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THE TECHNOLOGICAL PERFORMANCE OF EUROPE IN A GLOBAL SETTING

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The process of European integration is not based on a customs union, a common agricultural policy and a single currency only: it is also based on circulation of knowledge among individual member countries.[1] This is not associated to cultural and social values only, but also to the belief that economic growth, employment and welfare in the old continent are strictly associated to its capability to generate and diffuse new technologies. It is therefore not surprising that there is a major policy concern within governments, business and trade unions on the ways to promote scientific and technological activities and to foster innovation in firms.

The signals of a lag on the part of Europe both in comparison to Japan and the USA are increasing (see Fagerberg *et al.* 1999; Gambardella and Malerba 1999; Vivarelli and Pianta 2000; Chesnais *et al.* 2000), especially in the most dynamic sectors of the economy. It is increasingly evident that Europe is not managing to keep up in the new economy based on the intensive use of Information and Communication Technologies (ICTs). For example, statistics from OECD (1999b: 21) show that the USA and Japan invest respectively 8.0 and 7.5 per cent of their GDP in ICT. By contrast, Europe invests less than 6 per cent—with some exceptions, such as Sweden, which invests over 8 per cent. Looking at the share of ICT in granted patents (OECD 1999b: 25), the results are confirmed: in the USA patenting in these fields is growing rapidly (average annual rate of growth of 20 per cent from 1992 to 1998), while the European Union grows more slowly, at the rate of 14 per cent a year. Although Japan has a rate of growth slower than Europe (12 per cent a year), it started from a more advantageous position: in 1998, the share of ICT in granted patents was 18 per cent for Japan, 16 per cent for the USA and only 10 per cent for the EU.

These are just a few signs indicating that the USA (and Japan) have proven to be much more vital in the rising fields and industries. While in the 1980s we experienced the dramatic rise of Japan and other East Asian economies in hardware technologies linked to ICT (for an overview, see Freeman 1987; Mathews and Cho 2000), in the 1990s the USA has managed to recover its traditional economic leadership in knowledge-intensive industries by exploiting and disseminating ICTs in the service sector. Within the triad, Japan and the other East Asian economies continue to have

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a prominent position in the generation of the "hardware" component of ICTs, while the USA has a dominant position in the "software" component. Europe has neither of them. It is therefore not surprising that a substantial and increasing part of the EU budget and concern is devoted to promote scientific and technological advance.

In order to develop a proper innovation strategy, Europe has to face the fact that it is composed of a number of states that retain a substantial autonomy. What the old continent gains in terms of variety and diversity, it loses in terms of lack of cohesion and central policy decision-makers. Not surprisingly, Europe is rather an agglomeration of different innovation systems. While some regions of the European Union are strongly integrated in knowledge transmission, others continue to be peripheral and to be excluded by the major technology transfer flows. One of the core issues which should be addressed both at the national and at the European policy levels is therefore how to integrate the different local and national components into a single innovative system comparable to the American or the Japanese one.[2]

In the knowledge generation process, as in any other aspect of the economic and social life, Europe is not separated from the other parts of the world. The dissemination of new ideas, know-how and technical expertise does not respect the frontiers of individual states nor the European borders. While Europe is adjusting with difficulties to the new technological landscape characterized by the so-called new economy (see Soete 2001), the forces of globalization have affected science and technology as any other side of human life. How will the dynamics of globalization affect the European economy in the generation, transmission and dissemination of new knowledge? Are they allowing bridging the existing gaps with the USA and Japan?

This paper discusses the following issues. First, it seeks to identify the various meanings of the so-called "globalization of technology". Second, it reports some empirical evidence on the various forms of the globalization of technology. Third, it explores to what extent and in which direction the globalization of technology is affecting the European Union. Fourth, it offers an assessment of the role of science, technology and innovation policies carried out at the European level for the benefit of European welfare, competitiveness and growth.

Special attention is devoted to a new form of cross-border transmission of know-how and technology, namely international collaborations in scientific and technological activities. It will be shown that while European firms are more and more keen to undertake technological alliances with American counterparts, the European academic community is increasing its intra-European collaborations.

THE MULTIPLE MEANINGS OF GLOBALIZATION OF TECHNOLOGY

Globalization is one of the most widely used neologisms of this decade. It has been applied virtually to every aspect of human life (for an overview, see Held *et al.* 1999). A very large literature has been devoted to the globalization of technology and this is hardly surprising (for overviews, see Lundvall and Borrás 1998; Archibugi *et al.* 1999).

2 Maurseth and Verspagen (1999), Garcia-Fontes and Geuna (1999) and, more broadly, the chapters collected in Archibugi and Lundvall (2001) present some evidence and considerations relating to the lack of a proper European Innovation System.

On the one hand, new technologies are a fundamental vehicle for the transmission of information and knowledge across different regions. Without Internet, satellites and new telecommunications it would not be possible to transfer information, at low or negligible costs, from one part of the world to another and this is the material condition that allows globalization in aspects as different as finance, production, fashion, media and culture. On the other hand, the production and dissemination of inventions and innovations has become much more global in scope than in the past.

Two clarifications are needed concerning the globalization of technology: the first relates to its time dimension, the second to its spatial relevance. Concerning the time dimension, it should be noted that flows of knowledge among human societies have always existed, although they have become much deeper and wider over the last 30 years with the massive diffusion of new information technologies. Concerning the space dimension, some regions of the world, and most notably North America, Europe and Japan, have been much more affected than other parts of the world. This fact is hardly surprising since the same regions concentrate the largest part of the innovations produced worldwide: for instance, 85 per cent of the patents in force in 1998 were generated in the triad (EPO 1999).

