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The globalization of technological innovation: definition and evidence

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ABSTRACT

The concept of globalization of innovation is the zip between two fundamental phenomena of modern economies: the increased international integration of economic activities and the raising importance of knowledge in economic processes. The paper singles out three different components of the globalization of innovation: (1) the international exploitation of nationally generated innovations; (2) the global generation of innovations by MNEs; and (3) global techno-scientific collaborations. Empirical evidence on these three categories is here presented, suggesting that the relevance of global forces in innovation is rapidly increasing, although at a different pace for each of the three ongoing processes.

KEYWORDS

Technological change; multinational corporations; strategic technology agreements.

GLOBALIZATION AND INNOVATION

The notion of globalization of innovation, similarly to that of finance, production, culture and information, is now diffuse. Scholars, governments and international organizations have attempted to assess the changes that have occurred in innovative activities due to an ever increasingly globalized society.

Globalization is not a single phenomenon, but a catch-all concept to describe a wide range of forces. It has been defined very differently according to the social science within which it is applied. Paul Streeten (1996) has, half in jest, collected the various definitions in the literature. Here, we have applied a rather wide definition of globalization, which conforms to that provided by Giddens (1990: 64): 'the intensification of world-wide social relations which link distant localities in such a way that local happenings are shaped by events occurring many miles away

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and vice versa'. Thus, by 'globalization' we mainly refer to a high (and increasing) degree of interdependency and interrelatedness among different and geographically dispersed actors. In principle, therefore, there might be a higher globalization even with the same level of internationalization (Archibugi and Iammarino, 1998; Cantwell and Iammarino, 1998).

The term is used to describe the phenomenon of 'globalization' experienced by the world of invention and innovation. Strictly speaking, the economic application of new ideas and knowledge is not only 'technical', insofar as it can also be organizational, managerial, institutional. The new 'general purpose' technologies such as ICTs, biotechnology, new materials, etc., have been shown to intensify the science–technology interface and to be inextricably associated with the complex processes of organizational, institutional and infrastructural change (Freeman, 1994). In its most modest use – which is also the easiest to be recorded and thus quantified – the expression 'globalization of innovation' is short hand for the increasing international scope of the generation and diffusion of technologies. That technology, in the sense of knowledge directed towards the solution of specific human problems, is transmitted from one culture to another or from one society to another, is certainly not a novelty. Even though learning processes are long and cumbersome, technological knowledge transmission among peoples has met less resistance than occurred in the cases of cultural, religious, social or political habits. Technology has always constituted a fertile meeting place for different societies. If the assimilation and transfer of technology required lengthy time spans in the past, today it takes place with a much higher intensity and speed.

New technologies play a fundamental part in making globalization possible. Without aeroplanes, telephones, satellites, computers and televisions it would not be possible to transfer information from one place to another, thus allowing for the speed and the intensity which characterize the modern world. These give rise to a rate of diffusion and transfer of knowledge which is greatly superior to that of the past. In other words, it was the new technologies that allowed the emergence of the 'global village'.

The coming of a society based on knowledge has proceeded hand in hand with the enlargement of markets and the intensification of exchange. International trade and direct investments abroad have substantially increased, thus rendering the national economic systems increasingly integrated with each other. The pace of globalization and that of technological change have in fact been strictly interrelated and, from a long-term perspective, it appears less important to establish which one should be considered responsible for triggering the other rather than to establish that they mutually enforced each other. However, to what extent is the generation, transfer and diffusion of innovations transformed by the globalization which they themselves facilitate? The presumption here is that for many years there has been a circular process in which new technologies act as a 'lubricant' for economic and social globalization. In turn, globalization, while facilitating the circulation of people, goods, capital and above all, ideas and knowledge, allows for the sustenance of a historically unprecedented rate of technological change. The concept of globalization of innovation thus comes to be the zip between the two fundamental phenomena of modern economies: the increased international integration of economic activities and the raising importance of knowledge in economic processes.

In this paper we present some indicators on the empirical relevance of the globalization of innovation among the most developed countries. Ultimately, the question we ask is: does the globalization of innovative activities exist and to what extent? We thought it appropriate to refer to a previously outlined taxonomy of the globalization of innovation (Archibugi and Michie, 1995) since we are convinced that this taxonomy is a useful filter through which to interpret the phenomenon considered here.

A TAXONOMY OF THE GLOBALIZATION OF INNOVATION

Three main categories of the globalization of innovation were identified (Archibugi and Michie, 1995; 1997a): (1) the international exploitation of technology produced on a national basis; (2) the global generation of innovations; and (3) global technological collaborations. The three categories are complementary and not mutually exclusive, both at firm and country level. Firms, especially large ones, generate innovations in all different ways described here. From a historical point of view, these categories emerged in three successive stages, even though the second and the third added to, rather than substituted for the oldest one. The categories of this taxonomy are contained in Figure 1.

The international exploitation of technology produced on a national basis

The first category includes innovators' attempts to obtain economic advantages through the exploitation of their own technological competence in markets other than the domestic one. We have preferred to label this category as 'international' rather than 'global' as the actors introducing the innovations preserve in the main their national identity, even when the innovations are diffused and sold in multiple countries or the necessary knowledge has been sourced elsewhere. Clearly, the distinction

Categories	*Actors*	*Forms*
International exploitation of nationally produced innovations	Profit-seeking firms and individuals	Exports of innovative goods Cession of licenses and patents Foreign production of innovative goods internally designed and developed
Global generation of innovations	Multinational firms	R&D and innovative activities both in the home and the host countries Acquisitions of existing R&D laboratories or green-field R&D investment in host countries
Global techno-scientific collaborations	Universities and public research centres	Joint scientific projects Scientific exchanges, sabbatical years International flows of students
	National and multinational firms	Joint-ventures for specific innovative projects Productive agreements with exchange of technical information and/or equipment

Figure 1 A taxonomy of the globalization of innovation

Source: Elaboration on Archibugi and Michie (1995) between 'international' and 'global' becomes rather blurred when taking into account the huge intra-firm share of international trade and the increasing relevance of Global Production Networks. However, this confirms once more the differentiation between 'internationalized' activities (carried out in more than one country) and 'globalized' processes (interdependent and integrated across space).

