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Technological globalisation and innovative centres: the role of corporate technological leadership and locational hierarchy [1]

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Abstract

This paper examines two related propositions. First, that multinational corporations (MNCs) emanating from the most important locations in their industry are more likely to evolve towards technological strategies of geographically differentiating their innovative activities abroad. Second, that MNCs originating from weaker centres in the same industry tend rather to evolve towards a strategy of replicating in the profile of their technological development abroad the pattern of their home country specialisation. Using data on patents granted in the US to the largest European-owned firms for research carried out in European locations, the results from cluster analysis and from multiple linear regressions give broad support to these propositions. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Greater attention has been paid recently in the literature to the economics of industrial location and in particular, to industrial clusters. In the context of the recent emergence of global networks of trade and production and a move towards integrated technological systems, it becomes more important to understand how different types of activity are locationally dispersed within firms, and the role of multinational corporations (MNCs) in shifting the geographical division of labour.

Our study aims at a detailed consideration of the impact of MNCs on the location and characteristics of innovatory capabilities across national boundaries within Europe. Until now the MNC literature has typically focused on a binary measure of multinationality, distinguishing only between home and foreign activity. This paper investigates in greater depth the precise geographical and sectoral dispersion of technological activity in Europe by multinational firms, and by implication the potential of those MNCs to access, transfer and use knowledge in cross-border networks in Europe.

The principal geographical centres in technological activity have been identified separately for each industry. The identity of centres and the extent to which technological activity becomes geographically dispersed, vary between industries. In an interna-

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tional industry in which there is strong competition between MNCs based in different centres, there would be a stronger tendency for technological capacity to agglomerate geographically, but for MNCs to establish network linkages between these centres (Cantwell and Dunning, 1991). MNCs may pursue various strategies towards the international organisation of their technological activity which this paper examines. Their research activities in foreign centres can be either based in similar fields to their domestic research, or become more focused in their fields of technological development, according to locally specific knowledge in the host country. In this latter case, firms may utilise foreign technological activities as a means of complementing home country technological strengths. Such MNCs would need to construct internationally integrated corporate networks rather than a series of local market-oriented affiliates.

2. Background

It has been argued that the nature of technology is cumulative and context-dependent, and hence it is firm- and country-specific. Geographical proximity is important to the extent to which different lines of innovative activity influence one another, because of the existence of knowledge spillovers that are geographically bounded (Jaffe, 1986; Jaffe et al., 1993; Feldman and Audretsch, 1995). Given the uncodified, tacit nature of knowledge, such spillovers are not transmitted costlessly over geographical space; they are better transmitted through direct, frequent and face-to-face contact (Dosi, 1988). A significant geographical agglomeration of innovative activity may therefore be expected (Cantwell, 1991; Feldman, 1993; Feldman and Audretsch, 1995; Audretsch, 1995; Baptista and Swann, 1995; Almeida and Kogut, 1997). Innovation is expected to concentrate geographically in areas that provide agglomeration economies—or a high local density of specialised resources—that enhance and facilitate the innovation process. There is empirical evidence for a general tendency for innovations to cluster geographically, this being still more pronounced when considering individual industries.

States that contain concentrations of innovative inputs in some field of production will develop a comparative advantage in the industries in question. Since knowledge is cumulative, this advantage is self-reinforcing and may lead to further geographical agglomeration. In spatial terms, this would mean the emergence of geographical areas locked in by 'historical events' or 'chance' to a particular pattern of technological specialisation, and encourage the technology gaps between countries (which differ between fields of activity) to remain and even widen. Similarly, firms may be locked in to certain types of production and technologies. This phenomenon of 'path-dependence' and cumulativeness has been widely discussed in a variety of contexts, for example by Arthur (1989), who noted that modern and complex technologies often involve increasing returns to adoption.

This line of argument has important implications for the international diffusion of technology. The (international) diffusion of knowledge is argued not to be easy or 'automatic', so that international technological gaps have remained which, in turn, have led to international differences in economic performance (Verspagen, 1991). This means that, with the economies of agglomeration, while remaining within a paradigm, the leading countries or regions in any field—or international centres of excellence in research and innovation—will tend to maintain their position over time (Cantwell, 1991). The concept of a National System of Innovation is at the heart of contemporary studies on technical change and flows of knowledge, placing a major emphasis on the important role of nationally based institutions (including those of the state) in the innovation and diffusion processes (Patel and Pavitt, 1991b; Freeman, 1995; Patel, 1995). Within the EU, the trend towards a geographical concentration of technological activities sector by sector may become stronger still with the further progress of economic integration.

On the other hand, an increase in the process of globalisation has also been recognised in the recent literature. The ability of MNCs to develop integrated technological networks, to coordinate geographically diversified activities, has become an important direction of research in International Business (Dunning, 1993; Howells and Wood, 1993; Zander, 1995; Dunning, 1996). This view can be contrasted with the earlier theory of the product cycle model (Vernon, 1966) in which technology is diffused outwards from a single central location. The product cycle model represents a controversial depiction of international technology flows, which are seen as running from creation (in one location), through transfer to a firm or affiliate (in another location), to diffusion to a wider variety of firms in the host country. Overseas R&D, within the product cycle framework, is performed to facilitate the effective implementation of less profitable later stages of the cycle (embodying more accessible and standardised technologies). However, it has been suggested (Vernon, 1979) that a change in the attitude of MNCs has led, in some industries, to something similar to a programme of near simultaneous innovation in several major markets. The role of supply-side factors has therefore started to be emphasised as a reason in multinational firms for the decentralisation of R&D.

If knowledge diffusion is geographically bounded, MNCs could effectively have an important source of competitive advantage by locating in the technological centres of excellence to obtain access to differentiated streams of new knowledge (Almeida, 1996; Dunning, 1996; Fors and Zejan, 1996; Frost, 1996; Kümmerle, 1996a,b; Pearce, 1997; Dunning and Wymbs, 1997). In addition, it follows that the geographical dispersion of research to gain access to new lines of innovation may be related to technological diversification (Cantwell and Piscitello, 1997). The ‘new’ technologies are increasingly complex because of the complex nature of contemporary technological interdependencies (Dodgson, 1989). As a result, the firm may be obliged to broaden its technological activity through an international strategy if it wants to improve technological development even in its own immediate primary field of interest. The technological specialisation of each firm within its industry is closely related to the pattern of its corporate technological competence (Cantwell and Hodson, 1991; Cantwell, 1993). Given its focus on particular branches of technological development, a company may choose to concentrate its efforts on each area of activity in certain international locations rather than others.

An important debate has related technological globalisation to the significance of National Systems of Innovation. The globalisation phenomenon might be thought to increase the ease with which knowledge flows between countries. But globalisation also tends to increase national differentiation and technological specialisation. Finally, the two phenomena of globalisation and the relevance of the National System of Innovation may be seen as two complementary processes reinforcing one another in their development (Cantwell and Sanna-Randaccio, 1992; Archibugi and Michie, 1995; Cantwell, 1995; Howells and Michie, 1997). Countries have tended to narrow their technological specialisation and become more focused on areas of historical competitive advantage (Cantwell and Hodson, 1991; Cantwell, 1995). A country becomes therefore an attractive location for foreign-owned R&D in its sectors of specialisation. Simultaneously, the major firms, as a result of a shift towards ‘global’ strategies, have tended to geographically disperse research facilities to gain access to complementary paths of technological development. In this sense, globalisation makes the understanding of locational specificity more important, and the nation state remains a potent force in the competitive advantage of nations.

3. Hypotheses

This paper investigates technological globalisation, i.e., not just ‘internationalisation’, as being the generation of a complementarity between the geographical and sectoral (cross-technological field) dispersal of innovation in an industry, in the form of an internationally integrated network in a multinational firm. Geographical centres of technological agglomeration are identified and a hierarchy across those centres is established, industry by industry.

Differences in the geographical strategies of firms originating from higher order centres as opposed to lower order centres are then examined. The first proposition is that MNCs emanating from the higher order centres in any industry tend in recent years to have developed a more complex international division of labour, by geographically separating alternative fields of technological development (Cantwell and Sanna-Randaccio, 1992). Multinational firms from the leading centres are more likely to adopt strategies of differentiating their technological activity abroad (a special case of which is related diversification abroad) to support their core strengths at home. These MNCs would be better able to tap into the locally based technological expertise of their host countries and thereby be more likely to develop a more complex network of intra-firm cross-country specialisation in innovative activity. Their foreign research is increasingly 'home-base augmenting' rather than 'home-base exploiting', in the terminology of Kümmerle (1996a,b). Conversely, according to the second proposition, MNCs from lower order centres, when investing in a higher order centre for their industry, are more prone to simply extend their efforts in what are already their principal fields of technological endeavour, thus treating the higher order centre as a source of general expertise and skills, rather than as a source of more specific or specialised capability in some other particular fields.

