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LARGE FIRMS AND INTERNATIONALISATION OF R&D: 'HOLLOWING OUT' OF NATIONAL TECHNOLOGICAL CAPACITY?

by

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1. Introduction

Background

Large multinational companies play a dominant role in the innovation activities of their home country and control a vast proportion of world's stock of advanced technologies. Their decisions in terms of the mode, location and exploitation of their R&D results greatly influence the home country's technological potential and competitiveness (Patel and Pavitt, 1999). The growing significance of the internationalisation of R&D activities of large firms over the past two decades has therefore been cause of some concerns among innovation policy makers. In Europe this has resulted in a concern that the increasing level of activities of EU firms in foreign locations is resulting in a 'hollowing out' of national R&D. This is regarded as indicative of a weakening of the national innovation system and an erosion of the technological competitiveness (ETAN, 1998). In the United States the internationalisation of industrial R&D has brought with it worries about a possible impoverishment of the national technology base due to the increasing local R&D activities of foreign firms.

To be able to evaluate the potential impact on the home countries it is crucial to determine the extent and the nature of the R&D activity that has been relocated abroad. As the ETAN (1998) report puts it "*data still tend to be incomplete, may not be fully comparable and are subject to differing interpretation*". The aim of the paper is to use the latest available empirical data to investigate the general relationship between the degree of internationalisation of corporate R & D, one the one hand, and national technological performance, on the other. Our analysis is guided by two propositions. The first is that the improved performance (relative to Europe and Japan) of the USA in corporate R & D in the 1990s, compared to the 1980s, reflects the strongly increasing propensity of European and Japanese firms to increase the share of their R & D performed in the USA. The second is that this increasing propensity reflects corporate policies to improve their access to fast moving technological fields where the US is the world leader. These propositions implicitly assume that entrepreneurial European firms seek and find world frontier science and technology more easily in the USA than in Europe. The main objective of this paper is to bring together the latest available empirical evidence from various sources to examine these propositions.

Old versus New paradigm in Internationalisation of R&D

Studies of the drivers of internationalisation of R&D have traditionally focused on the location motives of international production to explain the geographical dispersion of innovation activities. The interpretation of this phenomenon was based on Vernon's product-cycle model (1966, 1977). The original product-cycle model (1966) is based on the assumption that innovation is a demand-led process: it arises from a market stimulus, i.e. firms tend to be stimulated by the needs stemming from the nearest market, the home market. The home market plays a dual role in this model: it is considered the source of stimulus of innovation and at the same time it is the preferred location for performing R&D activities. Innovating firms will therefore concentrate their R&D effort at home where they can benefit from both the availability of scientists and engineers with the required skills, and the proximity to and, interaction with, potential customers. Economies of scale in R&D activity and agglomeration effects, as well as the need for the coordination and control of expensive and risky investments are also reasons for keeping R&D and the initial stage of production in a common location (Vernon, 1977). Therefore in this model internationalisation of production was limited to mature and standardized products and minor adaptive and development work would be the only R&D to accompany the foreign production.

Nevertheless, this model, with its demand-led interpretation of the innovation process and the important role it gives to proximity to local costumers, has contributed significantly to our understanding of why foreign R&D is undertaken. As firms increasingly locate production closer to their customers and suppliers they need R&D laboratories to adapt the technologies and product developed at home to local conditions. The creation of such technical support laboratories, (see Hood and Young (1982), are then supposed to accompany the later stages of the production process abroad. Indeed they seem to follow a linear progression based on the age, growth and relative size of the international production of the MNE (Lall 1979). In this framework the technological advantages of the affiliates primarily reflect those of the home country (where the core of innovation activities continues to be concentrated) and foreign R&D units tend to enhance the existing parent-company technologies. This type of R&D site has been termed “home-base exploiting” (HBE) (Kuemmerle 1996) or “asset-exploiting” (Dunning and Narula 1995).

Over the last decade some of the factors encouraging centralisation of R&D activities have become less influential, i.e. the cost of technology transfer and the shortage of human capital and scientific infrastructures in the host countries. As multinationals have extended and diversified their global operations, they have set up global R&D networks. This strategy is based not only on the wish to rationalise R&D expenditures and to avoid duplication of R&D activities, but also indeed to absorb and acquire technological spillovers, either from the local knowledge base (be they agglomeration effects or from public infrastructure), or from specific firms. These R&D activities have been defined as “home-base augmenting” (HBA) (Kuemmerle, 1996) or “asset-seeking” R&D activity (Dunning and Narula, 1995). In such kinds of investments, firms aim either to improve their existing assets, or to acquire (and internalise) or create completely new technological assets by locating R&D facilities abroad. The assumption in such cases is that this provides access to location-specific advantages that are not as easily available in the home base and that might be associated with the presence of a lead market (Meyer-Kramer and Reger, 1999). While often reported to be a much smaller phenomenon in terms of international R&D expenditure (Patel and Vega 1999, Gerybadze and Reger 1999, Niosi

1999), the number of HBA sites seems to be increasing quite fast, particularly in technology-intensive sectors, such as biotechnology, computers and telecommunications (Kuemmerle, 1999, Serapio and Dalton, 1999, and Patel and Vega, 1999, Le Bas and Sierra, 2002).

Another factor affecting the tendency towards greater dispersion of technology is that large firms need to master an increasing range of potentially useful technologies (Granstrand et al., 1997), not all of which may be available in the home country. This is especially the case for large firms based in 'small' countries.

Overall companies are moving away from the old paradigm where subsidiaries were adapting technologies developed in the R&D headquarters, to a new paradigm which sees subsidiaries actively engaged in the creation of technological assets, as shown by the literature on 'centres of excellence' (Frost *et al.* 2002). Subsidiaries located in specialized pockets of expertise (e.g. Cambridge UK, New Jersey and California for biotechnology and Silicon valley and the Boston area for IT) are leveraging technological resources to be deployed by other unit of the organization.

