DANISH RESEARCH UNIT FOR INDUSTRIAL DYNAMICS

DRUID Working Paper No 01-08

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By
John Cantwell and Elena Kosmopoulou
July, 2001

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John Cantwell* and Elena Kosmopoulou**

Abstract

Based on empirical data at an aggregate level it has been argued that the propensity to internationalise corporate technological activity is higher among firms originating from smaller countries and in less research-intensive industries. However, more disaggregated evidence on the patenting of the world's largest firms suggests a more complex picture.

First, the share of foreign-located activity (through outward investment) depends positively upon the technological strength of each national group of firms in an industry, while the share of foreign-owned activity (through inward investment in a host country) may be deterred by the technological competitiveness of indigenous firms. The degree of internationalisation of technological development depends inversely as well on the extent of localised user-producer interaction in innovation in an industry or in the relevant national innovation system.

Second, the largest firms increasingly use international research networks as a means of corporate technological diversification. Thus, when technologically leading groups invest in innovation abroad they tend to switch towards the foreign development of complementary and supporting technologies outside the primary field of their own industry, which tends to remain relatively more concentrated at home. Likewise, while foreign-owned firms in the same industry may be deterred by the intensity of competition in the home centre of a leading national group, strong foreign-owned firms in other industries may pursue their diversification strategies by developing locally the primary technology of that centre (which is not primary for their own industry).

Keywords : Internationalisation, technological development

JEL: O33, L23

ISBN(87-7873-107-0)

Addresses for correspondence:

*Prof. John Cantwell
Department of Economics
University of Reading
PO Box 218, Whiteknights
Reading RG6 6AA, UK
Tel.: +44 (0) 1 118 987 5123
Fax: +44 (0) 1 118 975 0236
Email: J.A.Cantwell@reading.ac.uk

**Elena Kosmopoulou
Department of Economics
University of Reading
PO Box 218, Whiteknights
Reading RG6 6AA, UK
Tel.: +44 (0) 118 931 8233
Fax: +44 (0) 118 975 0236
Email: ElenaKosmopoulou@hotmail.com

[1] The authors wish to gratefully acknowledge financial support from a project of the European research network on 'The relationship between technological strategies of multinational companies and national systems of innovation: consequences for national and European science and technology policies (MESIAS)', funded under the EC's Key Action for Socio- for national and European science and technology policies (MESIAS)', funded under the EC's Key Action for Socio-Economic Research (contract number HPV1-CT-1999-0003). The second author would also like to thank Bo Carlsson and the participants of the DRUID winter conference for their useful comments.

1. Introduction

Innovation has been increasingly internationalised during recent decades, and while internationalisation is not itself a new phenomenon the number of large firms involved, and the importance of the technological activity that is carried out abroad has greatly increased (Bartlett and Ghoshal, 1989; Dunning, 1993; Cantwell, 1995). The largest US and especially European companies have made a major contribution to this process. The pursuit of international competitiveness at a country level follows historically defined trajectories, as part of different national and regional systems of innovation (Lundvall, 1988; Nelson, 1993; Cantwell, 2000).

At the firm level, the internationalisation of technological activities encourages the creation and diffusion of innovation by tapping into locally-specific resources and effectively deploying individually localised exchanges with indigenous firm capabilities in various sites (Pearce, 1989, 1999; Kuemmerle, 1998, 1999a, 1999b; Zander, 1998, 1999; Cantwell and Janne 1999a; Dunning and Wymbs, 1999). The world's largest firms in recent years have moved from employing international R&D as a means of better exploiting established competencies in accordance with the conditions of local markets and production conditions, towards the creation of local centres of excellence with differentiated but complementary sources of expertise. The geographical dispersion of research facilitates the multi-technological development of firms, and becomes positively associated with corporate technological diversification (Zander, 1997; Breschi, et.al.1998; Cantwell and Piscitello, 1999). Consequently, firms pursue their technological diversification partly through the internationalisation of the process of competence creation, complementing their domestic activity with suitably locally differentiated foreign-located lines of development (Cantwell and Piscitello, 1999, 2000).

2. Development of an analytical framework

In this context, we begin from but then explore how to go beyond two background propositions on the determinants of the internationalisation of corporate technological activity which can be found in the literature (see in particular Patel and Pavitt, 2000). While these propositions may be useful starting points for explaining cross-country and cross-industry variations in the degree of internationalisation they are insufficient. In showing that there are two further factors which also determine differences in the extent of technological internationalisation between countries and industries, we present a more general and comprehensive framework for the analysis of the international location of innovative activity in large firms.

The two background propositions with which we start are as follows. First is the supposition that large firms from small countries tend to be more highly internationalised in their technological development strategies, while large country multinational corporations (MNCs) tend to be less internationalised. The reason is that the constraints of small country size compel large firms originating from such economies to become internationalised more rapidly. Taken alone this proposition is an over-generalisation and may be misleading, since for example British firms have been highly internationalised for a long time while Swedish firms have been little internationalised until relatively recently. More importantly for our argument, the cross-national group pattern in the degree of internationalisation within each industry varies from one industry to another.

To explain the foundation for the second proposition, while firms develop a wide range of technologies to support a narrower range of products (Pavitt, Robson and Townsend, 1989; Granstrand, Patel and Pavitt, 1997), the geographical dispersion of production in multinational firms exceeds that of technological activity (Cantwell and Hodson, 1991). We might infer from this that technology is internationalised more in support of the geographical spread of production and markets, than the other way round, and indeed until recently this has been largely true (Cantwell, 1995; Cantwell and Piscitello, 2000). Until around 1980 international direct investments tended to be market-seeking or natural resource-seeking, and not technological asset-seeking. So historically when the internationalisation of technology followed the internationalisation of production, which in turn was motivated by a search for markets or resources, the share of foreign-located research tended to be greatest where it was needed to adapt products to locally differentiated markets (like in food products) or to adapt resource extraction to local conditions (like mining); and not in research-intensive industries, in which a higher proportion of research is directed towards the development of entirely new products and processes rather than simpler adaptation.

Thus, the second background proposition is that less research-intensive industries tend to be relatively more internationalised in their technological activity (in terms of foreign research shares) than are highly research-intensive industries. However, taken alone this is (also) an over-generalisation that may be misleading. Chemicals, pharmaceuticals, petrochemicals and office equipment (computing) are all research-intensive industries that have on average a substantial internationalisation of technological endeavour among large firms. More importantly again for our purposes, the ranking from highly internationalised industries down to the least internationalised is not uniform if we compare the cross-industry distribution for the firms of different nationalities of origin. So rather than explaining why on average food and pharmaceuticals are highly internationalised industries while aircraft is not, we need to be able to explain why the food firms of some home countries of origin are highly internationalised in their technological efforts, but the food companies of other countries are not.

To clarify the nature of the supplementary arguments that are necessary to build upon but qualify and go beyond the received wisdoms that technological development tends to be more internationalised on average in firms from smaller countries and in less research-intensive industries, we develop a new framework that embraces elements of these existing contentions. Yet at the same time our approach provides a more comprehensive explanation of the complex variations across countries and industries in the degree of internationalisation of technological activity that is observed in practice among large firms. Our framework introduces two new components in order to establish more precisely the determinants of the internationalisation of corporate innovative effort.

First, national groups of large industrial firms have unique and distinctive international technological profiles that reflect the path-dependent and historically bounded competencies that were originally developed in their home country (Cantwell, 2000) . In industries in which national groups of firms are strongest as technological leaders the extent of internationalisation of technology development will be relatively high (Cantwell, 1989). However, such multinational firms utilise their international networks for innovation in large part to promote their own comparative technological diversification (Cantwell and Piscitello, 2000). The investment that they conduct abroad tends to be more oriented towards general technological systems, relevant to most industries, which are either core to the current technological paradigm (such as information and communication technology or new materials) or carried forward from past paradigms (such as mechanical devices and instruments), while they tend to retain at home a higher proportion of technological development in the primary fields for their own respective industries.

Figure 1: The effect of leading locally-owned national groups on the degree and structure of internationalisation of innovation

Home/ Host Country Perspective

Level of Analysis	Outward	Inward
Industry	High Dgree of Internationalisation (H)	Local Deterrence in the Primary Industry (L)
Technology	Exploration for Diversification (M)	Local Attraction for Diversification (M)

Where: H	High internationalisation of technological activity in the industry or technological field in question
M	Medium-intensity internationalisation of technological activity in the industry or technological field in question
L	Low internationalisation of technological activity in the industry or technological field in question

Conversely, from the perspective of inward investment, in the industries in the host country is technologically strongest, the vibrant local presence of strong indigenous companies tends to deter foreign-owned firms of the same industry from conducting substantial levels of local development in the primary technologies of the industry in question. At the same time, the strongest firms of other industries might be attracted to locate development of the relevant technologies in such a centre of excellence, which lines of development for them would represent diversification from the primary technologies of their own industries. Since they are in another industry, they are not direct competitors of the local leaders.