In the last years, we have attempted to distinguish different meanings of the globalization of technology with a view to measure each of them quantitatively and to provide appropriate policy analysis on each dimension (see Archibugi and Michie 1995; Archibugi and Iammarino 1999, 2000). This taxonomy identifies three main categories:

(a) the international exploitation of nationally produced technology;
(b) the global generation of innovations by multinational enterprises (MNEs); and
(c) global technological collaborations.

The aim of this taxonomy is to classify individual innovations according to the main methods used to generate and exploit them. The categories are therefore not mutually exclusive at the firm level.[3] Enterprises, especially large ones, generate innovations following all the three procedures described. Moreover, although each category is meant to classify the generation of individual innovation, they also report information on how knowledge is geographically transmitted. The three categories of this taxonomy are described in Table 1.

The first category includes the attempts of innovators to obtain economic advantages by exploiting their technological competencies on markets other than the domestic one. We have preferred to label this category "international" as opposed to "global" since the innovation introduced preserves its own national identity, even when it is diffused and marketed in more than one country. Both large and small firms take part in this form of internationalization, although large firms are generally better equipped to commercialize in foreign markets their innovative products.

The second category is represented by the global generation of innovations. It includes innovations generated by single proprietors on a global scale. Only innovations produced by MNEs fit into this category. The innovations in this category are not any longer generated in one single country; on the contrary, they receive inputs

3 There is an additional category that should be added to this taxonomy, namely the innovations that are generated and used within the boundaries of a state. However, since this taxonomy is devoted to describe and interpret the globalization of technology, innovations that do not cross borders are not considered.

TABLE 1: A TAXONOMY OF THE GLOBALIZATION OF INNOVATION

Categories	Actors	Forms
International exploitation of nationally produced innovations	Profit-seeking firms and individuals	Exports of innovative goods. Cession of licences 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.

Source: Archibugi and Michie (1995).

from different research and technical centres that belong to the same MNE. Large and often giant firms compose the bulk of MNEs. For small firms it is rather problematic to generate innovations globally.

Recently, another form of globalization of innovative activities has asserted itself, midway—to a point—between the two categories described above. We have in fact witnessed a growing number of international agreements between enterprises, often situated in two or more countries, to develop given technological inventions together (Mytelka 1991; Dodgson 1993). The need to cut the costs of innovation has created new forms of industrial organization and new proprietary arrangements, which are now expanding beyond the technological sphere as such. Both small and large firms are active in this form of transmission of knowledge; in particular, small firms can use it as an alternative source to innovate preserving their ownership.

As a matter of fact, enterprises have imitated a method of generating and transmitting knowledge typical of the academic community. The academic world has always had a transnational range of action, with knowledge being transmitted from one scholar to another, then disseminated, without economic compensation being invariably necessary.[4]

THE QUANTITATIVE SIGNIFICANCE OF THE GLOBALIZATION OF TECHNOLOGY AND THE POSITION OF EUROPE

Once we have asserted that under the umbrella of globalization of technology there are different phenomena, it will be important to check what is the quantitative

4 Sometimes, firms and universities also collaborate among each other. However, the bulk of university–industry collaborations still take place within national boundaries.

importance of each of its main components. This will also allow us to assess how Europe is participating in the overall process, what is the impact of each of these forms and what are the policy implications. This is particularly important to design, at the local, national or European levels, appropriate policies.

It should, however, be recalled that in the majority of cases the available indicators do not report full information on the categories of globalization here singled out. In some cases the indicators include heterogeneous dimensions, in other cases they do not report the entire dimension. Nevertheless, the evidence here discussed is able to inform on the main significance and trends of the globalization of technology.

International exploitation of nationally produced technology

For a quantitative assessment, it might be useful, within this category, to separate the embodied from the disembodied components since both play a crucial role in firms' strategies (Evangelista 1999). The former is captured by traditional international trade indicators, the latter by indicators of the transmission of know-how such as patents, trade of licences, technical assistance and so on.

Table 2 recapitulates the evidence on this form of globalization. Although all commodities include a technological component, there are some that are more technology intensive than others. From the available classifications, it emerges that high-tech industries absorb more than one-fifth of the world trade in manufacturing (Guerrieri 1999; World Bank 1999). This share has considerably grown and it has more than doubled in the last 25 years. The position of Europe in this respect is hardly satisfactory. In absolute terms, high-tech exports as a proportion of total exports of European countries is equal to 20 per cent, as compared to 32 per cent for the USA and 26 per cent for Japan. This is the result of a decline which occurred over the last quarter of a century (World Bank 1999). European market share (that is, the ratio of European exports to world exports) in the science-based products (including intra-European trade) has declined from 48.6 per cent in 1970 to the 33.8 per cent in 1995. In this period, the rapid growth of Japan and of East Asian NICs have led to a reorganization of market shares, but it is of concern that Europe has lost almost 15 per cent market share against the 11 per cent of the USA (Fagerberg *et al.* 1999: 12).