2. Data

Most studies concerned with analysing the internationalisation of corporate R & D are based on one of two sets of measures:

- *R&D expenditures and employees*, where the OECD AFA database (1998) has recently brought together evidence from national surveys on the shares of domestic business funded R & D performed by foreign firms, and of R & D funded by domestically owned firms that is performed outside their home country.

- Patent statistics (Etemad and Seguin-Delude, 1987; Cantwell, 1992; Le Bas and Sierra, 2002, Patel and Pavitt, 1991; Patel, 1995,1996; Patel and Vega, 1997, 1998) where the inventor's address given in each published patent is used as a proxy measure for the geographical location of R & D activities.

The validity of these measures has been extensively discussed elsewhere[1]. Suffice to say that patenting-based data can be analysed in much greater detail and with much greater consistency than the available data on R & D activities. Moreover, as we have shown elsewhere, the patterns revealed by patenting statistics are consistent with those revealed by the R & D statistics that are available[2]. However for the purposes of this paper their deficiencies are as follows:

[1] See, for example, Cantwell (1992) and Patel (1995 and 1996).
[2] See Patel and Pavitt (2000) and Patel (1995 and 1996).

Firstly in the case of the R&D data from national surveys there is a lack of detail on the activities of national large firms. For our purposes we would like data on the amount of R&D undertaken by national large firms at home and in a foreign country in order to assess the main elements of the 'hollowing out' hypothesis. In this paper we use the only other data available: those from annual accounts of companies. The main problem with the company accounts data is that they cover *worldwide* activities of large companies, with no distinction between different locations of activity. Moreover while in some countries there are strict regulations concerning the type of expenditure that could be included as R&D in company accounts of publicly quoted companies (for example the UK and the US) in other countries these regulations do not always apply (for example in Japan). We argue below that a comparison of national R&D data from the OECD and company accounts data throws some new light on the debates about the internationalisation of R&D.

A large part of the analysis in this paper is based on data from the USPTO on the patenting activities of large firms based in US, Japan and Europe. The main drawback is that using US patent data for US companies and for US subsidiaries of non-US companies means that there will be an overestimation of the role of domestic R&D for the former and foreign R&D for the latter. On the other hand these data provide the level of detail in terms of location and technical field that is necessary for examining the 'hollowing out' hypothesis.

R&D data: Sources and Methods

R&D data have been collected from a number of sources. Mainly we used the Standard & Poor Compustat database (both the domestic and international version), which contains information extracted from financial reports of firms quoted in the US stock market. For firms not included in the Compustat database we used both data published by the R&D scoreboard and data reported in the company web site. We collected data on R&D expenditure from 1990 to 2000 for 421 companies (108 European, 114 Japanese, and 199 American).

Patent data: Sources and Methods

The data set has been compiled from information, supplied by the US Patent Office, on the name of the company, the technical class, and country of origin of the inventor, for each patent granted in the USA from 1985 to 2000. Additionally we have collected, for each firm data on its sales, employment, principal sector of activity, country of origin from the Compustat database. The main difficulty with the primary data is that many patents are granted under the names of subsidiaries and divisions that are different from those of the parent companies, and are therefore listed separately. In addition the names of companies are not unified, in the sense that the same company may appear several times in the data, with a slightly different name in each case. Consolidating patenting under the names of parent companies can only be done manually on the basis of publications such as '*Who Owns Whom*'. In the present study we have based the consolidations on the basis of *Who Owns Whom* 1999 (i.e. referring to company structure as of 1998)

There is one caveat that need to be borne in mind when interpreting the results of the analysis below. As our firms are consolidated for one year only: 1998, the time-trend analyses of patenting by firms between 1985 and 2000, reflects the firm as constituted in that year, and does not include any of the changes resulting from purchases or sales of subsidiaries or divisions since then. Thus, measured changes over time are composed of changes in those parts of the firm retained up to 1998, together with those resulting from acquisitions made up to 1998: in other words, what the firm kept and what it bought, up to 1998.

For each patent granted, we have the following information that we use in our analysis for the current study:

- **The technical field.** We have developed and used a 90-field classification based on aggregations of US patent classes.
- **The country of residence of the inventor**[3]**.** This is *not* necessarily the country from which their patent application was filed, and is a more accurate reflection of the country in which the technological activity was performed.

For the analysis of fast-growing subfields we have identified a 1000 (out of more than 70,000) technological sub-classes that the large firms are active in. These 1000 are the fields with the highest absolute increase in patenting from 1985-90 to 1995-2000. Their combined share of total patenting increased steeply from 0.9% to 11.2% of total US patenting over the period. The analysis below shows the types of technologies reflected in these fast-growing fields. The underlying assumption is that these reflect areas of greatest technological opportunity.

The selection of companies in our sample is based on their size. We used a threshold level of 3000 employees and 1 billion US$ sales. Of the 546 companies in our sample 224 appeared in the international R&D scoreboard in 1998. Table 1 shows the numbers of large firms in our database according to their principal product group and region of origin. US firms account for 40% of the sample, European firms for more than one third and Japanese for less than one third. The product groups most represented in our sample are machinery (accounting for 15% of the sample), chemicals, electrical and electronics, and motor vehicle and parts (almost 10%).

[3]More accurately the first named inventor. The number of US patents with inventors from different countries is around 1%.

Table 1. Distribution of Large firms by Principal Activity and Region.