In other words, the intensity of technological competition influences cross-sectoral patterns of international expansion. Competitive strengths in an industry on the part of a national group of firms encourage outward investment in foreign-located technological development but discourage the inward investment of foreign-owned companies in the same industry. However, the foreign-owned firms of other industries (which are not major competitors in output markets) may be attracted to source technology from a centre of excellence in the primary field of development in which local firms lead. Likewise, while the leading local companies tend to retain at home much of their development of their own primary technologies (given local expertise), what they locate abroad will be geared towards the foreign development of related or complementary fields.

Figure 2: The effect of tight localised coupling of capable downstream user (or upstream supplier) firms as the source of innovation on the degree of internationalisation of technological activity

Home/ Host Country Perspective

Level of Analysis	Outward	Inward
Industry	Dependence On Local Users or Suppliers (L)	Deterrence due to Established Local Inter-Firms Linkages (L)
Technology	Exploration of User or Supplier Capabilities (M)	Local Attraction for Diversification (M)

Where: M Medium-intensity internationalisation of technological activity in the industry or technological field in question

L Low internationalisation of technological activity in the industry or technological field in question

Thus, in general in the case of an area in which local firms are strong we expect to observe roughly the pattern illustrated in Figure 1 in terms of the degree of internationalisation of technological activity at the level of the industry, and at the level of the equivalent technological field. First, we expect outward investment in innovation to exceed inward investment, given the balance of corporate strengths. However, second, while in the case of outward investment the internationalisation of the industry will tend to exceed that in the corresponding technological field (since strong domestically owned firms diversify abroad), within inward investment the pattern tends to be the other way round (since foreign-owned firms in the same industry are those most deterred by the presence of dominant local companies).

To bring in now the second new component of our framework, an essentially reverse trend may be observed in industries and countries in which the basis of strong local technological competitiveness is a tight interrelatedness of companies in the industry with downstream local user firms or upstream supplier firms as the sources of innovation and as a crucial feedback to in-house innovation. This type of relationship places great importance on mutual trust and locally-specific knowledge creation because it demands a commitment of substantial resources and "has a cumulative and continuous property with a time dimension" (Lee, 1998, pp. 47-48) that induces national industrial groups to remain local in their innovative orientation (Lundvall, 1985, 1988). Hence, the more that the production of a national industrial group is aimed at local intermediate good markets, or depends upon locally-specific suppliers of innovative equipment or other inputs, the less internationalised they will tend to be in their research strategy.

We might expect this argument to apply in an industry such as metals, or machine tools, yet the same inward-looking approach to innovation may also be relevant to other industries with a strong indigenous advantage linked to inter-company and inter-industry interrelatedness. This is particularly likely to apply in the case of Japan, where a closely knit network of firms (such as in the form of Keiretsu) supports a broad dispersion of development across complementary technological fields (Scher, 1997). For example, we have a variety of industries in Japan such as the chemical, the computer, the electrical equipment, etc. whose technological development relies for support upon, and in turn helps to support competence development in a focus industry, most notably motor vehicles. In this case the chemical, computer, and electrical equipment industries can be regarded as to a greater extent than usual intermediate-good oriented and much of their technological effort is directed to the innovative support of the car industry. Of course, this does not mean that these industries provide only for the local market or that in some later stage of their development they will not become more international in their innovative activity. Instead, the Japanese chemical industry is, for example, among the leading national groups in paints.[2]

However, in general in a case in which the technological strength of local firms depends upon a tight localised inter-industry coupling of user-producer interaction in innovation, we expect to observe roughly the pattern illustrated in Figure 2, distinguishing again between the level of the focus industry and the level of the equivalent technological field. First, we expect outward investment in innovation to be low, quite likely to the extent that it is even weaker than inward investment. Yet in this case both outward and inward internationalisation in the industry will tend to be lower than in the corresponding technological field (since the firms of related industries may be better able to diversify into this field abroad or to tap into local excellence, while within the industry local firms would find it difficult to establish similar linkages or to operate more independently elsewhere, and foreign-owned firms find the inter-knit structure of the local industry a barrier to entry).

3. Data and methodology

Already in the 1960s work conducted by Schmookler (1966) and Scherer (1965) related firm size, and the volume of investment to the determinants of the rate and direction of inventive activity as measured by corporate patenting. Growing recognition since then of the importance of technology and technological change for the competitiveness and growth of both firms and countries led to a continuous effort in the exploration of the causal relationships between patenting activity and measured economic variables. There is almost unanimous agreement about the importance of patent statistics, although there is considerable debate among scholars about the essence of what exactly is being measured. A brief examination follows, to explain how we use corporate patent statistics in what follows.

[2] Kansai Paints and Nippon Paints Co., Ltd. are according to *Chemical Week* magazine among the leading top ten Paints and

Patents are an indirect measure of (the composition of) advances in knowledge inputs into the technological learning processes of firms. They provide a good proxy measure of the cross-sectoral distribution of technological activity for large firms (Cantwell, 1993), which tend to have a high propensity to patent (Mansfield, 1986). The database used for the study consists of patents granted in the US to the largest world firms. The data presented here are patents granted to 792 of the world's largest industrial firms, derived from the listings of Fortune 500 (Dunning and Pearce, 1985). Of these 792 companies 730 had an active patenting presence during the period 1969-1995. Moreover, 54 companies were added to these. They include (mainly for recent years, but occasionally historically) enterprises that occupied a prominent position in the US patent records, some of which are firms that were omitted from Fortune's listing for classification reasons (e.g. RCA and AT&T were classified in the service sector).

Patents granted in the US are a rich, historically consistent and often unique source of information. The patent record includes the name(s) of inventors, details about the time of application and granting of the patent, and the name of the firm to which the patent has been assigned (from which we can infer the name and location of the parent company, following a consolidation process as described below), as well as the location of residence of the first-named inventor, which as a general rule reflects the location of the research facilities that have led to the invention. Moreover, each patent document provides a historically consistent classification of the type of technology associated with each invention provided by the examiners of the US Patent and Trademark Office, who continuously update the US patent class system by reclassifying all earlier patents accordingly. Inventions have to satisfy three criteria in order to be entitled to a patent: novelty, non-obviousness and usefulness. The US

Coating firms (forth and sixth respectively), ranked by 1994 sales (*Encyclopedia of Global Industries*, 1996).

system is referred to as the first-to-invent system, in contrast to the EC and the Japanese, which are first-to-file systems.

The year 1984 is used as the base year in the consolidation process. In other words firms were consolidated in their 1984 form with respect to patents granted between 1969 and 1984, but post-1984 acquisitions have been taken into account. To identify the corporate groups, companies have been grouped according to their country of origin (home country of the parent company) and allocated to the industry of their primary output, according to the product distribution of their sales. As stated already, each patent granted to the world's largest firms has been classified into a type of technological activity. This classification scheme collects together appropriate classes and sub-classes from the US patent class system. Usually patents are assigned to several technological fields, but here the primary classification is used in all cases[3]. For the purposes of our study patents have been aggregated into six periods (dividing 1969-1995 into six). An extensive literature discusses the advantages and disadvantages of the use of patent data as a comparable indicator of technological activity (Pavitt, 1988; Griliches, 1990; Archibugi, 1992). These comprehensive accounts aim to raise caution as to the potential problems of interpretation of these data and state the limitations of the method rather than undermining its significance.

Although a detailed analysis is beyond the scope and scale of this paper one point that is significant to what follows is worth reiterating here. Small and medium-sized firms tend to have a relatively low propensity to patent their inventions. However, we only deal with the largest and most technologically advanced firms whose propensity to patent is high. This study focuses on patenting activity by the largest firms originating from the US or from

[3] For example: the German firm Bayer is classified in the chemical industry (the bulk of its sales is in chemical products). However, Bayer's patents are classified into chemical, mechanical, instrument, and etc. technological sectors (according to the primary classification of the US patent office).

selected European countries arranged by their nationality of ownership and examines the extent of internationalisation of their research facilities, and also looks at the patenting of all the world's largest firms which is sourced from research located in the equivalent set of host countries (the US and certain European countries).

For the purposes of an analysis based upon Figure 1 above we need an empirical measure of the nationality of technological leaders among large firms in each industry. The revealed technological advantage (RTA) index provides a proxy measure of the technological specialisation of each national group of firms, either across industries, or across types of technological activity. Therefore, the RTA at the cross-industry level, is defined as the share of US patents granted to the national group of firms in question in a particular industry, relative to that national group’s share of US patents granted to large firms in all industries; and at the cross-technology level, as the share of US patents granted to the group of firms in question in some given technological field, relative to that group’s share of US patents in all technological fields. Alternatively, which is a form we use later in the paper, the RTA can be devised to show the pattern of technological specialisation of a national group of firms within an industry, as opposed to across industries. This version of RTA is defined as the share in a particular technological field of US patents granted to the firms of some industry which are due to the national group in question, relative to that national group’s share of patenting in the same industry in all technological fields.

$$RTA_{ij} = (P_{ij} / \Sigma_i P_{ij}) / (\Sigma_j P_{ij} / \Sigma_i \Sigma_j P_{ij}),$$ where:

P	is the number of US patents granted to the firms any industry	P	is the number of US patents granted to the firms of a particular industry
i	is the primary industry of output	i	is the technological sector
j	is the national group of firms	j	is the national group of firms
(at the cross-industry level)			(at the intra-industry level)

or

i is the primary technological sector (at the all-industry cross-technological sector level)

The index gives values around unity. The greater the value, the more a group of firms has a comparative technological advantage in the industry (or field of activity) in question. The index controls for inter-sectoral and inter-country variations in the propensity to patent (Cantwell, 1993, 2000). We use this form of the index to establish firstly the profile of national technological strengths and weaknesses - that is, the industries or the technological categories in which the largest firms originating from a given country are technological leaders, and secondly, the profile of national technological specialisation within a few specific industries (chemicals and pharmaceuticals, electrical and office equipment, and metals and mechanical engineering).