An indicator of disembodied knowledge is represented by patent statistics and, in particular, by international patent flows. Patents are extended in foreign markets both to sell a product that embodies the innovation and to sell the innovation disembodied. Each invention is, on average, patented in more than four countries, as evidenced by the rate of diffusion across countries, that is the ratio between external (e.g. patent applications presented by inventors in foreign patent institutions) and resident patent applications (e.g. patent applications presented by inventors in their own country) (OECD 1999a: Table 78). A dramatic growth rate of external patent applications has occurred from 1990 to 1996, equal to 19.8 per cent a year (OECD 1999a: Table 74). This growth rate has been substantially higher than in industrial R&D expenditure, that was equal to 5.4 per cent a year from 1992 to 1997 (OECD 1999a: Table 22). The trend in external patent applications cannot therefore be related to an increased pace of technological change only, but also to an increasing propensity to exploit the

TABLE 2: EMPIRICAL EVIDENCE ON THE INTERNATIONAL EXPLOITATION OF NATIONALLY PRODUCED INNOVATIONS

		Results	
Indicator	Source	Stock	Trends
International trade	World Bank (1999)	High-tech exports absorb 19.6% of manufacturing exports in 1997: 32% in USA, 26% in Japan and less than 20% in Europe.	Growth of 10% in the world from 1991 to 1997.
	Fagerberg *et al.* (1999) Guerrieri (1999)	Science-based products absorb 21.5% of world trade.	European share in science-based products has declined from 48.6% in 1970 to 33.8% in 1995.
Patents extended in foreign countries	OECD (1999a)	On average 4.3 extensions for each patent in 1996.	Annual average growth by 19.8% in the period 1990–96. Pace particularly high in Europe, also because of new institutional devices.
Inward flows of patents	OECD (1999a) WIPO (1998)	Rate of dependency (foreign patents/domestic patents) is 1.2 in EU, 0.8 in USA and 0.15 in Japan in 1997.	Annual average growth of non-resident patents by 11.7% from 1990 to 1996.
Patents in the triad	EPO (1999)	85% of patents in the world in 1998 come from the triad.	International flows of patent applications between the three blocs increased by 43% from 1997 to 1998.
Patents in high-tech fields	EPO (1999)	Japan and the USA have a larger and increasing share of patents at the EPO in high-tech fields than Europe.	

results of innovation in overseas markets. The markets where pay-off from technological investment is sought are becoming more and more global. From a geographical point of view, US inventors have increased their propensity to extend their patents in foreign countries more than European inventions (9.5 per cent versus 8.0 per cent).

The other side of the coin is represented by the inflow of technology through patents registered into each national patent office. From 1990 to 1996 the annual growth rate of patent applications by non-residents constantly increased: the annual average growth rate for OECD countries was equal to 11.7 per cent (OECD 1999a: Table 73). In 1996 Europe as a whole had a dependence ratio (non-resident/resident patent applications) equal to 1.1 against 1.0 of the USA. In 1998 the ratios became 1.2 for Europe and 0.8 for the USA (WIPO 1998; NSF 2000), showing that Europe has increased its dependency from foreign technology, while the USA has reduced it.

Finally, it is interesting to focus the attention to patents in the fields with the higher technological component. The patents in high-technology fields registered today are likely to become the most successful products of tomorrow. If we consider the geographical origin of the inventions in high-tech fields registered at the European Patent Office, the penetration of the USA and Japan is greater than for patents in all fields. In 1999, US inventors accounted for 36 per cent of high-tech patents (against 28 per cent in all fields) and Japan for 21 per cent (against 16 per cent in all fields). Europe accounts for 50 per cent of applications presented at the European Patent Office in all fields, but its share declines to 38 per cent in high-tech fields (EPO 1999). The same happens for the inventions registered at the Japanese and US Patent Offices.

Global generation of innovations by MNEs

A variety of scholars have carried out research based on R&D and patent indicators providing fresh evidence on the global generation of technology, which is summarized in Table 3. Each indicator can be seen from two opposite perspectives: (a) the flows "received" by a country from firms of other countries, (b) the flows "disseminated" by the firm of a country in other countries (the sum of the two flows at the world level should of course be equal to zero). The business R&D which is funded by foreign companies is, in the OECD, equal to 14 per cent (OECD 1999a: 39), indicating that R&D is overall less internationalized than production. There are, however, large variations over countries, with some of them rather closed to foreign R&D investment and others more open. On the one extreme, there is the Japanese economy, which is the most typical case of a system of innovation where domestic firms concentrate their investment in their home country and the presence of foreign firms is sporadic. In fact, the Japanese innovation system has very limited inflows and outflows of FDI in R&D. On the other extreme there is Australia, where foreign firms account for nearly half of the total business R&D (OECD 1997).

In the three main European countries, Germany, France and the UK, the R&D inflow investment of foreign firms account for, respectively, 16.5, 14.9 and 18.5 per cent of the total national R&D expenditure of the manufacturing industry (while the bulk is still national). A greater importance is played by foreign affiliates in Spain (see Molero 1995), where they account for nearly one-third of total R&D expenditure of the manufacturing industries. Overall, European individual countries are slightly more open than the USA to foreign R&D, while the penetration of foreign firms in Japan is still negligible (1.4 per cent of the national R&D of the manufacturing industries only).

