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The globalisation of technology: a new taxonomy

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Much has been written on the increasingly international generation, transmission and diffusion of technologies, with the phenomenon having been given its own term—techno-globalism—and interpreted by some as displacing national systems of innovation and making redundant and futile any attempt by national governments to foster technological development domestically. This paper reconsiders the evidence by developing a new taxonomy and investigating separately: (a) the global *exploitation* of technology, (b) global technological *collaboration* and (c) the global *generation* of technology. We find quite distinct answers when the degree of globalisation is evaluated separately on these three definitions.

1. Introduction

This paper re-examines critically the meaning of a term which has become increasingly fashionable: 'techno-globalism'. The term is used to describe the phenomenon of 'globalisation' experienced by the world of invention and innovation.[1] In its most modest use the term is shorthand for the fact that the generation, transmission and diffusion of technologies is increasingly international in scope. Although the term originated in the media, the academic world has been quick to adopt it. Several international conferences have been devoted to exploring its nature (for a review, see OECD, 1992A; Freeman and Hagedoorn, 1992) and a major research programme has been carried out by the European Community's FAST programme on technological and economic globalisation (see Petrella, 1989). Recent studies have demonstrated how firms have exploited the new opportunities and developed 'global research strategies' (Casson, 1991) and 'networks' (Howells, 1990A) to undertake their innovation programmes which largely bypass their home country. Governments have promoted policies to foster collaboration across borders by both the business and academic communities.[2]

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[1] Globalisation is a term used by economists and sociologists alike. Giddens, for example, has defined globalisation as 'the intensification of worldwide social relations which link distant localities in such a way that local happenings are shaped by events occurring many miles away and vice versa' (1990, p. 64).

[2] The most notable example is provided by the European Union, which has launched a large variety of R&D and other programmes involving organisations based in more than one of its member states.

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All this has several implications for our understanding of the role of nation-states. It is generally assumed that globalisation will reduce the role and scope of nations, and it is not uncommon, including among technology analysts, for the terms 'national' and 'global' to be seen as opposites. In this case, globalisation reduces the effectiveness of policies at the national level for promoting and organising technological advance.

The aim of this paper is to analyse these issues in more detail by developing a taxonomy defining three distinct categories of technological globalisation: (a) the global *exploitation* of technology; (b) global technological *collaboration*; and (c) the global *generation* of technology. We reconsider the evidence in the light of this categorisation and suggest that the patterns of globalisation differ significantly between the three categories of technological activities. An attempt to quantify the evidence relevant for each of the three factors, from both a static and a dynamic perspective, is made.

The paper is organised as follows: the next section briefly sets out the key trends on invention and innovation internationally. Section 3 then presents our taxonomy of globalisation and for each of the three categories which we define, the available empirical evidence is reported. Section 4 relates this to the recent body of literature on national systems of innovations; we argue that the globalisation of technological activities has not led to a convergence in either the methods adopted by countries to innovate or in their profiles of sectoral specialisation. The final section explores the policy implications, in particular for the role of national governments.

2. Resources devoted to invention and innovation

Has technology become more important in advanced economies? If this were the case, globalisation of technology might simply reflect the increasing *national* efforts to innovate. Resources devoted to formal Research and Development (R&D) activities, which are one of the most important sources of knowledge, have indeed increased substantially over the last twenty years. Table 1 reports the average growth rates for the 1970s and for the 1980s of both total (columns 1 and 2) and industrial (columns 3 and 4) R&D for all OECD countries. For the vast majority of nations the growth rates in the 1980s were much higher than in the 1970s (the most notable exception being the UK). A comparison between total and industrial R&D also shows that, over the 1980s, industrial R&D increased in importance compared to other R&D.

Investment in R&D is sensitive to economic conditions, though, so the increase in R&D expenditure should be considered in the light of general economic growth. Figure 1 reports total R&D as a share of GDP and Fig. 2 reports business R&D as a share of industrial production, both for the major six countries. In spite of a long-term trend towards an increase in R&D intensity of advanced economies, the data also show that a slowdown occurred from the mid 1980s: both the US and the UK reduced the share of their GDP devoted to R&D, and in Germany and France its growth slowed.

It would be natural to expect that the growth of industrial R&D would lead to an increasing number of patent applications, since the majority of patents are taken out by firms. Columns 5 and 6 of Table 1 report the growth rates of domestic patent applications in the OECD countries; but, contrary to expectations, the growth rates have been moderate and sometimes even negative. The only major country with a consistently

Table 1. *Rates of growth of total R&D, industrial R&D and patenting in OECD countries*

