which includes computer, semiconductor, telecommunications, electrical equipment and other electronics – patents and technological alliances are concentrated in the same three technological classes. These classes are computers, telecommunications and semiconductors. Moreover, firms from all sectors in the *electrical-electronic filiere* develop a large share of external alliances among them. This process leads to a sort of technological convergence among the electrical-electronic companies. Only firms in the electrical equipment sector behave differently. They receive a large share of technologies from all the ICT sectors, but they are rarely the source of technologies to firms from the other sectors. Finally, alliances in other fields are very rare for the ICT firms, while companies in the electrical equipment and electronic sectors develop a high share of alliances in the chemical, pharmaceutical, automotive, aerospace, machinery and metal sectors.

Patents and alliances in chemical technologies show up in the top three positions for most of the firms in petrochemicals, chemicals and pharmaceuticals – the *chemical filiere*. This suggests that chemical technologies provide general and basic knowledge that cut across the three sectors in the *filiere*.

Second, in the pharmaceutical sector the top three technological classes in which firms patent are the same in which firms develop technological agreements. By contrast, in chemicals and petrochemicals, only one technological class is both in the top ranking for patents and technological alliances. This suggests that while pharmaceutical companies concentrate their innovative efforts in the same fields in which they also develop external technological agreements, petrochemical and chemical firms do differently. They focus internally on some technologies (i.e. chemicals, oil and plastics for petrochemical firms; chemicals, plastics and office equipment for chemical firms), and develop external linkages in other fields (chemicals, glass and pharmaceuticals in the case of petrochemical firms; pharmaceuticals, chemicals and computers in the case of chemical firms). Hence, the "convergence" between internal and external diversification strategies in these two industries is lower than in the pharmaceutical sector.

A third remark concerns the pattern toward the "downward specialisation" in the chemical and petrochemical sectors. By "downward specialisation" we mean that firms in the petrochemical sector enter the chemical sector, and that firms in the chemical sector move downward into the pharmaceutical sector. Both patents and alliances confirm this pattern. This is consistent with the history of the chemical industry in the past decades. Due to increased competition, firms' profitability in the chemical industry started to decline in the early 1960s. In the 1970s and 1980s, the oil shocks, the entry of competitors from the developing countries, the slower demand growth, the diminishing opportunities for product innovation made the profitability decline become a severe problem. Firms in a large number of chemical markets, especially basic intermediates, experienced excess-capacity. To solve their problems, firms started a process of restructuring. A number of companies in the US and Europe exited from the commodity chemical businesses, and moved into downstream sectors. In their place, many oil companies took over existing commodity chemical firms. This process led firms to specialise either on commodity chemicals, or on more downstream specialty sectors. The restructuring process occurred through a large number of inter-firm alliances and acquisitions, both in production and R&D (Arora and Gambardella, 1998).

A different example is given by the transportation equipment sectors, in which patents and alliances occur in different technological classes. Aerospace is a typical sector integrator of technologies for the realisation of a final complex product-system (i.e. aircraft, engine, missile). Firms in the aerospace sector internally develop process technologies, industrial machinery, industrial process equipment and electronic equipment. External technological alliances occur for the joint development of aircraft technologies, motivated by the exceptionally high costs of R&D projects and for the acquisition of other technologies to be integrated (i.e. computing, electronics). The technical classes in which firms concentrate the largest share of patents are different across firms in the aerospace sector, while in most cases firms develop technological and production and marketing alliances in the aerospace and parts technologies. By contrast, in the automotive industry, firms develop a larger share of alliances in the same sector in which they patent (motor vehicle technologies). A small number of alliances are used to get access to technologies and market assets in electronics, telecommunications, computers, semiconductors, electrical equipment, machinery and metal.

Firms in the machinery industry show a pattern similar to that in the automotive industry. However, the motivation that leads firms to establish a high number of collaborations with firms in other sectors are different from those that command the pattern of alliances in the automotive and aerospace sectors. The aerospace and aircraft sectors are integrators of technologies developed by others. They develop technological, production and market alliances to acquire knowledge that has to be integrated into the final products or processes. By contrast, the machinery sector is a transversal sector where firms develop alliances with firms in other sectors that are "users" of their products.

A final point concerns the pervasiveness and the general-purpose nature of the information technologies (Bresnahan and Trajtenberg, 1995). It is interesting that in non-IT sectors – such as the automotive, aerospace, machinery and chemical sectors – computer technologies and software show up in the top positions of technological alliances.