Is there any technological reason why a national government should prefer domestic or foreign firms? From a government perspective, it is relevant to assess what is the propensity of domestic and foreign firms to invest in innovative activities since it is in the national interest to acquire the greatest amount of scientific and technological activities within the country's territory. One way to assess this is to compare the R&D intensity of national and foreign affiliated firms. In the USA, home and host firms have the same R&D intensity. In all other countries, with the exception of Australia, the ratio of R&D expenditure to turnover of foreign affiliated firms is lower than for national firms (OECD 1997).

In all the European countries, the R&D intensity of national firms (strongly dominated by the so-called national champions) is substantially higher than those of host firms. In Germany foreign affiliated firms report a ratio R&D/sales which is

TABLE 3: EMPIRICAL EVIDENCE ON THE GENERATION OF INNOVATIONS BY MNEs

Indicator	Source	Results	
		Stock	Trends
Inward flows of R&D by foreign MNEs	OECD (1997, 1999a, b)	In the OECD, the average share of foreign controlled R&D is equal to 14% of total BERD.[a] Foreign affiliates account for from 1% (Japan) to 46% (Australia) of R&D in manufacturing. Greater intensity in R&D of national firms than foreign firms.	Significant increase in Europe. Increase in USA. Moderate increase in Japan.
Outward flows of R&D in host countries by MNEs	USA survey on R&D, National Science Foundation (2000)	7–10% of R&D of US firms is executed abroad (1980–96).	US overseas R&D has increased more than domestic R&D. European R&D in the USA has increased considerably. European firms have also increased considerably their R&D in other European countries.
Outwards flows	Patents granted in the USA by a sample of large firms, Patel and Vega (1999)	12.6% of patents are generated in foreign subsidiaries of large firms (1992–96): 22.7% in EU versus 8% in USA and 2% in Japan.	Small but constant increase. European firms are increasing the number of their overseas inventions both in Europe and in the USA.
Patents generated in foreign subsidiaries by large firms	OECD (1999b)	Country residents invent abroad 8% of their total owned patents (USA 9%, EU 4% and Japan 2%).	Growth of 33% from 1980s to 1990s, that is of 2.9% a year.
Inward flows	Patent applications at the EPO OECD (1999b)	Foreign residents own 8% of total patents invented domestically (EU 7%, USA 5% and Japan 3%).	Growth of 33% from 1980s to 1990s.

[a]Business Enterprises Research & Development.

almost half that for national firms (it is, however, significant that also foreign affiliates have a very high R&D intensity in Germany), and in all other countries it is always lower. In other words, there is robust evidence that domestic firms are more R&D intensive than foreign ones. If a government should choose between the localization in its own territory of a domestic or a foreign firm, it seems that there is a technological rationale to prefer the domestic one.

But in real life, there are rarely such clear-cut alternatives: the localization of R&D centres by foreign companies is generally not at the detriment of the R&D centres of national companies. Although foreign firms might be less keen to invest in R&D in host countries, there is no evidence that they crowd out the investment of national firms. On the contrary, there is abundant evidence that R&D centres tend to agglomerate. High R&D activity by national firms might therefore induce the localization of foreign firms, and vice versa (Cantwell 1995). And, in fact, the R&D intensity of foreign firms is higher in those countries where the R&D intensity of national firms is also high.

Another indicator of MNEs' global activity is represented by the number of patents developed in subsidiaries based in foreign countries. Patel and Vega (1999) and Cantwell and Janne (2000) have provided some evidence on the share of MNEs' innovative activities carried out in host countries based on US patent statistics. This shows that, by far, European firms as a whole have a much larger share of innovations developed in foreign subsidiaries than American and Japanese firms (22.7 per cent versus, respectively, 8.0 and 2.6 per cent of the total patenting of a sample of large firms). European large firms are much more international in the scope of their innovative activities than their American and Japanese competitors.

It is equally interesting to identify the geographical origin of this inventive and innovative activities (again, measured by patent statistics) and, in as much as Europe is concerned, the part that comes from other European firms and from firms outside Europe. European firms distribute their activities between the USA and other European countries. Firms based in all European countries, with the exception of small countries such as Belgium, Finland, Austria and Norway, have a greater level of technological activities in the USA than in other European countries. The preference for localization in the USA rather than in Europe is particularly significant for German firms (14.1 per cent in the USA versus 6.5 per cent in other European countries of the total patents owned by German-based large firms) and British firms (38.1 per cent in the USA versus 12.0 per cent in other European countries of the total patents of British-based large firms).

Global technological collaboration

Some evidence on the available statistics on global technological collaboration in both the business and the public sectors is reported in Table 4.

TABLE 4: EMPIRICAL EVIDENCE ON GLOBAL TECHNO-SCIENTIFIC COLLABORATIONS

		Results	
Indicator	Source	Stock	Trends
International inter-firm technology alliances	Hagedoorn (1996) National Science Foundation (2000)	60% of inter-firm technical agreements are international. 9.9% are intra-Europe, while 28.1% involve US–European alliances.	Nearly doubled from 1981–86 to 1993–98. Growth of US–European and intra-USA agreements. Decrease of intra-European agreements.
Internationally co-authored scientific papers	European Commission (1997) National Science Foundation (2000)	14.9 of the world's papers are internationally co-authored. European countries have more collaborations than USA and Japan. Strong patterns of intra-European co-authorship.	International co-authorships have nearly doubled from 1986–88 to 1995–97 (6.6% a year). Growth of intra-European collaborations; decrease of US–European collaborations.