4. Revisiting the general cross-country and cross-industry pattern of internationalisation

In Tables 1 and 3-6 we examine the internationalisation of research through the US patenting activity of the largest industrial firms of the most internationalised countries, by distinguishing between patents that are attributable to research outside the home country and those due to research located in the home country of the parent company. It soon becomes evident that the use of aggregate data at a global level provides only a partial picture of the degree of internationalisation that characterises the firms of particular countries or particular industries.

Table 1 sketches the overall picture of the extent of internationalisation of technological activity in the world’s largest firms. It examines the share of their US patenting from research in foreign locations organised by the nationality of the parent firm through the period 1969-1995.

Table 1: The percentage of US patents of the world's largest firms attributable to research in foreign locations, organised by the nationality of the parent firm, during the period 1969-95.

Country	1969-72	1973-77	1978-82	1983-86	1987-90	1991-95
France	8.16	7.74	7.17	9.19	18.17	33.17
Germany	12.77	11.05	12.07	14.47	17.05	20.72
Netherlands	50.40	47.37	47.65	53.99	53.96	55.69
Sweden	17.82	19.90	26.20	28.94	30.60	42.42
Switzerland	44.36	43.63	43.78	41.59	42.99	52.47
United Kingdom	43.08	41.24	40.47	47.09	50.42	55.79
European six sub-total *	28.41	25.27	24.64	27.12	30.38	34.98
United States	4.96	5.89	6.40	7.53	7.91	8.62
Japan	2.63	1.88	1.22	1.26	0.92	1.08
Belgium	50.00	54.24	56.27	71.21	56.04	67.25
Italy	13.39	16.03	13.85	12.59	11.14	16.47
Canada	41.19	39.30	39.49	35.82	40.12	43.96
Other Countries	16.58 *	19.92	22.38	20.40	17.39	8.73
Total of all Countries	**10.04**	**10.53**	**10.50**	**10.95**	**11.28**	**11.27**
Total excluding Japan	10.08	11.59	12.25	13.88	15.76	16.53

Source: US patent database compiled by John Cantwell of the University of Reading, with the assistance of the US Patent Trademark Office.

Notes: * The group of six European countries listed above, which are examined in this paper

** Less than 100 patents

In the world total a mild upward trend is observed. This tendency becomes much more obvious once Japanese-owned firms are excluded, and moreover a slight acceleration in the internationalisation process can be observed during the more recent periods. However, when including the Japanese-owned companies the absolute values of the world total percentages may be misleading, as the rising share in US corporate patenting of the little internationalised Japanese firms held back the increase in the aggregate proportion of patenting attributable to foreign-located research (Cantwell and Harding, 1998). The relatively low degree of internationalisation of the largest US and the Japanese firms drives down the global average, such that the latter provides only weaker recognition of the more highly international orientation of European firms, because of the dominant share of US patenting accounted for by US-owned and Japanese-owned national groups[4].

In sum, the overall picture in Table 1 shows that in line with the first background proposition outlined above, the largest firms which originate from small countries such as Switzerland and especially the Netherlands (see Cantwell and Janne, 1999b), as well as

Belgium tend to have a much higher level of patenting from international sources than do those of larger countries. At this general level the UK is the major exception to the proposition of an inverse relationship between the size of a domestic technological system and the internationalisation of that country's largest firms. The high degree of internationalisation which British-owned firms have inherited is linked to the role of Britain as an imperial power with strong overseas interests, and a long-standing liberal economic policy with respect to inward and outward capital movements as well as trade. In contrast, Swedish multinationals remained constrained for longer by the needs of the more locally integrated domestic economic and technological system of which they were part, despite the smaller size of their home country - and so they evolved internationally only in a 'tortoise-like' fashion (Zander, 1994).

Table 2.1 traces the comparative advantage in innovation of national industrial groups over the 1969-95 period as a whole, in order to be able to apply the framework suggested by Figure 1 and to identify the national origins of the technological leaders in each industry. RTA values above one denote comparative technological advantage in an industry.

Table 2.1: The revealed technological advantage (RTA) of selected nationally-owned groups of firms, across industries, during the period 1969-1995.

Industry	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink, and Tobacco	1.16	0.00	4.74	0.48	0.19	1.18	0.03	0.41
Chemicals	0.75	2.58	1.10	0.96	0.89	2.78	0.31	0.76
Pharmaceuticals	1.24	1.05	0.87	0.94	0.00	3.98	0.84	0.22
Metals	0.69	2.19	1.03	1.34	0.45	0.94	2.37	1.00
Mechanical Engineering	1.19	1.01	1.01	0.24	0.00	1.69	6.74	0.32
Electrical Equipment	0.84	0.67	0.51	1.12	3.29	0.36	0.87	1.54
Office Equipment	1.46	0.02	0.11	0.49	0.00	0.00	0.00	0.80
Motor Vehicles	0.64	1.58	1.24	1.07	0.00	0.00	0.87	1.82
Aircraft and Aerospace	1.65	0.22	0.84	1.35	0.00	0.00	0.00	0.00
Coal and Petroleum Products	1.43	0.02	2.79	1.64	0.00	0.00	0.00	0.08
Instruments	0.82	0.28	0.02	0.00	0.00	0.00	0.62	2.46
Other Manufacturing	1.13	0.16	0.94	1.31	0.00	0.46	1.58	1.01

[4] Half of the US corporate patents granted to the world's largest firms are assigned to US-owned companies, and about one-sixth are due to Japanese-owned large firms.

Table 2.2: The revealed technological advantage (RTA) of selected nationally-owned groups of firms, across fields of technological activity, during the period 1969-1995.

Technological Sector	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink, and Tobacco	1.33	0.36	2.41	0.27	0.23	1.11	0.79	0.29
Chemicals	1.00	1.58	1.18	0.99	0.52	2.23	0.33	0.65
Pharmaceuticals	0.93	1.80	1.56	1.22	0.40	3.59	0.86	0.45
Metals	1.11	0.67	1.11	1.05	0.67	0.64	1.80	0.83
Mechanical Engineering	1.08	0.89	1.36	0.97	0.59	0.66	2.22	0.72
Electrical Equipment	0.99	0.61	0.59	1.13	2.23	0.27	0.91	1.26
Office Equipment	0.87	0.42	0.26	0.83	1.50	0.07	0.27	1.89
Motor Vehicles	0.51	1.72	0.65	0.78	0.12	0.11	0.82	2.24
Aircraft and Aerospace	1.32	0.75	2.03	3.07	0.26	0.12	1.00	0.06
Coal and Petroleum Products	1.48	0.33	1.56	1.00	0.10	0.08	0.06	0.20
Instruments	0.90	0.83	0.67	0.74	1.16	0.46	0.86	1.52
Other Manufacturing	1.04	0.94	1.19	1.14	0.59	0.55	1.28	0.93

Smaller countries have a narrower range of industries in which their firms compete successfully as worldwide technological leaders. To take a few highlights, the largest US-owned firms are technological leaders in the pharmaceuticals and office equipment (computing) industries, German-owned companies are leaders in the chemicals and metals industries, UK-owned firms in the food products and coal and petroleum products (oil) industries, French-owned firms in the electrical equipment and aerospace industries, Dutch-owned firms in electrical equipment, Swiss-owned companies in pharmaceuticals, Swedish-owned firms in mechanical engineering, and Japanese-owned firms in the motor vehicle industry.

Table 2.2 gives instead the profile of national competencies in a variety of technological fields. Firms, in general, sustain a wider research in a variety of technological fields to support a narrower range of products. As a result of this the gap between large and small countries in the cross-sectoral dispersion of research is less pronounced than in Table 2.1. Moreover, a technologically competitive industry in most cases presumes a competitive primary technology and vice versa. However, this does not hold for computers in which two different national groups of firms share leadership. US-owned firms lead in the computing industry, while Japanese-owned firms have the strongest technological advantage in the development of the corresponding primary technologies, showing how Japanese firms are strongest in downstream industrial applications of computerised methods. In aircraft and aerospace UK-owned firms have an advantage solely in the technology (unlike US-owned and French-owned firms, that are leaders in the industry and in the technology), which owes to the British motor vehicle component firms whose expertise lies in engines in general.