Firms have incentives to expand their market range but their products might be unwelcome in host countries. Innovative products are often admitted into importing countries in the temporary absence of satisfactory internal surrogates when they represent radical advances; for example, at the beginning of the 1960s, many countries did their best to import the first computers. Such innovative products do not compete with those of local firms in the short run. A non-hostile receipt of innovative products is all the more likely the more similar the income level and the closer the commercial integration between the innovating country and the importing country. Both the exporting economy and the importing one have an interest in the exchange of products (starting from those with a higher innovative content), if such an exchange occurs within a framework of comparative advantages and for products with similar technological intensity. However, as soon as the firms of two countries are able to produce similar products, competition tends to be far fiercer than that typically encountered for traditional products, as innovative goods are deemed to be of strategic importance (cf. Pianta, 1988; Tyson, 1992; Scherer, 1992). Competitive struggles today involve semiconductors and aeroplanes much more than corn, wine and potatoes. Besides, it is easily predictable that international rivalry will involve more and more technology-intensive fields.

International trade is not the only way through which an innovative firm can benefit from its technological competence: it is possible that the innovator finds it more advantageous to sell the innovation disembodied, i.e. to licence it to foreign firms. This strategy is all the more convenient when there are various types of obstacles to international trade as for example in the case of: (1) high transportation costs; (2) barriers to imports; (3) high wage differentials between the innovating country and the importing country, which would render the cost of the new product too high for the income level of the imitating country. However, it is not always possible to licence technology to third countries. In order for a market for disembodied technology to exist, such a technology should be of a codified nature and the acquiring country should have an adequate capacity to absorb it (Bell and Pavill, 1997). To be effective, the transfer of technology, especially from North to South, needs more stringent co-operation forms such as those described in the third category of the taxonomy (technological collaborations).

Another significant way of exploiting innovations in foreign markets is through foreign direct investment (FDI). The conditions allowing international production are known: availability of capital, a willingness to geographically exploit ownership, technological and organizational advantages are required on behalf of the investing firm (Dunning, 1993). Economic and institutional stability and a sufficient level of economic development, or, in other words, location advantages, are required on behalf of the host country. It should be remembered that this first category only includes the productive activity operated in host countries which does not entail the creation of additional local technological capacity; if this were to be the case, we would be moving from the first to the second category of this taxonomy.

The global generation of innovations

The second category is the global generation of innovations, which includes innovations conceived on a global scale from the moment they are generated. Only innovations created by multinational enterprises (MNEs) are contained in this category. With very few exceptions (such as Shell and Unilever), it is easy to identify the country of origin of such companies, so much that to some they appear as national enterprises with multinational operations (Hu, 1992).

MNEs have often their own internal innovative network with units based in different countries. An efficient management of these geographically dispersed R&D and technical centres would imply that these centres do not simply provide inputs to the local production units, but that they are integrated into the overall innovative strategy of the MNEs. A substantial body of theoretical and empirical research has investigated how companies organize their internal innovative centres (Howells, 1997; Pearce and Singh, 1992; Florida, 1997; Grandstrand *et al.*, 1992; Zander, 1999). Bartlett and Ghoshal (1990) have singled out three main strategies which can be implemented by MNEs, whose significance varies across countries, industries and companies:

Centre-for-global

This is the traditional 'octopus' view of the multinational corporation: a single 'brain' located within the company headquarters concentrates the strategic resources (top management, planning and technological expertise) and distributes impulses to the 'tentacles' (that is, the subsidiaries) scattered across host countries. Even when some R&D is undertaken abroad, this is basically concerned with adapting products to the needs of the local users.

Local-for-local
Each subsidiary of the firm develops its own technological know-how to serve local needs. The interactions among subsidiaries are, at least from the viewpoint of developing technological innovations, rather weak. One the contrary, subsidiaries are integrated into the local fabric. This may occur with conglomerate firms, but also in the case of MNEs which follow a strategy of technological diversification through tapping into the competence of indigenous firms.

Local-for-global
This is the case of multinational corporations which, rather than concentrating their technological activities in the home country, distribute R&D and technological expertise in a variety of host locations. This allows the company to develop each part of the innovative process in the most suitable environment: semiconductors in Silicon Valley, automobile components in Turin, software in India. The effectiveness of such a strategy relies on the intensity of intra-firm information flows.

In general, it has been increasingly observed the emergence of the trend for MNEs to establish internal (intra-firm) and external (inter-firm) networks for the generation of technological innovation. Indeed, it has been the development of such cross-border corporate integration and intra-border inter-firm relationships – as new forms of technological governance – to make consider the MNE as the key-ring between the 'local' and the 'global' (Cantwell and Iammarino, 2001).

The global technological collaborations

In recent times, a third type of globalization of innovative activities has made a forceful entry on the scene. This, in some ways, is intermediate to the two preceding categories. Technological collaborations occur when two (or more) different firms decide to establish a joint venture with the aim of developing technical knowledge and/or products. Three conditions need to be respected: (1) the joint venture should be something more than an occasional and informal collaboration; (2) firms preserve their ownership; and (3) the bulk of the collaboration is related to sharing know-how and/or the generation of new products and processes (Mowery, 1992). We have witnessed an increasing number of agreements between firms for the communal development of specific technological discoveries (Hagedoorn and Schakenraad, 1993). Such collaborations often take place among firms of the same country, but in many cases they involve firms located in two or more countries, thus emerging as authentically global. These forms of collaboration for technological advances have promoted a variety of mechanisms for the division of costs and the exploitation of results. In a way, the necessity to reduce the costs of innovation – and to cope with its increasing complexity – has created new industrial organization forms and new ownership structures, which today are expanding beyond the simple technological sphere (Dodgson, 1993).