5 Diversification and economic performance

This section performs a multiple correlation exercise by means of OLS regressions. The purpose of these regressions is to describe the relationship between firms' performance and diversification strategies. We use a panel composed of 219 companies over 8 years during the period 1990–1997. From the Compustat database we collected various measures of performance. In order to check for the robustness of our results we performed five OLS regressions that use different measures of performance as dependent variables. Specifically, the regressions use as dependent variables on the return on invested capital, the return on total equity, the return on total assets, the gross profit margin, and the "Tobin's q" given by the ratio between the firm's market value and its book value. The regressors are our measures of internal and external diversification, the number of firms' patents and alliances in each year, the sales of the firms as controls for their size, and country, sectoral and time dummies.[4] Table 5.5 lists the variables of the regressions. All these variables are expressed in logs. The results of the econometric estimates are shown in Table 5.6.

Table 5.6 shows that our three measures of diversification – Herf ITD, Herf ETD, Herf EMPD – are positively correlated with firms' performances, meaning that firms that focus have also better economic results. However, only the coefficients of Herf ITD in the last three specifications and the coefficient of Herf ETD in all five specifications are significant. This suggests that not only do companies that focus internally have better performances, but also firms that engage in external technological agreements in few sectors have higher performances than companies that develop technological alliances in a large number of sectors.

Table 5.5 List of variables

Return on Invested Capital	Income Before Extraordinary Items divided by Invested Capital multiplied by 100 – 1990–1997
Return on Total Equity	Income Before Extraordinary Items divided by the average of the most recent two years of Shareholders' Equity – Total multiplied by 100 – 1990–1997
Return on Total Assets	Income Before Extraordinary Items divided by the average of the most recent two years of Assets – Total. This result is multiplied by 100 – 1990–1997
Gross Profit Margin	Total Revenue minus Cost of Goods Sold divided by Total Revenue* 100 – 1990–1997
Tobin's q	Market Value (Monthly Close Price multiplied by Common Shares Outstanding) divided by Book value – 1990–1997
Herf ITD	Internal technological diversification (ITD) proxied by the Herfindhal index of the annual number of patents assigned to each firm in the 27 technological classes shown in the Appendix (Table 5.3A) – 1990–1997
Herf ETD	External technological diversification (ETD) measured by the Herfindhal index of the annual number of firms' technological alliances in the 27 technological classes shown in the Appendix 1 (Table 5.3A) – 1990–1997
Herf EMPD	External diversification in production and marketing activities (EPMD) measured by the Herfindhal index of the annual number of production and marketing alliances in the 27 classes shown in the Appendix (Table 5.3A) – 1990–1997
No. of Patents	Number of annual patents assigned to each firm in 1990–1997
No. of Technological alliances	Number of annual technological alliances engaged by each firm in 1990–1997
No. of Production and Marketing alliances	Number of annual alliances in production and marketing engaged by each firm in 1990–1997
Sales-turnover	Gross sales reduced by cash discounts, trade discounts, returned sales, excise taxes, value-added taxes and allowances for which credit is given to customers – 1990–1997

Source: Compustat (1998).

Table 5.6 Estimates of the OLS regressions

	Dependent variables				
	Return on invested capital	*Return on total equity*	*Return on total assets*	*Gross profit margins*	*Tobin's q*
Constant	3.841*** (0.466)	3.644*** (0.450)	2.878*** (0.517)	5.975*** (0.258)	0.714 (0.879)
Herf ITD	0.087 (0.075)	−0.015 (0.073)	0.187** (0.078)	0.157*** (0.042)	0.367*** (0.076)
Herf ETD	0.188** (0.083)	0.158** (0.080)	0.216** (0.086)	0.133*** (0.046)	0.338*** (0.081)
Herf EMPD	0.000 (0.079)	0.016 (0.076)	0.048 (0.082)	−0.007 (0.043)	−0.074 (0.078)
No. of Patents	0.027 (0.029)	−0.030 (0.028)	0.030 (0.030)	0.048*** (0.017)	0.042 (0.030)
No. of Technological alliances	0.179*** (0.046)	0.151*** (0.044)	0.186*** (0.048)	0.176*** (0.026)	0.243*** (0.047)
No. of Production and Marketing alliances	−0.035 (0.052)	−0.020 (0.050)	−0.018 (0.054)	−0.012 (0.028)	−0.031 (0.051)
Sales-turnover	−0.099*** (0.036)	−0.014 (0.035)	−0.145*** (0.037)	−0.119*** (0.020)	−0.277*** (0.038)
Country dummies	Yes	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes
Number of observations	767	766	765	773	813
Adj. R-squared	0.401	0.382	0.465	0.570	0.534

Source: Compustat (1998), Techline (1999), SDC (1999).

Notes
$^{**}p<0.05$, $^{***}p<0.01$.
Standard errors in parenthesis.

Also the number of technological alliances is positively correlated with firms' performances. The coefficient of the number of technological alliances is positive and significant across all five specifications. Therefore, technological partnership is an effective means to get access to external knowledge that firms probably internalise and upon which the firm builds up internal competencies as suggested by the results in Table 5.4. This is particularly so if companies concentrate their efforts in few technological fields.