Table 3: The percentage of US patents of the world's largest firms attributable to research in foreign locations, organised by the nationality and industrial group of the parent firms, during the period 1969-1995.

Industry	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan	Total
Food, Drink and Tobacco	6.53	0.00 *	66.42	61.79	0.00 *	69.12	0.00 *	2.55	22.24
Chemicals	6.36	20.67	33.13	11.81	49.89	41.55	16.52	1.52	14.21
Pharmaceuticals	10.99	17.98	19.25	4.84	N.A.	59.36	15.33	0.83	16.16
Metals	6.16	7.79	46.03	8.83	63.44	41.33	18.89	0.75	10.32
Mechanical Engineering	7.08	7.04	56.47	1.27	N.A.	29.48	32.25	0.80	12.47
Electrical Equipment	6.57	14.09	30.03	24.31	51.93	34.19	36.16	0.92	9.74
Office Equipment	11.41	3.62	11.73	31.97	N.A.	N.A.	N.A.	3.49	10.34
Motor Vehicles	5.60	8.32	24.39	6.28	N.A.	N.A.	11.35	0.81	5.68
Aircraft and Aerospace	2.34	0.82	3.06	3.83	N.A.	N.A.	N.A.	N.A.	2.39
Coal and Petroleum	4.25	0.63	83.90	12.25	N.A.	N.A.	N.A.	0.52	15.08
Instruments	5.80	3.51	74.29 *	N.A.	N.A.	N.A.	32.13	0.77	3.37
Other	7.92	11.44	28.22	26.67	N.A.	29.03	26.41	2.87	10.39
Total	6.80	14.98	45.76	15.92	51.72	44.66	27.61	1.22	10.81

Source: As for Table 1
Notes: * Less than 100 patents for the group of firms from all research facilities
N.A. Not Applicable

Table 3 provides a view over the 1969-95 period as a whole of inter-industry, and cross-national group comparisons of the extent of internationalisation of technological development in the largest firms. There is not an even distribution of international R&D across national groups and industries, which would reflect in a uniform fashion their average contribution to foreign-located innovative activity. In food, as suggested by Figure 1 the leading groups, namely UK-owned (66%) and Swiss-owned firms (69%) as well as French-owned firms (62%), are the national groups responsible for the high foreign share in the world total (22%), but in this industry internationalisation is not high for the US-owned (7%) or German-owned companies (0%). In chemicals (world average ratio 14%), the high overall share abroad is primarily due to the high internationalisation of German companies, the world leaders in this industry (21%) which is again consistent with the scheme of Figure 1. In pharmaceuticals (world total 16%) it is the firms of the US (11%), Switzerland (59%) and to a lesser degree Germany (18%) that sustain an above-average industry foreign share to match their technological prowess (Table 2), and in petrochemical products the high overall foreign share is due entirely to the largest British-owned firms (84%), once more the technological leaders in this industry. At the other end of the spectrum, the instruments industry is one of the least internationalised according to the world total (a mere 3%), but not for Swedish-owned firms (32%).

Table 4: The percentage of US patents of the world's largest firms attributable to research in foreign locations, classified by the type of technological activity and nationality of the parent firms, during the period 1969-1995.

Technological Sector	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan	Total
Food, Drink and Tobacco	4.91	26.97	61.72	30.91 *	20.59 *	47.62	23.94 *	0.42	13.62
Chemicals	6.19	16.24	54.15	11.46	40.94	43.41	23.70	1.22	12.49
Pharmaceuticals	11.32	26.96	30.65	13.01	39.87	54.25	20.29	1.43	18.79
Metals	6.34	12.73	50.68	10.29	45.87	42.13	25.83	1.17	10.41
Mechanical Engineering	7.33	10.88	51.41	11.51	58.35	40.30	34.03	1.15	12.14
Electrical Equipment	6.80	13.63	32.55	23.74	52.96	36.61	25.91	1.17	9.36
Office Equipment	7.21	23.53	27.57	37.86	45.17	33.00	18.18	1.77	7.84
Motor Vehicles	7.00	9.24	19.20	9.16	76.60 *	16.67 *	16.58	0.84	5.57
Aircraft and Aerospace	1.21 *	3.06	9.84	0.90	64.29 *	25.00 *	6.25 *	2.94	2.58
Coal and Petroleum	3.43	5.63	68.74	2.44	40.74 *	62.96 *	20.00 *	1.37	8.62
Instruments	7.32	12.65	36.54	11.70	60.79	52.25	27.26	0.95	8.77
Other	6.05	10.64	38.75	16.44	52.58	42.38	19.19	1.49	9.33
Total	6.80	14.98	45.76	15.92	51.72	44.66	27.61	1.22	10.81

Source: As for Table 1
Notes: * Less than 100 patents for the group of firms from all research facilities
N.A. Not Applicable

Table 4 reorganises the same data instead by the type of technological activity rather than the industry of corporate ownership, and this differs from Table 3 by virtue of the 'multi-technology' character of production in any industry (Granstrand et. al., 1997). Partly as a result of this spread of the development of many technologies across industries, the dispersion of internationalisation of technological sectors in Table 4 is narrower than for the world total of industries in Table 3**.** Hence, the larger number of sectors is around average. Most of the international innovation within sectors in Table 4, as in Table 3, is due mainly to only a handful of national groups. More importantly, in contrast to Table 3, there is evidence of international technological diversification as proposed in Figure 1. Food, for example, is a technological sector on which stronger German-owned firms in industries other than food have placed the greatest emphasis upon diversifying into abroad (27%), while from a leading position in the industry US-owned companies abroad have very low activity (at 5%).

To elaborate further, Tables 3 and 4 show how individual national groups expand their research activities in a varied manner that has little to do with the average position of the relevant industry and technology. While in the more highly internationalised food, chemical, pharmaceutical and oil industries not all national groups have above-average foreign research shares, on the other side, instruments is one of the least internationalised industries (in the global average position), but Swedish-owned firms are internationalised, in an area in which they seem to be less constrained by domestically integrated structures than in other industries. In the most internationalised sectors of food, pharmaceuticals, chemicals and oil the main contributors are the national groups that are technological leaders in the relevant industries, as suggested from Figure 1.

The greatest internationalisation occurs in technological areas that do not always coincide with the core fields of the most internationalised industries, especially when individual national groups are considered separately. Significantly above average in its degree of internationalisation is the pharmaceutical technological field, which is due again largely to German-owned and US-owned firms, and to a lesser extent due to Swiss-owned companies, but the internationalisation of food technologies is in good measure due to the diversification abroad of German-owned firms from other industries. Likewise, unlike the indigenous companies of the comparatively weak computing industry in Germany, German-owned firms in other industries show great interest in developing computing technologies abroad. Further, unlike the high internationalisation of research in the coal and petroleum product industry, research in petrochemical technologies is below average in its degree of internationalisation.

Moreover, foreign-located activity is lowest not only in aircraft but also in the motor vehicles industry and technological area (see the totals in Tables 3 and 4) in contrast to what might be expected if the siting of research abroad were simply to facilitate adaptation to foreign markets. Internationalisation in the motor vehicle industry, like in the Japanese national system of innovation as a whole and to a lesser extent in the Swedish system, seems to be constrained by the importance of localised vertically integrated linkages for generating and transmitting innovation, as proposed in Figure 2.

Turning to the organisation of these data from the perspective of inward rather than outward investment, the focal point in Tables 5 and 6, we examine the degree of foreign penetration in each of our selection of host countries. In Table 5 the foreign shares of local activity are classified by industry and in Table 6 by the field of technological activity as derived from the US patent class system.

Table 5: The percentage of US corpoarate patents of the world's largest firms attributable to research in host countries due to foreign-owned firms, organised by the industrial group of the parent company, during the period 1969-1995.

Industry	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan	Total
Food, Drink, and Tobacco	17.50	99.64	15.45	55.25	82.16	29.77	83.33 *	4.84	22.24
Chemicals	14.61	6.49	29.55	33.31	11.60	3.78	13.32	5.30	14.21
Pharmaceuticals	9.91	13.91	50.34	19.34	100.00 *	4.13	2.87	16.40	16.16
Metals	10.92	9.87	29.62	11.20	48.68	15.00	1.81	2.24	10.32
Mechanical Engineering	5.05	25.84	47.16	52.00	100.00	14.81	1.48	6.67	12.47
Electrical Equipment	6.01	30.01	43.48	27.85	4.11	40.62	22.91	1.33	9.74
Office Equipment	1.41	86.34	76.71	56.76	100.00	100.00	100.00 *	16.06	10.34
Motor Vehicles	3.50	8.35	13.18	21.83	100.00	100.00 *	3.27	2.15	5.68
Aircraft and Aerospace	0.14 *	15.18	10.54	2.85	100.00 *	100.00 *	100.00 *	100.00	2.39
Coal and Petroleum Products	10.22	80.47	19.43	10.31	100.00	100.00	100.00 *	18.50	15.08
Instruments	0.87	29.90	97.79	100.00	100.00 *	100.00 *	2.16	0.43	3.37
Other Manufacturing	4.57	56.64	26.71	30.66	100.00 *	14.49	13.21	3.29	10.39
Total	7.11	16.87	33.73	25.86	26.50	15.25	9.93	3.52	10.81

Source: As for Table 1

Notes: * Less than 100 patents for the group of firms from all research facilities

Table 6 : The percentage of US corporate patents attributable to research in host countries due to foreign-owned firms, classified by the type of technological activity, during the period 1969-1995.