These two hypothesised trends represent the two extreme ends of a spectrum of possible paths that may be followed in the evolution of internationally dispersed technological activity in an MNC over time. Let us suppose that in the typical or stylised case of the early establishment of foreign technological activity, the MNC opens up research in some smaller sub-set of the lines of development that it has already at home. This early research is designed to help exploit existing technological strengths by adapting products for local tastes, adapting processes in accordance with local resource availabilities and production conditions, through to creating a new industry in the host country in question (Cantwell, 1995). However, over time this sub-set of activities of those initiated by the parent company evolves. In an MNC which moves towards a more closely integrated international network the affiliate begins to specialise more intensively in certain lines of development, and to some extent does so in place of both the parent company and other affiliates (particularly if they are all located in an integrated economic area, such as the EU), with the other parts of the network being able to concentrate their efforts in alternative directions. This has the effect of increasing the degree of the geographical differentiation of the profiles of technological activity carried out in different sites within the same firm. At the other extreme, the affiliate simply extends its adoption of the number of established lines of technological development conducted already in the parent company, such that its sub-set of activities come closer to the full range of fields which characterise home country research. Within this range, the focus of activity also comes to resemble more nearly the areas on which the parent company has concentrated too. This might be thought of as a consolidation of a 'miniature replica' strategy in technological terms by the affiliate in question (Pearce, 1997).

We suggest, then, that leading MNCs emanating from the higher order centres for their industry are more likely to evolve in the first direction of the international integration of increasingly geographically differentiated activity; while the affiliates of MNCs from lower order centres which are themselves located in higher order centres are more likely to evolve in the direction of the closer replication of the pattern of home country technological specialisation. The rationale for these hypotheses is in terms of inter-firm differences in the capability to innovate, and differences in absorptive capacity (the ability to pick up and utilise knowledge from the firm's external environment).

According to our first proposition, MNCs from higher order centres tend to have the highest degree of technological competence among firms in their industry, and hence they have the resources available and the expertise needed to be capable of managing and organising an international network of more independently creative affiliates with a greater differentiation of technological paths, and to be better able to strategically integrate such diverse lines of development at the corporate group level. These leading MNCs do not just have greater innovative and organisational capability, but also possess a greater absorptive capacity (Cohen and Levinthal, 1989) to be able to recognise the relevance of and then to make use of external sources of innovation or opportunities emerging from different technological traditions or avenues of experimentation elsewhere.

By contrast, according to our second proposition, firms from lower order centres tend to have a more restricted and narrowly focused sphere of technological competence, and so are less ambitious in their foreign research (as in the range of their innovative efforts in general). In most foreign locations their objective continues to be confined to the adaptation of products and processes originally pioneered at home. When foreign research does become more exploratory in character, usually in the main centres to take advantage of the local expertise and technological spillovers available there, then it is generally as a means of directly facilitating the main lines of development already established at home. Besides being less capable of embarking on new directions or organising more refined kinds of the cross-border specialisation of activity, they are less able to absorb at home (or elsewhere) the fruits of new initiatives which lie outside their acknowledged areas of existing expertise. For the firms of lower order centres, the perception of what is relevant from the new knowledge being created in their external environment, or their view of what new areas of research they might move into tends to be more closely constrained (Penrose, 1959).

4. Methodology and data

The technological specialisation of firms in specific locations and the position of centres in Europe will be examined using data on European-owned and located firms' patents granted in the United States for the recent period 1969–1995. A large literature has pointed out the limits as well as the significance of patent statistics as an internationally comparable indicator of technological activity (e.g., Acs and Audretsch, 1989; Griliches, 1990; Archibugi, 1992).

The patent database distinguishes both corporate ownership and the location of inventive activity, as well as provides a classification of the types of technologies being created. All patents granted under the names of affiliates have been consolidated into the relevant corporate group for the year 1984, the parent groups being the world's largest industrial companies (as listed in Dunning and Pearce, 1985, with a few additions of companies apparently missed from the *Fortune* listings). The consolidated firms are also allocated to their primary industry of output according to the product distribution of their sales, so that corporate patenting was divided into 14 broad industrial groups. We focus here on firms in three broad industrial groups in particular: chemicals and pharmaceuticals, metal products and mechanical engineering, and electrical equipment and computing. The problem of the variation amongst industries in the propensity to patent the results of innovation activity does not influence the analysis unduly, since it is conducted at an intra-industrial level. In each of these industries and for the total of all industries, patents were further classified by both the country of origin of the invention (or the location of the corporate research facilities responsible) and the country of location of the parent firm. The European countries considered comprise the 14 EU countries (all countries except Portugal, while Belgium and Luxembourg were aggregated together and referred as Belgium–Lux), and the EFTA countries of Switzerland and Norway.

Firms' sectoral patterns of technological specialisation can be observed by means of a 'Revealed Technological Advantage' index (RTA) as developed by Soete, Cantwell, and Patel and Pavitt. For our purposes here, we have identified groups of European firms, in which within a selected industry each group has a common European country of origin (the home country of the parent company), and is defined in each case with respect to their technological activity in a common European host country. The RTA index is defined as a group's share of all US patenting in a technological field, relative to its share of all US patenting in all fields—all large firms patenting in the US, irrespective of their country of ownership or of where technological development is located. [3] The index varies around unity, so a value greater than one suggests that the group of firms is comparatively advantaged or specialised in the considered sector of activity in relation to other firms in its industry, and a value less than one shows comparative disadvantage. Similarly, the RTA index of a country which plays host to the research of the largest firms can be calculated across industrial groups of companies, defined as that country's share of all US patenting in a given industry relative to its share of all US patenting in all industries.

[3] Denoting by P_{ij} the number of US patents of the group of firms j in a particular industry in the technological sector i, the RTA index for each group in that industry is defined as: $(P_{ij}/\Sigma_j P_{ij})/(\Sigma_i P_{ij}/\Sigma_{ij} P_{ij})$.

Firstly, a hierarchy across European locations is defined industry by industry. Secondly, descriptive statistical methodologies, including cluster analysis, are used to identify the main characteristics of the data for each industry. Cluster analysis is a statistical technique used for summarising and finding groups in data (Everitt, 1980; Aldenderfer and Blashfield, 1984; Bailey, 1994; Ketchen and Shook, 1996). In each industry, clusters of groups of firms, in different European locations, are constructed according to their profiles of technological specialisation across activities. The detailed pattern of intra-industry technological specialisation of the largest firms across different European locations is then examined. We wish to investigate differences in the geographical technological strategies of firms from higher order centres when operating in foreign centres below them, by comparison with those of firms from lower order centres when engaged in research in foreign centres above them in the hierarchy. Finally, with this purpose in mind, multiple linear regressions are used to study the distribution of technological specialisation which different national groups of firms are inclined to carry out in particular foreign centres, identifying particular firms where appropriate. Cross-section regressions of technological sectoral profiles are run for each industry.

5. Empirical study

5.1. Locational hierarchy in Europe: a preliminary view

For the purposes of this paper, the degree of technological specialisation across industries for firms located in each European country is used as a means of measuring the relative significance of locations in Europe for each industry, i.e., to identify a locational hierarchy in Europe industry by industry. The RTA index of technological specialisation across the 14 industrial groups and 15 countries has been constructed as described earlier. Table 1 shows the results for the industrial groups of chemicals and pharmaceuticals, metal products and mechanical engineering, and electrical equipment and computing.

Values of the RTA index greater than unity suggest that a given group of firms, in this case being located in a given host country, is positively or comparatively advantaged in the industrial activity in question. Due to economies of agglomeration in the geographical location of innovation, these countries are likely to have been able to attract the research-related investments of large firms through the presence of reserves of local scientific and technological experience, and appropriate methods of work in the given industry. On the one hand, industries of national technological specialisation will attract the investments of foreign MNCs as they wish to gain access to the local innovative capacity in those industries. On the other hand, domestic firms abroad build on their inherited national strengths to develop related ones through internationally integrated strategies, which may feed back to benefit their home base.