The coefficient of the number of patents over firms' performances is positive in four regressions, but it is significant only in one of them. This may reflect differences among sectors in the importance of technology over economic performance. To explore this issue, we run our regressions for each of the eight broad sectors shown in the Appendix. Apart from a few exceptions, the sectoral results (not shown here) are consistent with the estimates shown in Table 5.6. The coefficient of the number of patents is positive and significant in the chemical and pharmaceutical sector and in the electrical equipment sector.

As far as the internal technological diversification (Herf ITD) is concerned, the coefficient of Herf ITD is negative and significant only in the transportation equipment sector. In the other sectors, it is either positive and significant (in chemicals and pharmaceuticals and in the ICTs) or negative but not-significant (in the other five sectors). The coefficient of Herf ETD is positive and significant in the chemical and pharmaceutical sector. It is negative and significant in the electrical equipment industry. In the other sectors the coefficient of Herf ETD is not significant. The coefficient of Herf EPMD takes the positive sign in 5 sectors, but it is significant only in the metal sector. In the other industries the coefficient of this variable is not significant. Finally, the number of technological alliances is positive and significant in chemicals and pharmaceuticals, in the ICT sector and in transports. The number of alliances in production and marketing activities is negative and significant in chemicals and pharmaceuticals and in the "other manufacturing sectors".

These results are also consistent with another set of regressions (not shown here), in which we tested the correlation between the change in the degree of diversification from 1990 to 1997 and firms' economic performances. The results confirm that technological refocusing is positively associated with economic performances.

To sum up, when we run multiple correlation analysis to examine the relationship between firms' performance and the extent to which firms diversify internally and externally, the results indicate that:

1 internal technological focusing is positively correlated with firms' performances;
2 the external technological focusing is positively correlated with firms' performances;

3 the number of technological alliances is positively associated with firms' economic results.

The estimates are also robust across different specifications that use different indicators of firms' performances. It is worth noting that these results do not suggest that large firms refocus technologically. Rather, they say that less technologically diversified companies have also higher returns on invested capital, higher returns on total equity, higher returns on total assets, greater gross profit margins, and higher ratios of market value over book value. Better performances and technological focusing is also associated with a large number of cooperative agreements to get access to technological knowledge in a restricted number of sectors. Hence, firms that go in depth rather than in breadth in technological collaborations achieve better economic results.

A final comment on the estimates in Table 5.6 concerns the "relatedness" in firms' diversification strategies. Given the level of aggregation of technological classes on which we computed the Herfindhal indexes, these results may also suggest that only in very diversified sectors like the aerospace and the electrical equipment, internal and external technological diversification is positively associated with economic performance, as firms must invest in very different technologies to develop their products. In other sectors, our measure of technology focusing may indicate strategies of related diversification in several technological sub-fields. In this respect, our results may be consistent with the literature on relatedness and coherence in diversification. With respect to the effects of strategic alliances, this study suggests that the number of technological alliances is positively correlated with economic performances, when alliances are concentrated in the firms' core technologies. This is also consistent with other studies showing that mergers and acquisitions in unrelated sectors negatively affect company performances and lead to divestiture within a few years after the acquisition (Porter, 1987; Singh and Montgomery, 1987).

6 Conclusions

The aim of this chapter was to use added empirical evidence on the diversification strategies of large firms in different sectors. The chapter described the relationship between:

1 internal technological diversification and external technological diversification;
2 internal technological diversification and external market diversification;
3 firms' performances and the extent to which they diversify internally and externally.

To explore these issues, we compared the Herfindhal index of firms' patenting activity across 27 technological classes, with the Herfindhal index of technological alliances across the same technological classes. The results show that large firms from all sectors have, on average, a more diversified internal than external technological profile. This is consistent with the multi-technology view of the firm.

The comparison between firms' Herfindhal index in market alliances and the Herfindhal index in patents and technological alliances suggests that firms, on average, diversify more in technological alliances than in market alliances – even though there are some inter-sectoral differences. In general these results are consistent with existing literature showing that multi-technology firms might find it difficult to acquire the downstream competencies needed to enter different markets.

By simply comparing the top positions in which firms patent and develop technological alliances we also described the extent to which firms use strategic alliances to strengthen their internal competencies, or to enter different and complementary sectors. This comparison showed that in most cases large firms concentrate patents in the same technological classes in which they engage in strategic alliances. However, this pattern is more pronounced in sectors like the ICTs, chemicals and pharmaceuticals than in the others. In more diversified sectors, such as the aerospace, electrical equipment and machinery, firms develop a large share of technological and market alliances in complementary and non core technologies.