Product Group	*Europe*	*Japan*	*US*	*Total*
Aerospace & Defence	4		9	13
Biotech	2		4	6
Chemicals	18	25	24	67
Electrical/Electronics	18	23	19	60
Food, Drink & Tobacco	7	3	7	17
IT Related	4	7	25	36
Instruments	3	1	8	12
Machinery	44	22	19	85
Materials	4	4	9	17
Medical equipment	4		12	16
Metals	14	15	6	35
Mining & Petroleum	11	2	12	25
Motor Vehicles and parts	18	21	15	54
Paper	6	2	8	16
Pharmaceuticals	15	12	13	40
Photography and Photocopy	3	9	4	16
Rubber & Plastics	4	6	5	15
Telecommunications	7	2	7	16
All Product Groups	186	154	206	546

3. Analysis of 'Hollowing Out': A Road Map

As discussed in the introduction there are two main elements to the 'hollowing out' hypothesis. The first is concerned with the extent of innovative activities outside the home country, the second with the changing nature of such activity, and the third with the quality of the technological assets created outside the home country. We use a combination of the above data sources to address these elements as follows:

1. *Relationship between country technological performance and that of national large firms, foreign firms and other national firms and institutions.*

The underlying hypothesis is that national large firms are dominant players in national technological performance. We examine this relationship between country and company performance using 3 different data sets. Each of them provides partial answers. The first is a macro level 'growth accounting' type of exercise similar to that found in Patel and Pavitt (1991). The main aim here is to see the extent to which changes in industry-financed R&D are related to changes in the shares of national large firms at home and abroad. The main difficulty in such an exercise is the lack of detailed data from national R&D surveys, for example, for large firms (national and foreign) and of other firms. Below we use our data on US patenting to create proxy measures for activities of these firms by location.

The second element in examining the relationship between country and company performance is based on an analysis of company level R&D data from annual published accounts and the data from national R&D surveys (OECD data). The idea in this case is to see the extent to which growth rates of company R&D by nationality are comparable with growth rates of national R&D. The main difficulty with these data is that any changes in company level R&D cannot be decomposed into changes in the amount performed in the home country and the amount performed abroad. Nevertheless this analysis should show whether large firms are increasing (or decreasing) their R&D compared to the average of all firms conducting R&D in the home country.

The third type of analysis is a comparison of a country's R&D performance with the R&D performance of its firms in the US. This is based on a unique feature of the R&D survey in the US, which collects data by nationality and product group of the activities of the foreign firms active in the US. The idea here is to examine the extent to which foreign firms have increased their R&D activities in the US. In an ideal world such data would be available for all countries so that we could systematically examine the contribution made by large firms in different locations.

2. *Analysis of the type of technological activities undertaken in foreign locations.*

A number of recent studies have shown that firms are increasingly engaging in monitoring and scanning new technological developments in centres of excellence in foreign countries within their areas of existing strength (Le Bas and Sierra, 2002, and Patel and Vega, 1999). In this paper we throw some new light on this subject by analysing the involvement of firms in fast moving areas of technology outside their home country. In particular the following questions are addressed:

- At the company level, to what extent is internationalisation of R&D associated with strength in fast-growing technical fields?
- To what extent are activities in fast-growing technologies associated with the US?

3. *Analysis of the quality of foreign created technological assets*

The changing role of foreign located R&D units from technology adaptors to innovation creators should bring with it modifications in the type of their innovative contribution. Important innovations should not only be produced in the home country but also abroad in subsidiaries located in centres of excellence. Using the number of forward patent citations to assess the quality of the technological activities, we address the following research questions:

- Are the R&D activities performed abroad producing highly cited patents?
- To what extent are these important inventions originating from US subsidiaries?

4. Latest Trends in Internationalisation of Technology amongst Large Firms

This section presents some of the stylised facts concerning the latest trends in internationalisation of technology amongst the 546 large firms. The aim is to detect the main changes in the 1990s. In Table 2 we report the share of US patents originated from home country locations, foreign research facilities and US facilities according to the nationality of the parent company. Overall the share of US patents attributable to foreign locations is around 15 % but there is a great variation amongst different national groups of firms. European companies are the most engaged in undertaking R&D activities outside the EU, 28% of their patenting activity originates from foreign locations. American and Japanese companies show a much weaker propensity to perform their R&D activities abroad: only 9 % and 4 % of their activity is outside the home base.

Table 2. Internationalisation of Technology.

Nationality	% share of US patents in 1996-2000		% share in the US
	Home	Abroad	
Japan	95.7	4.3	3.4
US	90.5	9.5	
Europe	72.7	27.3*	25.1
Belgium	40.3	59.7	23.9
Denmark	69.8	30.2	25.1
Finland	73.3	26.7	11.5
France	60.2	39.8	19.8
Germany	73.0	27.0	18.0
Italy	70.4	29.6	19.6
Netherlands	46.7	53.3	21.6
Norway	43.9	56.1	8.2
Sweden	50.1	49.9	33.4
Switzerland	31.7	68.3	34.0
UK	37.4	62.6	49.8
All firms	85.3	14.7	6.7

* The proportion of total activities for all the European countries listed in this table located outside Europe

The degree of internationalisation varies substantially among European countries. Companies from small countries, such as Belgium, Switzerland, Netherlands, Sweden and Norway have among the highest shares of technological activity abroad, while firms from large countries, such as Germany and France, are still concentrating 70% of their efforts in the home country. The anomalies are the British firms: they are based in large country but are heavily engaged in R&D activities abroad, with more than 60 % of patents originated from foreign R&D facilities. The US appears to be the principal receiver of these R&D investments both by EU and Japanese firms.

The data in Table 3 show that there has been a modest overall increase in internationalisation of technological activities over the last 15 years. Again there major differences between EU firms and those from US and Japan. EU firms as a whole increased the proportion of their activities outside Europe by around 6% in the period since 1985. On the other hand US firms seem to have increased their activity abroad by less than 1%. At the same time Japanese firms are making increasing use of their foreign research facilities, showing an increase of patenting activity abroad of more than 2 per cent. With the exception of Dutch and Norwegian companies, all European companies have increased their proportion of R&D efforts abroad. The largest increases have been for firms based in Switzerland, Denmark, Italy and Germany. Table 3 also shows that the US has become the main beneficiary of these increases in internationalisation of technology.