Concerning the business sector, we rely on the classic database developed by John Hagedoorn and his colleagues (see Hagedoorn 1996). This has shown that as much as 60 per cent of the total strategic technology alliances recorded are international in scope. This form of generating technological knowledge has considerably increased its significance and the number of recorded agreements nearly doubled between 1981–86 and 1993–98.

As shown in Table 5, the largest and most increasing portion of alliances take place within the USA: 48.3 per cent of all the strategic technological alliances recorded in 1993–98 occurred among American firms only, against the 24.0 per cent in the 1981–86 period (NSF 2000). Moreover, the US firms have strong ties on both the Atlantic and the Pacific shores: in the 1993–98 period, US companies participated in as much as 84.9 per cent of the recorded technology alliances. On the contrary, the share of intra-European strategic technological alliances substantially declined: they accounted for 19.2 per cent in 1981–86, and less than 10 per cent in 1993–98. In absolute terms, while European–US partnerships have more than doubled (from 415 in 1981–86 to 971 in 1993–98), intra-European partnerships have remained stagnant (354 in 1981–86 and 344 in 1993–98).

European policy-makers should be concerned by the strong propensity of European firms for American, rather than European, partnerships. Policies carried out at the European level, and especially at the European Commission level, to foster co-operation in R&D and innovation in the continent have not been able to reverse the propensity of European firms for engaging in partnerships with American firms. The first possible explanation would be that the absolute amount of resources devoted to science and technology is much greater in US firms and that, obviously, firms engage in technology alliances with partners which have the adequate expertise. The greatest flow of alliances in the USA would therefore be just the outcome of the greatest investment in knowledge by US companies. In order to control for this factor, we have divided the number of European alliances undertaken with European, US and Japanese companies by the total amount of, respectively, European, US and Japanese business enterprises' R&D expenditure (BERD). This provides an indicator of the propensity of European companies towards collaboration in each of these regions. The results are reported in Table 6.

Although the attractiveness of the US economy is a bit smaller, it is confirmed that European companies have a greater propensity for American partnership even after taking into account the amount of resources invested in R&D. There are 1.25 European–US partnerships for each billion US dollar BERD, while the equivalent figure for intra-European partnership is just 0.78. Moreover, it emerges that the situation has dramatically changed within the last 15 years. In the 1981–86 period, European companies had a larger propensity for European rather than American partners. The figures were, respectively, 1.12 and 0.75 agreements for each billion US dollar BERD. It seems rather clear that the European business community has considerably changed its propensity for partnership over the last 15 years.

Partnerships and collaborations promoted by public research institutions and universities equally play a crucial role in the international dissemination of knowledge (see Table 4). Indicators based on the number of undergraduate and postgraduate students and of the internationally co-authored scientific papers also show a substantial

TABLE 5: DISTRIBUTION OF STRATEGIC TECHNOLOGY ALLIANCES BETWEEN AND WITHIN ECONOMIC BLOCS: 1981–98

		Interregional alliances							Intraregional alliances						
		Europe-Japan		Europe-USA		Japan-USA		Subtotal	Europe		Japan		USA		Subtotal
Period	Total counts	Counts	%	Counts	%	Counts	%	Counts	Counts	%	Counts	%	Counts	%	counts
1981–86	1,847	146	7.9	415	22.5	329	17.8	1,048	354	19.2	160	8.7	443	24.0	957
1987–92	2,578	148	5.7	665	25.8	334	13.0	1,493	449	17.4	90	3.5	892	34.6	1,431
1993–98	3,459	127	3.7	971	28.1	292	8.4	1,751	344	9.9	53	1.5	1,672	48.3	2,069

Source: National Science Foundation (2000).

TABLE 6: PROPENSITY OF EUROPEAN FIRMS FOR TECHNOLOGY ALLIANCES WITH EU, US OR JAPANESE PARTNERS

	Number of agreements involving European firms by Business R&D of the region (in billion US$ at constant 1992 PPP)		
Period	EU	USA	Japan
1981–86	1.12	0.75	0.83
1987–92	1.07	0.96	0.53
1993–98	0.78	1.25	0.39

Source: For strategic technology agreements, National Science Foundation (2000). For Business Enterprises R&D (BERD) at constant 1992 PPP US$, OECD (1999a, c).
Methodology: The number of strategic technological agreements recorded by the CATI-MERIT database have been divided by the stock at constant 1992 purchasing power parity US$ billion BERD of the region. It reads that in 1981–86 there have been 1.12 strategic technology agreements for each US$ billion of European BERD.

increase in the last decade (UNESCO 1996). A dramatic increase in the internationally co-authored papers—also facilitated by the diffusion of Internet and e-mail—is evident in all countries (Table 7). From 1986–88 to 1995–97, the percentage of internationally co-authored papers in the world nearly doubled (NSF 2000). European countries are individually keener to collaborate than the USA and Japan. This fact is not surprising given the smaller size of the scientific community in each country. From a dynamic viewpoint, however, it should be noted that the rate of increase has been higher in the USA and Japan than in European countries. The academic community in Europe is an asset, which can and should be exploited to increase the trans-border circulation of knowledge and know-how.

Does the academic community also share the same preference of European firms for American rather than for European partners? The National Science Foundation (2000) reports some data on the distribution of internationally co-authored collaborations across collaborating countries. Europe is by far the greatest collaborator for the American academic community. In 1995–97 as much as 60.3 per cent of the US internationally co-authored papers involved a European partner. Besides both the European Union as a whole and European individual countries have stronger ties with the European Union than with the USA. This fact could be misleading if we think that a paper co-authored by a Dutch and a Belgian scientist is classified as "international", while a paper co-authored by a Californian and a New Yorker is classified as national. Still, the USA remains the single nation involved in most collaborations by every European country.