	Average annual rates of change (percent)										(External patents)* ÷ (Domestic patents)		
	Total R&D expenditure		Industrial R&D		Domestic patents		Foreign patents		External patents				
	1970–1980	1981–1990	1970–1980	1981–1990	1970–1980	1981–1990	1970–1980	1981–1990	1970–1980	1981–1990	1971	1981	1990
United States	1·4	4·4	2·0	4·3	−2·0	4·2	5·0	5·3	−0·6	6·6	1·5	2·0	2·7
Japan	6·3	7·8	6·1	9·4	5·1	6·3	−0·8	4·9	5·5	9·9	0·3	0·3	0·4
Germany	4·0[a]	3·9	4·9[a]	4·2	−0·7	0·3	0·8	6·4	1·7	4·6	2·2	2·7	3·9
France	2·9	4·7	3·7	5·0	−2·4	1·6	0·2	7·0	3·0	6·8	1·8	2·8	4·4
United Kingdom	2·9[e]	2·0	3·0[e]	2·9	−2·4	−0·8	0·8	6·2	−1·7	7·3	1·3	1·6	3·0
Italy	2·8	7·0	3·6	7·4	n.a.	n.a.	n.a.	n.a.	1·8	7·4	1·5	n.a.	n.a.
The Netherlands	2·2	3·1	1·4	3·7	−2·1	2·8	1·5	9·0	0·1	6·6	4·9	6·1	7·8
Belgium	2·4[b]	3·3[l]	6·7[d]	4·1	−3·0	−0·1	−0·1	10·7	0·5	6·8	3·0	3·7	7·4
Denmark	3·1	7·0[h]	3·8	8·4[h]	1·7	1·9	−0·3	12·2	1·0	8·7	3·4	3·4	6·1
Spain	10·3	11·0	12·7	14·1	−4·5	3·1	0·2	20·2	1·3	8·1	0·5	1·0	1·8
Ireland	4·0[d]	6·0	5·2[d]	10·1	6·8	5·3	4·9	4·7	6·7	8·5	1·2	1·3	1·5
Portugal	2·9[c]	8·4[i]	4·6[c]	4·1[i]	−6·4	1·3	−0·5	7·5	−24·2	33·6	0·8	0·1	0·8
Greece	n.a.	12·7[h]	n.a.	12·6[h]	−0·8	−12·3	2·4	28·8	n.a.	8·5	n.a.	0·1	0·7
Switzerland	1·4[a]	5·0[h]	0·8[a]	5·1[h]	−3·1	−1·2	2·2	9·4	−1·3	2·9	4·3	4·9	7·3
Sweden	6·4[d]	5·1[h]	5·9[d]	5·2[h]	−0·5	−2·3	2·5	9·4	3·0	3·6	2·1	3·0	5·3
Austria	9·6[a]	4·6	9·8[a]	5·0[h]	0·3	−1·5	3·4	10·8	1·4	5·7	1·6	2·0	3·5
Norway	6·1	6·0[h]	7·3	6·9[h]	−2·7	2·6	−0·1	9·0	0·8	9·9	1·3	2·1	3·4
Finland	6·8[d]	8·7	6·8[d]	10·4	4·7	4·2	0·7	12·3	5·7	13·2	1·4	1·9	4·0
Australia	0·2[f]	6·6[g]	n.a.	13·1[h]	5·2	0·1	−2·0	5·8	6·7	10·5	0·5	0·7	1·8
Canada	2·5[c]	4·4	5·5	5·7	−1·1	3·0	−2·1	4·6	−0·5	4·1	2·5	2·9	2·4
OECD weighted average					1·3	4·1	0·9	7·2	0·9	5·9	1·2	1·3	1·5
OECD weighted average (excluding Japan)					−1·6	1·8	1·1	7·4	0·4	5·4	1·8	2·4	3·5

Source: Calculated from OECD, 1992B.
*External patent appl. in year *t* divided by domestic patent appl. in year *t*-1.
n.a.: not available.
[a]1970–1981 [d]1971–1981 [g]1981–1988 [l]1983–1990
[b]1971–1979 [e]1972–1981 [h]1981–1989
[c]1971–1980 [f]1973–1981 [i]1982–1988

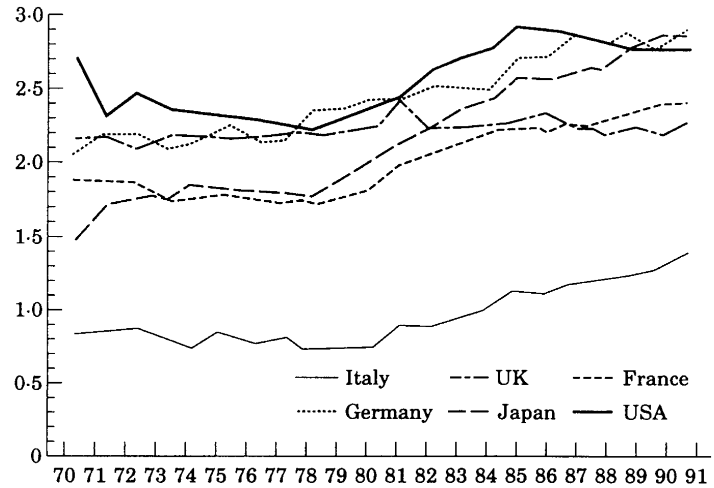

Fig. 1. *Total R&D as a percentage of GDP.*

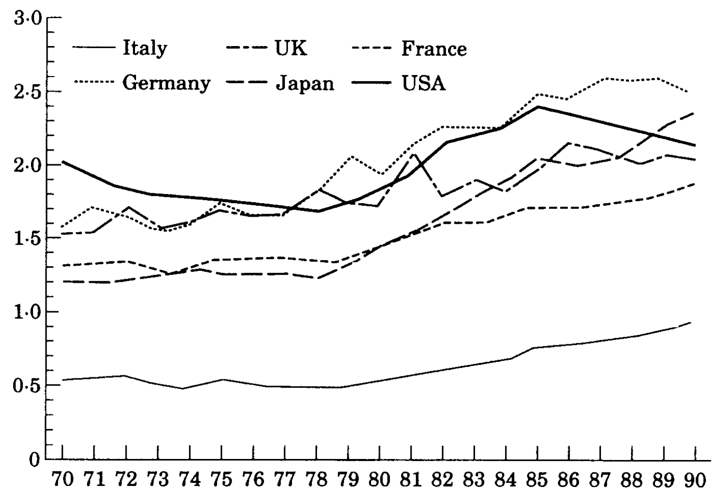

Fig. 2. *Business R&D as a percentage of domestic product of industry.*

high growth rate was Japan, at more than 5% a year in the 1970s, and more than 6% a year in the 1980s.[1]

These trends in domestic patenting and in R&D as a share of GDP suggest that the generation of knowledge has been relatively weak. One possible explanation might be that the international transmission of technology has become an effective alternative to the internal production of knowledge, allowing firms to avoid research duplication: the next section will explore this hypothesis, looking at the channels of international

[1] Some authors (see, for example, Evenson, 1989) relate the slowdown in domestic applications to a decreasing productivity of scientific and technological research (this issue is also discussed by Griliches, 1990). However, the decrease in domestic patents may also be related to a greater realism regarding the opportunities offered by the patent system.

technology transfer. The evidence presented in this section, though, suggests that any trend towards technological globalisation cannot be due to the growth of resources devoted to innovation at the national level *per se*.