Table 3. Changes in the Internationalisation of Technology: 1985 to 2000

	Change in US patenting between 1985-90 and 1996-2000	
Nationality	**% share abroad**	**% share in the US**
Japan	2.3	-0.7
US	0.5	
Europe	5.9	4.9
Belgium	6.0	18.1
Denmark	15.2	15.2
Finland	4.5	-0.2
France	8.7	5.5
Germany	10.2	6.7
Italy	14.6	12.1
Netherlands	-3.0	-4.0
Norway	-17.7	-2.9
Sweden	5.8	16.1
Switzerland	13.4	10.7
UK	8.6	5.1
All firms	1.0	4.9

Activities of EU Firms

Given these differing patterns and trends amongst the firms based in the three regions, we now focus on the activities of European large firms. Table 4 shows the main patterns of internationalisation of technology amongst EU firms, aggregated according to their principle activity. EU firms in IT, Instruments, Materials, Food, Drink and Tobacco,

Table 4. Internationalisation of Technology of EU firms

Product Group	% share of US Patents in 1996-2000 Home	Abroad	% share in other EU countries	% share in the US
Aerospace & Defence	89.2	10.8	5.7	3.3
Chemicals	63.1	36.9	11.4	23.2
Electrical/Electronics	52.3	47.7	19.4	26.3
Food, Drink & Tobacco	38.4	61.6	8.9	50.4
IT Related	29.1	70.9	42.0	27.9
Instruments	33.0	67.0	49.6	17.0
Machinery	68.2	31.8	14.6	15.9
Materials	39.8	60.2	13.6	44.1
Medical equipment	45.5	54.5	11.4	43.1
Metals	65.3	34.7	12.3	20.9
Mining & Petroleum	59.3	40.7	6.9	31.2
Motor Vehicles and parts	79.7	20.3	9.2	9.3
Paper	36.4	63.6	19.8	39.8
Pharmaceuticals	45.0	55.0	14.5	37.1
Photography and Photocopy	79.6	20.4	12.5	6.3
Rubber & Plastics	63.5	36.5	8.6	26.2
Telecommunications	57.3	42.7	14.6	24.2
All Product Groups	58.3	41.7	14.4	25.1

In these calculations we have eliminated Pharmacia & Upjohn Inc. a Swedish American Pharmaceutical company.

Table 5. Changes in Internationalisation of Technology of EU firms

	Change in US patenting between 1985-90 and 1996-2000		
Product Group	share abroad	share in other EU countries	share in the US
Aerospace & Defence	5.0	4.2	0.3
Chemicals	4.9	3.4	1.2
Electrical/Electronics	8.7	-1.4	9.0
Food, Drink & Tobacco	12.1	-2.0	14.0
IT Related	10.4	5.0	4.5
Instruments	17.3	6.9	10.0
Machinery	8.6	1.7	6.7
Materials	11.3	-4.8	15.8
Medical equipment	7.9	-4.5	12.5
Metals	1.5	-1.7	2.1
Mining & Petroleum	-11.3	1.4	-15.3
Motor Vehicles and parts	8.1	1.8	5.7
Paper	11.3	1.7	8.9
Pharmaceuticals	9.5	-1.8	8.9
Photography and Photocopy	17.8	11.9	4.8
Rubber & Plastics	-0.4	2.9	-4.8
Telecommunications	7.3	-16.5	20.6
All Product Groups	7.3	1.4	4.9

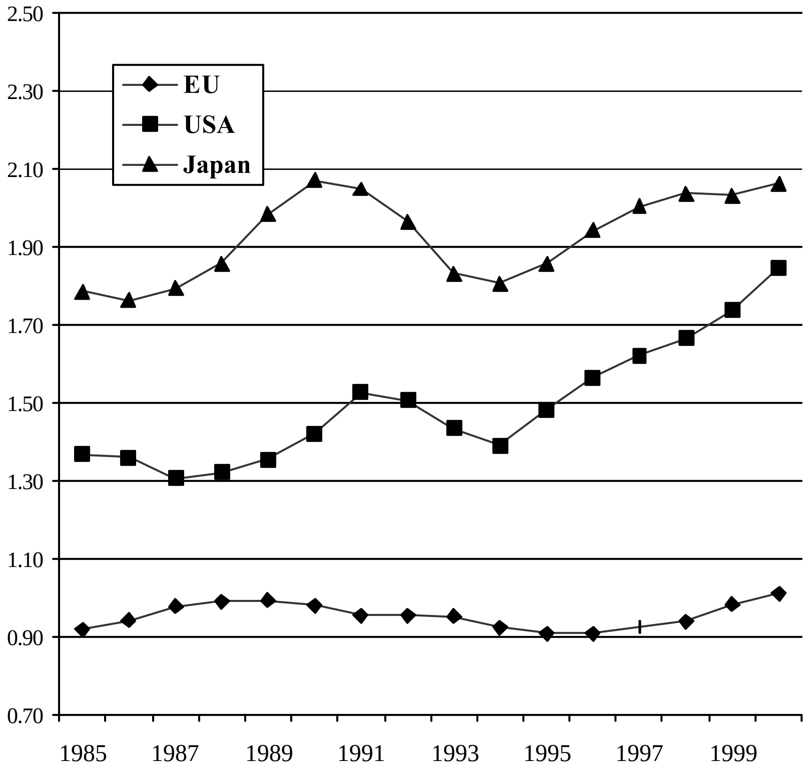
In these calculations we have eliminated Pharmacia & Upjohn Inc. a Swedish American Pharmaceutical company.

Paper, Pharmaceuticals, and Medical Equipment have produced more patents abroad than in the home country. In most sectors, with the exception of Instruments and IT which have allocated almost half of their innovative activity in other EU countries, they have concentrated their activities in the US. Thus overall the US has attracted significant R&D investments by European firms: almost 60 % of all EU firms' patents can be attributed to their US subsidiaries. The importance of the US has also increased quite substantially in the last decade (see Table 5), in most of the same industries that have a high volume of research conducted abroad.