But what is more important is the time dynamic analysis: by comparing the first period (1986–88) to the last one (1995–97), it emerges that intra-European collaborations are in proportion increasing, while European–American collaborations are decreasing for all the EU member countries. Although the absolute number of internationally co-authored articles is increasing for every pair of countries, the relative importance of US partnership is decreasing for each European country as

TABLE 7: PERCENTAGE OF INTERNATIONALLY CO-AUTHORED PAPERS PUBLISHED IN SELECTED COUNTRIES IN ALL PAPERS

Country	1986-88	1995-97	Growth (%)
USA	9.8	18.0	84
Japan	8.1	15.2	88
European Union	20.9	34.5	65
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).

well as for Japan, while the relative importance of intra-European collaborations is increasing.

It could be asked what would happen if we also considered intra-US co-authored articles, by looking at the data from the American perspective. The above tendency is enhanced: the share of intra-US articles in all US co-authored articles declined from 78 to 68 per cent in the period considered, while the co-authorships with EU countries grew from 11 to 19 per cent (NSF 2000: Table 6.51).

We therefore note an inverse tendency: the European business community has an increasing propensity for technological alliances with US firms, while the European academic community has an increasing propensity for intra-European partnership. But, as we will see in the next section, there is no guarantee that the incentives which have effectively induced the academic community to increase its collaboration will also work for the business community.

POLICY ANALYSIS

Before moving to specific policy instruments, it is important to identify what public policies, at the national or European levels, should pursue on each of the three dimensions of the globalization of technology singled out above. First of all, there is a crucial dimension that is common to each of the three components and that can be formulated as follows.

It is in the interest of a given territorial authority to promote the inter-exchange of embodied and disembodied knowledge when this offers new learning opportunities.

The basic assumption of this statement is that the key to achieve nations' long run economic growth and welfare is to increase learning. Globalization in technological activities provides advantages to individual nations if it allows them to learn (this is the main message of the chapters collected in Archibugi and Lundvall 2001). Although the benefits associated with each knowledge-intensive transaction will not be equally distributed among the participating nations, the relevant aim of public policies should be to involve national economic agents in knowledge exchanges. To put it in other words, it is better to get a bad deal than no deal at all. From the government perspective, it is an advantage to get its scientific and technological (S&T) community engaged in "marriages" even if the dowries are unbalanced rather than to stay with a population of "singles". In the globalizing economy it is very easy for a firm, an academic circle or an entire industry to become marginalized by the main knowledge flows. Since the pace of change is so rapid, the competitive position of the economy can easily be jeopardized (European Technology Assessment Network 1998).

A basic distinction between the cross-border transmission of knowledge which does or does not allow endogenous learning should be drawn: in the long run, it is not in the interest of a community to acquire systematically knowledge from abroad if the conditions to replicate it autonomously are lacking. This does not necessarily mean that each country should become self-sufficient in the generation of knowledge. No country today, not even the USA, is able to produce all the knowledge it uses; all countries are more or less specialized in selected science, technology and production niches, but surely none of them is self-sufficient (for a quantitative assessment, see Archibugi and Pianta 1992; Laursen 2000; Meliciani 2001). But it is in the interest of each country to develop some recognized strengths in technology-intensive sectors to compensate fields where the country is dependent on knowledge and technology generated abroad. The main advantages and disadvantages associated with each of the three suggested categories are reported in Table 8.

There is also a specific European dimension that should be considered. The European Commission has devoted an increasing part of its budget to research and technological development: from 2.5 per cent of the First Framework Programme (1984–87) to 4.6 per cent of the Fifth Framework Programme (1998–2002) (Sharp 2001). However, the resources made available by the European Commission still account for less than 6 per cent of the overall European Union's R&D budget. This indicates that a European policy for science and technology cannot rely on the European Commission's budget only, but should also involve more directly national governments and authorities.

Policies to promote the international exploitation of technology

The international exploitation of national technological capabilities has traditionally produced conflicts among governments and firms, as Friedrich List (1841) knew very well. Concerning the inward flows of technology-intensive products there is generally

TABLE 8: IMPACT OF THE GLOBALIZATION OF INNOVATION ON NATIONAL ECONOMIES

	Impact	
Categories	Inwards flows	Outwards flows
International exploitation of nationally produced innovations	Low profile of national institutions. Low learning in consumption goods. Medium learning in capital goods and equipment.	Expansion of the market and of the areas of influence. Maintenance of national technological advantages.
Global generation of innovations by MNEs	Acquisition of technological and managerial capabilities. Increased dependence on the strategic choices of foreign firms.	Missed technological opportunities for the internal market. Strengthening of the competitive position of national firms.
Global techno-scientific collaborations	Increase of techno-scientific flows and of sources of innovation. For developed countries, diffusion of their knowledge. For developing countries, acquisition of knowledge and learning opportunities.	

Source: Elaboration on Archibugi and Iammarino (1999).

low learning in consumption goods, while there is a more significant learning in the import of capital goods and equipment, since they involve the start-up of learning by doing (Arrow 1962) and learning by using (Rosenberg 1982).