For each industry, a hierarchy of locations in Europe can be established, defining higher to lower order centres, by ranking them according to the strength of their technological specialisation in that industry. To illustrate (Table 1), consider the chemical and pharmaceutical industrial group in which, respectively, Switzerland, Belgium–Lux and Germany have the three highest values in Europe of the RTA index, which reflects their significant comparative technological advantage in that industry, and consequently a higher position in the hierarchy. In the metal products and mechanical engineering industrial group, Sweden, and then Austria and Finland are first in the hierarchy. In the electrical equipment and computing industrial group, the Netherlands and Ireland represent the only two European locations to be comparatively specialised relative to the other locations.

However, the limited scope of the hierarchy as defined should be recognised. Firstly, difficulties can be created when constructing a RTA index that rely on small numbers of patents. Some small countries have been granted only low numbers of patents in the US. Consequently, they show substantial inter-industry variation in the RTA index and some very high or low values that may be misleading for the purposes of cross-country comparisons in any industry. These problems affect particularly such small European countries as Greece, Norway and Finland. Secondly, relatively small countries are in any case

Table 1
Values of RTAs by host countries for the activities of large firms in the selected three industries of output, ranked for the purposes of determining a hierarchy of European locations, 1969–1995

Chemicals and pharmaceuticals		Metal products and mechanical engineering		Electrical equipment and computing	
European host countries	RTA index	European host countries	RTA index	European host countries	RTA index
Switzerland	2.59	Sweden	4.11	The Netherlands	2.00
Belgium–Lux	2.32	Austria	3.80	Ireland	1.52
Germany	1.81	Finland	3.34	France	0.96
Norway	1.63	Greece	2.65	Greece	0.76
Italy	1.52	Norway	2.52	Norway	0.74
UK	1.40	Spain	1.95	Sweden	0.73
Denmark	1.15	Denmark	1.95	UK	0.71
France	1.08	Germany	1.71	Italy	0.67
Ireland	1.01	Switzerland	1.57	Germany	0.66
Greece	0.92	UK	0.99	Austria	0.65
Austria	0.75	Belgium–Lux	0.91	Switzerland	0.54
Spain	0.72	France	0.83	Spain	0.53
The Netherlands	0.57	Italy	0.48	Denmark	0.47
Sweden	0.52	The Netherlands	0.40	Belgium–Lux	0.45
Finland	0.07	Ireland	0.26	Finland	0.05

typically more internationalised and specialised in their technological activities than large ones (Archibugi and Pianta, 1992). Small and open economies are to some extent forced to specialise in selected niches due to a relative lack of resources and technological expertise to carry out relatively expensive contemporary R&D that entails many risks and uncertainties. In such a setting, a small open economy can be superior only in a limited range of technologies within any given industry. Technological advantages or disadvantages, measured by values of a broadly defined RTA index, will therefore be more neatly contrasted for small countries than for large ones. As a result of their high technological specialisation, some small countries may be represented among the highest order centres in the hierarchy for a particular industry, even though they are not overall the most important centres in the industry in question.

Finally, a locational hierarchy as defined for our purposes within each industrial group should not be interpreted too strictly but considered in a broader context, allowing for a more qualitative assessment of our countries as described in the literature (Patel and Pavitt, 1991a). Therefore, it is reasonable to expect that leading, higher order centres in a given industry are those that have the highest comparative technological advantages, measured by the RTA index (and inversely for lower order centres). However, it is admittedly often difficult to rank locations precisely, as more information is needed in order to evaluate the actual significance of slightly different values of the RTA index for different locations, e.g., where several—'higher order'—centres exhibit RTA values well above one.

5.2. Cluster analysis

The patent data were sorted into 18 broadly defined technological sectors derived from the US patent classification. In each industrial group, important technological sectors were selected on the criterion of possessing at least 100 patents from European-located research over 1969–1995 (listed in Annex Table 1). The three broad industrial groups of chemicals and pharmaceuticals, metal products and mechanical engineering, and electrical equipment and computing were examined. The firms were selected on the basis of both European location and ownership. These large firms were further aggregated into (1) domestic national groups with respect to their operations at home, and (2) national groups in each other non-domestic European location. The selected groups of firms were required to possess a minimum of 50 patents for each period. The composition of these groups of firms is reported in Appendices A–C. The sectoral patterns of technological specialisation of the different categories of firms are examined through the RTA index. It is worth noticing that while firms from the UK have reached a high degree of internationalisation of their technological activity, in some industries they have preferred the US to Europe as foreign location. As a consequence, it is not surprising that British-owned firms with sizeable European-located affiliates are generally poorly represented in this data set.

The technique of cluster analysis is useful to summarise the data and, in an explorative way, to group the different categories of firms into 'clusters' according to their similarities or dissimilarities in terms of technological specialisation (cross-sectoral distributions of RTAs). Two different methods have been chosen to produce the cluster solution: the Ward's hierarchical agglomerative method of the squared Euclidean distances and the density linkage method, using non-parametric density estimation. [4]

5.2.1. Results from the cluster analysis

The two clustering methods are carried out to check for the accuracy of the results as a form of validation procedure. The main results for the Wards' and density linkage methods are summarised in Tables 2–4. [5] The clusters' solutions provide a good overview of whether or not the patterns of technological specialisation in affiliates in foreign locations are similar to the equivalent for their parents and other companies located in their home domestic environment. When the technological specialisation pattern of a national group of firms originating from some given European country, and operating in a given foreign European location, is clustered away from its home country specialisation pattern, it suggests that this group has tended to adopt an internationally integrated strategy between differentiated lines of development carried out in geographically dispersed sites. Conversely, when the group of affiliates is clustered with its home country's operations, it is likely that those affiliates have continued to develop their home technological strengths in the foreign location in question.

For the chemicals and pharmaceuticals industrial group (Table 2), the best represented and most widely internationalised firms (within Europe) come from Germany and Switzerland, which are two important European higher order centres in this industry. German firms have tended to adopt a strategy of technological differentiation when they were settled in the UK, France or Italy, focusing in particular on the British, French and Italian expertise in pharmaceuticals technologies (which is not a German specialisation in terms of the RTA values). German affiliates located in Switzerland, though the outcome may be unclear, seemed relatively technologically distinctive in general and compared with their home lines of technological specialisation, highly specialised in food and tobacco, mechanical engineering and office equipment technologies. German affiliates in Belgium and in Austria seemed to continue to develop their home technological strengths in chemicals, although German firms may also have taken advantage

[4] Since clusters from the Ward's method can be heavily distorted by outliers, the method has been applied to the samples after having removed potential outliers (using estimated probability densities). The hierarchical agglomerative Ward's method was chosen because there is no need to predetermine the number of groups or clusters, and because it tends to produce the best results. It is the most commonly used clustering method and the one which in most studies tends to provide the best performance. In hierarchical agglomerative methods, each group of firms begins in a cluster by itself. In successive steps the two closest clusters are combined, thus reducing the number of clusters by one in each step. In the final step, all groups of firms are brought together in a single cluster. The relatively unbiased method of density linkage has also been used, since the Ward's method may be biased towards finding clusters possessing certain characteristics related to size (number of members), shape or dispersion. The chosen type of density linkage is the kth-nearest-neighbour method where $k=2$. For further reference see: Sarle (1983), Aldenderfer and Blashfield (1984), SAS Institute (1985), Bailey (1994), Ketchen and Shook (1996).

[5] The results from cluster analysis are originally presented with dendrograms (tree graphs). There is not a standard objective procedure to choose the relevant number of clusters. However, the SAS software package derives three measures that suggest the optimal number and composition of clusters: the Cubic Clustering Criteria, the Pseudo F statistic and the Pseudo t^2 statistic.

Table 2
Chemicals and pharmaceuticals industrial group

Number of clusters	Corporate groups' nationality	Foreign host country groups clustered with home country's operations	Foreign host country groups clustered away from home country's operations
4	Germany	AU–BL	UK–IT–FR
	Switzerland	G–UK–IT–FR	AU
	UK	G	FR–BL
	France	–	UK
	Belgium–Lux	–	UK–G
	Netherlands	–	UK
7 (7 modal clusters)	Germany	AU (SD)	UK–FR–IT–BL (AU–UK–FR–IT–BL)
	Switzerland	G–FR (G–FR)	AU–UK–IT (AU–UK–IT)
	UK	–	FR–BL–G (FR–BL–G)
	France	–	UK (UK)
	Belgium–Lux	–	UK–G (UK–G)
	Netherlands	(G)	UK (UK)

Ward's minimum variance cluster analysis, and the parenthesis contains the results for the Density Linkage cluster analysis.
Total number of corporate groups: 28. Note: the domestic corporate groups of Italy, Sweden and Norway were included but their European-based foreign technological activities did not meet the criteria for being kept in the sample. Norwegian, German firms in Switzerland and Dutch firms in Germany were excluded from the Ward analysis.
Cluster analysis on the selected domestic corporate groups and national corporate groups in the different foreign locations, 1969–1995.
Codes used for European host countries referred in Tables: Germany = G; Netherlands = ND; United Kingdom = UK; Switzerland = SD; Italy = IT; Sweden = SN; France = FR; Austria = AU; Belgium–Lux = BL; Norway = NW.

of locally-based technological expertise, for example in mechanical engineering in Belgium and metals technologies in Austria.