3. Three meanings of 'techno-globalism'

As is often the case with neologisms, the term 'techno-globalism' may have different meanings in different contexts and for different authors (see Chesnais, 1992). One such meaning is that an increasing proportion of technological innovations are exploited in international markets: we term this the *global exploitation of technology*. Second, there is international collaboration between firms, sharing know-how with competitors from different countries, along with a parallel process of international collaboration between governments and academic institutions: this we term *global technological collaboration*. A third meaning, dear especially to students of multinational corporations, is that firms are increasing the international integration of their R&D and technological activities: this we term the *global generation of technology*. These three meanings can be separated analytically.[1]

3.1. The global exploitation of technology

First, we consider the case of companies exploiting their technology in international markets. This is certainly not a new phenomenon, but it has increased its importance in recent times. The attempt to profit from innovations in international markets is the technological equivalent of international export flows. If a larger share of firms' output is absorbed by foreign markets, it is natural that firms will also try to take advantage of their technological capabilities internationally.

Our hypothesis is therefore that the global exploitation of technology is the consequence rather than the cause of the increase in international trade. However, a few technology-specific factors should be stressed. First, technology-intensive products are more likely to be traded internationally; Guerrieri and Milana (1995) found that high tech exports rose from 12·2% of world manufacturing exports in 1970, to 20·5% in 1989. Moreover, tradeable sectors, especially in manufacturing, are generally associated with high R&D and innovative performance (see Hughes, 1986). Second, several empirical studies have shown that countries' innovative capabilities are the main factor backing their export performance (see Soete, 1987; Fagerberg, 1988; Amendola *et al.*, 1994); in other words, a domestic technological capability is a necessary condition for a successful export performance. Third, technology can be exploited in foreign markets even when disembodied from products, for example via the transfer of licences and know-how. These factors create important feed-back effects leading to complex causal links: from domestic technological capabilities to export performance, and from export performance to the attempt to exploit technology internationally, either embodied or disembodied.

One way of measuring the international exploitation of innovations is to consider how firms protect them legally through patents in foreign markets. Firms undertake the cost and effort involved in extending a patent abroad if they expect to be compensated by either trading the disembodied invention or exporting products which embody it.

[1] A firm might exploit its new products in international markets without necessarily integrating its R&D laboratories internationally, nor undertaking international research joint ventures.

Table 2. *Domestic patents and foreign patents, 1990*

	Domestic patents (%)	Foreign patents (%)
USA	55·08	44·92
Japan	88·46	11·54
Germany	32·62	67·38
France	16·15	83·85
United Kingdom	21·46	78·54
Italy	n.a.	n.a.
The Netherlands	5·32	94·68
Belgium	2·09	97·91
Denmark	6·82	93·18
Spain	4·83	95·17
Ireland	15·50	84·50
Portugal	2·77	97·23
Greece	2·07	97·93
Switzerland	7·94	92·06
Sweden	6·92	93·08
Austria	5·13	94·87
Canada	6·76	93·24
Australia	24·63	75·37
Weighted average OECD	43·17	56·83
Weighted average OECD (excluding Japan)	22·17	77·83

Source: Calculated from OECD database, MSTI, 1992.

Firms also extend their patents into markets where they do not operate in order to block competitors and to prevent other firms from invading their own (or third) markets.[1]

From a static viewpoint, it should be stressed that a substantial share of the patent applications registered in advanced countries have a foreign origin (see Table 2): 45% of the total patent applications registered in 1990 in the United States came from abroad, while in countries with a lower volume of technological activity, such as Germany and France, they accounted for 67% and 84% respectively. The European Patent Office receives 45% of its applications from non-member countries. In the other OECD countries the share of foreign patent applications is as high as 90%. The only exception is Japan, where as many as 88% of applications are from domestic inventors. Although this is partly due to the institutional differences of the Japanese patent system (which does not allow more than one priority claim per application), as well as to linguistic and cultural barriers, it nevertheless indicates that Western technological penetration of Japanese markets is still rather low.

Patent data can also supply information about the rate of increase in the exploitation of inventions internationally, i.e. on its *dynamic* dimension. There are two ways of looking at this: the first from the viewpoint of the country 'invaded' by foreign patents and the second from the viewpoint of the country 'invading' other countries. Columns 7 and 8 of Table 1 report the rate of change in foreign patents (i.e the patent applications presented by foreigners in a country) and columns 9 and 10 on external patents (i.e. the number of applications presented by inventors of one country in other countries).

[1] For an analysis of the foreign patenting policy of multinational companies see Wyatt *et al.* (1985). The use of patenting as a technology indicator is reviewed in Griliches (1990) and Archibugi (1992).

All countries have been 'invaded' and 'invading' at much higher rates during the 1980s compared to the almost stagnant rates of the 1970s (see the data on foreign patents, columns 7 and 8, and external patents, columns 9 and 10 of Table 1, respectively).[1] Thus the 1980s have been characterised by a dramatic growth in the exploitation of inventions in international markets. This compares with the stagnant or even declining growth rates of domestic patenting documented above (Section 2). In other words, the data do not reflect an increase in the production of knowledge, but only an increase in its international exploitation. Some significant differences emerge across countries. Japan, for example, is 'invading' other countries at the highest rate among the G7 although it has been 'invaded' at a comparatively low rate. Countries which were on the periphery of technological competition are now both 'invading' and being 'invaded' at a substantial rate.

Columns 11, 12 and 13 of Table 1 report an index of external patent applications per domestic application for the years 1971, 1981 and 1990 to identify cross-country differences.[2] Not surprisingly, the index is particularly high for technologically dynamic small and medium-sized countries: the Netherlands rank first, followed by Belgium, Switzerland, Denmark and Sweden. Firms based in small and medium-sized countries do not find their internal market large enough to repay their investment in innovation, so that they would not be able to undertake many of their R&D projects if they were not able to exploit the results in international markets. Small countries with a low R&D intensity, including Greece, Ireland, Spain and Portugal, have a very low propensity to protect abroad their (already scarce) inventions. The value of the index is lower for larger countries than for small countries with a comparable R&D intensity. The value is very low for Japan (equal to only 0·4); although this result is due partly to the nature of the Japanese patent system (see above), it also suggests that, in spite of the fast growth of Japanese patents abroad over the last decade, Japan has a vast technological potential yet to be exploited internationally. In more general terms, these data indicate that the contribution of small and technologically dynamic countries to the global exploitation of inventions is high. Although the same trend affects large countries, they are comparatively more oriented towards the national than the global market. Not all countries have the same propensity to exploit their inventions globally. But, taken together, these data provide strong evidence for the first meaning of techno-globalism: firms' propensity to trade and exploit their inventions and innovations internationally has grown considerably.