However, it was not the private sector that discovered this form of knowledge transmission. The academic world has always had a transnational radius of action: knowledge is traditionally transmitted from one scholar to another and thus disseminated without always requiring pecuniary compensation.

EMPIRICAL RELEVANCE OF THE THREE DIMENSIONS OF THE GLOBALIZATION OF INNOVATION

How important are the three aspects of the globalization of innovation identified above? And, more importantly, what are the tendencies currently predominating? In order to answer these questions it is necessary to find appropriate measuring devices. None of the available indicators entirely represents the three aforementioned categories. Some indicators do not represent them totally (in the sense that they exclude significant parts of the phenomenon), others do not represent them exclusively (in the sense that they include phenomena that are not part of the object treated). There are further indicators that represent the phenomenon neither totally nor exclusively. In spite of these limitations, this section reviews the available empirical evidence.

The evidence on the international exploitation of technology

The first indicator of international exploitation of technology is represented by international trade flows. Although this is a heterogeneous indicator, which includes both innovative and non-innovative products, it is clear that trade is a fundamental means for the international diffusion of innovations, especially embodied innovations. During the post-war period, trade has been growing constantly: the export ratio of goods and services to GDP in advanced countries went from 9.4 percent in 1970 to 20.9 percent in 1995 (OECD, 1996a). While all categories of commodities embody knowledge, this is greater in sectors with the highest technological content. Indeed, as shown by Guerrieri and Milana (1995), the sectors in which trade has grown most rapidly are those with the highest technological content. Among these, the electronics industry is outstanding, as its growth rate has been double with respect to that of total manufacturing. As a whole, high tech products, which constituted 9.5 percent of world trade in 1970, represented more than 29 percent in 1995 (Guerrieri, 1999). The technology–trade causal relationship is often a two-way one (Pietrobelli and Samper, 1997). On the one hand, technological competence has a positive impact on exports and competitiveness; on the other, international trade boosts the generation and the transfer of innovations, thus giving rise to cumulative causation mechanisms. Figures 2 and 3 show that the correlation between the R&D intensity (measured by the ratio R&D/value added) and the degree of internationalization (measured by the ratio exports/value added) for the six most industrialized countries was remarkably higher in 1996 than in 1975, confirming that the link between technological intensity and internationalization has been considerably strengthened over time.

Science-based sectors – such as Aircraft (ISIC 3845), Professional Goods (ISIC 385) and especially Office and Computing Machinery (ISIC 3825) – show a remarkable increase in the degree of internalization, endorsing also the fact that the technology–trade relationship holds particularly for technology-intensive areas of production (see also Daniels, 1997). The notable exception is Drugs and Medicines (ISIC 3522). In this sector, a stronger technological intensity does not correspond to an increase in internationalization: the position of the sector with respect to the X-axis remained basically unchanged over the two decades. This is likely to be due to the fact that the international exploitation of technological capabilities in this sector takes place mainly through foreign direct investment.

The number of patents registered abroad can be considered an indicator of the will to exploit in foreign markets innovations both embodied in products (a product is patented in order to prevent others from producing a similar good and thus to cover all the existing market) and disembodied (an innovation is patented in order to licence it). Table 1 reports the annual rates of growth of selected technological indicators for the main OECD countries in two different periods. It shows that industrial R&D and resident patents (i.e. the patent applications of the inventors in their home country) have grown at a moderate pace, and sometimes have even experienced a negative rate of change. On the contrary, non-resident patents (i.e. the patent applications of foreign inventors in the country, which show to what extent a country has been 'invaded' by foreigners) and external patents (i.e. national inventors patenting abroad, which show to what extent a country is 'invading' other countries) have registered remarkable rates of growth, particularly during the most recent decade (1987–97).

Table 2 reports further elaboration on the same data. The first two columns show the average number of external patents for each resident patent in 1987 and 1997. Each patent application can in fact be extended in several countries. While a patent application was extended, on average, in 1.3 countries in 1987, it was extended in as many as 6.2 countries in 1997 (OECD, 2000a). This is not necessarily due to the increase of resources devoted to science and technology. As shown in columns 5

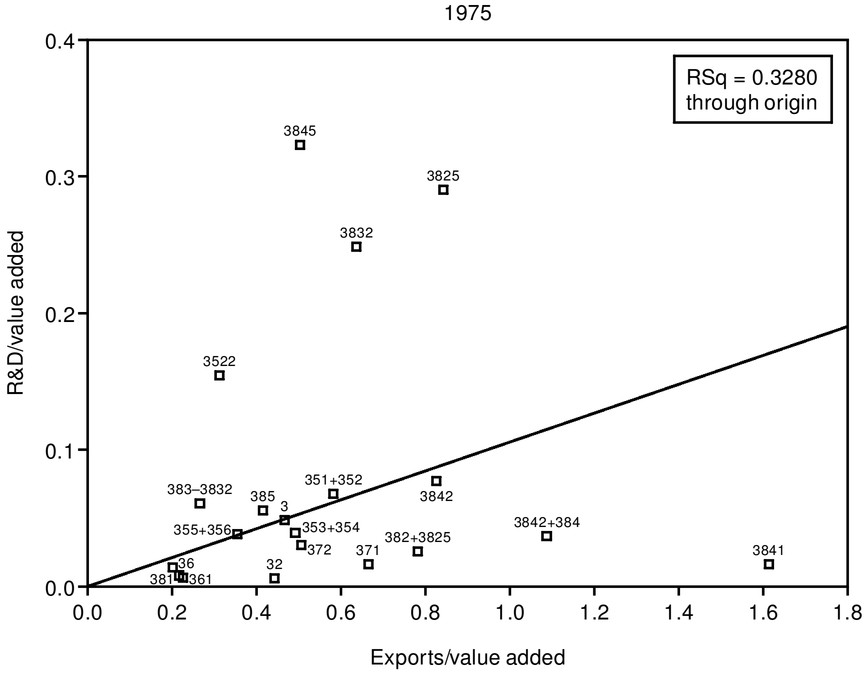

Figure 2 R&D intensity and internationalization.

