LARGE FIRMS IN THE PRODUCTION OF THE WORLD'S TECHNOLOGY: AN IMPORTANT CASE OF "NON-GLOBALISATION"

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Abstract. US patenting by 686 of the world's largest manufacturing firms shows that their share of the world's production of technology is less than their share of R&D activities, and varies greatly amongst sectors. In most cases, the technological activities of these large firms are concentrated in their home country, the characteristics of which influence the volume and trends in their technological activities much more strongly than the international component of these activities. At the same time, these large firms are major elements in the volume and the pattern of sectoral specialisations in their home countries' technological activities.

In this paper, we shall use recently developed data, based on US patenting, to evaluate the importance of the technological activities of the world's largest firms in different sectors and countries. There are at least two interrelated reasons for doing this.

The first is that technological change is a central feature in economic development, structural change and improvements in efficiency in all countries.

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Recent studies have shown that technological activities—as measured through R&D and international patenting—are statistically significant determinants of differences in export and productivity performance amongst the major OECD countries [Soete 1981; Fagerberg 1987, 1988]. At the same time, major international differences have emerged over the past twenty-five years in trends—and subsequent levels—of these activities, both in these countries and in the large firms based on them [Pavitt and Patel 1988; Franko 1989]. Briefly stated, the Japanese have had the strongest upward trend, the Anglo-Saxons (UK and USA) and the Dutch the weakest, and the other continental Western Europeans have grown at rates between the two. By the mid-1980s, the countries spending the highest proportion of national resources on business-funded technological activities were Sweden, Switzerland, FR Germany and Japan, followed at some distance by the USA, and then by Belgium, Canada, France, the Netherlands and the UK.

The second is that the debate continues about the degree to which these technological activities are localised in large firms. The heavy concentration of R&D activities in large firms [Freeman 1982] has led some analysts to conclude that they have a dominant position in countries' development of new technology. On the other hand, a number of studies using other measures show that R&D activities considerably underestimate the volume of technological activities in firms that are too small to have functionally specialised R&D departments [Acs and Audresch 1989; Kleinecht 1987; Pavitt et al. 1987].

A parallel debate is taking place about the extent and the implications of the international concentration of large firms' technological activities, most often when technology has been made a central explanatory variable in the internationalisation of business.[1] In Vernon's early formulation [1966] and in subsequent analyses by Dunning [1980] and Cantwell [1989], home markets are important determinants of large firms' technological advantage, through the nature and extent of inducement mechanisms that stimulate technical change, and of positive externalities that influence the effectiveness of firms' response to these stimuli.

However, in later formulations, Vernon [1979] and Dunning [1989] suggest that large firms are increasingly footloose in their R&D activities, thereby weakening the links between the development of their technology and their home country. Such trends towards "techno-globalism" are an essential component of currently fashionable predictions of the emergence of "The Stateless Corporation" [*Business Week* 1990]. In the context of these debates, we shall try to answer three questions.

First, how important are large firms in the production of the world's technology? Using US patenting statistics, we show in the third section that the aggregate level of importance is less than that shown by R&D expenditures, with considerable variations amongst technological sectors.

Second, how important are the technological activities of large firms in those of their home countries and elsewhere? We show in the fourth section the considerable variation both in the relative importance of large firms in their home countries' technological activities, and in the degree of internationalisation of their activities. But in most of the countries at the world's technological frontier, the foreign technological activities of large firms are still not the major feature.

Third, how do the volume, trends and sectoral patterns of large firms' technological activities relate to those of their home countries? In the fifth section we show that the two are closely correlated, and that country-specific factors dominate over firm-specific factors.

We begin with a description of the nature, strengths and weaknesses of the database.

THE DATA SET, ITS ADVANTAGES AND LIMITATIONS

The Nature of the Data Set

The data set has been compiled from information, provided by the US Patent Office, on the name of the company, the technical sector, and the country of origin, of each patent granted in the USA from 1969 to 1986. One difficulty with this source is that many patents are granted under the names of subsidiaries and divisions that are different from those of their parent companies, and therefore are listed separately.

Consolidating patenting under the names of parent companies can only be done manually, on the basis of publications like "Who Owns Whom." We have now extended our earlier consolidations for the UK and FR Germany [Patel and Pavitt 1989] to cover 686 of the world's largest firms. With the help of the Economics Department at the University of Reading, we have also included in our data set the following information on each firm: country of origin and sales, employment and R&D expenditures for years 1972, 1977, 1982 and 1984. Not all these three variables are available for all the firms for each of the years.

Table 1 lists the top twenty firms patenting in the USA in the period 1981-86, according to our own consolidated classification, and to the original classification by the US Patent Office. It shows that some firms have very similar numbers of patents in both classifications; in particular, US General Electric, Hitachi, IBM, Toshiba, RCA, Canon, Westinghouse, Dow, Nissan and Mobil. However, other firms have considerably more patents in our consolidated classification, and consequently higher rankings: in particular, Bayer, Siemens, Philips, AT&T, Du Pont, Hoechst, Allied, Matsushita and United Technologies. At the bottom of the sample, firms' annual sales in 1984 were about $900 million.