3.2. Global technological collaboration

The second category we analyse is technological collaboration to develop know-how or innovations involving partners in more than one country, where each of the partners preserves its institutional identity and ownership. This can involve government research agencies and the academic community (the economic equivalent of non-profit cultural exchanges) as well as the business sector (the technological equivalent of international joint ventures). International R&D joint ventures have received much

[1] It is true that new institutional facilities have made it easier to extend a patent in more than one country, most notably the European Patent Office (EPO). However, countries which are not members of the EPO have also experienced a comparable growth in the number of foreign patent applications received. Institutional developments seem to be more the consequence of the global exploitation of technology than its cause.

[2] Since inventors are allowed one year to extend abroad the applications they have presented at home, the domestic patent applications considered here refer to the year *t*-1.

attention over the last few years. Governments, international organisations (most notably the EU), and business firms have been prone to collaborate and share know-how with foreign partners. This has led the academic community to create new databases to account for the phenomenon and to develop models to explain it (the empirical literature and the available databases are reviewed by Chesnais, 1988, and by Gugler and Dunning, 1992. The theoretical literature on R&D co-operation, although not necessarily at the international level, is reviewed in Katz and Ordover, 1990).

Technological collaborations can be divided into those undertaken by non-profit institutions and by the business sector. The two communities have different propensities to transfer know-how: non-profit institutions are generally more prone to collaborate and to disclose the results of their research and, in fact, the academic community has long been international in scope. In order to explore the dimension of cross-border collaboration, several studies have focused on internationally co-authored papers since they are one of the measurable outcomes. Frame and Narin (1988) found that the percentage of papers which are internationally co-authored (of the total number of co-authored papers) doubled between 1974 and 1984. As expected, countries with a small scientific community have a higher propensity to co-author their papers with colleagues from other countries. While the proportion of co-authored scientific papers in 1984 having authors from more than one country was equal to 9·3% in the US, it was 16·1% in Britain, 18·5% in Germany, and 19·2% in France. Japan produces a much lower proportion of internationally co-authored papers, at 6·8%.

To what extent can a similar pattern be identified for the business community? Economists have traditionally viewed firms operating in competitive markets as unwilling to co-operate with their rivals, especially in a strategic area such as technical know-how. However, a closer look at the phenomenon has shown that firms are more willing than generally believed to share their technical know-how with their competitors (see Baumol, 1992).

To monitor technical agreements, Merit at the University of Limburg has developed a database of agreements made known to the press (Cati-Merit; see Hagedoorn and Schakenraad, 1990, 1993). Three new technology fields (biotechnology, new materials and, especially, information technologies) account for more than 70% of all the agreements monitored. Moreover, in these areas there has been a dramatic increase in the number of agreements (see Fig. 3). To a large extent, therefore, the overall growth reflects the increasing importance of these fields with agreements in other fields having increased at a much slower rate if at all (an exception being the chemical industry).

However, R&D joint ventures may not be such a *new* trend as is generally believed. During the 1960s and 1970s, there was less awareness of the willingness of firms to share their know-how. R&D joint ventures may have gone unrecorded because of a lack of understanding as well as of interest. In the 1980s, the phenomenon became more visible and new surveys were undertaken to account for it. We share the view that 'although technology cooperation between companies probably goes back many decades, it has experienced a major boost during the 1980s' (Hagedoorn & Soete, 1991, p. 209), but we would also point out that this is confined to a very few, although crucial, fields. Two reasons why agreements are so popular in fast-growing technologies are, first, that these new technological paradigms are more knowledge-intensive than in the past, and successful innovative performance relies on the capability to acquire information on what

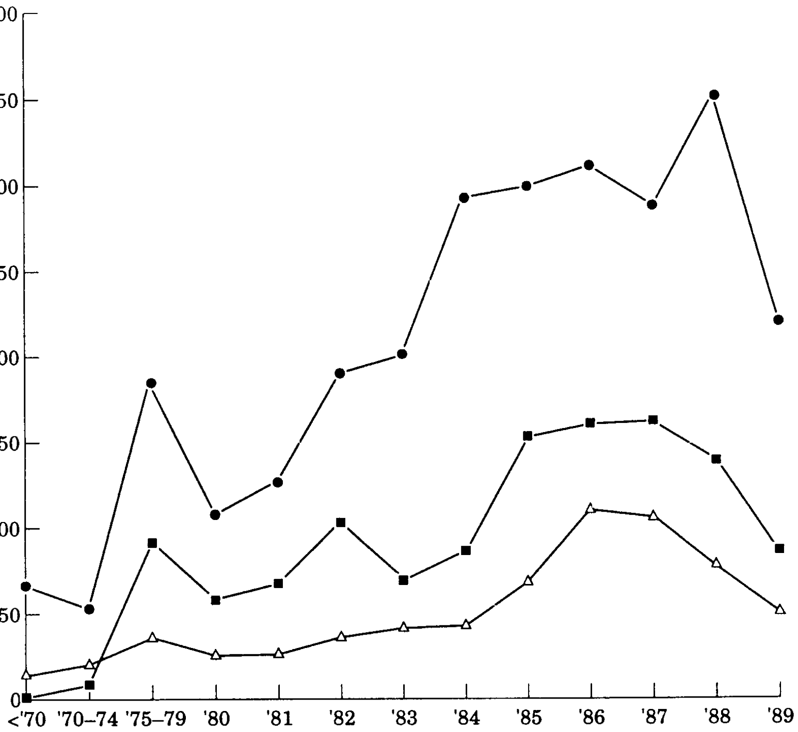

Fig. 3. *Growth of newly established technology co-operation agreements in biotechnology (■) information technology (●) and new materials (◇).*
Source: Cati-Merit data bank.