Technological Sector	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan	Total
Food, Drink, and Tobacco	8.28	30.85	20.73	45.71 *	80.43	24.66	16.92 *	6.68	13.62
Chemicals	9.81	8.09	35.54	21.19	46.45	4.92	10.20	6.05	12.49
Pharmaceuticals	15.78	8.05	41.55	37.61	13.24	2.54	5.23	9.39	18.79
Metals	5.68	28.78	34.86	20.37	30.56	17.47	7.89	2.31	10.41
Mechanical Engineering	6.73	25.73	28.35	26.58	52.32	23.58	7.22	3.82	12.14
Electrical Equipment	5.09	25.13	39.45	28.66	6.76	47.49	7.72	3.10	9.36
Office Equipment	5.32	29.37	50.53	40.46	3.80	63.59	22.34	2.06	7.84
Motor Vehicles	5.38	7.01	20.79	21.62	66.67 *	10.00 *	1.23	2.17	5.57
Aircraft and Aerospace	0.86	9.09	0.87	4.76	0.00 *	14.29 *	14.29 *	2.94	2.58
Coal and Petroleum Products	4.61	14.14	18.32	9.09	92.83	23.08 *	0.00 *	3.34	8.62
Instruments	5.13	20.63	37.05	30.58	13.23	36.87	27.19	2.56	8.77
Other Manufacturing	5.49	16.33	19.75	16.06	33.17	19.17	5.58	3.12	9.33
Total	7.11	16.87	33.73	25.86	26.50	15.25	9.93	3.52	10.81

Source: As for Table 1

Notes: * Less than 100 patents for the group of firms from all research facilities

Considering the world as a whole in Table 5 (as in Table 3), foreign penetration is highest in the industrial sectors of food, pharmaceuticals, petrochemicals, chemicals, and machinery. Looking more closely, however, host country variations again suggest a more complex picture which reflects the pattern suggested by Figure 1. The foreign penetration of the food industry is much below average in the UK (15% as against the national average of 34%) in which local firms are technologically strong (Table 2). In pharmaceuticals Switzerland, Sweden, France and Germany have low levels of foreign research penetration, in line with Figure 1 in the case of the Swiss and German leaders, while the UK has attracted considerable foreign attention. The UK pharmaceutical case might be thought of as an exception to Figure 1, but it seems that there are only a few cases of such centres of excellence in which inward investment is encouraged and outward investment discouraged in the same industry (comparing Tables 3 and 5), and such centres do seem to be exceptional and are difficult to create. In chemicals Switzerland and Germany (whose firms are the leaders - see Table 2) together with the Netherlands have witnessed minimal penetration in comparison with the tendency in the world as a whole. Moreover, the two countries of major comparative strength in coal and petroleum product technology - that is the UK and the Netherlands - have both developed strong research bases in petrochemicals at home that have allowed little scope for foreign penetration.

The world total in Table 6 reveals again a quite different view of international activity when considering the type of technological activity (as opposed to the industry) that is sited abroad. As seen already from the identical world total column in Table 4, differences with the equivalent industries shown in Tables 3 and 5 are apparent in petrochemicals and in chemicals that now feature below average, while mechanical engineering is now above average. This suggests that oil companies use their foreign-located development more for mining and the mechanical technologies involved in the extraction of crude oil, rather than to innovate in petrochemicals themselves. A similar pattern, even if to a lesser extent, may apply in other industries. The level of international activity in food is also considerably less as a technological field as opposed to an industry (Cantwell and Santangelo, 1999, 2000). Thus, although in terms of the absolute level of activity firms tend to do most abroad in the same line of innovation as at home (Patel and Vega, 1999), namely in the primary technological field of their own industry - it is after all scarcely surprising that chemical firms develop mainly chemical technology and so on, whether at home or abroad - in relative terms in their foreign-located activity they tend to diversify away from the primary field of their own industry, becoming proportionally more active in the development of complementary and supporting technologies.

Moreover, Tables 5 and 6 show, from the host country's perspective, in which industries and technologies the world's largest firms tap into local host country research expertise, and the degree of accessibility they enjoy. Countries such as the US, the UK and Germany, while they play host to local technological development in a wide variety of industries and technologies, do not tend to experience penetration in their domestic research to the same extent in those activities in which their indigenous firms are strongest, as indicated in Figure 1. Foreign ownership of research facilities is of little significance in the US in computing, for instance, in the UK in food (in both the relevant industry and technological field), in both countries in petrochemicals (at least in the technological field), and in Germany in chemicals and pharmaceuticals (in both the industry and technological area). These are all signs of the deterrence of technological leadership.

However, from a weaker position France is to almost the same extent open to foreign-owned research as its indigenous firms are themselves internationalised in food and computing, but to a rather lesser degree in mechanical engineering technologies (in comparison with the machinery industry). Lastly, from a position in which local strength comes mainly from the firms of other related industries, although the Swedish instrument industry receives little local development by foreign-owned firms in the industry, there is significant penetration in instrument technologies by the foreign-owned firms of other industries, consistently with Figure 2.

In Tables 7, 8, and 9 we add into the story (i) the technological specialisation across fields (primary and other) that characterise national groups of firms in three major industries; (ii) the spatial distribution of such specialisation between home and foreign-located activity; and (iii) the profile of technological specialisation by foreign-owned firms that host countries attract in each of the industries in question.

Table 7: Technological Specialisation within the Chemicals and Pharmaceuticals Industry*

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	1.60	0.36	0.61	0.52	0.61	0.29	1.37	0.58
Chemicals	0.92	1.22	0.89	0.99	1.11	1.34	0.53	0.98
Pharmaceuticals	0.96	0.89	1.56	1.11	0.68	1.16	1.81	0.62
Metals	1.40	0.52	0.64	1.51	0.40	0.08	1.82	0.61
Mechanical Engineering	1.13	0.73	1.16	1.55	1.45	0.26	1.41	0.91
Electrical Equipment	1.17	0.38	0.79	0.92	0.20	0.12	1.54	1.75
Office Equipment	0.87	0.47	0.19	0.09	0.00	0.21	0.61	3.21
Motor Vehicles	*1.20*	*0.41*	*3.70*	*0.84*	*10.70*	*0.00*	*0.00*	*0.45*
Aircraft and Aerospace	*1.90*	*0.56*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Coal and Petroleum	1.21	0.95	1.72	0.61	1.44	0.09	0.00	1.22
Instruments	1.08	0.66	0.40	0.41	0.37	0.45	2.56	1.71
Other Manufacturing	1.23	0.66	1.19	0.74	1.40	0.15	0.85	1.19

Table 7.1: The revealed technological advantage (RTA) from domestically-owned activity in selected host countries, across fields of technological activity and during the period 1969-1995.

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	0.70	0.76	1.23	2.09	0.38	0.32	0.56	0.51
Chemicals	0.85	1.04	0.79	0.73	0.69	1.16	0.53	0.86
Pharmaceuticals	1.59	1.32	1.17	1.36	0.50	1.47	2.00	0.50
Metals	1.16	0.96	1.51	2.99	0.74	0.25	1.34	1.63
Mechanical Engineering	1.12	0.76	1.60	1.06	3.86	0.42	1.42	1.39
Electrical Equipment	1.24	0.55	1.54	1.11	1.82	0.10	1.08	2.64
Office Equipment	0.27	0.81	0.24	2.21	0.00	0.30	0.81	16.19
Motor Vehicles	*1.42*	*0.46*	*1.34*	*0.00*	*0.00*	*0.00*	*11.15*	*0.00*
Aircraft and Aerospace	*0.00*	*0.00*	*2.15*	*0.00*	*4.93*	*0.00*	*0.00*	*0.00*
Coal and Petroleum	0.48	0.36	0.72	0.48	0.87	0.26	0.00	1.92
Instruments	0.84	0.81	0.86	1.89	0.47	0.98	2.32	0.62
Other	0.85	0.74	1.37	0.60	1.54	0.26	0.96	0.62

Table 7.2: The revealed technological advantage (RTA) from foreign-located activity by firms of selected home countries, across fields of technological activity and during the period 1969-1995.