Table 2 shows the numbers of large firms in our database, according to their home country and to their principal sector of activity. Just under half

TABLE 1
Top 20 Patenting Firms in the USA (1981-86): Patel and Pavitt list versus the US Patent Office List

Company Name	Patel and Pavitt	US Patent Office
General Electric Company (US)	4587	4527
Hitachi	3710	3416
Bayer	3352	2304
IBM	3207	3207
Siemens	3151	2480
Toshiba	3094	2855
Philips Corporation	2968	2464
AT&T	2732	1980
RCA	2716	2716
E.I. Du Pont	2401	1971
Hoechst	2270	1327
Canon	2266	2266
Westinghouse	2145	2090
Ciba-Geigy	1992	1709
Allied Corporation	1989	1085
Dow Chemical Company	1961	1816
Nissan	1960	1887
Mobil Oil	1907	1749
Matsushita	1895	1276
United Technologies	1889	1028

Note: Firms ranked by number of patents in the Patel and Pavitt classification.

the firms are US owned, about one-fifth are Japanese and just under one-third are European. The UK is the largest European contributor, followed by FR Germany and France. In terms of the industrial distribution, firms with their principal activity in mechanical engineering and metal goods account for 21% of the sample, those in chemicals and pharmaceuticals for 16%, and those in electrical, electronic and computing machinery for 12%.

Advantages and Disadvantages

Patent statistics have been used frequently by economists and other analysts as a proxy measure of technological activities.[3] Their general advantages compared to other measures, such as R&D expenditures, are that—with the advent of modern information technology—they are readily available over long time periods; they can be broken down in great statistical detail, according to firm, technical field and geographical location; and they capture technological activities undertaken outside R&D departments, such as design activities in small firms, and production engineering in large firms. Their main general disadvantage is that, like other routine measures of technological activities, they do not measure satisfactorily one of the major fields of technological growth, namely, software.

The advantages and disadvantages specific to our database are along three dimensions: the nature of the technological activities measured, variations in the propensity to patent, and the interpretation of trends over time.

TABLE 2
The Distribution of the 686 Large Firms in the Sample by Principal Activity and Country

	US	JP	CA	UK	GE	FR	SE	CH	NL	IT	BE	NO	FI	OT	Total
Chemicals	35	25	-	2	5	5	-	1	2	2	1	1	-	1 (AU)	80
Pharmaceuticals	18	4	-	3	2	-	-	2	-	-	-	-	-	-	29
Mining (Coal & Oil etc)	29	10	3	5	4	2	-	-	1	1	1	1	1	-	58
Textiles, Cloth. & Leather	12	5	-	2	1	1	-	-	-	-	-	-	-	-	21
Rubber and Plastics	6	3	1	1	1	1	-	-	-	1	-	-	-	-	14
Paper & Wood products	21	6	4	1	1	-	4	-	-	-	-	-	2	1 (IE)	40
Food	33	15	2	14	-	4	1	2	1	-	-	-	-	-	72
Drink and Tobacco	8	1	4	8	-	-	-	-	1	-	-	-	-	1 (AU)	23
Non-metallic Minerals	11	6	1	6	-	2	-	1	-	-	-	-	1	-	28
Metal Manufacture	22	13	6	2	13	4	1	1	1	1	2	1	-	1 (AU)	68
Mechanical Engineering	37	12	2	9	6	1	4	2	2	-	-	-	2	-	77
Electrical/Electronics	31	18	1	4	4	2	3	1	1	1	-	-	-	-	66
Computing Machinery	12	2	-	1	1	1	-	-	-	1	-	-	-	-	18
Instruments	10	6	-	-	1	-	-	-	1	-	-	-	-	-	18
Motor Vehicles	12	19	-	3	6	3	2	-	-	1	-	-	-	1 (ES)	47
Aircraft	14	-	-	2	1	4	-	-	-	-	-	-	-	-	21
Other Transport	3	1	-	1	-	-	-	-	-	-	-	-	1	-	6
Total	314	146	24	64	46	30	15	10	10	8	4	3	7	5	686

Notes:
(1) Country Definitions: US=United States, JP=Japan, CA=Canada, UK=United Kingdom, GE=FR Germany, FR=France, SE=Sweden, CH=Switzerland, NL=Netherlands, IT=Italy, BE=Belgium, NO=Norway, FI=Finland, OT=Others: AU=Austria; IE=Ireland; ES=Spain.
(2) There are two companies where the home country is not easily identifiable: Shell, which we regard as Dutch, and Unilever which we regard as British.

The Nature of the Technological Activities Measured

Since a patent is granted normally in recognition of technical novelty, our data is better able to capture technology creation than technology diffusion-transfer-imitation. For those who assume that technology is information (i.e., costly to create, but virtually costless to transfer and reproduce), this distinction is a rigid one. However, in the real world of technology that is complex, partially tacit and specific,[4] the diffusion-transfer imitation of technology generally requires technological activities by the imitator, which sometimes result in improvements over the original.[5]

Patenting activities do reflect this type of imitation, which is typical of advanced country companies competing close to the world's technological frontier. However, they do not reflect many other types of imitation and related technological activities not involving originality, such as trade in capital goods and know-how, on-the-job training, assimilative R&D and production engineering, and the foreign education of scientists and engineers. These are particularly important forms of imitation for developing countries (see Rosenberg and Frischtak [1985]).

Variations in the Propensity to Patent

Patenting is also an imperfect reflection of novel technological activity. Its primary function is to act as a legal barrier against imitation. Three kinds of variation in the propensity to patent the results of technological activities must therefore be borne in mind.