is going on in the field and, second, that for industries in their infant stage it is particularly necessary to acquire information, and therefore also to share it.[1]

Table 3 reports the international distribution of technology co-operation agreements in new technologies. Not all of them are international in scope.[2] The major agglomeration of joint ventures is in the United States: as many as 63% of the agreements recorded involve at least one US-based company and 28% of the agreements occur within US-based firms (the determinants of US firms' international collaborative ventures are discussed in Mowery, 1992). European firms collaborate more with American than with other European partners in all three fields: intra-European joint ventures amount to 19% of the total while European–US ones amount to 21%. The Cati-Merit database divides the determinants of such international collaboration into 'market access' and 'technology access': in all three fields considered the technological determinant proves more relevant than does access to the market. This suggests that the reason for European firms

[1] For a discussion of the necessity to disclose information in order to acquire it, see von Hippel (1987) and Carter (1989). Cainarca *et al.* (1992) have shown that inter-firm agreements are typical in the infancy of technological life cycles.

[2] The data at our disposal do not allow the separation of intra-European agreements between those which involve more than one European country from those within the same country. The Cati-Merit database is also likely to underestimate joint ventures between Japanese firms because of linguistic barriers.

Table 3. *International distribution of technology co-operation agreements in biotechnology, information technologies and new materials (number, with percentages given in parentheses), 1980–1989*

	Biotechnology	Information technologies	New materials	Total
Western Europe	233	509	118	860
	(18·4)	(18·7)	(17·2)	(18·6)
Western Europe–USA	245	599	133	977
	(20·2)	(22·0)	(19·3)	(21·2)
Western Europe–Japan	38	177	49	264
	(3·1)	(6·5)	(7·1)	(5·7)
USA	428	707	139	1274
	(35·3)	(26·0)	(20·2)	(27·6)
USA–Japan	155	406	94	655
	(12·8)	(14·9)	(13·7)	(14·2)
Japan	58	95	88	241
	(4·8)	(3·5)	(12·8)	(5·2)
Other	66	225	67	358
	(5·4)	(8·3)	(9·7)	(7·8)
Total	1213	2718	688	4619
	(100)	(100)	(100)	(100)

Source: Hagedoorn and Schakenraad (1990).

co-operating more with US-based firms is the larger technological capabilities offered by American companies.[1]

3.3. Global generation of technology

We now turn to the third meaning of 'techno-globalism', i.e. the development of firm-based strategies in research and technology across different countries for generating inventions through the 'development of global research networks' (see Howells, 1990A, 1990B), made technically feasible by the new information networks (Antonelli, 1991). This third meaning is the technological equivalent of foreign direct investment.

While the first two uses of the term involve both national and multinational firms, the business and the public sectors, and innovations developed by organisations and by individuals, this third meaning applies to a single actor only: the multinational corporation. Governments and other public institutions, including universities, may collaborate internationally in R&D projects but it is unlikely that they will be in a position to generate inventions 'globally',[2] and by definition, uninational firms base their production facilities, including their R&D laboratories in their home country. This third meaning of techno-globalism is therefore more restricted than the former two.

Multinationals are key players in the technological race: according to the OECD, multinational firms account for 75% of all industrial R&D in the OECD countries (OECD, 1992A).[3] The global generation of inventions has far-reaching implications for our understanding of the multinational corporation and not surprisingly it has received much attention from researchers of foreign direct investment (for a survey, see Dunning,

[1] These issues are also addressed in Casson (1991) and Linne *et al.* (1991).

[2] Universities and public research centres do not, as a rule, establish subsidiaries in foreign countries.

[3] However, such figures for R&D (as well as patents, particularly patents extended abroad) are likely to overestimate the importance of large firms: see Archibugi *et al.* (1991). The role of large and small firms in technological change is the subject of continuing controversy in innovation studies (see, among a large literature, Acs and Audretsch, 1989; Malerba and Orsenigo, 1993).

1992). For a long time, multinationals were viewed as organisations with headquarters centralising the most important assets: top management, strategic planning, and R&D laboratories. In other words, the multinational was seen as a sort of polyp with its brain in the home country and tentacles in the host countries. If a substantial proportion of inventions are now generated in host countries this would imply that a crucial part of the brain had been decentralised into the tentacles. In fact, researchers in the field of international production have argued that the implementation of foreign R&D laboratories by multinational companies is generally a consequence of their foreign direct investment (see Casson, 1991; Dunning, 1992).[1]

From the perspective of the individual nation-states, there are both pros and cons in having their firms locating R&D outside the borders of their country, and likewise for hosting the R&D of foreign firms. On the one hand, there are advantages in hosting the largest possible amount of skilled activities, although foreign firms are less controllable by national policies. On the other hand, having domestic firms based in foreign countries may weaken national technological capabilities in strategic areas; while this argument is generally understood for defence (governments rarely allow national military procurement to be heavily dependent on foreign controlled firms), it is often overlooked for strategic civilian sectors.[2] A large share of R&D performed abroad by home-based firms may also indicate that the domestic infrastructure is inadequate.

A variety of approaches have been used to identify and measure the decentralisation of R&D and other inventive activities (for a survey, see Howells, 1990A). However, most of the research has focused on selected case studies of specific multinationals. Although this evidence has provided some very useful insights at the microeconomic level, it is difficult to assess to what extent the cases of what are particularly internationalised firms can be generalised. Patel and Pavitt (1991A) analysed the global generation of inventions by considering the location of the inventions registered at the US patent office by the world's largest 686 firms for the period 1981–1986.[3] Nearly all these firms have a substantial part of their production in host countries. Patents are a particularly appropriate measure to test the location of the inventions since they are attributed to the country of residence of the inventor rather than to that of the owner. Columns 1 and 2 of Table 4 therefore report the share of patenting from nationally- and foreign-controlled large firms as a percentage of total national patenting, and column 3 reports the share of patents granted to other firms, government agencies, universities and private inventors (these three columns are as a percentage of total national patenting in the US).