5. Latest Trends in Industry Financed R&D expenditures: EU, Japan and the US.

The main aim of this paper is to relate the above trends in internationalisation of R&D to the innovation performance of countries. This section briefly examines the trends in one of the key indicators of national technological performance: industry financed R&D as a percentage of GDP.

Figure1. Industry-financed R&D Expenditures as a % of GDP:1985-2000



As Figure 1 shows over the last 15 years the three regions accounting for more than 90% of the world's R&D expenditures have seen contrasting trends in their innovation performance. Japan has maintained its lead throughout the period, but the US has been catching up fast since the mid-1990s. By contrast the EU countries taken as a whole have substantially lagged behind. The more detailed data show that there are a number of smaller EU countries able to match the performance of Japan and the US: Finland and Sweden. On the other hand the UK, France and Germany lag some way behind. The purpose of the next section is to relate these trends to those the technological activities of national large firms.

6. Comparing National Technological Performance with Company Performance

Analysis of US Patent data

The aim of this section is to relate the differences in national technological performance noted in the above section to the trends in internationalisation of technology amongst the largest firms shown in section 4. The first step in examining this relationship is to analyse the contributions made by large firms (national and foreign) to national technological performance. This is done in Table 6, which uses the data on patenting in the USA in the second half of the 1990s to compare the composition of the technological activities of the 13 countries. These countries account for more than 90% total OECD R & D expenditures funded by business enterprises, and of total US patenting.

Table 6. Large Firms in National Technological Activities: 1996-2000

Country	National Sources of Patenting in the US (3 columns add up to 100%) — Large Firms: Nationally Controlled	Large Firms: Foreign controlled	Other	Patenting in the US by Nationally Controlled firms from Outside the Home Country (% of National Total)
Belgium	6.0	61.6	32.4	8.9
Denmark	32.9	12.5	54.6	14.2
Finland	50.3	5.5	44.2	18.3
France	49.9	13.9	36.2	33.1
Germany	45.8	14.4	39.8	17.0
Italy	11.5	23.7	64.8	4.8
Netherlands	52.0	13.4	34.6	59.3
Norway	18.5	8.5	73.0	23.7
Sweden	37.1	16.2	46.7	37.0
Switzerland	35.0	9.2	55.8	75.3
UK	20.3	27.5	52.1	34.0
Japan	77.0	2.0	21.0	3.4
US	35.2	5.8	59.0	3.7

Note: All columns are as percentage of total national patenting in the US, 1996-2000.

The first two columns show the shares of total national patenting in the USA granted to the nationally-controlled large firms, and to the foreign-controlled large firms, in our data base, whilst the third column gives the combined share for the other national sources (i.e government agencies, other firms and individuals). Thus, assuming that US patenting reflects national technological activities, Table 6 shows that 6 % of technological activity in Belgium came from Belgian large firms, 61.6 % from non-Belgian large firms, and the remaining 32.4% from other sources in Belgium (firms, government agencies, individuals). The fourth column shows US patenting by nationally controlled firms from outside the home country –expressed as a percentage of total national patenting in the US. Thus again taking Belgium as an example, we see that technological activities of Belgian-controlled large firms undertaken outside Belgium amount to 8.9 % of the total technological activities inside Belgium.

By adding up the first two columns, we can see that the relative importance of our large firms varied from around 30% of national technological activities in Norway and Italy to over 60% in the Japan, Belgium, Netherlands, France and Germany, with the remaining seven countries (and Europe taken as a whole) in the range from 36% to 54%. In 4 out of the 13 countries nationally controlled large firms account for around 50% or more of the national total. In a further 4 countries this proportion is more than one–third. Foreign firms are important players in a number of EU countries, e.g. in Belgium, UK and Italy.

The final column of Table 6 shows even greater variation amongst countries in the relative importance of the technological activities of our large firms outside their home countries, from more than 75% of the national total for Switzerland, to less than 4% for Japan and the US. A comparison of the first and fourth columns of the Table shows that in 7 out of the 13 countries home based activities of national large firms are more important than their foreign activities.

In our earlier work (Patel and Pavitt, 1991) we analysed the links between aggregate technological performance countries (measured in terms of levels and rates of growth of R&D and US patenting) and each of the 4 components of national technology outlined in Table 6, for the period upto the mid-1980s. The results based on simple correlations showed that there was no relationship between national performance and these structural components. Similar correlations for the period 1996-2000 give very similar results. Given the differences in the patterns and trends of internationalisation of technology between US and Japan on the one hand and the EU countries on the other, the same exercise was repeated on the basis of the EU countries only. Again the resulting correlations were statistically not significantly different from zero. In other words differences in the shares of national, foreign and other firms are not related to national technological performance.

In Table 7 we present some correlations between country performance (measured as industry-financed R&D as a proportion of GDP and US patenting per capita) and the performance of national, foreign and other firms (measured as per capita US patenting in each case). The first half of the Table examines the relationship in levels and the second half in terms of growth rates. Both measures of country technological performance (RDGDP and PATPC) are correlated (albeit weakly in the case of R&D) with home based and total activity of national large firms (NLFH and NLFT). However they are not at all correlated with the activities of firms abroad (NLFA). The same relationship holds in terms of growth rates. These results suggest that countries with a high level of innovation performance also have high-performing large firms.

Table 7. Correlations between Technological Performance of Countries and Nationally Based Large Firms

	RDGDP	***NLFH***	***FLF***	***ONF***	***NLFA***	***NLFT***
NLFH	**0.68***					
FLF	0.20	-0.23				
ONF	0.51	0.50	0.09			
NLFA	0.46	0.09	0.14	0.25		
NLFT	**0.77***	**0.83***	-0.12	**0.56***	**0.60***	
PATPC	**0.72***	**0.86***	0.03	**0.85***	0.21	**0.80***

Note: * Correlation is significant at the 0.05 level (2-tailed).