First, there are variations amongst countries, reflecting differences in the costs (e.g., patenting fees) and benefits (e.g. degree of protection, prospective size of market) of patenting. Patenting in the USA is a reliable metric, since screening procedures are homogeneous and rigorous, and success provides relatively strong protection in a large market. Thus, a recent survey of patenting behaviour of multinational firms shows that the USA is the first foreign country in which they normally seek patent protection [Bertin and Wyatt 1988]. For this reason, the international distribution of the sources of US patenting show statistically highly significant similarities to the international distribution of business enterprise R&D expenditures, both in aggregate and in specific sectors [Soete and Wyatt 1983; Soete 1987; Patel and Pavitt 1987].[6]

Second, there are variations in the propensity to patent amongst technical fields, reflecting differences in the relative importance of patenting as a protection against imitation, compared to other factors, such as secrecy, know-how, first-comer advantages on learning curves.[7] For this reason, it is advisable to normalise numbers of patents as a proportion of their respective technical fields.

Third, there are variations amongst firms in the propensity to patent, reflecting ex ante uncertainties and differing patenting practices over the wide range of patents with relatively low value.[8] Nonetheless, statistically significant correlations have been found in the USA between inter-firm differences in R&D, and in US patenting [Soete 1978; Pakes and Grilliches 1983].

Interpretation of Time Trends

Given lack of time and other resources, our consolidated classification of the 686 firms has been compiled for only for one year—1984. Our time-trend analyses of patenting by companies between 1969 and 1986 therefore reflect the firms as constituted in 1984, and none of the changes resulting from purchases or sales of divisions before or since then. Thus, measured changes over time are composed of those of the parts of the firm retained up to 1984, together with those of acquisitions made up to 1984: in other words, what the firm kept and what it bought, up to 1984.

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Table 3 shows, for thirty-three technical fields and in aggregate, the shares of US patents granted in 1981-86 to the large firms in our sample, to other firms, to government agencies, and to individuals.[9]

Aggregate

In aggregate, our set of large firms account for just under half the world's technological activities, as measured by US patenting, and for about 60%

TABLE 3
Sources of US Patenting in 33 Technical Sectors: Percentage Shares in 1981-86

	Large Firms	Govt. Agen.	Priv. Ind.	Other Firms
Semiconductors	80.28(138)	3.94	2.69	13.08
Hydrocarbons, mineral oils, etc.	79.45(158)	0.82	5.77	13.96
Agricultural Chemicals	78.98(92)	0.96	4.29	15.76
Organic Chemicals	77.04(348)	1.73	2.71	18.52
Photography and photocopy	73.40(147)	0.39	5.84	20.36
Calculators, computers, etc.	69.23(281)	1.61	7.14	22.03
Inorganic Chemicals	67.37(218)	2.81	5.57	24.24
Bleaching Dyeing and Disinfecting	65.20(125)	1.94	7.75	25.11
Road vehicles and engines	62.45(179)	0.34	20.49	16.72
Electrical devices and systems	59.62(327)	3.26	11.38	25.74
Drugs and Bio-affecting agents	59.48(215)	3.35	8.08	29.09
Power Plants	58.17(153)	2.48	20.79	18.56
Telecommunications	57.41(289)	6.54	13.69	22.36
Image and sound equipment	57.42(207)	1.80	17.61	23.17
Chemical Processes	56.36(503)	2.36	10.91	30.36
Plastic and rubber products	55.58(327)	1.56	14.01	28.84
Metallurgical and other mineral proc.	53.30(372)	1.75	13.94	31.02
Gen. Electrical Industrial Apparatus	50.30(407)	2.17	15.73	31.80
Food & Tobacco (proc. and products)	48.96(175)	1.61	15.50	33.92
Non-metallic minerals, glass, etc.	48.50(431)	1.24	20.22	30.04
Mining and wells mach. and processes	47.68(178)	0.89	22.47	28.95
Nuclear Reactors and systems	47.45(38)	6.83	7.60	38.11
Aircraft	43.05(62)	14.44	23.47	19.04
Instruments and controls	40.93(491)	3.55	22.06	33.46
Gen. Non-electrical Industrial Equip.	39.86(433)	0.97	25.33	33.84
Appar. for chemicals, food, glass, etc.	39.76(516)	0.97	21.42	37.85
Metallurgical and metal working equip.	34.99(379)	0.68	27.18	37.16
Assembling & material handling appar.	29.97(377)	0.87	28.85	40.30
Other transport equip. (exc. aircraft)	28.46(197)	1.39	42.01	28.14
Non-electrical specialized machinery	27.63(481)	0.76	30.39	41.22
Miscellaneous metal products	23.35(444)	0.67	40.28	35.70
Other n.e.c.	13.49(241)	5.25	65.71	15.55
Textile, clothing, leather, wood prod.	13.08(117)	0.71	52.06	34.15
All Sectors	49.10(660)	2.11	19.68	29.10

Notes:
(1) Table is sorted by the share of large firms.
(2) Each row adds up to 100.
(3) The number of large firms active in technical sector is in parenthesis.

of that undertaken by firms. This distribution confirms what we found in an earlier study of the UK and FR Germany [Patel and Pavitt 1989], namely, a lower concentration of technological activities amongst large firms when measured by US patenting than by R&D expenditures. Although strict comparisons at the world level are not possible, national surveys in OECD countries show that typically about 80% of firms' R&D activities are concentrated in firms with 10,000 or more employees. Given that the cut-off level of employment at the lower end of our sample is about 8,000 employees, the proportion of total patenting accounted for by our large firms would have to be more than 80% to reach the same level of concentration as R&D expenditures.