The share of patenting controlled by foreign firms is 10% or less in all the countries considered other than Belgium, the United Kingdom and Canada. The share of foreign-controlled patenting is very low for the two largest OECD countries, the US and Japan, amounting to 3·1% and 1·2% respectively. European countries are more likely to host foreign R&D, although a substantial part of this is intra-European; the share of patenting in Europe controlled by non-European large companies is only slightly higher

[1] Pearce and Singh (1992) show that the single most significant factor determining the development of subsidiary R&D units by multinationals is 'to help to develop new products for the local market'.

[2] Tyson (1992) makes the additional point that 'foreign direct investment could threaten national security by transferring control over key military technologies to foreign firms or investors in concentrated industries' (p. 146).

[3] Patel and Pavitt (1991A) considered patents registered in one country only, i.e. a sub-set of the world patented inventions considered above (Section 3.1). However, there is strong evidence to suggest that patents registered at the US patent office are a significant and representative sample of high quality patented inventions (see Archibugi and Pianta, 1992).

Table 4. *Large firms in national technological activities (patents granted by the US patent office)*

	National source of patenting (3 columns add up to 100%)			Patenting by foreign-controlled large firms as a % of total large firms' patenting from that country	Patenting by large firms operating outside their home country (as a % of national total)	Patenting by large firms operating outside their home country (as a % of large firms' patents from outside and inside the country)	Balance of patenting from foreign-controlled firms in the country and patenting abroad by nationally controlled firms
	Large firms						
	Nationally controlled	Foreign controlled	Other	Cols {2/(1+2)} × 100		Cols {5/(1+5)} × 100	Col. 2 − col. 5
	1	2	3	4	5	6	7
Belgium	8·8	39·7	51·5	81·9	14·7	62·6	25·0
France	36·8	10·0	53·2	21·4	3·4	8·5	6·6
FR Germany	44·8	10·5	44·2	19·0	6·9	13·3	3·6
Italy	24·1	11·6	64·3	32·5	2·2	8·4	9·4
Netherlands	51·9	8·7	39·4	14·4	82·0	61·2	−73·3
Sweden	27·5	3·9	68·6	12·4	11·3	29·1	−7·4
Switzerland	40·1	6·0	53·9	13·0	28·0	41·1	−22·0
UK	32·0	19·1	49·0	37·4	16·7	34·3	2·4
W. Europe	44·1	6·2	49·7	12·3	8·1	15·5	−1·9
Canada	11·0	16·9	72·1	60·6	8·0	42·1	8·9
Japan	62·5	1·2	36·3	1·9	0·6	1·0	0·6
USA	42·8	3·1	54·1	6·8	3·2	7·0	−0·1

Note: All columns refer to patents granted by the US patent office between 1981 and 1986. The first three columns are calculated as a percentage of total national patenting in the US.

Source: Patel and Pavitt, 1991A and calculations from the data.

than for the US and Japan, at 6·2%: if Western Europe is seen as a 'single market', the amount of foreign-controlled inventions is not substantially higher than for the US and Japan. This evidence indicates that the global generation of inventions is far from being with us.

However, the share of foreign-controlled patenting should be considered in relation to the sub-total of patents controlled by large firms since, as stated above, this third meaning of techno-globalism cannot be applied to the whole national economy but only to multinational corporations.[1] Column 4 of Table 4 reports the share of patents controlled by foreign large firms as a share of the patents taken out by all (national and foreign) large firms. Foreign firms account for 82% and 61% of large firms' technological activities in, respectively, Belgium and Canada. They are also important in the UK (37%) and Italy (32%). Industrial and innovation policies towards large firms in these countries need therefore to take account of the fact that a substantial proportion of technological activities are undertaken by firms belonging to the 'foreign legion' which may prove more volatile than home-based large firms.

Column 5 of Table 4 reports the percentage of patents controlled by firms operating from outside the home country.[2] Not surprisingly, the countries ranking first are those traditionally associated with financial and international capital: the Netherlands (with a share as high as 82%), Switzerland (28%) and the UK (17%).[3] This tendency to operate from host countries reflects a number of factors, such as in some cases a long tradition of foreign direct investment, but also, particularly in the case of smaller countries, the relative lack of technological expertise at home. German, French and Italian large firms have a much lower propensity to undertake R&D in host countries. Both Japanese and US large firms carry out a negligible part of their technological activities in host countries: US and Japanese multinationals still operate along the lines of the well known 'polyp' model and do not decentralise strategic activities, at least as far as R&D is concerned.

Column 7 of Table 4 reports the balance between foreign-controlled patenting at home and patenting abroad of nationally-controlled firms. For the majority of countries, the difference in the national technology level would not change much in the absence of multinational activity since the outward flows are balanced by the inward flows. The US, Japan and Western Europe as a whole break even. The Netherlands and Switzerland have a net loss, while Belgium, Italy and Canada gain.

It has been argued that patenting in the US is not a reliable indicator of the global generation of innovations (see Chenais, 1992), and it is therefore important to compare the results based on patents with those found using other technological indicators such as R&D. Pearce and Singh (1992) considered the geographic distribution of R&D employees of a sample of multinational corporations and their results showed an even smaller globalisation of multinationals' R&D activity than is indicated by the patent data. A detailed comparison is made by Patel (1995, Table 2) between overseas R&D and patenting for US multinationals, and this shows that the two distributions are rather similar, even at the industry level.

[1] This approach was applied to patenting in the US by Cantwell and Hodson (1991) whose results proved very similar to those of Patel and Pavitt (1991A).

[2] While column 2 of Table 4 refers to the patents granted to investors who reside in a given country and are employed by foreign firms, column 5 refers to inventors who are employed by national firms but reside in foreign countries.

[3] The data of Patel and Pavitt (1991A) include 10 Netherlands-based firms, 10 Swiss-based firms and 64 UK-based firms.