Note: All variables calculated at constant US$ and PPP.
Source: OECD STAN Database, 1999; OECD R&D Expenditure in Industry; OECD Basic Science and Technology Statistics, 2000.
Key:

Sectors

3000 Total manufacturing
31 Food, beverages & tobacco
32 Textiles, apparel & leather
352+351–3522 Industrial chemicals + (other chemicals – drugs & medicines)
3522 Drugs & medicines
353+354 Petroleum refineries + petroleum & coal products
355+356 Rubber products + plastic products
36 Non-metallic mineral products
371 Iron & steel
372 Non-ferrous metals
381 Metal products
382–3825 Non-electrical machinery – office & computing machinery
3825 Office & computing machinery
383–3832 Electrical machinery – radio, TV & communication equipment
3832 Radio, TV & communication equipment
3841 Shipbuilding & repairing
3843 Motor vehicles
3845 Aircraft
3842+3844+3849 Railroad equipment + motorcycles & bicycles + transport equipment nec
385 Professional goods

Countries

France, Germany, Italy, Japan, UK, US

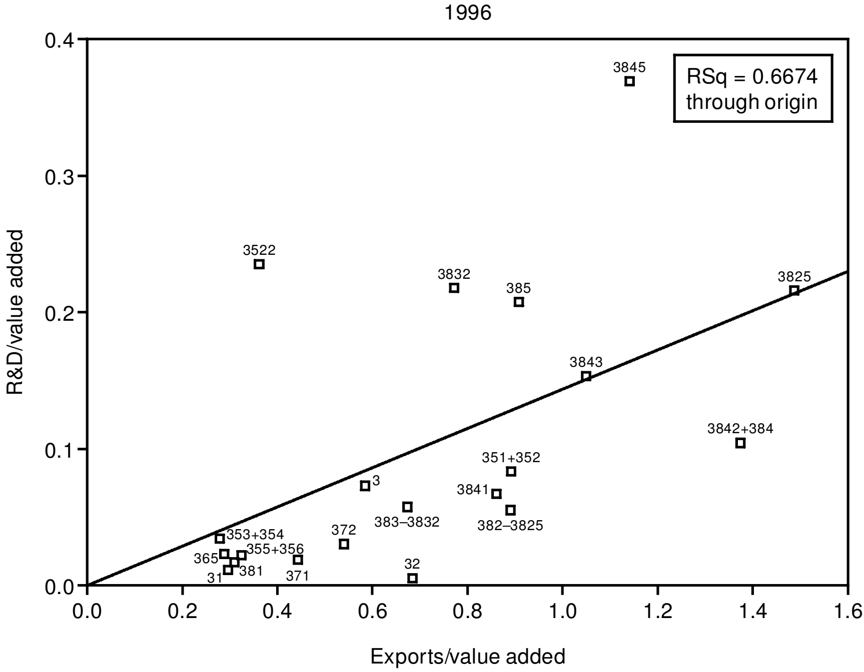

Figure 3 R&D intensity and internationalization

Note: All variables calculated at constant US$ and PPP.
Source: OECD STAN Database, 1999; OFCD R&D Expenditure in Industry; OECD Basic Science and Technology Statistics, 2000.
Key:
Sectors

3000 Total manufacturing
31 Food, beverages & tobacco
32 Textiles, apparel & leather
352+351–3522 Industrial chemicals + (other chemicals – drugs & medicines)
3522 Drugs & medicines
353+354 Petroleum refineries + petroleum & coal products
355+356 Rubber products + plastic products
36 Non-metallic mineral products
371 Iron & steel
372 Non-ferrous metals
381 Metal products
382–3825 Non-electrical machinery – office & computing machinery
3825 Office & computing machinery
383–3832 Electrical machinery – radio, TV & communication equipment
3832 Radio, TV & communication equipment
3841 Shipbuilding & repairing
3843 Motor vehicles
3845 Aircraft
3842+3844+3849 Railroad equipment + motorcycles & bicycles + transport equipment nec
385 Professional goods

Countries
France, Germany, Italy, Japan, UK, US

Table 1 Rates of growth of industrial R&D and patenting in the OECD countries.