Differences amongst Sectors

Table 3 also shows major differences amongst sectors in the relative importance of large firms and of the other sources of the world's technological activities. Government agencies are relatively unimportant in aggregate but account for more than 5% in nuclear reactors, aircraft and telecommunications—all technologies heavily influenced by military programmes. As in our earlier analyses, large firms are relatively important in chemicals (eight sectors with shares between 56% and 79%), motor vehicles (62%), and electrical and electronic products (five sectors between 57% and 80%), but unimportant in capital goods (seven sectors between 23% and 40%).

Table 4 confirms a significant positive correlation across sectors between our large firms' patenting shares, and the shares of the top twenty technically active firms ranked according to sales; and it confirms a significant negative relationship with shares of patenting of "Private Individuals." It also shows that the sectoral shares of "Other Firms," encompassing the very small up to 8,000 employees, are more similar to those of private individuals than to those of our large firms.

A Possible Explanation of Intersectoral Differences

Recent analysis has shown that intersectoral differences in the concentration of technological activities can be best understood in the context of dynamic interactions between technological opportunities and their appropriability, on the one hand, and the competitive growth of innovative firms, on the other. Briefly stated, higher technological opportunity and appropriability will result in higher concentration [Dasgupta and Stiglitz 1980; Nelson and Winter 1982; Levin et al. 1985]. Both R&D-intensive sectors (particularly chemical and electronic products) and capital goods sectors have abundant technological opportunities. One of us has shown elsewhere that the low appropriability and concentration in capital goods is positively related to a greater spread of technological activities in capital goods amongst UK firms with different principal sectors of activity [Pavitt et al. 1987]. See, also, Malerba and Orsenigo [1988].

Our data tend to confirm this pattern. Table 3 shows relatively low concentration of capital goods technology activities in our large firms, together with a relatively high proportion of these firms producing some capital goods technology, albeit at a relatively low level. This is reflected in the significant and positive correlations shown in Table 4 between sectoral levels of concentration of technological activity, on the one hand, and the

TABLE 4
Correlation Matrix of Various Measures of Concentration of Technological Activities: 33 sectors, 1981-86

	Lfirms	Govt.	PInd	OthF	CRSale20
Govt.	-0.040				
PInd	-0.909*	-0.008			
OthF	-0.625*	-0.230	0.273		
CRSale20	0.661*	0.266	-0.564*	-0.576*	
HIPPG	0.606*	0.417	-0.524*	-0.573*	0.806*

Notes:
For each sector:
LFirms = The share of large firms.
Govt = The share of government agencies.
PInd = The share of private individuals firms.
OthF = The share of firms other than the large firms in our sample.
CRSale20 = The share of top 20 technologically active firms sorted according to sales.
HIPPG = Hirfindahl Index calculated as the sum of squared shares of the firms active in each technical sector aggregated according to their Principal Activity.

*Correlation Coefficient significantly different from zero at the 5% level.

Herfindahl index of concentration, aggregated according to the sectors of our large firms' principal activity, on the other.

This is because capital goods technology remains largely mechanical. Important mechanical inventions and innovations can still be made without the specialised equipment and range of formal skills required in chemical and electronic technologies [Freeman 1982]. The spatial and design skills of individuals and small groups remain important sources of technology, as do users with experience in operating capital goods. These competences are spread widely across industries and firms, which provide multiple possibilities of entry into promising areas of capital goods technology, thereby reducing the possibilities of appropriation by first-comers. We shall be considering this explanation in greater econometric depth in a future paper.

LARGE FIRMS IN HOME COUNTRIES' TECHNOLOGICAL ACTIVITIES

The previous section shows considerable variations amongst sectors in the technological activities of the world's largest firms. In this section, we also show variation in their contribution to the world's leading technology-producing countries.

This emerges from Table 5, which uses our data on patenting in the USA in the first half of the 1980s to compare the composition of the technological activities of the eleven countries that account for more than 95% of total OECD R&D expenditures funded by business enterprises, and of total US patenting. 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 database, whilst the third

TABLE 5
Large Firms in National Technological Activities, 1981-86

	National Sources of Patenting in US (3 columns add up to 100%)			Patenting in US by Nationally Controlled Firms from Outside Home Country (% of National Total)
	Large Firms			
Country	Nationally Controlled	Foreign Controlled	Other	
Belgium	8.8	39.7	51.5	14.7
France	36.8	10.0	53.2	3.4
FR Germany	44.8	10.5	44.2	6.9
Italy	24.1	11.6	64.3	2.2
Netherlands	51.9	8.7	39.4	82.0
Sweden	27.5	3.9	68.6	11.3
Switzerland	40.1	6.0	53.9	28.0
UK	32.0	19.1	49.0	16.7
W. Europe	44.1	6.2	49.7	8.1
Canada	11.0	16.9	72.1	8.0
Japan	62.5	1.2	36.3	0.6
USA	42.8	3.1	54.1	3.2

Note: All columns as percentage of total national patenting in US, 1981-86.

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 5 shows that 8.8% of technological activity in Belgium came from Belgian large firms, 39.7% from non-Belgian large firms, and the remaining 51.5% from other sources in Belgium (firms, government agencies, individuals).

The fourth column shows US patenting by nationally controlled firms from outside their home country, expressed—like the other three columns—as a percentage of total national patenting in the USA. Thus, again by way of illustration, the technological activities of Belgian-controlled large firms undertaken outside Belgium amount to 14.7% of total technological activities inside Belgium, whilst the equivalent proportion is a massive 82% for Dutch-controlled large firms, and a miniscule 0.6% for Japanese-controlled large firms.