RDGDP Industry-financed R&D Expenditures as a % of GDP in 1998
NLFH Per capita Home-based US patenting of National Large Firms: 1996-2000
FLF Per capita US Patenting of Foreign Large Firms active in the country: 1996-2000
ONF Per capita US Patenting of Other National Firms active in the country: 1996-2000
NLFA Per capita US patenting of National Large Firms Abroad: 1996-2000
NLFT Per capita US patenting of National Large Firms at Home and Abroad: 1996-2000
PATPC Per Capita aggregate US patenting for the country: 1996-2000

	GRD	***GNLFH***	***GFLF***	***GONF***	***GNLFA***	***GNLFT***
GNLFH	**0.59***					
GFLF	0.35	0.19				
GONF	0.50	0.34	0.25			
GNLFA	0.35	0.45	-0.01	-0.40		
GNLFT	**0.63***	**0.96***	0.15	0.19	**0.64***	
GPATPC	**0.69***	**0.87***	0.41	**0.72***	0.13	**0.78***

Note: * Correlation is significant at the 0.05 level (2-tailed).

GRD Growth of Industry-financed Industrial R&D, defined as the proportionate change between 1985-90 and 1996-2000.
GNLFH NLFH in 1996-200 minus NLFH in 1985-90
GFLF FLF in 1996-2000 minus FLF in 1985-90
GONF ONF in 1996-2000 minus ONF in 1985-90
GNLFA NLFA in 1996-2000 minus NLFA in 1985-90
GNLFT NLFT in 1996-2000 minus NLFT in 1985-90
GPATPC PATPC in 1996-2000 minus PATPC in 1985-90

Company versus Country R&D expenditures

Another way of examining the relationship between country and company performance is by analysing the extent to which the trends in national R&D expenditures (as measured by the national surveys) are similar to the trends in the expenditures of national large firms (as reported in their annual accounts). Table 8 shows that in general the latter are growing faster than the former. The discrepancy is highest for EU firms, especially in the second half of the 1990s. Thus while national R&D in the UK grew on by 2.4% per annum in 1996-2000, the R&D expenditures of the 33 UK based large firms had a growth rate of

7.6% per annum. Table 8 shows that the only country that does not confirm to this pattern in the latest period is the US, where national R&D expenditures are rising faster than the R&D expenditures of US firms.

Table 8. Comparing Trends in National and Company R&D.

	Growth rate 1990-1995		Growth rate 1996-2000	
Country	R&D by Large Firms	Industry-financed National R&D	R&D by Large Firms	Industry-financed National R&D
France	2.8	2.1	3.4	2.1
Germany	1.7	1.1	5.2	3.1
Japan	0.6	0.1	2.1	0.7
Netherlands*	0.1	0.9	3.2	2.7
Sweden*	5.0	4.6	7.4	3.0
Switzerland	2.7	0.6	3.7	1.1
UK	0.6	1.1	7.6	2.4
US	3.2	2.5	3.7	4.3

*In the second period growth rate calculated for 1996-99

The other point to note is that while all EU countries have been increasing their industrial R&D at a much slower rate than the US in the period 1996-2000, the same does not hold when comparing EU companies with US companies. On average UK, Swedish and German companies increased their R&D expenditures faster than their US counterparts.

Changes in national R&D expenditures can be decomposed into changes due to the home based activities of national large firms, plus those due to the expenditures of foreign firms and other actors involved in industrial R&D (mainly smaller firms). The available data on the activities of foreign firms (OECD, 1998) shows that they have been increasing their share in most countries. The evidence of decreasing share of home-based activities, especially for EU large firms, discussed above, together with the data presented in Table 8, would suggest that there might be some truth in the 'hollowing out' hypothesis. However without more accurate information on the R&D expenditures of other national firms, it would be difficult to arrive at a firm conclusion.

Company R&D in the US

Another piece of the jigsaw can be constructed on the basis of the activities of foreign firms in the US. Here the aim is to compare the growth of R&D expenditures of EU and Japanese firms with the growth of their overall expenditures as shown by company accounts, and the growth of national R&D. There is one caveat that needs to be borne in mind when making these comparisons. The two datasets may involve different sets of firms: the US R & D survey may or may not cover the same firms as covered by the company accounts data base. The analysis here is based on the assumption that both datasets contain two strongly overlapping populations of large firms.

Table 10 shows that for EU firms R&D expenditures in the US have been growing at a much faster rate than either national R&D or total company R&D for the period since 1985. For example the US subsidiaries of French firms have increased their R&D by more than 5% per annum in the 1990s, at the same time French industrial R&D has grown by around 2% and the overall R&D of large French firms by around 3%. The main result of this analysis is that the US has become an increasingly important base for EU technology.

Table 9. Comparing Trends in Foreign R&D in the US with National and Company R&D for EU firms

	Growth rate 1985-89		Growth rate 1990-95			Growth rate 1996-99		
Country	**R&D by US subsidiaries**	**Industry-financed National R&D**	**R&D by US subsidiaries**	**Industry-financed National R&D**	**R&D by Large Firms**	**R&D by US subsidiaries**	**Industry-financed National R&D**	**R&D by Large Firms**
France	17.2	3.9	5.9	2.1	2.8	5.7	2.3	3.0
Germany	10.5	2.6	6.8	1.1	1.7	11.1	3.2	6.1
Netherlands	17.2	4.6	3.1	0.1	0.1	5.5	0.6	2.6
Sweden	4.6	0.9	0.4	0.9	5.0	5.4	2.7	5.3
Switzerland*	10.7	1.2	5.4	0.6	2.7	-0.9	1.1	3.6
UK	10.1	4.2	2.2	1.1	0.6	4.8	2.4	6.8

* Growth rate calculated for the period 1986-89
Source of R&D by US subsidiaries: U.S. Bureau of Economic Analysis, Foreign Direct Investment in the United States: Operations of U.S. Affiliates of Foreign Companies.