It is obviously an advantage for a country to exploit its technological innovations in foreign markets since it leads to the expansion of the internal production and of the areas of influence. A large market share, moreover, allows to achieve economies of scale and scope and therefore to preserve and develop the expertise in fields of excellence. There is a long and controversial practice of export incentives and today the trade rivalry is gaining importance in technology-intensive sectors at the expense of traditional sectors: agriculture and materials are losing importance *vis-à-vis* electronics and software (see Scherer 1992; Tyson 1992).

But international trade rivalry is not only shifting within industries, it is also changing its nature and an increasing concern of policy-makers has been directed to disembodied knowledge. Intergovernmental negotiations and litigation are more and more related to intellectual property rights violations, copyright infringements and similar issues rather than to the physical transfer of commodities across borders. In this area, there is a strong need to redefine the rules of the game (see David and Foray 1996; David *et al.* 1999; David 1999).

Within Europe, government policies are somehow limited by the integration acts adopted. In fact, the single market should favour intra-European trade and make it more difficult for individual countries to protect their own internal market from other European countries. But the available data show that, in as much as technology-intensive products are concerned, there is also a strong propensity to trade with the USA and Japan. The European policies aimed at creating a European technological identity have, so far, not been successful. This fact, however, does not necessarily lead to the policy conclusion that a new pan-European protectionism should be implemented. It is more important to increase European production and expertise in the knowledge-based industries than to limit high-technology imports from other countries.

There is also a strong need to redefine the rules for the trade of disembodied knowledge. One important step would be to agree on a common European patent law and practise, although crucial components of contemporary knowledge, and most notably software, are outside the scope of patent protection (for an assessment, see European Technology Assessment Network 1999). The legal framework for intellectual property rights protection in Europe should therefore be much more comprehensive than what is provided by patent legislation.

While large firms easily have their own international networks to both sell their know-how and to acquire the know-how from other firms, small firms do need support for both commercializing their innovations and monitoring the international technological developments which might be relevant for their business.

Policies to support the global generation of innovations by MNEs

What should be the attitude of governments towards:

(a) national firms locating their R&D and innovation centre abroad; and
(b) home-based MNEs investing in R&D and innovation at home?

There are both advantages and disadvantages associated with each of the two aspects. On the one hand, it is certainly an advantage if MNEs hosted in a country also invest in innovative projects and contribute to up-grade its technological competence. On the other hand, there is the danger that the activities of MNEs will crowd out national firms. However, the risk of crowding out national firms is much more associated with FDI in the country than with the technological component of FDI. A strong presence of, for example, foreign automobile companies can be an obstacle to the development of a national automobile industry. But once a foreign company has invested in the country, it is certainly in the national interest that part of it is directed on R&D. Governments might have their own reasons to encourage or discourage FDI, but once FDI is hosted, the larger the technological component the better it is for the country. On the contrary, there is robust evidence that technology-intensive productions and skills tend to agglomerate geographically (Cantwell and Iammarino 2001).

But a substantial amount of R&D carried out by foreign MNEs increases the dependency of the nation on the strategic choices of foreign firms, which may have preferential ties with the governments of their home country. Once R&D investment by host MNEs is accepted, there is a wide range of public policies which should be carried out in order to secure the benefits to the nation and the loyalty of foreign firms. Some policies can be associated with education and training of the workforce: an excellence in the availability of skill-intensive employees is often the best guarantee to secure foreign firms' loyalty and to diffuse the technical expertise across other firms.

The other and equally controversial side of the coin is how to assess the R&D investment of the national large firms (the so-called "national champions") in foreign countries. On the one hand, this can be seen as a lost technological opportunity for the home country, but on the other hand, it might be an open window into technologically dynamic countries that strengthen the competitive position of national firms.

From the public policy perspective, the reasons that induce firms to locate overseas part of their R&D and innovative activities should be explored. Sometimes this can be related to the lack of adequate infrastructures or human resources in the home country (and this should have direct policy implications). If, on the opposite, national firms need to keep a window open on the technological opportunities of other countries, governments may consider to implement policies aimed to disseminate the know-how acquired abroad in the home nation. Again, in the long run the best way to disseminate know-how is by associating it to peoples, for example by supporting the training of staff in the foreign subsidiaries of the "national champions".

As stated above, MNEs only generate innovations globally. Small and medium-sized firms are not generally using this channel since they have not the organization and the financial resources to invest in overseas R&D labs. But this does not mean that small and medium-sized firms have not the need to acquire technical information from other countries. They might sometimes manage to bridge the gap by using other forms and most notably cross-border collaborations.

It is rather difficult to envisage a common European policy for the global generation of innovations. Since the European Union is based on the free circulation of capital each nation competes with the others in order to attract investments. Likewise, nations compete to attract the part of FDI that has the largest knowledge component. So far, government policies *vis-à-vis* MNEs have been national in scope and it seems to be more likely that multinational corporations agree on a common policy towards the European Union than the European Union member countries agree on a common policy towards multinational corporations.

Policies for global technological collaboration

In the case of global technological collaborations, the distinction between inward and outward flows disappears since each country involved in collaboration receives and provides some expertise simultaneously. Of the three forms of globalization of technology here discussed, this is the most typical example of a positive sum game since the members involved can manage to increase their expertise and the externalities associated with it. It is therefore comprehensible that an intergovernmental organization such as the European Union has strongly focused its policy action on this category. This, in fact, does not provoke direct conflicts among the participating countries since all of them can potentially take advantage from the collaborations promoted.