	Annual average growth rates (percent)							
Countries	*Industrial R&D (1)*		*Resident patents (2)*		*Non-resident patents (3)*		*External patents (4)*	
	1970–80	*1987–97*	*1970–80*	*1987–97*	*1970–80*	*1987–97*	*1970–80*	*1987–97*
US	2.0	2.4	–2.0	5.2	5.0	5.0	–0.6	22.1
Japan	6.1	3.8	5.1	1.1	–0.8	6.6	5.5	14.1
Austria	9.8[a]	4.6[e]	0.3	–1.9	3.4	11.6	1.4	13.6
Belgium	6.7[c]	2.9	–3.0	1.5	–0.1	10.5	0.5	17.0
Denmark	3.8	5.8	1.7	2.6	–0.3	24.2	1.0	24.4
Finland	6.8[c]	6.8	4.7	2.3	0.7	25.9	5.7	27.3
France	3.7	2.0	–2.4	0.4	0.2	6.3	3.0	13.6
Germany	4.9[a]	0.4	–0.7	3.1	0.8	6.1	1.7	13.0
Greece	n.a.	6.1[f]	–0.8	–12.4[j]	2.4	19.8	n.a.	24.2
Ireland	5.2[c]	13.7	6.8	1.1	4.9	35.8	6.7	22.9
Italy	3.6	–0.7	n.a.	–1.7[k]	n.a.	8.2[m]	1.8	12.8
Netherlands	1.4	1.2	–2.1	0.7	1.5	9.1	0.1	18.5
Portugal	4.6[d]	6.2[f]	–6.4	1.5	–0.5	38.7	–24.2	17.6
Spain	12.7	4.1	–4.5	2.4	0.2	13.5	1.3	23.1
Sweden	5.9[c]	4.5	–0.5	1.5	2.5	9.9	3.0	21.9
UK	3.0[b]	–0.1	–2.4	–1.0	0.8	6.0	–1.7	18.6
Norway	7.3	1.7	–2.7	2.9	–0.1	13.2	0.8	34.8
Switzerland	0.8[a]	–0.1[g]	–3.1	–3.4	2.2	10.2	–1.3	13.4
Australia	n.a.	7.4	5.2	1.4	–2.0	9.8	6.7	18.6
Canada	5.5	4.1	–1.1	2.7	–2.1	6.0	–0.5	25.2

Notes:
n.a. = not available [a]1970–81 [b]1972–81 [c]1971–81 [d]1971–80 [e]1985–93 [f]1986–97 [g]1986–96 [j]1987–96 [k]1992–96 [m]1992–97
(1) Million US$ at 1995 PPP
(2) Resident patents: inventors in their home country
(3) Non-resident patents: foreign inventors in the country
(4) External patents: national inventors patenting abroad
Source: Calculations on OECD, MSTI (2000).

Table 2 Relation between industrial R&D, resident, non-resident and external patents. OECD countries, 1987, 1997.

Countries	*External patents (4) ÷ Resident patents (2)*		*Non-resident patents (3) ÷ Resident patents (2)*		*Resident patents (2) ÷ Industrial R&D (1)*		*External Patents (4) ÷ Industrial R&D (1)**	
	1987	*1997*	*1987*	*1997*	*1987*	*1997*	*1987*	*1997*
US	2.7	14.8	0.95	0.93	0.6	0.8	1.5	11.2
Japan	0.3	1.1	0.11	0.19	7.4	5.5	2.2	6.3
Austria	2.8	13.9	10.95	45.07	2.5[b]	1.4[d]	7.0[b]	n.a.
Belgium	5.8	35.3	36.92	93.26	0.3	0.3	2.6	11.0
Denmark	5.8	46.4	7.62	61.98	1.2	0.9	7.4	44.4
Finland	3.1	34.5	3.49	34.12	2.0	1.3	6.3	45.3
France	3.7	14.0	3.74	6.99	1.0	0.8	3.5	10.7
Germany	3.5	10.1	1.46	1.99	1.2	1.6	4.5	16.5
Greece	0.2	5.4	7.32	127.73[a]	17.0[c]	2.2	2.2	13.2
Ireland	1.3	11.9	3.96	102.08	3.7	1.0	5.5	13.4
Italy	n.a.	12.1	n.a.	10.14[a]	n.a.	1.1[e]	3.6	13.7
Netherlands	7.7	43.5	14.02	34.01	0.7	0.6	5.2	29.9
Portugal	1.6	8.5	37.02	1148.22	0.6[c]	0.4	1.2	4.5[g]
Spain	1.4	9.7	12.43	38.31	1.1	0.9	1.5	9.1
Sweden	4.9	38.6	8.31	20.12	1.2	0.8	6.3[b]	35.6[g]
UK	2.4	17.6	2.62	5.52	1.4	1.3	3.5	22.8
Norway	2.7	50.0	8.37	23.93	1.0	1.1	2.9[b]	66.4[g]
Switzerland	7.1	37.9	7.54	31.87	1.1[c]	0.7[f]	7.3	29.3
Australia	2.0	9.2	2.07	4.97	4.7	2.5	8.7	23.9
Canada	3.6	35.4	10.53	14.81	0.6	0.5	1.8	14.3

Notes:
n.a. = not available [a]1996 [b]1985 for R&D [c]1986 for R&D [d]1993 for R&D
[e]1993 for patents [f]1996 for R&D [g]1995 for R&D
(1) Million US$ at 1995 PPP
(2) Resident Patents: inventors in their home country
(3) Non Resident Patents: foreign inventors in the country
(4) External Patents: national inventors patenting abroad
* External Patent Applications in year t divided by industrial R&D in year t-1
Source: Calculations on OECD, MSTI (2000).

and 6, the ratio of resident patents per unit of industrial R&D declined from 1987 to 1997 in almost all countries (with the notable exceptions of the US, Germany and Norway, where the increase was anyway negligible). On the contrary, the ratio of external patents per unit of industrial R&D grew dramatically in the same period (see columns 7 and 8 of Table 2). Columns 3 and 4 report the ratio between non-resident and resident patents. A ratio equal to 1 shows that the number of patented inventions generated in the country is equal to the number of foreign inventions for which patent protection is sought in the country. In small countries foreign patents strongly outnumber the domestic ones; only Japan and the US have a number of domestic patents which is greater than the foreign one. With the exception of the latter country, all economies increased their dependency from abroad in the period 1987–97.