Finally, the multiple correlation analysis suggested that technological refocusing, both through internal and external strategies, is positively associated with firms' economic performances. The number of technological alliances is also positively related with economic performances. Further empirical investigation at a more disaggregated technological level may better explore the relationship between relatedness in technological diversification and economic performances. This would provide a support to the competence based theories of the firm, to the results on coherent diversification and diversification in product and market operations.

7 Appendix Sample descriptive statistics and industrial and technological classifications

Table 5.A1 Number of firms by sector and region

Broad sector	*Sector*	*Canada*	*Europe*	*Japan*	*South Korea*	*United States*	*Total*
Chemicals and Pharmaceuticals	Chemicals		9	3		5	*17*
Chemicals and Pharmaceuticals	Petrochemicals		9	2		9	*20*
Chemicals and Pharmaceuticals	Pharmaceuticals		5			8	*13*
Electrical Equipment	Electrical Equipment		2	4	1	4	*11*
Electronics	Other electronics		2	10	1	15	*28*
ICT	Computers		1	3		20	*24*
ICT	Telecommunications	2	3			12	*17*
Machinery	Machinery			3		14	*17*
Metal	Metal		7	5		5	*17*
Other Manufacturing	Food and tobacco		2	2		5	*9*
Other Manufacturing	Wood and paper					9	*9*
Transportation Equipment	Aerospace		2	1	1	10	*14*
Transportation Equipment	Automotive		8	9	1	5	*23*
		2	*50*	*42*	*4*	*121*	*219*

Source: elaborations from SDC (1999) and Techline (1999).

Table 5.A2 Number of patents by sector and region

Broad sector	*Sector*	*Canada*	*Europe*	*Japan*	*South Korea*	*United States*	*Total*
Chemicals and Pharmaceuticals	Chemicals		15,037	1,776		9,734	*26,547*
Chemicals and Pharmaceuticals	Petrochemicals		6,136	851		7,902	*14,889*
Chemicals and Pharmaceuticals	Pharmaceuticals		10,542			10,260	*20,802*
Electrical Equipment	Electrical Equipment		2,186	21,023	3,512	10,347	*37,068*
Electronics	Other electronics		10,071	31,236	3,274	27,246	*71,827*
ICT	Computers		91	12,228		22,542	*34,861*
ICT	Telecommunications	1,516	1,812			14,528	*17,856*
Machinery	Machinery			8,525		11,670	*20,195*
Metal	Metal		4,468	4,121		2,354	*10,943*
Other Manufacturing	Food and tobacco		2,016	270		1,366	*3,652*
Other Manufacturing	Wood and paper					2,522	*2,522*
Transportation Equipment	Aerospace		892	633	416	21,118	*23,059*
Transportation Equipment	Automotive		6,638	10,330	925	7,460	*25,353*
		1,516	*59,889*	*90,993*	*8,127*	*149,049*	*309,574*

Source: elaborations from Techline (1999).

Table 5.A3 List of technological classes, and concordance with industrial sectors of alliances

	Technological class	
1	Agriculture	Agriculture; Forestry and fishing
2	Oil and Gas Mining	Metal mining; Coal mining; Petrochemicals (extraction)
3	Power Generation and Distribution	Electric distribution equipment; Electrical industrial apparatus
4	Food and Tobacco	Tobacco; Beverages; Fats and oils; Cane sugar, except refining; Grain mill and bakery products; Preservated fruits and vegetables; Dairy products; Meat products; Other food
5	Textile and Apparel	Textile mills; Apparel and other textile products; Leather
6	Wood and Paper	Lumber and wood; Furniture and fixtures; Paper
7	Chemicals	Chemicals
8	Pharmaceuticals and Biotechnology	Pharmaceuticals and biotechnology
9	Medical Equipment and Medical Electronics	Measurement and control
10	Plastics, Polymers and Rubber	Rubber and plastic
11	Glass, Clay and Cement	Petrochemicals; Stone, clay and glass products
12	Primary Metals	Metal – primary
13	Fabricated Metals	Metal – products
14	Industrial Machinery and Tools	Construction and related machinery; Engines and turbines; Farm and garden machinery; Machinery
15	Industrial Process Equipment and Miscellaneous Machinery	Other industrial and process equipment machinery
16	Office Equipment and Cameras	Photographic equipments
17	Heating, Ventilation and Refrigeration	Other machinery
18	Computers and Peripherals	Computer and data processing and services; Computers and office equipment
19	Telecommunications	Telecommunication equipment; Household audio and video equipment; Telecommunication services
20	Semiconductors and Electronics	Semiconductors; Other electronics
21	Measurement and Control Equipment	Measurement and control
22	Electrical Appliances and Components	Electric lighting and wiring equipment; Household appliances; Miscellaneous electrical equipment and supplies
23	Motor Vehicles and Parts	Automotive; Motor vehicles and passenger car bodies; Motor vehicles parts and accessories; Motorcycles, bicycles and parts; truck and bus bodies
24	Aerospace and Parts	Aircraft; Aircraft engines; Aircraft parts and auxiliary equipment; Guided missiles, space vehicles, parts
25	Other transport	Other transport; Railroads; Water transportation
26	Miscellaneous Manufacturing	General building contractors; Heavy construction, except building; Miscellaneous manufacturing; Non metallic minerals, except fuel; Special trade contractors
27	Others	Printing, publishing and allied industries

Source: elaborations from Techline (1999) and SIC classification.