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	0.84	0.42	0.44	0.44	4.47	1.17	0.00	0.85
Chemicals	0.98	0.97	0.93	0.80	0.90	0.98	0.79	1.00
Pharmaceuticals	1.35	0.88	2.08	1.98	0.61	0.62	0.95	1.18
Metals	1.05	0.78	0.82	0.66	0.36	1.41	2.84	0.77
Mechanical Engineering	0.85	1.95	0.57	1.82	1.35	1.70	1.50	0.42
Electrical Equipment	0.83	0.98	0.40	0.38	0.58	0.85	0.00	1.96
Office Equipment	1.26	0.20	0.07	0.14	2.60	1.27	0.00	0.46
Motor Vehicles	*0.29*	*0.70*	*0.49*	*5.93*	*0.00*	*0.00*	*0.00*	*0.00*
Aircraft and Aerospace	*0.00*	*2.26*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*3.41*
Coal and Petroleum	0.53	0.40	0.18	0.19	3.39	0.74	0.00	0.47
Instruments	1.01	0.74	0.65	0.53	1.17	1.17	2.66	0.55
Other Manufacturing	0.64	0.91	0.47	0.38	1.61	0.97	1.01	1.44

Table 7.3: The revealed technological advantage (RTA) from foreign-owned activity in selected host countries, across fields of technological activity and during the period 1969-1995.

* The sectors represented in italics have less than 1,200 patents

Table 8: Technological Specialisation within the Electrical and Office Equipment Industry*

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	*1.50*	*0.71*	*0.00*	*0.00*	*0.00*	*0.00*	*3.03*	*0.54*
Chemicals	1.25	0.75	0.41	0.50	0.92	0.64	0.29	0.78
Pharmaceuticals	*0.88*	*0.51*	*1.29*	*0.23*	*4.13*	*0.48*	*0.00*	*1.04*
Metals	1.21	0.99	0.86	0.78	1.10	2.28	1.81	0.65
Mechanical Engineering	1.12	0.88	0.85	0.57	0.66	1.83	1.98	0.85
Electrical Equipment	0.97	1.07	1.11	1.23	1.19	0.97	1.06	0.97
Office Equipment	0.89	0.48	0.59	0.74	0.83	0.16	0.45	1.38
Motor Vehicles	0.40	0.78	0.44	0.34	0.07	1.56	3.98	2.30
Aircraft and Aerospace	*1.57*	*0.14*	*4.23*	*4.23*	*0.63*	*0.00*	*0.00*	*0.13*
Coal and Petroleum	*1.09*	*2.76*	*1.09*	*0.77*	*0.62*	*0.00*	*0.00*	*0.73*
Instruments	0.92	1.49	1.59	1.27	0.88	0.93	0.59	1.01
Other Manufacturing	1.09	1.42	1.04	0.90	0.81	2.06	1.45	0.83

Table 8.1: The revealed technological advantage (RTA) from domestically-owned activity in selected host countries, across fields of technological activity and during the period 1969-1995.

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	*0.00*	*0.00*	*0.00*	*0.00*	*0.59*	*0.00*	*0.00*	*0.00*
Chemicals	1.19	0.36	0.88	0.23	0.70	0.68	0.30	0.51
Pharmaceuticals	*1.42*	*1.56*	*0.40*	*0.00*	*1.62*	*0.00*	*0.77*	*0.00*
Metals	1.09	0.56	0.80	0.32	0.78	1.50	2.24	0.63
Mechanical Engineering	1.33	0.35	1.16	0.30	0.58	0.94	3.05	0.54
Electrical Equipment	0.93	1.12	0.98	1.40	1.23	1.03	0.87	0.94
Office Equipment	0.89	1.28	0.44	1.54	0.63	0.09	0.13	1.97
Motor Vehicles	0.60	0.42	0.53	0.09	0.80	1.75	1.45	0.99
Aircraft and Aerospace	*0.07*	*0.00*	*0.00*	*0.47*	*0.94*	*0.00*	*0.00*	*0.00*
Coal and Petroleum	*1.37*	*0.00*	*0.00*	*0.00*	*1.15*	*0.00*	*0.00*	*0.00*
Instruments	1.03	1.49	1.72	0.48	1.30	0.71	0.58	0.95
Other Manufacturing	0.92	0.38	1.18	0.24	0.77	4.84	1.96	0.68

Table 8.2: The revealed technological advantage (RTA) from foreign-located activity by firms of selected home countries, across fields of technological activity and during the period 1969-1995.

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	*0.00*	*0.73*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Chemicals	0.67	0.58	0.62	0.46	2.10	0.48	0.21	1.94
Pharmaceuticals	*0.64*	*0.42*	*4.45*	*1.43*	*0.00*	*0.54*	*3.83*	*0.22*
Metals	0.78	1.27	1.24	0.56	0.93	0.64	1.11	0.53
Mechanical Engineering	0.67	1.52	1.05	0.54	1.82	1.17	1.06	0.74
Electrical Equipment	1.18	0.94	1.08	1.21	0.90	1.17	0.50	0.86
Office Equipment	1.06	0.69	0.75	1.14	0.35	0.54	0.52	0.88
Motor Vehicles	1.14	0.39	0.14	0.45	4.24	0.15	0.69	1.13
Aircraft and Aerospace	*0.00*	*0.14*	*0.24*	*0.99*	*0.00*	*0.00*	*8.80*	*0.00*
Coal and Petroleum	*0.00*	*1.41*	*4.64*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Instruments	0.96	1.20	1.20	1.03	0.75	1.27	3.64	1.59
Other Manufacturing	0.65	1.52	0.79	0.69	1.08	1.04	0.92	0.61

Table 8.3: The revealed technological advantage (RTA) from foreign-owned activity in selected host countries, across fields of technological activity and during the period 1969-1995.

* The sectors represented in italics have less than 1,200 patents

Table 9: Technological Specialisation within the Metals and Mechanical Engineering Industry*

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	*1.13*	*0.92*	*0.16*	*0.38*	*0.00*	*0.34*	*2.74*	*0.38*
Chemicals	0.84	1.68	0.91	3.22	1.14	1.39	0.44	0.95
Pharmaceuticals	*0.90*	*1.35*	*1.12*	*2.78*	*0.00*	*2.63*	*1.58*	*0.51*
Metals	0.97	0.57	1.27	1.06	0.77	1.00	0.94	1.42
Mechanical Engineering	1.06	0.95	0.90	0.42	1.51	1.14	1.03	0.68
Electrical Equipment	0.99	0.64	1.28	1.37	0.19	0.56	1.65	1.31
Office Equipment	*0.99*	*1.21*	*0.61*	*0.62*	*0.58*	*0.17*	*0.51*	*1.72*
Motor Vehicles	1.20	0.83	0.17	0.04	0.27	0.66	0.24	1.16
Aircraft and Aerospace	*0.89*	*1.96*	*1.60*	*0.38*	*0.00*	*0.00*	*4.04*	*0.21*
Coal and Petroleum	*1.11*	*1.37*	*0.29*	*0.92*	*0.00*	*0.41*	*0.47*	*1.06*
Instruments	1.06	0.83	1.31	0.44	0.85	0.49	0.96	1.27
Other Manufacturing	0.93	1.23	0.97	0.50	0.41	0.83	1.19	1.26

Table 9.1: The revealed technological advantage (RTA) from domestically-owned activity in selected host countries, across fields of technological activity and during the period 1969-1995.

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	*0.42*	*0.32*	*1.70*	*0.00*	*1.34*	*2.36*	*3.63*	*0.00*
Chemicals	0.48	1.30	0.83	2.35	0.27	0.70	0.36	0.78
Pharmaceuticals	*0.39*	*0.39*	*0.94*	*1.86*	*1.08*	*1.91*	*1.27*	*7.06*
Metals	1.12	0.72	0.81	0.97	0.77	1.45	0.74	0.85
Mechanical Engineering	1.23	0.91	1.28	0.49	1.60	1.33	1.54	0.65
Electrical Equipment	1.03	1.11	1.02	0.62	0.54	0.45	1.02	0.85
Office Equipment	*0.74*	*0.96*	*0.69*	*0.00*	*0.00*	*0.08*	*0.18*	*3.47*
Motor Vehicles	0.90	1.47	0.51	0.00	0.16	0.08	0.43	2.46
Aircraft and Aerospace	*0.00*	*1.90*	*1.52*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Coal and Petroleum	*0.57*	*0.00*	*0.84*	*1.39*	*0.00*	*0.20*	*0.15*	*2.10*
Instruments	1.19	0.71	0.47	0.09	0.27	0.32	0.78	2.42
Other Manufacturing	0.64	1.36	0.81	2.43	1.14	0.83	0.42	1.05

Table 9.2: The revealed technological advantage (RTA) from foreign-located activity by firms of selected home countries, across fields of technological activity and during the period 1969-1995.