Summary of the results: Country vs Company performance

The evidence presented so far would suggest that home-based technological activities of large firms continue to have a big influence on the activities of their home countries. A simple version of the ‘hollowing out’ hypothesis, namely a negative relationship between technological performance of home countries and high (and increasing) share of activities undertaken in foreign locations by national large firms cannot be supported by the evidence discussed in this section. At the same time the available data in the case of the EU, where these concerns are the greatest, show that EU based firms have been increasing their worldwide R&D at a much faster rate than the average of all firms in their home countries, especially in the second half of the 1990s. Moreover in most cases the R&D expenditures of their subsidiaries in the US have grown at even a faster rate than their overall expenditures. This would suggest that some form of ‘hollowing out’ might be occurring. In the next two sections we explore the type of technological activities undertaken by EU firms outside their home countries.

7. Internationalisation and Involvement in Fast-Growing areas of Technology

The previous sections have shown increasing internationalisation of technology amongst EU firms. The purpose of this section is to analyse the type of technological activities involved in this process. For this analysis we have identified the fastest growing (FG) fields of activity in terms of US patenting amongst our sample of large firms in the period since 1985 upto 2000. As Table 10 shows a majority of these fields can be found in high-technology areas of IT and Biotechnology.

Table 10. Distribution of Fast-Growing fields by Technology

Technology area	% share of US patents in 1996-2000
Computers and semiconductors	40.3
Drugs and Bioengineering	22.1
Audio visual	11.1
Telecommunications	7.8
Other	18.9
Total	100.0

We address two sets of questions. Firstly to what extent is the greater internationalisation of R&D of EU companies associated with strength in FG technical fields. Secondly to what extent are EU firms' activities in FG technologies associated with the US?

Table 11 throws some light on the first question, by comparing the volume of patenting of EU firms with that of all firms within each product group. In other words it shows the strength of EU firms in FG areas compared to their major competitors within each sector. At the aggregate level the EU companies account for a relatively small share of patents in FG fields (14.6% in 1996-2000). However within some of the product groups their share is much higher: more than 50% in Food, Drink and Tobacco and Pharmaceuticals, and more than 40% in Chemicals and Mining and Petroleum. The main weakness is related to European IT firms, who account for less than 5% of FG patents attributable to all IT companies. Finally one product group where EU firms are improving their position rapidly is Telecommunications.

In Table 12 we compare the share of foreign patenting in FG compared to their share of foreign patenting overall. A value of greater than unity of the index presented in this table indicates that EU firms are more internationalised in FG areas than overall and vice-versa. At the aggregate level, EU firms are much more internationalised in fast moving technologies than overall. This is particularly the case in some of the product groups already identified above as areas of strength for EU firms: Mining and Petroleum, Pharmaceuticals, and Food, Drink and Tobacco.

Table 11. Percentage Share of Patents in Fast-Growing Areas owned by EU firms according to Product Groups

Product Group	85-90	91-95	96-00
Biotech			10.8
Chemicals	44.1	31.5	43.1
Electrical/Electronics	29.5	19.7	19.3
Food, Drink & Tobacco		69.6	57.4
IT Related	4.5	3.3	2.3
Machinery	21.7	26.7	18.5
Medical equipment		2.4	7.0
Metals		22.4	23.3
Mining & Petroleum	44.4	37.4	47.4
Motor Vehicles and parts	29.3	17.5	16.3
Pharmaceuticals	40.0	45.9	52.3
Telecommunications	10.2	21.5	32.4
Overall	17.6	14.1	14.7

Table 12. Comparing internationalisation in Fast-Growing Areas with overall internationalisation of technology for EU firms.

Product Group	85-90	91-95	96-00
Biotech			2.10
Chemicals	1.58	0.89	0.75
Electrical/Electronics	0.99	0.98	1.08
Food, Drink & Tobacco		1.24	1.33
IT Related	1.37	1.03	0.98
Machinery	0.66	0.86	1.19
Medical equipment			0.47
Metals		1.37	1.24
Mining & Petroleum	0.96	1.32	1.53
Motor Vehicles and parts	0.89	0.70	0.80
Pharmaceuticals	1.40	1.49	1.33
Telecommunications	1.68	0.91	1.05
Overall	1.33	1.22	1.21

See Text for the value of the Index

Table 13. Share of EU firms' patents in Fast-Growing areas invented in the US .

Product Group	85-90	91-95	96-00
Biotech			20.8
Chemicals	42.3	18.9	18.2
Electrical/Electronics	14.2	21.7	30.0
Food, Drink & Tobacco		62.5	66.4
IT Related	15.4	12.5	20.8
Machinery	15.4	12.5	20.8
Medical equipment			6.3
Metals		17.6	28.6
Mining & Petroleum	31.3	57.5	56.5
Motor Vehicles and parts	8.7	8.1	15.3
Pharmaceuticals	40.6	50.3	52.5
Telecommunications	3.1	6.7	25.3
Overall	25.6	27.5	31.7

Finally Table 13 shows the proportion of FG patents of EU firms that are invented in the US. It shows clearly that EU firms have a high level of activity in the US, and this is especially the case in the 3 sectors that have already been identified as areas of strength: Mining and Petroleum, Pharmaceuticals, and Food, Drink and Tobacco. In these sectors between a half and two-thirds of all patents in FG areas are invented in the US.

The message from this analysis is clear. In the areas with high levels of technological opportunity within Pharmaceuticals, Food, Drink and Tobacco, and Mining and Petroleum, EU firms are both strong and highly internationalised. Moreover large part of their activity in these areas is concentrated in the US. The main problems are concerned with the performance of IT related firms, who account for a very small proportion of fast moving technologies.