Table 5.A4 Number of technological alliances by sector and region

Broad sector	*Sector*	*Canada*	*Europe*	*Japan*	*South Korea*	*United States*	*Total*
Chemicals and Pharmaceuticals	Chemicals		233	30		177	*440*
Chemicals and Pharmaceuticals	Petrochemicals		86	8		97	*191*
Chemicals and Pharmaceuticals	Pharmaceuticals		218			373	*591*
Electrical Equipment	Electrical Equipment		31	307	1	108	*447*
Electronics	Other electronics		274	295	4	529	*1,102*
ICT	Computers		6	327		1,531	*1,864*
ICT	Telecommunications	76	77			615	*768*
Machinery	Machinery			90		53	*143*
Metal	Metal		50	73		18	*141*
Other Manufacturing	Food and tobacco		10	11		16	*37*
Other Manufacturing	Wood and paper					23	*23*
Transportation Equipment	Aerospace		36	16	20	216	*288*
Transportation Equipment	Automotive		171	75	16	205	*467*
		76	*1,192*	*1,232*	*41*	*3,961*	*6,502*

Source: elaborations from SDC (1999).

Table 5.A5 Number of production and marketing alliances by sector and region

Broad sector	*Sector*	*Canada*	*Europe*	*Japan*	*South Korea*	*United States*	*Total*
Chemicals and Pharmaceuticals	Chemicals		332	30		179	*541*
Chemicals and Pharmaceuticals	Petrochemicals		467	18		438	*923*
Chemicals and Pharmaceuticals	Pharmaceuticals		66			73	*139*
Electrical Equipment	Electrical Equipment		94	158	2	157	*411*
Electronics	Other electronics		239	198	0	183	*620*
ICT	Computers		7	116		585	*708*
ICT	Telecommunications	67	64			434	*565*
Machinery	Machinery			68		93	*161*
Metal	Metal		160	135		56	*351*
Other Manufacturing	Food and tobacco		59	4		92	*155*
Other Manufacturing	Wood and paper					32	*32*
Transportation Equipment	Aerospace		59	27	111	176	*373*
Transportation Equipment	Automotive		353	242	38	228	*861*
		67	*1,900*	*996*	*151*	*2,726*	*5,840*

Source: elaborations from SDC (1999).

Table 5.A6 Herfindhal indexes of sample firms, 1990–1997

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Aerospace	AlliedSignal Inc	0.081	0.16	0.17
Aerospace	BF Goodrich Co	0.128	0.39	0.59
Aerospace	Boeing Co, The	0.084	0.38	0.47
Aerospace	British Aerospace PLC	0.127	0.31	0.21
Aerospace	Daewoo Electronics Co Ltd	0.177	0.18	0.2
Aerospace	General Dynamics Corp	0.166	0.17	0.25
Aerospace	Lockheed Martin Corp	0.074	0.26	0.23
Aerospace	McDonnell Douglas Corp	0.086	0.24	0.45
Aerospace	Mitsubishi Heavy Industries Inc	0.084	0.16	0.14
Aerospace	Northrop Grumman Corp	0.086	0.38	0.56
Aerospace	Rockwell International Corp	0.098	0.14	0.37
Aerospace	Rolls-Royce PLC	0.201	0.26	0.52
Aerospace	Textron Inc	0.112	0.55	1
Aerospace	United Technologies Corp	0.116	0.22	0.24
Chemicals	Akzo Nobel NV	0.165	0.38	0.43
Chemicals	Asahi Chemical Industry Co Ltd	0.158	0.2	0.4
Chemicals	BASF Group	0.236	0.44	0.46
Chemicals	Bridgestone Corp	0.203	0.25	0.51
Chemicals	BTR PLC	0.121	–	0.18
Chemicals	Colgate Palmolive Co	0.472	0.56	0.48
Chemicals	Degussa AG	0.213	0.31	0.26
Chemicals	Dow Chemical Co	0.204	0.29	0.31
Chemicals	E I DuPont de Nemours & Co	0.142	0.13	0.17
Chemicals	Goodyear Tire & Rubber Co	0.329	1	0.36
Chemicals	Henkel KGAA	0.219	0.76	0.83
Chemicals	Hoechst AG	0.256	0.35	0.41
Chemicals	Imperial Chemical Industries PLC	0.193	0.34	0.67
Chemicals	Mitsubishi Gas Chemical Co	0.235	0.51	0.48
Chemicals	Montedison SpA	0.296	0.43	0.18
Chemicals	Procter & Gamble Co, The	0.178	0.37	0.38
Chemicals	Rhone Poulenc SA	0.235	0.45	0.47
Computers	3COM Corp	0.419	0.49	1
Computers	Apple Computer Inc.	0.427	0.71	0.75
Computers	Compaq Computer Corp	0.359	0.56	0.72
Computers	Dell Computer Corp	0.3	0.72	1
Computers	Digital Equipment Corp	0.389	0.62	0.83
Computers	Electronic Data Sys Corp	0.42	1	0.72
Computers	EMC Corp	0.578	1	1
Computers	Fujitsu Ltd	0.204	0.5	0.37
Computers	Harris Corp	0.232	0.3	0.38
Computers	Hewlett-Packard Co	0.146	0.51	0.6
Computers	IBM	0.289	0.53	0.69
Computers	Lexmark Int'l Inc	0.305	1	–
Computers	Microsoft Corp	0.732	0.75	1
Computers	NCR Corp	0.202	0.88	0.8
Computers	NEC Corp	0.224	0.33	0.29
Computers	OKI Electric Industry Co Ltd	0.2	0.36	0.38
Computers	Oracle Corp	0.686	0.83	1