Swiss affiliates appear to have a pattern of technological specialisation distinctive from their home base when located in Austria, and probably when located in the UK or Italy. While Swiss-owned research located in Austria is strongly focused on chemicals and pharmaceuticals technologies (also an indigenous Swiss specialisation), another distinctive important technological sector is rubber and plastic products. Swiss affiliates operating in Germany and France seemed to have a similar technological specialisation to that of the Swiss domestic firms in the industry, being particularly specialised across the principal fields of chemicals and pharmaceuticals. In France, Swiss affiliates were also specialised in other manufacturing and non industrial, and the local area of expertise in mechanical engineering. The story is similar for Swiss affiliates operating in the UK and Italy, specialised in chemicals, but the pattern was however less clear as these affiliates became more specialised in professional, photographic and scientific instruments (which is not a Swiss speciality).

British-owned firms in France are highly specialised in other manufacturing and non-industrial, and pharmaceuticals which is also a French indigenous area of expertise. In Belgium, British affiliates are mostly specialised in the important Belgian research sectors of chemicals (also British speciality), and rubber and plastic products. The pattern is more difficult to interpret for British firms operating in Germany as they are particularly specialised in their home technological strengths in mechanical engineering, other manufacturing and non-industrial and pharmaceuticals, and also in a few other areas in metals, non-metallic mineral products, and professional and scientific instruments.

The Belgian pattern of foreign technological activity was more distinctively focused in a few areas when located in Germany (chemicals and pharmaceuticals) and the UK (chemicals and food and tobacco products). However, the Belgian technological activity abroad reflects in this case the dominant position of the leading Belgian firm Solvay. The French foreign technological activity in the UK, represented by the firm Rhone-Poulenc, was more narrowly specialised in pharmaceuticals compared with the broader range of French domestic technological activity. Dutch-owned firms in Germany (principally Akzo) are particularly specialised in mechanical engineering, rubber and plastic products, and non-metallic mineral products technologies, which are also home lines of specialisation. Swedish and Norwegian firms, while their foreign operations were not large enough to be represented in this sample, showed a specific distinctive pattern of technological specialisation, and stayed apart from any other European cluster (being highly specialised in metals, and other manufacturing and non-industrial technologies).

This first analysis provides some support for the suggested hypotheses. Large firms originating from the leading centres in the chemicals and pharmaceuticals industry—Germany, to a lesser extent Switzerland—tend to have adopted international strategies of the differentiation of technological activity across geographically separate sites for a significant part of their research. Swiss-owned firms operating in Germany seemed broadly to extend their home country technological specialisation, while they appear to be more prone to broaden their fields of technological development when operating in other European locations. Large firms such as the French Rhone-Poulenc, the Belgian Solvay and the Dutch Akzo seem to have moved towards a more geographically differentiated and internationally integrated strategy with respect to the composition of their foreign technological activity, which is nevertheless still importantly based on their home technological strengths. This outcome reflects the concentration of those firms' technological capability abroad in only a few of their home expertise areas. Smaller and/or less significant European countries or centres in the industry such as Sweden and Norway tend to have very distinctive, concentrated, patterns of technological specialisation.

With regard to the metal products and mechanical engineering industrial group (Table 3), the cluster results are more difficult overall to interpret than for chemicals and pharmaceuticals. One of the reasons for that could be that the mechanical engineering industry is much less geographically concentrated. Swedish-owned firms located in Switzerland, Italy,

Table 3
Metal products and mechanical engineering industrial group

Number of clusters	Corporate groups' nationality	Foreign host country groups clustered with home country's operations	Foreign host country groups clustered away from home country's operations
4 (4 modal clusters)	Sweden	(SD)	UK–FR–ND–G (UK–FR–ND–G–IT)
	Switzerland	–	ND–G–IT (ND–G–IT)
	Germany	FR–AU (FR–SD)	SD (AU)
	Austria	–	G (G)
	Netherlands	(G)	G
	UK	–	G (G)
7	Sweden	–	UK–FR–ND–G (UK–FR–ND–G–IT–SD)
	Switzerland	–	ND–G–IT (ND–G–IT)
	Germany	FR–AU (FR–SD)	SD (AU)
	Austria	–	G (G)
	Netherlands	(G)	G
	UK	–	G (G)

Ward's minimum variance cluster analysis, and the parenthesis contains the results for the Density Linkage cluster analysis.
Total number of corporate groups: 25. Note: the domestic corporate groups of Belgium–Lux, Finland, Norway and France were included but their European-based foreign technological activities did not meet the criteria for being kept in the sample. Norwegian, Swedish firms in Switzerland and Italy were excluded from the Ward analysis.
Cluster analysis on the selected domestic corporate groups and national corporate groups in the different foreign locations, 1969–1995.
Codes used for European host countries referred in Tables: Germany = G; Netherlands = ND; United Kingdom = UK; Switzerland = SD; Italy = IT; Sweden = SN; France = FR; Austria = AU; Belgium–Lux = BL; Norway = NW.

the UK, France, the Netherlands, and Germany seemed to carry out foreign research in related but geographically differentiated technological activity, thought all specialised abroad in the broad technological field of mechanical engineering which is also a Swedish home speciality. Swedish firms in Switzerland are heavily focused on the home Swiss-specific domestic activity of pharmaceuticals and to a lesser extent on mechanical engineering and rubber and plastic products. Swedish affiliates in Italy are particularly concentrated and differentiated in their technological activities (high values of the RTA index) in motor vehicle and then in mechanical engineering, metals, other transport equipment and rubber and plastic products. In the UK, Swedish affiliates are specialised in the British indigenous specialities in metals and power plants. Swedish firms located in France and the Netherlands are developing related technologies in professional and scientific instruments, and in addition metals technologies in the Netherlands. Swedish-owned affiliates located in Germany, at that level of technological classification, are distinctively specialised in mechanical engineering.

Foreign-owned firms from the UK and Austria were relatively technologically distinctive in Germany compared to their respective specialisation patterns in their home countries, both specialised, for example, in the locally based expertise in chemicals. Swiss affiliates also had a distinctive pattern of technological specialisation throughout 1969–1995 in Germany (mechanical engineering, non-metallic mineral products and metals), the Netherlands (mechanical engineering) and Italy (metals and chemicals). The technological pattern of German and Dutch firms abroad may be unclear for interpretation. German affiliates in France are engaged in some of their home fields of technological specialisation in chemicals (also a French speciality) and other manufacturing and non-industrial; and also in other important French indigenous fields in electrical equipment and rubber and plastic products. Norwegian large firms were here again specialised in quite different technological fields by comparison with the other European firms in the sample.

Sweden seem to be the major centre for technological activity in Europe for the metal products and mechanical engineering industry. As this might sug-

Table 4
Electrical equipment and computing industrial group

Number of clusters	Corporate groups' nationality	Foreign host country groups clustered with home country's operations	Foreign host country groups clustered away from home country's operations
3	Netherlands	FR–BL–AU–UK–G	SD–SN
	France	IT–BL–G	–
	Germany	NW–SD–AU–SN	–
	UK	–	–
	Sweden	–	SD
	Switzerland	–	–
6 (6 modal clusters)	Netherlands	BL–AU (BL–UK–FR)	SD–SN–FR–UK–G (SD–SN–AU–G)
	France	–	IT–BL–G (IT–BL–G)
	Germany	AU	NW–SD–AU–SN (SN–AU–NW–BL)
	UK	–	(FR)
	Sweden	–	SD (SD–G)
	Switzerland	–	(G)

Ward's minimum variance cluster analysis, and the parenthesis contains the results for the Density Linkage cluster analysis.
Total number of corporate groups: 26. Note: the domestic corporate groups of Italy was included but its European-based foreign technological activities did not meet the criteria for being kept in the sample. German firms in Belgium, British firms in France, Swiss and Swedish firms in Germany were excluded from the Ward analysis.
Cluster analysis on the selected domestic corporate groups and national corporate groups in the different foreign locations, 1969–1995.
Codes used for European host countries referred in Tables: Germany = G; Netherlands = ND; United Kingdom = UK; Switzerland = SD; Italy = IT; Sweden = SN; France = FR; Austria = AU; Belgium–Lux = BL; Norway = NW.

gest, Swedish metals and machinery firms are seen to have adopted a more internationally integrated strategy for their technological activity across national boundaries in Europe.