However, this does not mean that the advantages and disadvantages are equally distributed among the participants. As in many marriages of convenience, one of the partners can easily take advantage. In particular, it is likely that the learning potential of each partner will be different. The partner with greater knowledge will have more to teach but it will also be quicker in learning from others. Public authorities are not in the position to detect the learning potential involved in each collaboration. It is much more important for a country to become a junction of exchange of knowledge and technical expertise than to secure returns from each exchange.

The available evidence has shown, as expected, that the countries with the higher share of scientific and technical collaborations are those with the higher technological capabilities. This is hardly surprising since prospective collaborators are searched among those who have already an accumulated knowledge.

Probably, the most significant policy to foster cross-border collaborations has been implemented by the European Union. In fact, the bulk of the financial resources of the European Union for science and technology has been devoted to schemes of collaborative nature. This has however been combined with the competitive selection of projects. The European Commission has tried to select on the grounds of competitive bids the best projects among those applicants willing to collaborate with teams in other countries. There is a strong economic rationale for applying such a combination of competitive and co-operative incentives. First, the competitive nature of the selection process should allow to fund the most promising projects. Second, the requirement of cross-border collaboration helps to disseminate and diffuse knowledge across regions with a view to achieving higher cohesion.

However, it has been shown that the European Union's schemes have not altered the propensity of European firms towards American partnerships. On the contrary, the share of strategic technology partnership of European firms in the USA has substantially increased in the 1990s: (1) in absolute number, (2) as a share of the total European technology agreements, and (3) in proportion of the business R&D investment. Intra-European business collaborations have remained stagnant, but declined as a share and in proportion of the business R&D investment.

It could be argued that the reorganization of the European single market has led companies to search for partners which are not direct competitors. But in this case, it should be explained why Pan-American partnership collaborations have also increased substantially. It is more likely that the massive investment of the US economy in new technologies had its centripetal effect on European companies. We therefore expect that a substantial increase of R&D investment in Europe would also lead to a substantial increase in both intra and extra-European strategic technology partnering.

We have also pointed out an opposite trend in the academic community: intra-European partnerships have increased and Europe as a whole is becoming more important as a junction of scientific knowledge.

The propensities in the business world should raise serious policy concern. Are R&D funds managed at the European level too low in comparison to the R&D funds managed at the national level to provide visible benefits? Should the general philosophy of promoting intra-European business collaborations be revisited? There is a significant opportunity to use the European academic community as a vehicle for greater access to global knowledge networks. This suggests that policies that will increase public/business co-operation in Europe might also lead to increase international co-operation among firms.

It has often been discussed whether the financial schemes to foster collaborations and partnerships of the European Union should be limited to member countries or should also be open to prospective collaborators from other regions, and most notably the USA. The view here suggested argues that the key discriminating point should be associated to learning: it might be in the interest of Europe to involve and fund the participation of selected non-European partners if this provides additional learning potential. It means that some not-European firms could transmit to

European partners the know-how originated in their home country, either in production process or in final products that incorporate a high degree of innovation and technology.

CONCLUSION

The suggested taxonomy of the globalization of technology can help in understanding the European gap in the learning economy and to inform policy actions. Although the evidence here reviewed is fragmentary, a few clear signals do emerge.

First, Europe is not at the core of the globalizing learning economy. Europe is less integrated into the world markets than the USA in key dimensions of knowledge production, transmission and dissemination. Moreover, Europe is loosing ground on almost all the dimensions involved.

Second, the analysis of the three suggested categories of our taxonomy of the globalization of technology provides some indications on where to focus on policy making, especially when this is carried out at a level, such as the European one, which is supra-national. In spite of the good mixture of competitive and co-operative incentives, the European Commission's policies have not managed to generate a European Union for business R&D. If we recall that the budget of the European Commission for Research and Technological Development is less than 6 per cent of the total European expenditure, this is hardly surprising. But we have also suggested that the increasing importance of the European internal market might lead European companies to compete more among each other and, consequently, to share technological expertise with US-based companies since they are less likely to be direct market competitors.

Third, there is also a strong centripetal force of the American economy. Many European firms have a preference to locate a substantial R&D and innovative activities in the USA rather than in other European countries. Likewise, they have become keener to sign strategic technological alliances with US counterparts than with European ones also because of the attractiveness of the size, quality and direction of research carried out on the other shore of the Atlantic.

It has also been shown, however, that the European academic community has a stronger and increasing propensity towards intra-European collaborations. On the contrary, US–European academic collaborations are decreasing. It still needs to be assessed to what extent this is related to the European Commission's policies.

If the European Union should be integrated also in knowledge creation, it will be wise to think that not only an increasing effort towards the generation and transmission of knowledge is needed, but also that the various political actors need a stronger co-ordination. European countries have joined in a monetary union but they are leaving to the national level the management of knowledge. If knowledge is becoming the driving force of the globalizing learning economy a stronger policy action in the field is needed. Lundvall (2001) has suggested the making of a European High Level Council for Innovation and Competence Building with authority and powers comparable to the European Central Bank. This proposal is certainly utopian, but the political actors involved should realize that we are moving into an age dominated by globalization and knowledge. If Europe has to defend its position in the new learning economy, the management of knowledge deserves the same attention and authority as the management of money.

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