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 Canada and Sweden to just over 60% in the Netherlands and Japan, with the remaining seven countries (and Western Europe taken as a whole) in the range from 36% to 54%. By comparing the first and second columns, we see that the relative importance of nationally controlled and foreign-controlled large firms varied more widely amongst countries: national firms from more than 60% in Japan to less than 10% in Belgium, mirrored by foreign firms from nearly 40% in Belgium to just over 1% in Japan. Simple correlation tests show that neither the relative importance of large firms in total technological activities, nor the mix between national and foreign ones, are significantly related to country size as measured by Gross Domestic Product.

The fourth column of Table 5 also 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 80% of the national total for the Netherlands, to less than 1% for Japan. On the basis of data for 140 large firms, Cantwell and Hodson [1990] have shown that the degree of internationalisation of large firms' technological activities is closely correlated to that of production. The same is true for countries in Table 5.

However, a comparison of the first and fourth columns of Table 5 shows that, in spite of considerable variations amongst the large firms based in different countries, their technological activities remained far from globalised. Only Belgium and Dutch large firms executed more of their technological activities outside their home country than inside. British, Canadian, Swedish and Swiss firms executed between 30% and 42% abroad, whilst firms from the three largest technological countries—FR Germany, Japan and the USA—performed less than 15% outside, as did France and Italy.

Finally, if we compare the second and fourth columns of Table 5, we can conclude that, for most countries, the international technological activities of our large firms are not a dominant feature of national technological systems. Only for the Netherlands and Switzerland did the foreign-executed technological activities controlled by large national firms amount to more than 20% of the national total; and only in Belgium and Canada were foreign large firms relatively more important than national ones. In eight out of the eleven countries in Table 5 (and for Western Europe as a whole), less than 20% of national technological activities were foreign-controlled, and at the same time the technological activities executed abroad by nationally controlled firms performed amounted to less than 20% of national technological activities. This is a long way from any "globalisation" of the world's technological activities.

LARGE FIRM PERFORMANCE AND COUNTRY PERFORMANCE

The third and fourth sections showed that the large firms in our sample produce about half the world's frontier technology, but that their relative importance varies considerably amongst sectors and amongst the eleven frontier countries, as does the degree of internationalisation of their technological activities. In this section, we shall probe more systematically into the links between the technological performance (measured in terms of levels and rates of growth of technological activities) of our large firms, and of these eleven countries. There remain a number of unresolved analytical and policy questions about the effects on a country's technology of the presence of large firms, and about the nature and direction of the interactions between such firms and their home countries. We shall use our data to test a number of simple relationships that have not been tested before. Given the complexities of the real world, we still shall not be able to give complete and conclusive answers.

Structure, Internationalisation and Country Performance

There is a continuing debate about the effects of the structure of industry—and of related technological activities—on a country's technological performance. Some argue that heavy concentration and the prevalence of large firms reduces competition and technological pluralism, and thereby results in a lower level of aggregate technological activities. Others argue the contrary, that large firms can more easily mobilise the required range of skills, reach critical thresholds, and deal with risk, thereby resulting in a higher level of technological activities.

Contradictory arguments are also put forward about the effects on countries' technological activities of multinational firms. For some, a high proportion from foreign-controlled multinationals is likely to augment national activities; for others, it is either the consequence or the cause of deficiencies in nationally controlled activities. Similarly, a high proportion of technological activities undertaken by large firms outside their home countries is for some a sign of strength, and for others a sign of weakness.

Table 6 shows that differences in countries' technological performance, measured in terms of business-funded R&D as a percent of GDP in 1983 (RDGDP), are positively and significantly correlated with differences in performance measured in terms of US patenting per capita (PATPC). Neither performance measure is significantly correlated with shares of national large firms in national technological activities (NLFHSH), nor with shares of foreign large firms (FLFSH). Similarly, neither performance measure is correlated with the extent to which national large firms have internationalised their technological activities (NLFASH). However, improvements in national technological performance, measured as real growth of business-funded R&D between 1967 and 1985, is positively correlated with increasing shares of national large firms, at almost the 5% level of significance.

The considerable amount of remaining variance may be explained by another factor, namely, the influence of sectors of national technological specialisation on the shares of national large firms in national technological activities. This cannot be tested statistically, given insufficient degrees of freedom. However, Table 5 shows that, although they are very different in aggregate technological performance, Canada, Italy and Sweden have in common both a revealed technological advantage[10] in capital goods [Pavitt and Patel 1988], and relatively unconcentrated technological activities as in capital goods (see Table 3). Similarly, Japan and the Netherlands have very different patterns of aggregate performance, but similar relative technological advantages in concentrated sectors: electronics and automobiles (Japan only).

TABLE 6
Structural Correlates of National Technological Performance, 1981-86: 11 OECD Countries

	RDGDP	PATPC	NLFHSH	FLFSH	ONFSH	NLFASH
PATPC	0.765*					
NLFHSH	0.578	0.431				
FLFSH	-0.435	-0.553	-0.724*			
ONFSH	-0.421	-0.097	-0.756*	0.096		
NLFASH	-0.061	-0.036	0.250	0.001	-0.362	
NLFTSH	0.254	0.197	0.701*	-0.373	-0.658	0.865*

Notes:
For each country:
RDGDP = Business-financed Industrial R&D as a percentage of GDP in 1983.
PATPC = Per capita US Patenting, 1981-86.
NLFHSH = Share of National Patenting in USA by National Large Firms: 1981-86.
FLFSH = Share of National Patenting in USA by Foreign Large Firms active in the country: 1981-86.
ONFSH = Share of National Patenting in USA by Other National Firms active in the country: 1981-86.
NLFASH = National Large Firms US patenting from abroad as a percentage of the National Total: 1981-86.
NLFTSH = Total National Large Firms US patenting (home and abroad) as a percentage of the National Total: 1981-86.
*Correlation Coefficient significantly different from zero at the 5% level.