US inventors and firms have considerably increased their penetration in external markets, as shown by the doubling of the ratio of external to resident patents. The same ratio is particularly high for technologically dynamic small and medium sized countries, such as the Netherlands, Denmark, Belgium, Switzerland and all the Scandinavian economies. The case of Japan is not particularly significant: the country has a large number of domestic inventions, since its patent system is not comparable to that of other countries. The Technology Balance of Payments (TBP) – which reports data on financial flows connected to the use of patents, licences, trademarks, inventions, etc. – is another indicator of the increased internationalization of innovative activities, especially of disembodied technical know-how. The financial transactions measured by the TBP include those occurring both between different firms and between different subsidiaries of the same multinational corporation. International exchanges of technological know-how and services have increased with respect to the internal business R&D expenditure (cf. OECD, 1999a). With the notable exception of Japan and France, both payments and receipts for technology recorded substantial annual rates of growth in the period 1987–97 – 10.8 percent and 13.8 percent respectively on average for the G6 (OECD, 2000a). This suggests a growing interdependence between the national-based innovative activities and the transfer/acquisition of technology to and from abroad.

What are the reasons underlying the substantial increase of the need for innovative firms to extend the geographical dimension of their market? This seems to be directly linked to the increasing costs of innovation on the one hand, and to the reduction in the life cycle of products on the other. Given that innovations are becoming increasingly costly and rapidly obsolete, innovators must be in the position to commercialize them in increasingly large markets.

From a geographical point of view, as we have seen, the countries which are most involved in this form of globalization are the smallest and the most technologically dynamic – in other words, those showing a higher degree of international integration. The limited dimension of their domestic market, in fact, has always induced firms to search abroad for a market for their products, in particular for products requiring higher investment. Small and medium sized countries have greater difficulties in promoting innovative programmes on a large scale, unless they have access (guaranteed, whereas possible, by intergovernmental agreements or by the existence of customs unions) to foreign markets (Molero, 1995).

The evidence on the global generation of innovations

This category only includes multinational enterprises and, depending on the strategy they follow, their efforts to generate innovations combining the expertise of their affiliates in more than one foreign location. A first indicator of this category is represented by the distribution of MNEs' R&D between the home and the host country: the data for selected countries are reported in Table 3.

Columns 1 and 2 report the distribution of R&D in manufacturing performed within each country by type of ownership of the firm (foreign or national). This shows to what extent countries have been 'attractive' for R&D-related foreign direct investment. The data show that the R&D performed by foreign subsidiaries accounts for more than 20 percent of total R&D in manufacturing in Canada, the Netherlands and the UK. The role of foreign firms is equally significant in the majority of advanced economies. The only country with a very low share of R&D performed by foreign firms is Japan; in this country as much as 99 percent of R&D in manufacturing is financed by Japanese-owned companies.

Table 3 Distribution and intensity of R&D in manufacturing industries by National Firms and Foreign Affiliates. Main OECD countries, 1996 and 1994.

	% of National total 1996		*R&D intensities* 1994*	
Countries	*Foreign affiliates*	*National firms*	*Foreign affiliates*	*National firms*
US	12.0	88.0	2.5	2.5
Japan	0.9	99.1	1.2	2.5
Germany	16.4(1)	83.6(1)	3.2	6.3
France	18.6	81.4	1.8(2)	2.7(2)
UK	39.5	60.5	1.5	1.9
Netherlands	24.0	76.0	0.8(3)	2.7(3)
Sweden	18.7	81.3	2.4	3.8
Finland	11.5(4)	88.5(4)	2.6	2.5
Canada	40.3	59.7	0.9	1.7

Notes:
(1) 1995
(2) 1991
(3) 1993
(4) 1997
* Ratio between R&D expenditure and turnover
Source: OECD, 1999b.

To a large extent, there is a link between R&D and the production of MNEs' foreign affiliates, although this is far from being uniform across countries. Columns 3 and 4 of Table 3 report the R&D intensities (i.e. the ratio of R&D expenditure to turnover) of foreign affiliates and national firms. While in the US national and foreign affiliated have the same propensity to invest in R&D, in all other countries, with the exception of Finland, the propensity of foreign affiliates to finance R&D is much lower than for national firms. National governments are particularly interested to acquire such information, since this allows them to know if inward foreign direct investment contributes on a par with domestic capital to the creation of the national technological competence (for the policy implications of the globalisation of innovation see Archibugi and Iammarino, 1999). Overall, the data confirm the widespread belief that, in the 1990s, MNEs were still more prone to locate their R&D facilities in the home country, rather than in foreign locations.

So far, we have looked at the inward flows of investment in R&D. A specular perspective is represented by the outward flows of R&D investment. Unfortunately, these data are not available for all countries. However, the US government, since the 1960s, has collected data on the R&D performed abroad by its MNEs, because of the general concern that skill-intensive jobs could be displaced abroad. These data show that, on average, over the 1990s slightly more than 10 percent of the R&D of US firms is executed abroad and that the share has slightly increased over time (NSF, 2000; Dalton and Serapio, 1995).

Outward flows of investment related to the generation of innovation can also be identified by looking at the patents owned by multinational corporations but generated in host countries. This allows us to take into account a larger number of countries. Each patent record provides information on the address of the inventor and the name of the owner (which in most cases is a corporate group), thus allowing the identification of the geographical location of both of them. On the basis of a significant sample of large innovative firms during the period 1992–96, Patel and Vega (1997) showed that 87.4 percent of their patented inventions was generated in the firm's country of origin and only 12.6 percent in subsidiaries located abroad (see Table 4). Although there is an increase between 1979–84 and 1992–96 (see also Patel, 1995), this is not sufficient to state a radical intensification of the phenomenon.

However, as already shown by R&D data, there are significant cross-country differences. Large Japanese firms generate 97.4 percent of their patented inventions in their country, whereas American firms concentrate in the US a relatively smaller share (92 percent). European firms show a greater tendency towards decentralization: considering Europe as a 'single market', the share of patents generated outside the continent

Table 4 Geographic location of the US patenting activity of large firms according to their country of origin, 1992–96 (percentage shares).