Among the electrical equipment and computing group (Table 4), the Netherlands emerges clearly as a dominant centre, due to the exceptional position of its domestic firm Philips. The strong position of the Netherlands as a major centre in Europe corresponds with a relative Dutch technological advantage in electrical-related activity. In addition, the Dutch large firms exceptionally (along with Belgian firms) conduct on average more of their technological activities abroad than within their home country.

By comparison with the sectoral spread of activity in the parent company, the majority of Philips' foreign affiliates seemed to have engaged in a complementary but differentiated set of technological activities. Subsidiaries in Switzerland and Sweden had comparable sectors of technological specialisation, especially in the development of other manufacturing and non-industrial technologies which are not a Dutch specialisation, and in a Dutch speciality in pharmaceuticals. Subsidiaries located in Austria showed a technological focus comparable to their home advantage in metals technologies, but were distinctive in their specialisation in office equipment and mechanical engineering. In Belgium, Dutch affiliates were specialised in their home fields of expertise in pharmaceuticals, metals and electrical equipment, and in the host-specific technological field of other manufacturing and non-industrial. Philips' affiliates operating in Germany seemed to have similarities with their home technological specialisation in rubber and plastic and non-metallic mineral products, although it has also concentrated on other transport equipment technologies and professional and scientific instruments which are indigenous technological advantages. Philips when located in France has relied on some of its home technological strengths in pharmaceuticals and electrical equipment, but also on other manufacturing and non-industrial technologies which are not Dutch specialities, but represent the pattern of locally based French expertise. Philips in the UK showed sectoral patterns of technological advantages in electrical equipment and pharmaceuticals which are both Dutch and British specialities, and professional and scientific instruments and other manufacturing and non-industrial, two important British specialisation areas.

As for the large firms of other nationalities, German firms operating in Sweden, Austria, Switzerland, Belgium or Norway appeared to concentrate their research activity on a few selected technologies; professional and scientific instruments in Sweden (also a German speciality), other manufacturing and non-industrial technologies in Austria and Switzerland (and electrical equipment), pharmaceuticals in Belgium, and office equipment in Norway. Swiss affiliates in Germany were distinctively specialised overall especially in nuclear reactor technologies, which emulates the most important technological specialisation of German domestic firms in this industry.

5.3. Regression analysis

For the purposes of regression analysis, the same data were again classified into 18 sectoral groups of technological activity. In addition, the 18 technological groups were further disaggregated into 56 technological sectors. The most important technological sectors both at the levels of 18 and 56 sectors were identified like earlier on the criterion that taken together, firms in the three industrial groups considered in turn possessed at least 100 US patents in each field during 1969–1995 (Appendix D).

This part of our study aims to analyse and explain the extent to which the degree and the composition of specialisation in technological activity in affiliates in foreign centres is similar or dissimilar to that in their parent companies, and to that of indigenous firms in the relevant host country. The hypothesis is that for firms from the leading centres or centre in an industry, their geographically dispersed technological activities have tended to become more specialised (and perhaps also diversified) in accordance with the pattern of local comparative advantage in innovation in each host country. In contrast, it is expected that firms from less important centres in the same industry have tended to focus upon and extend (in depth rather than breadth) their home technological strengths in their foreign research. To test this proposition, cross-section regressions were run using the selected groups of firms. In all regressions, the dependent variable measures the technological specialisation pattern of foreign-located research in a particular centre that is carried out by a particular national group of firms. The explanatory variables are those of both the corresponding domestic (parent company) and foreign (indigenous firm) patterns of technological specialisation. The regression equations are as follows:

$$\mathrm{RTA}_{ij} = \alpha + \beta_i \, \mathrm{RTA}_{ii} + \beta_j \, \mathrm{RTA}_{jj} + \varepsilon_{ij}$$

where RTA_{ij} represents the RTA index or technological specialisation pattern of the foreign-located research of the national group of firms i in the foreign location j, RTA_{ii} signifies the RTA index or technological specialisation pattern of the domestic national group of firms i in their own country i, and RTA_{jj} the RTA index or technological specialisation pattern of the foreign national group of firms j in their own country j. The regression equation was first run using the level of technological classification of 18 sectors, and then again using the level of 56 sectors. To control for the skewness in some of our RTAs distributions, the regressions were run using the logarithmic transformation of the RTA index. To avoid the problem with zero values which occur in the logarithmic transformation, a constant of 1 was added to the RTAs, i.e., $\ln(\mathrm{RTA}+1)$. The results of the regressions are reported in Tables 5–7.

5.3.1. Results from the regression analysis

Higher order centre firms in the chemicals and pharmaceuticals industry (Table 5), namely German-owned firms, appear to have foreign patterns of technological specialisation closely related to locally-based technological expertise when operating in lower order centres. The technological specialisation of German firms in Italy is significantly and positively influenced by the domestic specialisation of indigenous Italian firms at the broader level of technological disaggregation, since German firms are especially active in Italian research in pharmaceuticals and rubber products. However, this statistical significance does not continue to hold at a more detailed level of disaggregation due to the absence of technological activity of German firms in Italy in the development of inorganic chemicals, which is relatively important to the domestic Italian firms. Even though the technological activity carried out by German firms in the UK cannot be significantly explained by the regressions, a more qualitative analysis of the RTA distributions reflects a quite similar pattern to that found for German-owned research in Italy, as one would expect from the fact that the UK is a less important centre overall for the chemicals and pharmaceuticals industry than is Germany. While German affiliates in the UK are active in important British research in pharmaceuticals, they are not active in the other principal sectors of technological development of British-owned chemical firms at home, in particular textile and clothing machinery and equipment.

The technological specialisation of Swiss firms in France is significantly and positively influenced, at the more detailed level of technological disaggregation, by both the home and host countries' technological strengths. Swiss firms in France are especially active in bleaching and dyeing processes, which are a specialisation of both Switzerland and France, in other organic chemicals and pharmaceuticals which are a domestic Swiss specialisation, and in general industrial equipment and specialised chemical machinery which is a French speciality. British-owned firms located in Belgium (mainly ICI) develop technologies, at the more detailed level of disaggregation, in synthetic resins and fibres, chemical and allied equipment, and rubber and plastic products, which are also important to the domestic activity of the large Belgian firm Solvay.

Swiss firms that operate in the UK appear to have their local activity positively influenced by their home strengths in chemicals technologies at both levels of technological disaggregation, and especially in bleaching and dyeing and other organic compounds. The significant negative coefficient on the host country technological specialisation for the regression of Swiss firms in the UK is due to the influence of Ciba-Geigy. This Swiss firm acquired the photographic British firm Ilford, which is highly specialised in photographic chemicals and equipment, while these technological fields are not important for domestically-owned British firms in the chemicals and pharmaceuticals industry. However, the UK is a centre for the photographic research of foreign-owned firms, in a history that traces back to the early UK research laboratory of Eastman-Kodak

Table 5
The results of the cross-section regressions using the logarithms of the selected corporate groups over 1969–1995, for the chemicals and pharmaceuticals industrial group, using the 56 and 18 sectoral groups classification of technological activities

Dependent variables national origin (i)	Host European location (j)	Cross-section regressions on the selected technological sectors among 18			Cross-section regressions on the selected technological sectors among 56		
		Overall regression significance	Estimated β_i	Estimated β_j	Overall regression significance	Estimated β_i	Estimated β_j
Germany	UK	ns	0.50	−0.12	ns	−0.23	−0.08
Germany	Italy	s*	0.02	1.39*	ns	0.08	0.41
Germany	France	ns	0.90	0.13	ns	0.19	0.02
Germany	Benelux	ns	0.37	0.17	ns	0.28	−0.08
Germany	Switzerland	ns	−1.41	1.10	ns	−0.35	0.62
UK	Germany	ns	0.44	−0.17	s**	1.17*	−0.81
UK	France	ns	1.08	0.08	ns	0.44	−0.10
UK	Belgium–Lux	ns	−0.16	0.41	ns	−0.13	0.31*
France	UK	ns	0.73	−0.12	ns	−0.37	0.30
The Netherlands	Germany	s**	1.75**	−1.76	s**	1.20**	−0.73
The Netherlands	UK	ns	0.12	0.52	ns	0.12	0.02
Belgium–Lux	Germany	s*	0.02	1.36**	s*	0.37*	0.62
Belgium–Lux	UK	ns	−0.07	0.35	ns	0.29	0.24
Switzerland	Germany	s**	0.50*	0.73*	s**	0.94**	0.13
Switzerland	UK	ns	0.67	−0.14	s**	0.51**	(−0.67)**
Switzerland	Italy	ns	0.94	−0.11	ns	0.14	0.29
Switzerland	France	ns	0.71	0.46	s**	0.73**	0.78**
		Number obs. = 12			Number obs. = 29		

** and * indicate significance at the 1 and 5% level, respectively.
Significant positive correlations were found between the national domestic corporate groups of Germany and Italy, and Germany and Switzerland at both levels of classification.