An additional step towards a dynamic analysis is made by Patel (1995) providing evidence on the pace of internationalisation of large firms' patenting activity and finding that in the last five years (1986–1990) the patents of foreign-controlled firms increased, for all countries, by only 1%. If we compare this rate of change to the rate of change in both foreign patent applications and patent applications extended abroad, we see that the global generation of technology is growing at a much slower pace than is its international exploitation. The available empirical results (Patel and Pavitt, 1991A; Cantwell and Hodson, 1991; Pearce and Singh, 1992; Patel, 1995) therefore suggest that a disproportionate importance has been given to the third meaning of techno-globalism. Large multinational firms do show a tendency towards a growing international integration of business. But, to repeat, however important large firms may be, they are not the only producers of innovations. In conclusion, we share Casson's view that 'the story of globalised R&D is the story of a fairly small number of very large firms carrying out research in a small number of leading industrialised countries' (1991, p. 272).

Finally, we compare how the generation of technology, on the one hand, and technological collaboration, on the other, vary across regions. The international generation of technology has to date been a peculiarly intra-European phenomenon. It is not only, as noted above, that the US and Japanese firms have not pursued the global generation of technology to any significant extent (Table 4, columns 5 and 6), but also that European firms have a tendency to choose other European countries to locate their foreign R&D facilities which therefore has the character of European *regionalisation* rather than globalisation. This is even more significant when compared with the inter-firm technical agreements discussed above, which often involve partnerships between European and American firms. While European firms have a propensity to share their know-how with American competitors, they still prefer to locate foreign research within the European continent.

4. The impact of globalisation on national technological specialisation

The results obtained for each of the three categories above suggest that the role of national innovation policy is not necessarily becoming less important because of globalisation. The exploitation of innovations requires national governments to settle the regime according to which new technologies can be exploited within their borders. International collaborations rely on the nature of the national technological capabilities associated with the prospective partner. As for the generation of innovation, this is still largely organised within the boundaries of nation-states. These results—suggesting that the role of nations in the organisation of innovative activities remains crucial—are consistent with the new body of literature emphasising the role of national systems in organising and promoting innovation (see Porter, 1990; Lundvall, 1992; Nelson, 1993). More importantly, the categorisation proposed suggests that the dichotomy global/national is a false one.

The hypothesis of international technological accumulation (see Pavitt, 1988; and Cantwell, 1991) stresses that capabilities are nation-specific, differentiated and cumulative. A large body of evidence has shown that nations have different sectoral strengths and weaknesses (see Soete, 1987; Patel and Pavitt, 1991B; and Archibugi and Pianta, 1992) which tend to persist over time (Cantwell, 1989). We therefore assume that one of the factors which influence firms in either co-operating with foreign firms or investing in a foreign country is the technical expertise that those firms or countries have to offer and that firms will try to exploit these national advantages in their international innovation strategies. Thus, for example, American foreign investment in the German chemical industry is related to the traditional excellence of Germany in the field (see Cantwell, 1989). Similarly, a significant proportion of European companies' foreign direct investment in the US is in bio-technology because of the higher technological competence of American firms.

The 'polyp' firm appear to use its tentacles to acquire from each country its excellence in research rather than to decentralise its brain. However, this is not always feasible since national technological capabilities may or may not be easily appropriated by foreign companies. Some of them will typically be associated with the technological advantages of national firms and are unlikely to be appropriable by foreign firms, as indicated by international business studies.[1] The Cati-Merit database indicates that technological complementarity is the key factor promoting joint R&D, while the technological competence of the partner is the main rationale for foreign direct investment in R&D (Hagedoorn and Schakenraad, 1990, Tables 4 and 5). In other words, one of the key factors behind the internationalisation of R&D is the acquisition of knowledge. The choice between collaboration and foreign direct investment is influenced by the nature of ownership advantages: firms might decide on foreign direct investment when technology is easily appropriable, but on a partnership when it is not.

The effects of this strategy should also emerge at the sectoral level. We would expect: first, the sectors with a high presence of foreign firms to be those of national excellence of the host country; and second, that the difference between the sectoral strengths and weaknesses of countries tend to increase rather than to decrease over time. The first predicted outcome is confirmed by the empirical work of Patel and Pavitt (1991A) and Cantwell and Hodson (1991): the vector of the indices of national technological specialisation (as measured by patents) is positively associated with the vector of foreign controlled patenting in the same nation for the majority of countries.[2] This evidence supports the hypothesis that multinational firms do not extend their R&D internationally to replicate research and innovations in the sectors where their home country is already strong, but rather to acquire the know-how which is lacking at home. The second outcome is confirmed by research showing that the differences in the degree of technological specialisation have increased for the majority of countries (Archibugi and Pianta, 1992).[3] Table 5 reports the degree of technological specialisation as measured by patents registered in the two main patent offices (the United States and the European

[1] A review of this large literature is provided by Dunning (1992). See also Granstrand *et al.* (1992) and Kogut (1992).

[2] The index of technological specialisation is equal to $I_{ij}=(p_{ij}/\sum_i p_{ij})/(\sum_j p_{ij}/\sum_{ij} p_{ij})$, where p_{ij} is the number of patents of country *i* in the sector *j*. Both Patel and Pavitt (1991A) and Cantwell and Hodson (1991) consider patents registered by all countries at the US patent office subdivided by country of residence of the inventor and home country of the owner firm.

[3] By degree of specialisation is meant how a country concentrates or disperses its innovations across sectors. Chi-square values were calculated for each country on the vector containing the percentage distribution of its patents in the classes considered. The expected values with which the country shares have been compared are the values of the percentage distribution of the world total. The percentages of the vectors were multiplied by 100. The chi-square value of the country *i* is defined as $c=\sum_j (AS_{ij}-ES_j)^2/ES_j$, where AS_{ij}, is the actual share of patents of country *i* in the class *j*, and ES_j is the expected share, i.e. the share of the world total. If the sectoral distribution of a country is identical to the percentage distribution of the total for all countries, the value of the chi square will be equal to 0 (see Archibugi and Pianta, 1992, p. 104).