			Of which, hosted in		
Nationality	*Home*	*Abroad*	*US*	*Japan*	*Europe*
US	92.0	8.0	–	1.1	5.3
Japan	97.4	2.6	1.9	–	0.6
Europe	77.3	22.7	21.1	0.6	–
Germany, F.R.	78.2	21.8	14.1	0.7	6.5
France	65.4	34.6	18.9	0.4	14.2
UK	47.6	52.4	38.1	0.5	12.0
Italy	77.9	22.1	12.0	0.0	9.5
Netherlands	40.1	59.9	30.9	0.9	27.4
Belgium	33.2	66.8	14.0	0.0	52.6
Sweden	64.0	36.0	19.4	0.2	14.2
Austria	90.6	9.4	2.2	0.0	7.2
Finland	71.2	28.8	5.2	0.0	23.5
Switzerland	42.0	58.0	31.2	0.9	25.0
Norway	63.0	37.0	1.5	0.0	33.3
All Companies	87.4	12.6	5.5	0.6	5.5

Source: Patel and Vega (1997)

is equal to 22.7 percent. Looking at individual countries, the propensity of firms to generate innovations abroad is even greater: large firms based in Belgium, the Netherlands, Switzerland and the UK have more than a half of their patents in their subsidiaries abroad. German, Italian, French, Swedish and Norwegian multinationals, on the contrary, have a larger share of their innovations produced at home. Using the same data, Cantwell (1995) and Cantwell and Kosmopoulou (2000) also considered long-term trends. They showed that the innovative activities carried out in the subsidiaries located abroad of a sample of North American and European firms more than quadrupled, going from 4 percent in the period 1920–24 to 16.5 percent in the period 1991–95. The analyses of Cantwell and Patel and Vega also allow the identification of the countries in which such firms tend to decentralize their innovative activities. At an aggregate level, more than 90 percent of such activities is hosted by the US, Western Europe and Japan, confirming that the globalization of innovation by multinational firms has rather to be seen as a process of 'triadisation'. Not even the East Asian dynamic economies have managed to absorb a substantial share of multinationals' R&D.

As far as the sectoral dimension if concerned, firms operating in industries with higher technological opportunities (Computers, Scientific

Instruments, Aeronautics, Motor Vehicles) show a strong propensity to concentrate their technological activities in their country of origin. The firms with the greatest innovative activity in host countries are those belonging to traditional sectors: drink and tobacco, food, building materials, other transport, mining and petroleum industries (cf. Patel, 1995, tab. 6: 150; Pavitt and Patel, 1998). In the case of natural resources, this tendency can be explained by the necessity to situate technological activities locally. But also many industries producing consumer goods need technological competence in the country of production, in order to satisfy both consumer tastes and national legislative standards. An intermediate case is represented by pharmaceutical and chemical firms, in which the propensity towards the global generation of innovations is above the average. This might be related to institutional factors rather than strictly technological ones: it is convenient for firms which are constrained by governmental regulations, such as the pharmaceutical producers, to perform their R&D activities locally, so that their products can conform to national standards and satisfy the needs of special 'clients' such as the governments (Håkanson, 1992).

The empirical evidence considered up to this point has concentrated on two indicators, R&D and patents, which capture the most important and codified technological activities. However, a question emerges as to whether the globalization of multinational enterprises is greater for technological activities which are less formal but equally important for the firms' competitive strategy. Multinational corporations, in fact, transfer knowledge to subsidiaries at more than one level. These activities include technical assistance, the often informal exchange of techno–scientific information, the transmission of organizational and managerial methods, etc. They are connected to production, and it is thus reasonable to assume that they should be directly related to direct investment abroad both in production and innovation.

It is worth noting, moreover, that the reported indicators capture only a small part of innovations in a sector which is becoming both increasingly important in technological change and globalized: software. As it is transferred at very low cost, some firms have a tendency to subcontract it to centres in countries with much lower labour costs than their own (Antonelli, 1991) and to satisfy their own software needs by tight interactions between headquarters, subsidiaries and specialized suppliers. However, there is still no empirical research quantifying the importance of such a phenomenon.

We may conclude that each member of the triad is differently affected by this form of globalization of innovation. Japan does not participate substantially to the global generation of innovation: on the one hand, foreign firms are still reluctant to locate R&D facilities in Japan, on the other hand, Japanese firms are reluctant to decentralize R&D facilities abroad. Both inward and outward R&D and knowledge-related foreign direct investment largely contaminate the US. The most dynamic situation is to be found in the European countries, where a substantial part of national technological competencies is performed by foreign-owned affiliates and where national firms are more and more locating their R&D facilities both in other European countries and in North America. The most significant data, however, are probably the sectoral ones. They show that, contrary to what occurs in the first category, traditional industries are still more globalized than high-tech ones.

The empirical evidence on the global technological collaborations

The available information on global technological collaborations is more fragmented. This is partly attributable to the nature of the phenomenon, which is less easily quantifiable than the other two categories. First, every collaboration has a different economic and technological significance, and it is difficult to merge them into a homogeneous unit of measurement. Second, the nature of the collaborations, precisely because of their intermediate form, is not easily identifiable. A precious source of information is the Merit database on strategic technological alliances (cf. Hagedoorn and Schakenraad, 1990, 1993; Hagedoorn, 1996). This shows that the new strategic alliances for technological purposes have substantially increased since 1970 to this day and they are particularly relevant in crucial technological areas such as biotechnology, new materials and, especially, information technologies. Although it is not possible to estimate the total expenditure on innovation associated with these collaborations, they turn out to be a relatively new phenomenon, which is particularly significant for those industries in which technological change has been more intense and where the risks connected to innovation are higher. Agreements crossing national boundaries constitute by now almost 60 percent of the registered ones. Among these, around 40 percent involves the North America–Europe–Japan triad, whereas those involving countries outside the triad (mainly Southeast Asian countries) have exceeded 20 percent during the 1990s. In spite of this, as emerges from an in depth reading of a review of the literature promoted by UNCTAD (Pietrobelli, 1996), firms in developing countries are only marginally involved in such collaborations.