8. Internationalisation and Quality of Foreign Technological Activities

In this section we examine the 'quality' of the foreign produced technological assets vis-à-vis the home country technological activity. To this end we use the number of citations received by a patent as a proxy measure of its economic and technology value. We begin by identifying the most highly cited patents belonging to our firms. We then compare the proportion of such patents originating from outside the home country to its overall share of foreign patents.

Patent citations have been shown to be correlated with the value of innovations (Trajtenberg, 1990) and the total number of citations received by a patents has been used in other studies as an indicator of the relative importance of patents (Trajtenberg et al. 1997, Lanjouw and Schankerm, 1999). The underlying idea is that if a patent cites another patent then this signifies that the cited patent has opened up a new and successful line of invention. Additionally if certain patents are cited repeatedly then this implies that technological content of these cited patents has proven to be particularly "valuable".

We use the NBER patent and citations database (Hall *et al*. 2001), containing utility patents granted from 1963 to the end of 1999 and citations from patent granted in 1975-99, to extract the number of citations received by patents granted to our large firms. Citations counts have to be controlled for the fact that the number of citations that a patent receives varies over time and across technological fields. The first arises because an 'older' patent might receive more citations than a 'younger' patent, not because of its intrinsic value but simply because it has been in existence for a longer period. The second effect arises because patents in certain technological fields can have a more or less wider impact on others fields and therefore receive a different number of citations.

Thus to identify the most highly cited patents we extract the 75 percentile of the distribution of citations received in each year and in each 3-digits patent class.[4] Using the address of the first inventor we analyse the geographic location of these most highly cited patents. The main question we want to address is the extent to which such patents belonging to EU firms originate from foreign locations. In order to do this we divide the foreign share of these most highly cited patents by the overall foreign share of a company's patents. A ratio greater than unity implies that a company's most valuable patents are more internationalised than the average across all patents. Additionally to assess the importance of the US as location for these highly cited patents we construct a similar ratio only on the basis of patents invented in the US. The results are reported in Table 14.

[4] We do not account for self-citations and intra-group citations. However this should not have any significant impact on our findings since both the number of citations received by patents invented at home and abroad will be equally affected by these two biases.

Our findings show that across all product groups EU firms are much more internationalised in terms of these most highly valued patents than in aggregate. In particular the US is a relatively more important location for such patents. This is especially the case for US invented patents in Materials, Medical Equipment, Metals, Photography and Photocopy, and Rubber and Plastics. An interesting point to note is that with the exception of a few sectors (Aerospace & Defence, Instruments, Motor vehicles and parts, Photography, and Pharmaceuticals) the index shows a decreasing trend indicating that relative foreign share of highly cited patents is declining over time. This is counter to the hypothesis that there is increasing internationalisation amongst the most strategic and valuable technological assets belonging to EU firms. We plan to further assess the validity of this hypothesis by analyse in more detail where exactly these important patents originate and in which technological areas.

Table 14. Comparing European owned highly cited foreign patents with the share of foreign patenting activity

	1985-1991		1992-1998	
Product Group	**Abroad**	**US**	**Abroad**	**US**
Aerospace & Defence	1.06	1.06	1.36	1.42
Chemicals	1.09	1.19	0.99	1.08
Electrical/Electronics	1.12	1.39	1.10	1.23
Food, Drink & Tobacco	1.05	1.22	1.03	1.12
IT Related	1.02	1.47	1.06	1.33
Instruments	1.38	0.74	1.15	1.10
Machinery	1.19	1.17	1.09	1.13
Materials	1.21	1.42	1.11	1.20
Medical equipment	1.51	2.01	1.02	1.09
Metals	1.36	1.71	1.11	1.21
Mining & Petroleum	1.19	1.20	1.09	1.11
Motor Vehicles and parts	1.20	1.25	1.28	1.28
Paper	1.09	1.45	1.09	1.25
Pharmaceuticals	1.13	1.18	1.09	1.18
Photography and Photocopy	1.28	1.63	1.52	1.71
Rubber & Plastics	1.50	1.72	1.28	1.35
Telecommunications	0.93	1.55	1.02	1.31
All product groups	1.14	1.28	1.09	1.20

9 Conclusions

This paper has explored the latest trends in the relationship between national technological performance and internationalisation of corporate R&D. The main aim was to detect any sign of 'hollowing out' of national technology. It is clear from the evidence presented above that the notion of a simple structural relationship between national R&D performance and growing internationalisation of technology does not hold. Indeed there appears to be no systematic relationship, either positive or negative, between the two in the 1990s. On the contrary the above results suggest that home-based technological activities of large firms continue to have a big influence on the activities of their home countries.

Nevertheless the available data in the case of the EU, where these concerns about 'hollowing out' are the greatest, show that European firms have been increasing their worldwide R&D at a much faster rate compared to the average of all firms in their home countries, especially in the second half of the 1990s. Moreover R&D expenditures of their subsidiaries in the US have grown at even a faster rate than their overall expenditures.

There are important differences amongst the EU firms according to their principle activity. In the areas with high levels of technological opportunity within Pharmaceuticals, Food, Drink and Tobacco, and Mining and Petroleum industries, EU firms are both strong and highly internationalised. Moreover large part of their activity in these areas is concentrated in the US. One important area of concern for the EU is the IT related sector. Here EU firms have a small presence in fast moving areas of technology. These firms are highly internationalised with most of their activity concentrated within the EU, and not in the US where some of the leading edge technologies in IT related areas can be found.

From a policy perspective it becomes important to learn about the motives of EU firms in locating their activities in the US. An important unexplored question is the extent to which greater internationalisation of technology is related to access to leading edge science. This is of obvious importance in the Pharmaceutical industry, where one of the crucial linkages that a successful firm needs to develop is with the science base. One possible explanation for the high level of activity of the EU Pharmaceutical firms is the need to access world frontier science related to biotechnology.

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