Technological Sectors	United States	Germany	United Kingdom	France	Netherlands	Switzerland	Sweden	Japan
Food, Drink and Tobacco	*1.85*	*0.99*	*0.52*	*0.67*	*1.04*	*2.95*	*0.00*	*0.00*
Chemicals	0.75	0.49	0.72	0.53	0.55	0.82	0.75	1.22
Pharmaceuticals	*1.34*	*0.17*	*0.73*	*0.00*	*0.00*	*2.77*	*0.00*	*1.25*
Metals	1.06	1.03	1.18	0.70	1.94	0.74	0.81	0.94
Mechanical Engineering	1.05	1.42	1.29	1.40	1.14	1.38	1.34	1.00
Electrical Equipment	1.26	0.69	0.66	0.80	0.20	0.50	0.33	1.56
Office Equipment	*0.77*	*0.42*	*0.51*	*0.17*	*0.00*	*1.22*	*0.00*	*0.58*
Motor Vehicles	0.82	0.71	1.03	0.16	0.12	0.12	0.00	1.00
Aircraft and Aerospace	*0.57*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Coal and Petroleum	*0.18*	*0.59*	*0.00*	*0.81*	*0.62*	*0.00*	*0.00*	*1.39*
Instruments	0.61	0.90	0.64	1.61	0.76	1.24	0.50	0.57
Other Manufacturing	1.11	0.58	0.75	0.62	1.25	0.52	1.68	0.58

Table 9.3: The revealed technological advantage (RTA) from foreign-owned activity in selected host countries, across fields of technological activity and during the period 1969-1995.

* The sectors represented in italics have less than 1,200 patents

5. The explanation of variations between national industrial groups of firms

Although national groups of firms have distinctive technological profiles, a comparative analysis of their competitive position, their degree of internationalisation and of foreign-owned inward investment in the equivalent countries reveals some common underlying determinants, which have been illustrated in Figures 1 and 2 above. The most technologically competitive national industrial groups tend to be also as expected the most internationalised in the cross-country distribution of each country of origin. However, the home countries of these leading national groups tend to receive comparatively lower inward investment in technological development in the equivalent industries, as proposed in Figure 1.

UK-owned firms lead in the food industry (Table 2.1 and 2.2), to be followed only at a distance by US-owned and Swiss-owned firms. British-owned firms are also highly internationalised in both the food industry and the food technological field (66% and 62% in Tables 3 and 4). However, foreign-owned firms when considering technology-based investment in the UK, seem overwhelmed by indigenous competitiveness, and have only a modest innovative presence in the country (15% and 20% in Tables 5 and 6). Moreover, it is clear that UK-owned food industry firms are more internationalised as a whole than are UK-owned firms in the development of food technology as such (that is, the food firms conduct abroad the development of non-food technologies to a greater extent than at home); while foreign-owned firms are more attracted to the UK to develop food technology than in the food industry itself (it is the firms of other industries that in part source food-related technology from a UK location).

Likewise, Swiss-owned, and in particular German-owned firms are the technological leaders in the chemical industry (Table 2). Both national groups have a high degree of internationalisation (42% and 21% in Table 3). Swiss-owned firms have become just slightly more internationalised in the primary technological sector (43% in Table 4) than in the industry (which may be due to the even greater strength of the Swiss pharmaceutical firms, and their emphasis on the development of related chemical technologies abroad), but the German group remains consistent with Figure 1, and is more active internationally in the chemical industry than in chemical technologies (16% in Table 4). However, both host countries (Switzerland and Germany) receive minimal attention from foreign-owned research in this industry (4% and 6% in Table 5), although the local sourcing of chemical technologies by foreign-owned firms of other industries is indeed slightly higher (5% and 8% in Table 6). This is consistent with the pattern of Table 7.3 which shows that in inward investment in Germany from foreign-owned chemical and pharmaceutical firms, the local operation of the companies concerned are technologically specialised in the mechanical engineering (1.95) and aircraft (2.26) fields, but not in the primary chemical technologies. Foreign-owned chemical firms in Switzerland too are specialised in inward research-based investment in a number of technological sectors, such as mechanical engineering (1.70), metals (1.41), office equipment (1.27) and even food and instrument technologies (1.17), but not in chemical technologies.

Swiss-owned and US-owned firms have the strongest technological base in the pharmaceuticals industry (Table 2). Swiss-owned companies are very active internationally in this industry (59% in Table 3) and also, although to a lesser extent, in the corresponding technological sector (54% in Table 4). At the same time Switzerland has little to fear from foreign penetration in either pharmaceutical technologies (4% in Table 6), or the even weaker inward innovation from foreign-owned firms in the industry (3% in Table 5). As discussed above in the case of chemicals, Table 7.3 shows that foreign-owned chemical and pharmaceutical firms in Switzerland specialize in innovative activity in a number of technologies, but not in pharmaceutical technologies[5]. US-owned firms in the pharmaceutical industry are, with respect to the US average, quite internationalised in both the industry (11% in Table 3), and very slightly more in the primary technology (11% in Table 4). Further, despite the accessibility of the US as a host to foreign-owned innovation, much more is accomplished in the technological field than is achieved in the industry itself (10% and 16% in Tables 5 and 6).

The technological advantage of Swedish-owned firms in machinery is without any serious challenge from other national groups that cluster around average. Swedish-owned firms in this industry are highly internationalised in their organisation of innovation, even if the internationalisation of the technology is just above that of the industry (32% and 34% in Tables 3 and 4). The relative strength of the development of mechanical technology abroad may be due to the close relationship between the mechanical engineering industry and other

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[5] However, although the sector is subject to small number problems if following the ground rule that it has less than 1,200 patents (Cantwell and Kotecha, 1997; Cantwell and Harding, 1998), metal and mechanical engineering firms (Table 9.3) do a considerable amount of innovation in pharmaceutical technologies in Switzerland (2.77).

industries in Sweden, in particular electrical equipment (1.65), but also aircraft and aerospace, food and pharmaceuticals (although the latter sectors are not very important in absolute terms) as Table 9.1 suggests from the perspective of the distribution of technological efforts of the Swedish metal and machinery firms at home. On the other hand, innovation by foreign-owned firms in Sweden is consistent with Figure 1, since although low, innovation in the relevant technology is greater than it is in the industry (2% and 7% in Tables 5 and 6).

Dutch-owned firms have the strongest position in the electrical equipment industry (Table 2). Correspondingly, Dutch-owned firms are highly internationalised in both the industry and primary technology (52% and 53% in Tables 3 and 4), and the Netherlands has a low degree of penetration by foreign-owned research, but one which is higher for the firms of other industries accessing local innovation in electrical technology (4% and 7% in Tables 5 and 6).

In the computing industry and field of technological activity, US-owned firms are without hesitation the industry leaders, and have a relatively high share of foreign-situated research, which is higher in the industry than in the technological sector (11% and 7% in Tables 3 and 4). However, Tables 5 and 6 show once again an indication of entry deterrence in their own home country. Foreign-owned research in the US industry is very low especially when compared to the high interest in computing technologies (5% in Table 6), and suggests the interest of foreign investors from other industries in acquiring US computing technologies. In addition, Table 8.3 indicates that, although inward investment in computing technologies is above average (1.06), foreign-owned electrical equipment and computing firms in the US favour investment in the electrical equipment (1.18) and motor vehicle (1.14) technological sectors.

In motor vehicles German corporate strength is quite prominent as Table 2 shows. The industry, on the whole, is moderately internationalised in terms of innovation and the German-owned national group is consistent with this picture (8% and 9% in Tables 3 and 4). However, foreign-owned innovation, although low in Germany, is higher than what one would expect for a leading group (8% and 7% in Tables 5 and 6), which may be due to the relocation of the technological efforts of the UK component companies in Germany at the time when the indigenous UK vehicle industry declined. UK competitiveness on the other hand is exaggerated (Table 2.1) because the motor-vehicle industry includes both a relatively weak vehicle assembly industry and the much stronger vehicle and transport component firms. This amalgamation of a weak car industry and much stronger component firms helps to account for the average industry but the somewhat higher technology internationalisation (always in respect to the relevant country and industry average figures - 24% and 19% in Tables 3 and 4). Inward innovation conducted by foreign-owned firms in the UK shows the same mixed effect (13% and 21% in Tables 5 and 6), suggesting again that a more disaggregated level of investigation has to be employed in order to assess the different technological strengths and the different degrees of internationalisation of each sub-group of firms. Of course, in the most recent years very little locally-owned vehicle assembly activity remains in the UK.

The leading national groups in aircraft and aerospace, US-owned firms and French-owned firms (Tables 2.1 and 2.2) operate in an industry with a relatively low propensity to patent. However, despite the difficulties of small numbers, and taking into consideration the special situation of this industry, both the US and French cases conform to the theoretical framework of Figure 1. US-owned firms have high - with respect to the industry - outward internationalisation (2% in Table 3) while the US has low inward investment in the technology (1% in Table 6, but 0% in the industry in Table 5). Comparing the aircraft industry with the national average, France as well has much lower inward investment (3% and 5% in Tables 5 and 6) than the extent to which its firms engage in outward development abroad (4% and 1% in Tables 4 and 5**)**. Furthermore, inward research activity by foreign-owned firms in both countries is much higher in the primary technological field than it is in the industry as a whole (see Tables 5 and 6).

UK-owned firms in coal and petroleum products (oil) lead the industry and technological field (Tables 2.1 and 2.2) and have a long-standing international tradition (84% in Table 3 and 69% in Table 4). In comparison, in line with the contentions of Figure 1, foreign-owned innovation in the UK remains at exceedingly low levels in both industry and technological field (19% and 18% in Tables 5 and 6).