(Cantwell and Hodson, 1991), and so the pattern of Swiss-owned technological development in the UK follows a local tradition of foreign-owned (as opposed to indigenous) research in this field.

On the other hand, lower order centre firms in the chemicals and pharmaceuticals industry that operate in the higher order centre of Germany seem to continue to develop their home technological strengths. We find that the coefficient of the home domestic pattern of technological specialisation (β_i) is nearly always significant and positive for the regressions involving the British, Dutch, Swiss and Belgian firms located in Germany. British firms in their German research replicate their home country technological profile, particularly at a detailed level of technological disaggregation in textile and clothing machinery and equipment. Dutch-owned firms in Germany (strongly dominated by one firm: Akzo) extend their home country technological specialisation in textile and clothing machinery and equipment and rubber products. Swiss firms in Germany significantly fit at both levels of disaggregation their home country lines of specialisation in bleaching and dyeing processes, agricultural chemicals and pharmaceuticals. At the broader level of disaggregation, Swiss firms' technological specialisation is also significantly related to the local German specialisation, as chemicals and pharmaceuticals and biotechnology are broadly two areas of technological specialisation of both countries. The Belgian firm Solvay in Germany reproduces its home country lines of specialisation in inorganic chemicals, when looking at the detailed level of technological disaggregation. Nevertheless, this pattern is lost at a broader level of technological classification as chemicals is treated as a large consolidated field and in this case the pharmaceuticals sector becomes relatively better represented as the most important local specialisation of Solvay in Germany.

Higher order Swedish-owned firms in the metal products and mechanical engineering industrial group (Table 6) do not in general statistically fit the local profile of technological specialisation when operating in lower order centres. Swedish-owned firms in Switzerland do reflect locally-based technological specialisation in chemical processes and other organic compounds, and especially in pharmaceuticals. Those affiliates do not however operate in other important Swiss indigenous specialities such as textile and clothing machinery, and yet reflect some of their home-specific specialisation such as in electrical devices and systems technologies. At a more disaggregate level of the technological classification therefore, the statistical fit would tend to be more with the home Swedish profile of technological specialisation. Swedish firms located in the UK are sourcing British domestic research in power plants, extending their home specialisation in metal working equipment, and developing their parents' areas of technological specialisation in other important British research sectors in other manufacturing and non-industrial technologies, metallurgical processes and other industrial equipment (but not in other British areas of expertise, in particular ships and marine propulsion). As a consequence, the technological specialisation of this group of firms significantly fit their home Swedish lines of specialisation at the more detailed level of technological disaggregation.

Since Sweden is overall a major European centre in this industry, one would expect Swedish-owned firms to have begun to carry out foreign research that reflects some important host-specific technological strengths when looking qualitatively at the RTA distributions in greater detail. In Germany, Swedish affiliates are specialised in indigenous research in textile and clothing machinery, but they do not research in the other important German research areas of chemicals (chemical processes, inorganic chemicals, synthetic resins and fibres, other organic compounds), pharmaceuticals and printing and publishing machinery. Swedish firms in the Netherlands are active in locally-based research in other specialised machinery, metallurgical processes and metal working equipment, but not in the important Dutch specialities of distillation processes, chemical processes, chemical and allied equipment, assembly and material handling equipment and rubber and plastic products. Swedish affiliates located in France are engaged in local fields of technological specialisation in rubber and plastic products, although they are also distinctively specialised in textile and clothing machinery. French domestic technological research is otherwise relatively focused on the chemicals and pharmaceuticals sectors. Finally, all Swedish affiliates except those in Switzerland show some specialisation in metal working equipment, which is a sector

Table 6
The results of the cross-section regressions using the logarithms of the selected corporate groups over 1969–1995, for the metal products and mechanical engineering industrial group, using the 56 and 18 sectoral groups classification of technological activities

Dependent variables national origin (i)	Host European location (j)	Cross-section regressions on the selected technological sectors among 18			Cross-section regressions on the selected technological sectors among 56		
		Overall regression significance	Estimated β_i	Estimated β_j	Overall regression significance	Estimated β_i	Estimated β_j
Germany	Switzerland	ns	0.19	0.42	ns	0.02	0.13
Germany	Austria	ns	0.64	0.51	ns	0.45	0.08
Germany	France	ns	0.49	0.15	ns	0.08	0.38*
UK	Germany	ns	0.03	0.09	ns	−0.04	0.21
The Netherlands	Germany	s*	0.99**	−0.14	s*	0.51*	−0.05
Switzerland	Germany	ns	0.04	−0.23	ns	0.37	−0.26
Switzerland	The Netherlands	ns	0.11	0.43	s**	0.81**	0.19
Sweden	Germany	ns	−0.10	−0.24	ns	0.11	−0.16
Sweden	The Netherlands	ns	−0.03	0.43	s*	0.34	0.26
Sweden	UK	ns	0.27	0.67	s*	0.45*	0.14
Sweden	France	ns	0.12	−0.12	ns	0.42	−0.15
Sweden	Switzerland	ns	0.26	0.90	s*	0.69*	0.12
Austria	Germany	ns	0.31	−0.08	ns	0.47	0.43
		Number obs. = 15			Number obs. = 37		

** and * indicate significance at the 1 and 5% level, respectively.

domestic Swedish technological advantage. However, the Swedish home pattern of technological specialisation is more highly specialised in nuclear reactors, electrical devices and systems, and other manufacturing and non-industrial technologies (having higher values of the RTA index). German firms that operate in a lower order centre, France, reflect some important French specialisation in other organic compounds, synthetic resins and fibres, inorganic chemicals (which are also some German specialisation areas), and rubber and plastic products.

As we might expect from the fact that the Netherlands is relatively a lower order centre than Germany in the metal products and mechanical engineering industrial group, Dutch firms located in Germany seem to replicate their home technological specialisation. At both levels of disaggregation, Dutch firms significantly fit their home technological profile, particularly in other specialised equipment and rubber products, and then in chemical, allied and metal working equipment. Swiss affiliates in the Netherlands also seem to fit significantly their home profile of specialisation because of a particularly strong focus there upon textile and clothing equipment.

As far as the electrical equipment and computing industrial group is concerned (Table 7), Dutch-owned affiliates, from the highest order European centre in that industry, seem to source locally-based technological expertise throughout their foreign technological activity. Dutch-Philips-foreign activity in the UK, in particular its subsidiary Mullard, fits statistically at a detailed level of disaggregation some features of local British specialisation such as in telecommunications, other electrical communication systems, other instruments and controls, and other manufacturing and non-industrial technologies. Philips activity in the UK also fits both the Dutch and British specialisation in illumination devices and special radio systems technologies, and in addition has a particular emphasis on semiconductors. Philips exploits French technological strengths in special radio systems, other manufacturing and non-industrial technologies, and other instruments and controls, with a significantly positive coefficient at the more detailed level of disaggregation. In addition, Dutch technological activities in France significantly fit the home parent activities in pharmaceuticals and other fields which are also French indigenous specialities, such as electric lamps manufacturing, illumination devices, and image and sound equipment. Philips in Germany operates in German-specific domestic activities in railways and railway equipment, mechanical calculators and typewriters, and other instruments and controls, when looking at the detailed level of technological disaggregation. However, a significant relationship is found with home activities at the more disaggregated level due to a specialisation in electric lamp manufacturing, rubber and plastic products and image and sound equipment. Philips technological activities in Switzerland and in Sweden seem to be quite specific and focused on other manufacturing and non-industrial technologies, and so the regressions do not produce a significant fit.