	GRD	GNLFHSH	GFLFSH	GONFSH	GNLFASH
GNLFHSH	0.670				
GFLFSH	-0.393	-0.356			
GONFSH	-0.445	-0.808*	-0.263		
GNLFASH	0.437	0.347	-0.337	-0.146	
NLFTSH	0.636	0.724*	-0.414	-0.487	0.898*

Notes:
For each country:
GRD = Growth of Industry-financed Industrial R&D, defined as the proportionate change between 1967 and 1985.
GNLFHSH = NLFHSH in 1981-86 minus NLFHSH in 1969-74.
GFLFSH = FLFSH in 1981-86 minus FLFSH in 1969-74.
GONFSH = ONFSH in 1981-86 minus ONFSH in 1969-74.
GNLFASH = NLFASH in 1981-86 minus NLFASH in 1969-74.
GNLFTSH = NLFTSH in 1981-86 minus NLFTSH in 1969-74.
*Correlation Coefficient significantly different from zero at the 5% level.

Nationally Controlled Firms and Country Performance

We have shown in an earlier paper the strong correlation between the shares of US patents granted to countries, and the shares granted to their national large firms [Patel and Pavitt 1990]. But this begs the question of causality: Do country characteristics determine the behaviour of their national large firms, or vice-versa?

We have argued elsewhere that firm behaviour may be strongly influenced by country-wide factors: the degree to which the national financial system properly evaluates intangible, firm-specific assets accumulated through technological activities; the national system of basic research, and education and training of management and the work force, that influence the quality of major decisions about technology, and of implementation and learning; and the economic climate—and particularly expectations about growth and profits—that influences firms' propensities to invest in technological activities [Pavitt and Patel 1988]. On the other hand, it can be argued that large firms are not closely coupled to countries: they think and act in terms of world markets, world sources of finance, and world sources of management and worker skills: in typical situations of uncertainty and oligopoly, their discretionary decisions can have major impacts on the rate and direction of countries' technological activities.

Our data can throw some modest empirical light on this debate. We shall typify the competing hypotheses as "country-dominated" and "firm-dominated." In both cases, we would observe a high correlation between country performance and national large firm performance. However, in a country-dominated system, we would also expect a positive and significant correlation between the performance of the two main component parts of national technological activities, namely, the home-based activities of national large firms, and the activities of other national firms. In a firm-dominated system, we would expect instead a high correlation between the performance of the home-based activities of national large firms, and of their foreign activities.

Table 7 shows that aggregate national technological performance is country-dominated rather than firm-dominated. Country performance, measured as business-funded R&D as a percent of GDP in 1983 (RDGDP), or as per capita US patenting in 1981-86 (PATPC), is strongly correlated with the performance of national large firms, measured as per capita US patenting (NLFT), but it is even more strongly correlated with the domestic performance of these large firms (NLFH). It is also significantly correlated with the performance of other national firms (ONF), but not with the foreign performance of national large firms (NLFA). In addition, there is no significant correlation between national large firms' domestic performance, and their foreign performance. Table 7 also shows the same relations hold even more decisively in performance in growth of technological activities.

Sectoral Performance

Whilst differences in countries' aggregate technological performance are closely correlated with differences in the domestically based performance of large firms, the same may not necessarily hold in specific sectors, especially those where technological activities are concentrated in large, multinational firms. We therefore ran correlations, similar to those in Table 7, for each of the thirty-three sectors shown in Table 3, with the performance measures being levels and rates of change of per capita US patenting.

What emerges is a pattern remarkably similar to the one in Table 7. Only in five chemical and chemical-related sectors and in power plant are there

TABLE 7
Correlations between the Technological Performance of Countries and Nationally Controlled Firms

	RDGDP	NLFH	FLF	ONF	NLFA	NLFT
NLFH	0.811*					
FLF	0.159	0.114				
ONF	0.665	0.825*	0.292			
NLFA	0.313	0.432	0.348	0.459		
NLFT	0.720*	0.909*	0.241	0.797*	0.769*	
PATPC	0.765*	0.941*	0.280	0.965*	0.482	0.890*

Notes:
For each country:
RDGDP = Industry-financed Industrial R&D as a percentage of GDP in 1983.
NLFH = per capita Home-based US patenting of National Large Firms: 1981-86.
FLF = per capita US patenting of Foreign Large Firms active in the country: 1981-86.
ONF = per capita Home-based US patenting of Other National Firms active in the country: 1981-86.
NLFA = per capita US patenting of National Large Firms from abroad: 1981-86.
NLFT = per capita US patenting of National Large Firms (home and abroad): 1981-86.
PATPC = per capita aggregate US patenting for the country: 1981-86.
*Correlation Coefficient significantly different from zero (5% level).