Table 5.A6 continued

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Computers	Pitney Bowes Incorporated	0.187	0.56	–
Computers	Racal Electronics PLC	0.28	0.72	0.39
Computers	Seagate Technology	0.534	0.64	1
Computers	Silicon Graphics Inc	0.466	0.62	0.81
Computers	Sun Microsystems Inc	0.493	0.56	0.74
Computers	Unisys Corp	0.311	0.38	0.62
Computers	Wang Laboratories Inc	0.725	0.64	1
Electrical equipment	ABB Asea Brown Boveri	0.09	0.15	0.11
Electrical equipment	AMP Incorporated	0.486	0.21	0.33
Electrical equipment	Electrolux AB	0.115	0.28	0.33
Electrical equipment	Emerson Electric Co	0.11	0.38	0.44
Electrical equipment	General Electric Co	0.072	0.11	0.14
Electrical equipment	Hitachi Ltd	0.142	0.23	0.1
Electrical equipment	Samsung Group	0.166	1	0.5
Electrical equipment	Sankyo Co Ltd	0.337	0.33	0.16
Electrical equipment	Sharp Corp	0.191	0.34	0.29
Electrical equipment	Toshiba Corp	0.142	0.27	0.17
Electrical equipment	Whirlpool Corp	0.153	1	0.4
Food and tobacco	Coca Cola Co, The	0.23	0.28	0.96
Food and tobacco	Conagra, Inc.	0.248	0.38	0.57
Food and tobacco	Japan Tobacco Inc	0.184	0.66	0.5
Food and tobacco	Nabisco Group Holdings Corp	0.652	–	–
Food and tobacco	Nestle SA	0.192	0.5	0.76
Food and tobacco	Philip Morris Companies Inc	0.322	0.63	0.82
Food and tobacco	Sara Lee Corp	0.222	0.33	0.52
Food and tobacco	Snow Brand Milk Products Co Ltd	0.24	1	0.5
Food and tobacco	Unilever NV	0.332	0.34	0.38
Machinery	American Standard Cos Inc DE	0.133	–	0.5
Machinery	Applied Materials Inc	0.204	0.52	1
Machinery	Baker Hughes Inc	0.19	0.5	0.38
Machinery	Black & Decker Corp, The	0.127	1	0.5
Machinery	Brunswick Corp	0.172	0.63	0.33
Machinery	Caterpillar Inc	0.134	0.22	0.5
Machinery	Cummins Engine Company Inc	0.301	0.29	0.33
Machinery	Deere & Company	0.208	–	1
Machinery	Dover Corp	0.142	–	0.5
Machinery	FMC Corp	0.107	0.56	0.22
Machinery	Halliburton Co	0.273	0.36	0.38
Machinery	Ingersoll-Rand Co	0.144	0.5	0.56
Machinery	Kawasaki Heavy Industries Ltd	0.086	0.25	0.22
Machinery	Komatsu Ltd	0.107	0.33	0.3
Machinery	Mitsubishi Electric Corp	0.14	0.32	0.2
Machinery	Parker-Hannifin Corp	0.153	–	0.38
Machinery	Tyco International Ltd	0.222	–	–
Metal	Alcatel	0.219	0.42	0.37
Metal	Aluminum Company of America	0.121	0.44	0.5
Metal	Ball Corp	0.144	0.28	0.47