The Swiss company Brown-Boveri (now ABB) in Germany is highly specialised in the German technological strength in nuclear reactors and railway equipment, with positive and significant coefficients on the host German pattern of technological specialisation at both levels of technological classification. The research activity of Brown-Boveri (later ABB) in Germany is also found to be influenced by the home specialisation of the parent, especially in power plants, internal combustion engines, general industrial and metal working equipment. Swedish affiliates in Germany seem significantly and positively influenced by the host pattern of technological specialisation at the broad level of disaggregation. Swedish-owned firms in Germany are broadly specialised in the indigenous research fields of nuclear reactors, transport equipment (also Swedish specialities), rubber and plastic products and photographic instruments. However, this does not continue to hold significantly at the more detailed level of disaggregation, at which Swedish affiliates are mostly specialised in their home-specific area of other transport equipment, and to a lesser extent in nuclear reactors, general industrial equipment (also German specialities) and in general metal products. On the other hand, Swedish firms located in Switzerland seem significantly to explore the Swiss specialised research areas in power plants, general industrial equipment, metallurgical processes (also Swedish specialisation but in a much lesser extent) and in metal working equipment.

British-owned firms in their French research broadly extend their home technological strengths at

Table 7
The results of the cross-section regressions using the logarithms of the selected corporate groups over 1969–1995, for the electrical equipment and computing industrial group, using the 56 and 18 sectoral groups classification of technological activities

Dependent variables national origin (i)	Host European location (j)	Cross-section regressions on the selected technological sectors among 18			Cross-section regressions on the selected technological sectors among 56		
		Overall regression significance	Estimated β_i	Estimated β_j	Overall regression significance	Estimated β_i	Estimated β_j
Germany	Switzerland	ns	−0.36	−0.12	ns	−0.05	−0.05
Germany	Sweden	ns	0.01	−0.32	ns	0.25	−0.09
UK	France	s*	2.09*	−0.13	ns	0.04	0.34
France	Germany	s*	0.72*	−0.15	ns	0.41	−0.02
France	Italy	ns	0.03	0.40	ns	0.22	0.17
The Netherlands	Germany	ns	0.36	0.42	ns	0.28*	0.38
The Netherlands	UK	ns	0.35	0.36	s**	0.36*	0.44*
The Netherlands	France	ns	0.32	0.43	s**	0.30*	0.71**
The Netherlands	Switzerland	ns	0.48	−0.42	ns	−0.01	−0.17
The Netherlands	Sweden	ns	0.18	−0.45	ns	0.39	0.03
Switzerland	Germany	s**	0.57*	1.90**	s**	0.51**	1.59**
Sweden	Germany	s**	0.28	1.86**	s**	0.59**	0.27
Sweden	Switzerland	s**	0.16	1.07**	s**	−0.16	0.97**
		Number obs. = 14			Number obs. = 35		

** and * indicate significance at the 1 and 5% level, respectively.
Significant positive correlations were found between the national domestic corporate groups of Sweden and Germany at the 18 sectors classification, and the UK and France at both levels of classification.

the more aggregate level in transport equipment, rubber and plastic products and electrical equipment technologies. Looking at the detailed level of technological classification, British affiliates in France are heavily focused on railway equipment technologies, much more than the domestic research of either British or French firms, respectively, might have suggested. French firms in Germany similarly replicate overall their home country lines of specialisation in other manufacturing and non-industrial technologies, electrical equipment and instruments. At a more detailed level of technological disaggregation, the statistical significance does not carry through due to the specialisation of French domestic research in special radio systems, which is not an area of specialisation of French-owned affiliates in Germany, which instead focus more on image and sound equipment or telecommunications.

6. Some conclusions

The cluster analysis gives some support to the hypothesis that leading multinational firms from the major European centres in their industry tend to carry out technological activity abroad which is relatively differentiated from their domestic technological strengths. The German and Swiss firms, leaders in the chemicals and pharmaceuticals industry, tend to be most prone to use internationally integrated strategies of cross-border specialisation. Swedish firms in the metal products and mechanical engineering industry are similarly indicated to adopt strategies of related technological differentiation abroad. The leading Dutch firm Philips seems to have developed a still more internationally integrated technological strategy. It is therefore suggested that these largest leading European firms are moving towards international strategies for technological development to generate geographically dispersed but complementary streams of innovation through the construction of international research networks in Europe.

The results of the regressions suggest similarly that the relative significance, or hierarchy, of national centres plays a role in explaining the technological specialisation pattern of foreign-located affiliates in the chemicals and pharmaceuticals, mechanical and electrical equipment industrial groups. German-owned firms, from one of the highest order centres in the European chemicals and pharmaceuticals industry, seem more likely to engage in geographically diversified technological strategies, taking advantage of locally specific foreign expertise. In contrast, firms from lower order centres tend to develop their foreign-located research in Germany in their own domestic fields of technological strengths, extending the depth of their established lines of activity in the most important centre in the locational hierarchy of their industry. They treat Germany as a reservoir of general expertise in chemicals, while the dominant German companies seek locally specialised expertise abroad.

In the metal products and mechanical engineering industry, Swedish-owned firms, from the highest European centre in that industry, reflect partly the technological specialisation pattern of host locations. Lower order centre firms operating in higher order centre in the hierarchy seem likely to replicate their home technological strengths. Dutch firms operating in Germany replicate their home country technological profile as may be expected from the fact that the Netherlands is a centre of less importance than Germany in the European metals and machinery industry. Finally, the leading Dutch firm, Philips, lifts the Netherlands into a position as the major European centre in the electrical equipment and computing industrial group. Philips' foreign affiliates tend to be more prone to develop complementary but diversified technologies in accordance with the specialisation of their host locations, having been able to tap into locally specific technological expertise, in particular when located in lower order centres in France and the UK.

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Appendix A. Selected sectoral groups of technological activities (patents ≥ 100, indicated by *), 1969–1995; 56 and 18 technological groups classification of US Patent Data

	Chemicals and pharmaceuticals industrial group		Metal products and mechanical engineering industrial group		Electrical equipment and computing industrial group	
	56 Technological groups classification 29 Selected	18 Technological groups classification 12 Selected	56 Technological groups classification 37 Selected	18 Technological groups classification 15 Selected	56 Technological groups classification 35 Selected	18 Technological groups classification 14 Selected
Food and tobacco products	1*	1*	1	1	1	1
Distillation processes	2*	2*	2*	2*	2	2*
Inorganic chemicals	3*	2*	3*	2*	3	2*
Agricultural chemicals	4*	2*	4	2*	4	2*
Chemical processes	5*	2*	5*	2*	5*	2*
Photographic chemistry	6*	2*	6	2*	6*	2*
Cleaning agents and other compositions	7*	2*	7*	2*	7*	2*
Disinfecting and preserving	8	2*	8	2*	8	2*
Synthetic resins and fibres	9*	2*	9*	2*	9*	2*
Bleaching and dyeing	10*	2*	10	2*	10	2*
Other organic compounds	11*	2*	11*	2*	11	2
Pharmaceuticals and biotechnology	12*	3*	12*	3*	12*	3*
Metallurgical processes	13*	4*	13*	4*	13*	4*
Miscellaneous metal products	14*	5*	14*	5*	14*	5*
Food, drink and tobacco equipment	15	5*	15	5*	15	5*
Chemical and allied equipment	16*	5*	16*	5*	16*	5*
Metal working equipment	17*	5*	17*	5*	17*	5*
Paper making apparatus	18*	5*	18*	5*	18	5*
Building material processing equipment	19	5*	19*	5*	19	5*
Assembly and material handling equipment	20*	5*	20*	5*	20*	5*
Agricultural equipment	21	5*	21*	5*	21	5*
Other construction and excavating equipment	22	5*	22	5*	22	5*
Mining equipment	23	5*	23*	5*	23	5*
Electrical lamp manufacturing	24	5*	24	5*	24*	5*
Textile and clothing machinery	25*	5*	25*	5*	25*	5*

Appendix A. (continued)