As far as the total international strategic agreements are concerned, there has been a considerable increase in the second half of the 1980s, which was apparently stabilized during the 1990s (see Table 5). The fastest growth has been registered by the collaborations between Europe and the US, especially in the biotechnology sector. The number of collaborations established by Japanese firms still remains rather limited, even though it is increasing especially in the information technologies sector.

Table 5 Number of international strategic technology alliances by technological field, 1980–98.

	1980–84	*1985–89*	*1990–94*	*1995–98*
Total	1286	2540	2477	2655
Information technology	469	927	1132	1135
Biotechnology	230	499	490	633
All other	587	1114	855	887
Across regions	709	1306	1191	1193
Information technology	258	438	490	463
Biotechnology	99	216	261	322
All other	352	652	440	408
Within regions	577	1234	1286	1462
Information technology	211	489	642	672
Biotechnology	131	283	229	311
All other	235	462	415	479

Source: National Science Foundation (2000), from J. Hagedoorn, MERIT, Co-operative Agreements and Technology Indicators data-base.

The increase registered by the intra-European agreements is instead attributable mainly to the biotechnology sector; the latter has recorded the most significant growth in the number of international alliances both across and within geographical macro-regions.

Strategic agreements among firms do not cover entirely the phenomenon of global collaborations. As stated above, the academic world established these collaborations well before the business world. The academic world has also an influence over industry and its globalization acts as a vehicle for the transfer of knowledge.

Among the forms contributing to the dissemination of knowledge we can refer to the increasing number of students attending specialization courses in foreign countries. They represent an uninterrupted channel for the transfer of scientific and technical knowledge, both for developed and for developing countries. In the most advanced countries the number of foreign students enrolled in higher education (university level) had a surprising growth rate over the 1980s and the first part of the 1990s. Apart from the strong inflows registered especially in the small Scandinavian economies, the highest growth rates have occurred in the Asian–Pacific area, where the number of foreign students registered in higher education increased at an average annual rate of around 15 percent in Japan and 12 percent in Australia. The area of origin, for this latter case, is the Asian continent itself, a proof of the fact that learning and knowledge processes are characterized by cultural elements whose similarities are more likely to manifest within the same macro-area (cf. Iammarino and Michie, 1998). Furthermore, the inward flows of foreign students are even more consistent at the postgraduate level. In the US, for example, 24 percent of students attending postgraduate courses in 1994 came from other countries, a percentage that has grown constantly over time (UNESCO, 1996). Thus, it is not surprising that universities and other public research centres have now even started to operate direct investments abroad, establishing branches in other countries (Malerba *et al.*, 1991). We can note the paradox that, while firms are imitating universities and developing their know-how through technological collaborations, some universities are imitating firms by becoming multinationals.

The intensity of international scientific collaborations can also be measured through the number of articles written in collaboration by academics of different countries; in just a decade the share of internationally co-authored papers in the world has almost doubled (NSF, 2000). Even though the majority of scientists continues to work in strict collaboration with fellow countrymen, direct international collaborations are acquiring an increasing weight, also facilitated by the diffusion of Internet. This is evident to a substantial extent in the European countries, where the share of internationally co-authored scientific articles, as a percentage of total co-authored articles, was much higher than in the US or Japan in both 1986–88 and 1995–97 (see Table 6). The importance of a global academia would be certainly greater if reference were to be made to the acquisition of information from abroad through scientific literature, congresses, conferences or personal contacts.

Does the empirical evidence on the techno-scientific collaborations provide a conclusive answer as to the relevance of global technological collaborations? They started to appear systematically among firms not more than a quarter of a century ago, but they are firmly established today repeating, it would seem, what occurred in the academic world in the remote past. They mainly concern the technological areas with highest opportunities and which are closest to basic research, whereas they are less common in traditional sectors. Even though the bulk of them involves essentially the Triad countries, a certain vitality has emerged in the new industrialised countries of East Asia since the beginning of the 1990s.

CONCLUSIONS

In this paper we have shown that the globalization of innovation is not a single phenomenon, but a catch-all concept to describe a wide range of forces. The attempt to estimate their weight according to geographical location and industrial sectors shows that the importance of global forces in innovation is rapidly increasing, although at a different pace for each of the three ongoing processes.

The dimensions of globalization summarized in the taxonomy have not affected the various world regions at the same time and with the

Table 6 Percentage of internationally co-authored papers published in selected countries in all papers.

Country	*1986–88*	*1995–97*	*Absolute growth*
US	9.8	18.0	84%
Japan	8.1	15.2	88%
European Union			
UK	16.7	29.3	75%
Germany	20.7	33.7	63%
France	22.2	35.6	60%
Italy	24.0	35.3	47%
Netherlands	21.3	36.0	69%
Sweden	24.0	39.4	64%
Denmark	25.9	44.3	71%
Finland	20.9	36.1	73%
Belgium	31.2	46.6	49%
Austria	27.1	43.6	61%
Ireland	28.9	41.9	45%
Spain	18.8	32.2	71%
Greece	27.6	38.3	39%
Portugal	37.6	50.8	35%
World	7.8	14.8	90%

Note: The world totals appear lower than those of individual countries because for world totals each internationally co-authored paper is counted only once, while each collaborating country is assigned one paper. In 1997 each internationally co-authored paper involved an average of 2,22 countries.
Source: National Science Foundation (2000).

same intensity. The expansion of global forces has instead remained circumscribed to the most developed part of the world up to now, so much so as to have been defined a process of 'triadisation', in other words, of increasing polarization of economic and innovative activities in the Triad economies.

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