	GRD	GNLFH	GFLF	GONF	GNLFA	GNLFT
GNLFH	0.678					
GFLF	0.121	0.439				
GONF	0.468	0.927*	0.521			
GNLFA	0.595	0.175	0.064	0.103		
GNLFT	0.789*	0.957*	0.416	0.870*	0.453	
GPATPC	0.578	0.980*	0.526	0.982*	0.142	0.929*

Notes:
For each country:
GRD = Growth of Industry-financed Industrial R&D, defined as the proportionate change between 1967 and 1985.
GNLFH = NLFH in 1981-86 minus NLFH in 1969-74.
GFLF = FLF in 1981-86 minus FLF in 1969-74.
GONF = ONF in 1981-86 minus ONF in 1969-74.
GNLFA = NLFA in 1981-86 minus NLFA in 1969-74.
GNLFT = NLFT in 1981-86 minus NLFT in 1969-74.
GPATPC = PATPC in 1981-86 minus PATPC in 1969-74.
*Correlation Coefficient significantly different from zero (5% level).

strong correlations between country performance and the domestic performance of nationally controlled large firms, on the one hand, and their foreign performance, on the other: agricultural chemicals, pharmaceuticals, organic chemicals, dyestuffs and food. Even in the last three of these sectors and in power plant, performance is also correlated with that of other domestic firms.

In twenty-seven out of the thirty-three sectors, country differences are significantly correlated with differences in firms' domestic activities, but not their foreign activities. These sectors comprise all capital goods, materials, transport, and electrical and electronics. In two sectors—hydrocarbons and motor vehicles—national performance is significantly correlated only with the domestic activities of national large firms; and in one sector—textiles—it is significantly correlated only with other domestic firms. In the other twenty-four sectors, national performance is significantly correlated with both. In none of the sectors is national performance significantly correlated with that of foreign large firms.

Finally, the domestic performance of large firms is significantly correlated with that of other domestic firms, in about half the sectors, comprising relatively unconcentrated capital goods sectors, materials, and the concentrated sectors of electronics. Linkages between the performance of these two major elements of national technological activities could be of two types. Horizontally, rivalrous behaviour may lead to imitative increases or decreases in technological activities in certain product fields. Vertically, vigorous technological activities in large users of capital goods may induce a complementary response amongst suppliers.[11]

Firm Specialisation and Country Specialisation

This leads to the last element in our analysis, namely, the interactions between the sectors of technological specialisation of national large—and other categories of—firms, and those of our 11 countries. These are shown in Table 8 which correlates, for each of the eleven countries in Table 5, their revealed technology advantage (RTA) in 1981-86 in each of the thirty-three technological sectors in Table 3, with the RTAs of the various categories of firm in Table 7.[12] The following conclusions emerge.

First, Table 8 shows that the sectoral patterns of technological advantage of large firms and their home countries are significantly similar. The sectoral RTAs of all eleven countries are significantly correlated with those of nationally based large firms (NLFT). This is the dominant relationship between firm and country specialisations in FR Germany, Netherlands, Switzerland, Sweden and the UK; whilst the RTAs of other national firms (ONF) are more highly correlated with countries' specialisations in Canada, France, and Italy.

Second, the sectoral specialisations of foreign large firms (FLF) are strongly correlated with those of their host countries in Belgium and Canada where, as we saw in Table 5, they account for a larger share of national technological activities than national large firms. Otherwise, there are significant correlations between the two in Japan.

Third, the links between the domestic technological specialisations of national large firms (NLFH), and those of other national firms (ONF), are weak: they are significantly correlated only in Canada and Japan.

Finally, the sectoral specialisations of national large firms in foreign countries (NLFA) often reflect those of parent firms (NLFH), with the strong exceptions of France and the USA. In the latter, national large firms are relatively strong in their foreign technological activities in pharmaceuticals,

TABLE 8
Sectoral Specialisations in Technological Activity: Correlations of RTA Indices for 11 Countries across 33 Sectors, 1981-86

Country	Country and NLT	Country and ONF	Country and FLF	NLFH and ONF	NLFA and NLFH	NLFA and Country
United States	0.88*	0.68*	0.32	0.35	-0.11	0.18
Japan	0.89*	0.68*	0.68*	0.54*	0.85*	0.71*
Canada	0.58*	0.94*	0.54*	0.48*	0.33	0.35
Belgium	0.49*	0.48*	0.72*	0.16	0.59*	0.30
FR Germany	0.90*	0.25	0.26	-0.05	0.57*	0.48*
France	0.44*	0.83*	0.06	-0.05	-0.19	-0.30
Italy	0.62*	0.90*	0.29	0.33	0.27	0.15
Netherlands	0.68*	0.29	0.35	-0.16	0.61*	0.51*
Switzerland	0.93*	0.22	-0.08	0.05	0.55*	0.48*
Sweden	0.78*	0.70*	0.02	0.18	0.45*	0.46*
United Kingdom	0.57*	0.27	0.04	0.09	0.44*	0.17

Notes:
See Note 12 for a definition of the RTA Index.

For each country, the RTA Indices are for:
Country = All US Patenting.
NLFH = Home-based US Patenting of National Large Firms.
FLF = US Patenting of Foreign Large Firms active in the country.
ONF = Home-based US Patenting of Other National Firms active in the country.
NLFA = US Patenting of National Large Firms from abroad.
NLFAT = US Patenting of National Large Firms (home and abroad).

*Correlation Coefficient significantly different from zero (5% level).

machinery, automobiles, and photography and photocopy, all sectors of relative domestic weakness.