Table 5. *The degree of technological specialisation. Chi square values of the percent distributions by sectors of patents and patent citations*

	Chi-squares by 41 SIC classes				Chi-squares by 31 IPC classes	
	Patents granted in the US		Patent citations in the US		Patent applications at the European Patent Office	
	1975–1981	1982–1988	1975–1981	1982–1988	1982–1986	1987–1991
United States	0·94	1·31	1·05	2·06	7·92	8·16
Japan	13·46	14·68	12·96	14·96	19·58	20·92
EEC	3·84	4·50	5·76	6·90	3·24	4·74
Germany	8·16	10·05	13·51	15·39	3·55	7·04
France	4·00	3·86	4·01	3·83	11·16	11·05
United Kingdom	5·91	6·85	10·43	17·91	5·97	4·35
Italy	21·85	24·53	25·55	25·21	34·92	32·81
The Netherlands	23·06	20·46	27·52	22·48	22·02	34·93
Belgium	30·72	38·84	56·02	110·56	39·01	49·64
Denmark	24·63	31·88	41·06	62·40	n.c.	n.c.
Spain	46·88	53·52	88·73	101·09	n.c.	n.c.
Ireland	77·99	22·42	84·78	50·58	n.c.	n.c.
Portugal	139·81	212·25	289·36	299·57	n.c.	n.c.
Greece	96·13	89·96	153·46	290·15	n.c.	n.c.
Canada	12·38	14·09	16·56	18·41		
Switzerland	36·16	34·39	38·54	56·12	25·92	32·79
Sweden	24·72	24·74	23·70	23·15	44·24	49·97

Source: Archibugi and Pianta, 1992 and calculations on data from the European Patent Office.
n.c.: not calculated.
SIC: Standard Industrial Classification.
IPC: International Patent Classes:
—the chi-square values are used as measures of the distance between percent distribution of patents (by SIC or IPC classes) of the world and those of each country;
—the EEC data by IPC classes include only the six major countries: Germany, France, Italy, The Netherlands, Belgium, United Kingdom;
—residual classes (i.e. 'Other Industries' and 'Unclassified' for the SIC classification and 'Others' for the IPC classification) have been excluded.

Patent Office). It emerges that the majority of countries have increased their degree of specialisation.

The effects of techno-globalism on national technological specialisation does not seem therefore to be leading to any greater uniformity in patterns of strengths and weaknesses. Nations are becoming *increasingly* different and the international operations of large firms are exploiting and developing this diversity.

Conclusions

This paper has brought empirical evidence to bear on the various hypotheses arising from the growing literature on the globalisation of technological activities. We have suggested that there is both reality and mythology behind the claims. We have introduced an

Table 6. *Three meanings of 'techno-globalism'*

	Actors	Economic equivalent	Measure(s)	Source	Results: Stock	Results: Flow
(a) Global *exploitation* of technology	Profit-seeking organisations. Uni- and multi-national firms	International trade flows (as opposed to foreign direct investment)	Patents extended in foreign markets	Tables 1 and 2	Patents were on average extended in 3–4 foreign markets in 1990	6% average annual growth rate for the OECD countries during the 1980s
(b) Global technological *collaboration*	Business sector	International joint-ventures	Inter-firm technical agreements	Hagedoorn & Schankeraad, 1990, 1993	Not available	6% annual growth comparing the 1985–1989 to the 1980–1984 periods
	Academic and public research communities	Non-profit cultural exchanges	Co-authored scientific papers	Frame & Narin 1988	10% of co-authored papers in 1984	Doubled between 1973 and 1984
(c) Global *generation* of technology	Multinational corporations	Foreign direct investment (as opposed to trade flows)	Patents in the USA of firms from outside their home country	Table 4 and Patel & Pavitt, 1991A and Patel, 1995	3·8% of patents in 1981–1986	1% growth between 1981–1985 and 1986–1990

analytical distinction between three different processes which were previously subsumed in the literature under the single term 'techno-globalisation' (see Table 6).

The strongest case for techno-globalism is the international exploitation of inventions developed within each nation. The majority of inventions are already exploited globally, and this process is continuing at a rapid pace. The willingness of firms to exploit their innovations in external markets does not necessarily imply that they will be successful. This depends on policies implemented by national governments, which can discourage the import of products which incorporate innovations or regulate in other ways the market for disembodied innovations. Significantly enough, one of the main new controversies in the GATT negotiations was the insistence by the USA on a higher degree of international protection for industrial and intellectual property rights.

The second aspect we have considered is that of global technological collaboration. Although it might be expected that firms would be more willing to share their know-how with other firms which do not compete in the same market, empirical results show that the main determinant is the competence of the partner rather than access to markets. This seems to be the reason why collaboration among European firms, in spite of all the policies designed to encourage it, has not taken place to a greater degree. A significant increase in technological co-operation has in fact taken place only in the fast growing technological fields, and the growth in aggregate measures reflects the increasing importance of these technologies. The importance of technical partnership may be related to the slowdown in the growth of industry financed R&D. Joint ventures have become a source of know-how which is complementary to the financing of in-house R&D. They also effect national technological capabilities, since firms try to collaborate with firms based in countries which have endowments lacking in the home country. We have suggested that this tendency is behind the measured increase in the diversity of national technological specialisation.

Third, evidence of the globalisation of production of technology seems much weaker than for the above two concepts. The concept, and therefore the evidence, only relates to multinational corporations and, although these are major actors in technological innovation, they are not the only ones. Nevertheless, we have suggested that the technological activities of foreign firms compared to the total activities of large firms should be of concern for policy makers in all European countries (and, to a lesser degree, in the US).

These hypotheses are consistent with the theory of international technological accumulation, which indicates that countries have their own sectors and fields of competitive advantage. One reason why multinational firms do not globalise their technological facilities more is that they themselves are aware of the role of nations in providing infrastructure, facilities and other tangible and intangible assets for a successful location of their R&D and innovative capacity.

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