	Chemicals and pharmaceuticals industrial group		Metal products and mechanical engineering industrial group		Electrical equipment and computing industrial group	
	56 Technological groups classification 29 Selected	18 Technological groups classification 12 Selected	56 Technological groups classification 37 Selected	18 Technological groups classification 15 Selected	56 Technological groups classification 35 Selected	18 Technological groups classification 14 Selected
Printing and publishing machinery	26	5*	26*	5*	26*	5*
Woodworking tools and machinery	27	5*	27	5*	27	5*
Other specialised machinery	28*	5*	28*	5*	28*	5*
Other general industrial equipment	29*	5*	29*	5*	29*	5*
Mechanical calculators and typewriters	30	9*	30*	9*	30*	9*
Power plants	31	6	31*	6*	31*	6*
Nuclear reactors	32	7	32*	7*	32*	7*
Telecommunications	33	8*	33*	8*	33*	8*
Other electricals communication systems	34	8*	34	8*	34*	8*
Special radio systems	35	8*	35	8*	35*	8*
Image and sound equipment	36	8*	36	8*	36*	8*
Illumination devices	37	8*	37	8*	37*	8*
Electrical devices and systems	38*	8*	38*	8*	38*	8*
Other general electrical equipment	39*	8*	39*	8*	39*	8*
Semiconductors	40	8*	40	8*	40*	8*
Office equipment and data processing systems	41*	9*	41*	9*	41*	9*
Internal combustion engines	42	10	42*	10*	42	10*
Motor vehicles	43	10	43*	10*	43	10*
Aircraft	44	11	44	11	44	11
Ships and marine propulsion	45	12	45*	12*	45	12*
Railways and railway equipment	46	12	46*	12*	46*	12*
Other transport equipment	47	12	47*	12*	47*	12*
Textile, clothing and leather	48	13	48	13	48	13
Rubber and plastic products	49*	14*	49*	14*	49*	14*
Non-metallic mineral products	50*	15*	50*	15*	50*	15*
Coal and petroleum products	51*	16*	51*	16*	51	16
Photographic equipment	52*	17*	52	17*	52*	17*
Other instruments and controls	53*	17*	53*	17*	53*	17*

Appendix A. (continued)

	Chemicals and pharmaceuticals industrial group		Metal products and mechanical engineering industrial group		Electrical equipment and computing industrial group	
	56 Technological groups classification 29 Selected	18 Technological groups classification 12 Selected	56 Technological groups classification 37 Selected	18 Technological groups classification 15 Selected	56 Technological groups classification 35 Selected	18 Technological groups classification 14 Selected
Wood products	54	13	54	13	54	13
Explosive compositions and charges	55	18*	55	18*	55	18*
Other manufacturing and non-industrial	56*	18*	56*	18*	56*	18*

Appendix B. Chemicals and pharmaceuticals industrial group, 1969–1995

Corporate groups by nationality	Patenting activity in the different European host countries (indicated by 1* for patenting in 1969–1982 only, 2* for patenting in 1983–1995 only and * for patenting in both)					
British	Germany	France	Belgium–Lux			
ICI	*	*	*			
Beecham group	*	*				
Boc group	*	1*	1*			
Glaxo	1*	2*				
Wellcome Foundation		1*				
Boots		1*				
Reckitt and Colman		2*				
Albright and Wilson						
German	UK	Italy	France	Belgium–Lux	Switzerland	Austria
Bayer	*	*	*	*	*	*
Hoechst	*	*	*	*	*	*
BASF	*	*	*	*	*	1*
Henkel	*	*	2*		*	*
Boehringer Ingelheim	1*	2*	1*	2*		*
E. Merck	*	2*			*	2*
Boehringer Mannheim	*	2*		1*	*	1*
Chemische Werke Huls	*	1*	1*			*
Schering	2*	2*	*			*
Rutgerswerke	2*					1*
Dutch	Germany	UK				
Akzo	*	*				
DSM	2*	2*				
Swiss	Germany	UK	Italy	France	Austria	
Ciba-Geigy	*	*	*	*	*	
Roche/SAPAC	*	*	*	*	*	
Sandoz	*	*	*	*	*	
French	UK					
Rhone-Poulenc	*					
L'Oreal	2*					
L'Air Liquide						
Charbonnages de France						
Entreprise Miniere et Chimique						
Usines de Melle						

Appendix B. (continued)

Corporate groups by nationality	Patenting activity in the different European host countries (indicated by 1* for patenting in 1969–1982 only, 2* for patenting in 1983–1995 only and * for patenting in both)	
Belgian	Germany	UK
Solvay	*	*
Swedish		
AGA		
Astra		
Nitro Nobel		
AB Pharmacia		
Perstorp		
Italian		
Montedison		
Norwegian		
Norsk Hydro		

Selected corporate groups in the different European locations (total patents ≥ 50)

Appendix C. Metal products and mechanical engineering industrial group, 1969–1995

Corporate groups by nationality	Patenting activity in the different European host countries (indicated by 1* for patenting in 1969–82 only, 2* for patenting in 1983–1995 only and * for patenting in both)		
British	Germany		
Vickers	*		
Babcock International	*		
Rio Tinto-Zinc	1*		
British Steel	1*		
BTR	*		
IMI	*		
Northern Engineering Indus	1*		
TI Group	2*		
Johnson Matthey	2*		
Hawker Siddeley			
Dowty Equipment			
Metal Box			
John Brown			
Baker Perkins			
Delta Group			
Consolidated Gold Fields			
German	Switzerland	Austria	France
Gutehoffnungshutte	*	*	1*
Degussa	*	*	*
Flick	*	*	*
Kugelfischer Georg Schafer	*		
Metallgesellschaft	1*	*	2*
WC Heraeus	1*	*	
KHD	1*	1*	
Thyssen	1*		1*
Mannesmann	*	*	*
Klockner-Werke	1*	1*	
Schubert and Salzer	*		
Pintsch	1*		
Krupp		*	1*
Linde	2*	1*	2*

Appendix C. (continued)

Corporate groups by nationality	Patenting activity in the different European host countries (indicated by 1* for patenting in 1969–82 only, 2* for patenting in 1983–1995 only and * for patenting in both)					
German	Switzerland	Austria	France			
Deutsche Babcock			1*			
KHD			1*			
Rheinmetall			*			
WC Heraeus		2*				
TH Goldschmidt						
Salzgitter						
Norddeutsche Affinerie						
Preussag						
Dutch	Germany					
Hoogovens Group	*					
Thyssen-Bornermisza	*					
Swiss	Germany	The Netherlands	Italy			
Sulzer Bros	*	*	*			
Alusuisse	*	2*	*			
Georg Fisher	*	*				
Adolphe Saurer	2*					
Schindler Holding						
Swedish	Germany	France	The Netherlands	Switzerland	Italy	UK
SKF	*	*	*	1*	*	*
Sandvik Group	*	*	1*	*	1*	*
Alfa-Laval	1*	1*	*	*	2*	1*
Atlas Copco	1*					
Svenska Rotor Maskiner	1*					
Asea	*	*		1*		*
AB Bofors	1*			1*		
Boliden	2*			1*		
Statsforetag	2*	2*				
PLM				2*		
Uddeholms						
Fagersta Jernverks						
Avesta Jernverks						
SSAB						
Austrian	Germany					
Voest-Alpine	*					
French						
Pechiney Ugine Kuhlmann						
Usinor						
Vallourec						
Imetal						
Sacilor						
Schneider						
Belgian						
Cockerill-Sambre						
Metallurgie Hoboken-Overpelt						
Luxembourg						
Arbed						
Norwegian						
Elkem						
Finnish						
Valmet						
Nokia						

Selected corporate groups in the different European locations (total patents ≥ 50)

Appendix D. Electrical equipment and computing industrial group, 1969–1995

Corporate groups by nationality	Patenting activity in the different European host countries (indicated by 1 * for patenting in 1969–1982 only, 2 * for patenting in 1983–1995 only and * for patenting in both)					
German	Switzerland	Sweden	Austria	Norway		
Siemens	*	*	*	2 *		
AEG-Telefunken	1 *		1 *			
Bosch-Siemens Hausgerate						
Nixdorf Computer						
British	France					
General Electric	*					
Thorn Emi	*					
Plessey	1 *					
BICC						
Standard Telephones and Cables						
ICL						
Racal Electronics						
French	Germany	Italy	Belgium–Lux			
Generale d'Electricite	*	*	*			
Thomson-Brandt	*	*	*			
CII-Honeywell Bull	1 *	2 *				
Sagem						
Dutch	Germany	UK	France	Switzerland	Sweden	Austria
Philips	*	*	*	*	*	*
	Belgium–Lux					
	*					
Swiss	Germany					
Brown Boveri	*					
Landis and Gyr						
Swedish	Germany	Switzerland				
Electrolux	*	*				
LM Ericsson	*	*				
Asea-Brown Boveri	2 *	2 *				
Italian						
Olivetti						
Zanussi Group						

Selected corporate groups in the different European locations (total patents > or = 50)

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