CONCLUSIONS

The main conclusion of this paper is that—despite being a critical resource in the global competition and performance of both companies and countries—the production of technology remains far from globalised. Its heavy concentration in the industrialised—as compared to the developing countries—has been recognised for a long time. What we have shown is that, even in the major countries at the world's technological "core," the production of technology remains highly "domesticised" in two senses. First, in most of the countries at the world's technological frontier, the foreign technological activities of large firms are still not the major feature. Second, large firms' technological performance is strongly dependent on the performance of the home country, and not independent of it. These conclusions are very similar to the reported results of Porter's recent research on the sources of competitiveness [1989]. What happens in home countries still matters greatly in the creation of global technological advantage.

Nonetheless, large firms influence countries in other ways. Large firms are particularly important for the production of technology in R&D-intensive

sectors and automobiles. In all our eleven countries, large national firms have a significant influence on sectoral specialisations, whilst other national firms are significant in seven countries, and foreign large firms in three.

Our evidence is in general consistent with the earlier analyses of Dunning [1980], Cantwell [1989] and our own [Pavitt and Patel 1988; Pavitt 1988b]: country-specific factors create both the general conditions that determine the volume of technological activities, and the specific inducement mechanisms that determine their direction. These lead to accumulated firm-specific advantages that are reflected in international patterns of trade, production and related technological activities. It therefore becomes important to understand the nature of the country-specific factors that make up what Andersen and Lundvall [1988] have called "national systems of innovation," including the system of education, training and basic research that forms the infrastructure for firm-specific technological accumulation.

We also need a better understanding of the reasons why large firms keep most of their technological activities at home. Certain key features related to major innovations may help explain the advantages of geographical concentration: the primacy of multidisciplinary and tacit knowledge inputs, and the commercial uncertainties surrounding outputs. Physical proximity facilitates the integration of multidisciplinary knowledge that is tacit and therefore "person-embodied" rather than "information-embodied." It also facilitates the rapid decisionmaking needed to cope with uncertainty. For this reason, it may well be more efficient to have technological activities nationally concentrated, with international "listening posts" and adaptive capabilities maintained through small foreign laboratories, frequent international exchanges often involving what are called "strategic alliances," and proximity to an internationally outward looking system of higher education [Casson 1990; Dosi 1988; Grandstrand and Sjolander 1990; Mowery 1988; Pavitt 1989; Pearce 1990].

In spite of this, we expect to see greater internationalisation of large firms' technological activities in the future, not because it is inherently more efficient, but because it is politically necessary. Uneven technological and competitive developments amongst firms and countries create imbalances, tensions and threats of restrictions on entry into foreign markets. Measures to deal with these threats often involve foreign production and related R&D support, and sometimes independently targeted R&D activities.

In this context, the policies of Swedish large firms are revealing. They perform about 30% of their technological activities outside Sweden (see Table 5), and Hakanson and Nobel [1989] have found that political factors (particularly those related to establishment within European Community countries) have been important in more than 60% of the decisions taken since 1980 to establish R&D activities abroad.

Similar and even more powerful pressures are now on firms in another technologically high performing country, namely Japan, to expand foreign investment and related R&D activities in Europe and North America [Grandstrand et al. 1989]. However, we can see from Table 5 that they have a long way to go before their technological activities become anywhere near "globalised." We can also see that Dutch firms have travelled furthest down this route. It would be intriguing to know whether they intend to continue, or—on simple grounds of managerial efficiency—would prefer in an ideal world to turn back.

NOTES

1. See, in particular, Vernon [1966, 1979], Buckley and Casson [1976], Cantwell [1989].

2. On the reasons why firms internationalise their technological activities, see Hakanson and Nobel [1989], Cantwell and Hodson [1990], and R. Pearce [1990] for recent contributions.

3. For a more detailed discussion of the uses and abuses of patenting statistics as a measure of technological activities, see Pavitt [1988].

4. For a fuller discussion, see Dosi [1988a].

5. For an analysis of the conditions under which this is likely to occur, see Teece [1986].

6. US patenting slightly overestimates technological activities performed in the USA, compared to those performed in other countries, since firms have a higher propensity to patent on home than on foreign markets. It also severely underestimates the considerable volume of R&D undertaken in the USSR and other (former?) centrally planned economies, the efficiency of which is very low in innovation and diffusion, when compared to market economies (see Hanson and Pavitt [1987]).

7. For systematic evidence on intersectoral variations in the relative importance of these barriers, see Levin et al. [1987]; Bertin and Wyatt [1988].

8. On the varying patent practices of firms, see Bertin and Wyatt [1988]. On the skew distribution of the value of patents, see Pakes and Shankerman [1983].

9. Government agencies are granted patents principally in government-funded R&D programmes in defence, aerospace, energy and basic science. Recent studies in Canada and Italy show that, within the category "Individuals" are a significant proportion of commercially active small firms [Amesse et al. 1990; Malerba and Orsenigo 1990].

10. For an analytical discussion, see Dosi [1988b]. Such effects can certainly be observed in the UK: multiple reductions of activity in computers and semiconductors; multiple increases in pharmaceuticals and agricultural chemicals; the positive effects of the National Coal Board in coal-mining machinery [Patel and Pavitt 1987b].

11. Revealed technology advantage (RTA) is defined as the share of a country (or firm, or category of firms) in US patenting in a sector, divided by the share of that country (or firm, or category of firms) in US patenting in all sectors. Some readers will note the similarity to the measure of "revealed comparative advantage" used in analyses of international trade.

12. As an index of specialisation, revealed technology advantage (RTA) corrects for differences amongst countries, categories of firms, and sectors, in the total volume of patenting activity.

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