Table 5.A6 continued

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Metal	Gillette Co, The	0.125	0.5	0.17
Metal	Illinois Tool Works Inc	0.173	0.5	1
Metal	Kobe Steel Ltd	0.083	0.24	0.29
Metal	Mannesmann AG	0.146	0.28	0.16
Metal	Metallgesellschaft AG	0.116	0.21	0.25
Metal	Nippon Steel Corp	0.088	0.18	0.21
Metal	NKK Corp	0.102	0.2	0.35
Metal	Pechiney SA	0.129	–	0.5
Metal	Reynolds Metals Co	0.174	0.63	0.19
Metal	Sumitomo Electric Industries Ltd	0.099	0.34	0.19
Metal	Sumitomo Metals Industries Ltd	0.113	0.14	0.16
Metal	Thyssen AG	0.115	0.21	0.15
Metal	Usinor Sacilor	0.188	–	0.5
Metal	Viag AG	0.13	0.33	0.18
Other electronics	Allegheny Technologies Inc	0.086	–	1
Other electronics	Alps Electric Company Ltd	0.182	0.31	0.43
Other electronics	Canon Inc	0.191	0.33	0.42
Other electronics	Cisco Systems Inc	0.721	0.55	0.48
Other electronics	Eastman Kodak Co	0.19	0.22	0.15
Other electronics	Fuji Photo Film Co Ltd	0.226	0.13	0.27
Other electronics	Honeywell Inc	0.078	0.21	0.26
Other electronics	Intel Corp	0.401	0.33	0.56
Other electronics	Kyocera Corp	0.119	1	–
Other electronics	Litton Industries Inc	0.189	0.38	0.31
Other electronics	Matsushita Electric Industrial Co Ltd	0.152	0.22	0.22
Other electronics	Micron Technology Inc	0.281	0.58	0.56
Other electronics	Omron Corp	0.149	0.45	0.36
Other electronics	Philips Electronics NV	0.16	0.22	0.2
Other electronics	Pioneer Electronic Corp	0.283	0.44	0.82
Other electronics	Raytheon Co	0.116	0.18	0.17
Other electronics	Ricoh Co Ltd	0.24	0.28	0.34
Other electronics	Samsung Electronics Co Ltd	0.182	0.63	–
Other electronics	Siemens AG	0.093	0.2	0.12
Other electronics	Sony Corp	0.242	0.33	0.35
Other electronics	Tandy Corp	0.338	0.72	0.56
Other electronics	TDK Corp	0.175	0.32	0.38
Other electronics	Texas Instruments Incorporated	0.212	0.35	0.28
Other electronics	Thermo Electron Corp	0.108	1	0.28
Other electronics	TRW Incorporated	0.201	0.21	0.2
Other electronics	Western Digital Corp	0.264	0.42	1
Other electronics	Xerox Corp	0.267	0.6	0.54
Other electronics	Zenith Electronics Corp	0.381	0.54	1
Petrochemicals	Amoco Corp	0.205	0.2	0.38
Petrochemicals	Atlantic Richfield Co	0.183	0.59	0.53
Petrochemicals	British Petroleum Co PLC	0.228	0.87	0.33
Petrochemicals	Chevron Corp	0.313	0.31	0.45
Petrochemicals	ENI-Ente Nazionale Idrocarburi	0.238	0.59	0.28
Petrochemicals	Exxon Corp	0.223	0.46	0.35