However, the reverse trend is observed in the metals industry, in which localised user-producer interaction with the firms of other industries is often of great importance in innovation. As illustrated in Figure 2, we expect to observe considerably lower outward internationalisation in this industry than the strength of the relevant national groups might otherwise indicate, accompanied by a consistently higher internationalisation of the primary technology with respect to the industry. For inward investment, foreign penetration of the industry in centres with strong indigenous firms is also lower as suggested by Figure 2, but somewhat higher in the technological field compared to the industry (in which latter respect the scheme of Figure 2 is in line with that of Figure 1).

Swedish-owned companies are the technological leaders in the metal industry and the metals technological field (Table 2). The Swedish-owned industry's internationalisation is relatively low (19% in Table 3) while the internationalisation of the technological field is moderate (26% in Table 4).

The RTA figures in Table 9.1 in the case of Swedish-owned mechanical engineering firms (see also discussion above), suggest that the cause may be the close connection with other firms situated in Sweden. Foreign-owned innovation, although at a low degree, is higher in the technological field than in the industry, indicating again that local capabilities are tapped into indirectly more by non-metal industry firms (2% and 8% in Tables 5 and 6). This is in line with the Tables 7.3 and 8.3, which show that metal technologies are noticeably accessed locally by foreign-owned firms in the chemical and pharmaceutical (2.84), and electrical equipment and computing (1.11) industries respectively.

Besides the Swedish-owned, German-owned and French-owned firms are leaders in the metals industry too (Table 2.1). Both national groups and their home economies follow patterns that are consistent with Figure 2. They have a moderate level of internationalisation that is more prevalent with respect to the primary technological field (13% and 10% in Table 3) than in the metals industry (8% and 9% in Table 4). Moreover, inward investment in the industry is lower than is the level of outward internationalisation with respect to the relevant national averages, and more to the point, the industry is significantly less affected by foreign penetration (10% and 11% in Table 5) than the field of the primary technology (29% and 20% in Table 6). Furthermore, foreign-owned specialisation in metal technologies in Germany in the industry (1.03 in Table 9.3) and the higher RTA figure for foreign-owned local specialisation in metals in the electrical and computing industry (1.27 in Table 8.3) is an additional indication of the difficulty foreign-owned direct competitors may face in their effort to tap into innovation in the primary metal technologies, and suggests that local German technological resources are more easily accessed indirectly by firms that are not competitors in output markets. The same is true, although to a lesser extent, for France, in which foreign-owned metal and machinery firms prefer to develop locally the non-primary instruments (1.61

in Table 9.3) and the less strong mechanical engineering technologies (1.40 in Table 9.3) rather than those of metals (0.70 in Table 9.3).

Although the theme of Figure 2 is most obvious in the case of metals, the same internationalisation-suppressing effect is relevant to other national industrial groups for which a strong indigenous advantage is inward-looking. The higher the degree to which innovation depends upon localised inter-industry linkages within or between companies, the less will be the imperative and the capacity to internationalise, not because of the inability to compete in markets on a global scale, but instead because the main driving forces behind innovation lie in the form of location-specific relationships with other local industries.

Even if this is true, to some extent, for a number of national industrial groups, it is in Japan that this framework has greatest relevance, due to the particular form of historically developed business organisation as in the keiretsu structure (hub and spike). Japanese-owned firms have a leading position in motor vehicles, instruments, and electrical equipment (Table 2.1 and 2.2). Yet the internationalisation of innovation in these industries is moderate in terms of both industry and even country levels, and in all three cases the internationalisation of Japanese-owned firms is higher in the development of primary technologies than in the corresponding industries (in motor vehicles 0.81% and 0.84%; in instruments 0.77% and 0.95%; in electrical equipment 0.92% and 1.17% in Tables 3 and 4 respectively). Further, inward penetration from foreign-owned firms is generally very low in Japan, and the local sourcing of the relevant primary technologies is more common among foreign-owned companies from other industries (motor vehicles 2.15% and 2.17%; instruments 0.43% and 2.56%; electrical equipment 1.33% and 3.10% in Tables 5 and 6 respectively).

6. Conclusions

Our results support the conclusions that first, the internationalisation of the corporate research and development tends to be higher in an industry in which a national group of firms is especially technologically strong, and the firms in question tend to diversify their technological activity through such international operations. Second, inward penetration in locations of domestic technological excellence tends to be low in the same industry, but attracts to a greater extent the investments of stronger firms from other industries to source the primary technology of the industry of host country excellence, since for them local technological cooperation need not be constrained by market rivalry. However third, national groups of firms whose technological strength is bound up with inter-industry linkages in innovation in their own home country (or national system of innovation) have greater difficulty in internationalising their technological base, both in an outward and in an inward direction.

To conclude, while we must be careful in our cross-country cross-industry analysis that in looking at the trees we do not lose sight of the forest, we have seen that restricting ourselves to a panoramic or 'average' view may be misleading if it skates over the complexity that is associated with substantial variations in the quality and type of the timber. Our picture is altogether richer when we compare the experiences of different national groups with varying strengths in the degree of their internationalisation of corporate technology at an industry level and at the level of technological fields instead of just examining the totals that represent global average values.

What is especially notable from our findings is the restatement they provide of the significance of technological ownership advantages as a condition for internationalisation (Cantwell, 1989; Dunning, 1995). Some commentators have attempted to present the latest phase of asset-seeking investments of MNCs abroad which promotes their corporate technological diversification - a facet that we have also emphasised ourselves, both here and elsewhere (Dunning and Wymbs, 1999; Cantwell and Piscitello, 2000) - as somehow in conflict with the notion that MNCs require some initial ownership advantages. Instead, we observe that the augmenting and strengthening of ownership advantages through internationally dispersed innovation is complementary to the initial advantages of firms developed in their home base. It is the technological leaders of each industry with the strongest inherited ownership advantages that are best able to develop an international network of innovation (Cantwell, 1995) and so extend their advantage.

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Danish **R**esearch **U**nit for **I**ndustrial **D**ynamics

The Research Programme

The DRUID-research programme is organised in 3 different research themes:

- The firm as a learning organisation
- Competence building and inter-firm dynamics
- The learning economy and the competitiveness of systems of innovation

In each of the three areas there is one strategic theoretical and one central empirical and policy oriented orientation.

Theme A: The firm as a learning organisation

The theoretical perspective confronts and combines the resource-based view (Penrose, 1959) with recent approaches where the focus is on learning and the dynamic capabilities of the firm (Dosi, Teece and Winter, 1992). The aim of this theoretical work is to develop an analytical understanding of the firm as a learning organisation.

The empirical and policy issues relate to the nexus technology, productivity, organisational change and human resources. More insight in the dynamic interplay between these factors at the level of the firm is crucial to understand international differences in performance at the macro level in terms of economic growth and employment.

Theme B: Competence building and inter-firm dynamics

The theoretical perspective relates to the dynamics of the inter-firm division of labour and the formation of network relationships between firms. An attempt will be made to develop evolutionary models with Schumpeterian innovations as the motor driving a Marshallian evolution of the division of labour.

The empirical and policy issues relate the formation of knowledge-intensive regional and sectoral networks of firms to competitiveness and structural change. Data on the structure of production will be combined with indicators of knowledge and learning. IO-matrixes which include flows of knowledge and new technologies will be developed and supplemented by data from case-studies and questionnaires.

Theme C: The learning economy and the competitiveness of systems of innovation.

The third theme aims at a stronger conceptual and theoretical base for new concepts such as 'systems of innovation' and 'the learning economy' and to link these concepts to the ecological dimension. The focus is on the interaction between institutional and technical change in a specified geographical space. An attempt will be made to synthesise theories of economic development emphasising the role of science based-sectors with those emphasising learning-by-producing and the growing knowledge-intensity of all economic activities.

The main empirical and policy issues are related to changes in the local dimensions of innovation and learning. What remains of the relative autonomy of national systems of innovation? Is there a tendency towards convergence or divergence in the specialisation in trade, production, innovation and in the knowledge base itself when we compare regions and nations?

The Ph.D.-programme

There are at present more than 10 Ph.D.-students working in close connection to the DRUID research programme. DRUID organises regularly specific Ph.D-activities such as workshops, seminars and courses, often in a co-operation with other Danish or international institutes. Also important is the role of DRUID as an environment which stimulates the Ph.D.-students to become creative and effective. This involves several elements:

- access to the international network in the form of visiting fellows and visits at the sister institutions
- participation in research projects
- access to supervision of theses
- access to databases

Each year DRUID welcomes a limited number of foreign Ph.D.-students who wants to work on subjects and project close to the core of the DRUID-research programme.

External projects

DRUID-members are involved in projects with external support. One major project which covers several of the elements of the research programme is DISKO; a comparative analysis of the Danish Innovation System; and there are several projects involving international co-operation within EU's 4th Framework Programme. DRUID is open to host other projects as far as they fall within its research profile. Special attention is given to the communication of research results from such projects to a wide set of social actors and policy makers.

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Jonna Jacobsen
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DK-9220 Aalborg OE
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E-mail: druid-wp@business.auc.dk