Table 5.A6 continued

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Petrochemicals	Idemitsu Kosan KK	0.24	0.22	0.42
Petrochemicals	Japan Energy Corp	0.102	1	0.22
Petrochemicals	Mobil Corp	0.279	0.51	0.43
Petrochemicals	Norsk Hydro A/S	0.128	0.28	0.21
Petrochemicals	Occidental Petroleum Corp	0.382	0.56	0.51
Petrochemicals	Petrofina SA	0.345	0.5	0.54
Petrochemicals	Phillips Petroleum Co	0.291	0.44	0.5
Petrochemicals	Royal Dutch Petroleum Co	0.243	0.5	0.32
Petrochemicals	Schlumberger Ltd	0.226	0.45	0.24
Petrochemicals	Soc Nationale Elf Aquitaine	0.227	0.42	0.29
Petrochemicals	Texaco Inc	0.269	0.28	0.58
Petrochemicals	Total S.A.	0.146	0.5	0.55
Petrochemicals	USX Corp	0.221	0.22	0.33
Petrochemicals	Veba AG	0.171	0.32	0.19
Pharmaceuticals	Abbott Laboratories	0.25	0.59	0.44
Pharmaceuticals	American Home Products Corp	0.303	0.76	1
Pharmaceuticals	Bayer AG	0.262	0.31	0.36
Pharmaceuticals	Bristol-Myers Squibb Co	0.296	0.65	0.64
Pharmaceuticals	Eli Lilly and Co	0.453	0.71	0.54
Pharmaceuticals	Glaxo Wellcome PLC	0.411	0.66	1
Pharmaceuticals	Johnson & Johnson	0.305	0.56	0.41
Pharmaceuticals	Merck & Co Inc	0.437	0.82	0.59
Pharmaceuticals	Novartis AG	0.258	1	0.33
Pharmaceuticals	Pfizer Inc	0.321	0.55	0.43
Pharmaceuticals	Roche Holding Ltd	0.411	0.88	0.52
Pharmaceuticals	SmithKline Beecham Group PLC	0.447	0.78	0.8
Pharmaceuticals	Warner-Lambert Co	0.285	0.83	0.5
Telecommunications	AT&T Corp	0.646	0.38	0.36
Telecommunications	Ameritech Corp	0.538	0.53	0.63
Telecommunications	BCE Incorporated	0.251	0.45	0.65
Telecommunications	Bell Atlantic Corp	0.677	0.47	0.51
Telecommunications	BellSouth Corp	0.613	0.6	0.59
Telecommunications	British Telecommunications PLC	0.268	0.39	0.59
Telecommunications	CBS Corp	0.108	–	0.72
Telecommunications	General Elec Co PLC, The	0.128	1	–
Telecommunications	GTE Corp	0.131	0.42	0.59
Telecommunications	Lucent Technologies	0.224	0.22	0.63
Telecommunications	MCI Worldcom Inc	0.64	0.48	0.63
Telecommunications	Motorola Inc	0.247	0.3	0.37
Telecommunications	Nokia Group	0.492	0.6	0.37
Telecommunications	Northern Telecom Ltd	0.253	–	–
Telecommunications	SBC Communications Inc	0.412	0.5	1
Telecommunications	Sprint Corp	0.687	0.52	0.64
Telecommunications	US West Communications Inc	0.512	0.63	0.76
Transportation equipments	Bayerische Motoren Werke Ag	0.338	0.22	0.52
Transportation equipments	Chrysler Corp	0.184	0.2	1
Transportation equipments	Daimler-Benz Ag	0.129	0.13	0.18

Table 5.A6 continued

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Transportation equipments	Dana Corp	0.305	0.38	0.54
Transportation equipments	Denso Corp	0.132	–	1
Transportation equipments	Fiat S.P.A.	0.141	0.27	0.27
Transportation equipments	Ford Motor Co	0.163	0.3	0.39
Transportation equipments	Fuji Heavy Industries Co Ltd	0.334	0.33	0.5
Transportation equipments	General Motors Corp	0.126	0.22	0.3
Transportation equipments	Honda Giken Kogyo KK	0.207	0.3	0.66
Transportation equipments	Hyundai Corp	0.176	0.24	0.28
Transportation equipments	Isuzu Motors Ltd	0.31	1	0.78
Transportation equipments	Lear Corp	0.171	1	0.56
Transportation equipments	Man AG	0.178	0.38	0.18
Transportation equipments	Mazda Motor Corp	0.341	0.42	0.77
Transportation equipments	Mitsubishi Motors Corp	0.422	0.56	1
Transportation equipments	Nissan Motor Co Ltd	0.244	0.15	0.49
Transportation equipments	Renault, Regie National Des Usines	0.173	–	1
Transportation equipments	Robert Bosch GmbH	0.201	0.22	0.22
Transportation equipments	Suzuki Motor Corp	0.478	0.56	1
Transportation equipments	Toyota Motor Corp	0.224	0.22	0.42
Transportation equipments	Volkswagen AG	0.381	0.28	0.66
Transportation equipments	Volvo AB	0.18	0.25	0.64
Wood and paper	Avery Dennison Corp	0.149	0.25	0.5
Wood and paper	Boise Cascade Corp	0.262	–	1
Wood and paper	Georgia-Pacific Corp	0.187	1	1
Wood and paper	International Paper Company	0.152	0.56	0.38
Wood and paper	Kimberly-Clark Corp	0.164	0.5	0.47
Wood and paper	Mead Corp	0.248	1	1
Wood and paper	Union Camp Corp	0.163	–	1
Wood and paper	Westvaco Corp	0.165	0.5	1
Wood and paper	Weyerhaeuser Company	0.119	0.56	0.76

Source: elaborations from SDC (1999) and Techline (1999).

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Notes

1 We are aware of the limitations of patent-based proxies for measuring firms' innovative activity, and for comparing sectors and countries' innovative output. For a review see Griliches (1990).
2 Company-level aggregation of subsidiaries was performed before selecting the data.
3 We also calculated the Concentration Ratio for patents and alliances by firms and sectors. The results are consistent with the Herfindhal indexes.
4 We also run the OLS regressions by using different controls for the size of the companies. The results in Table 5.6 do not change significantly.

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