THE INTERNATIONALISATION OF TECHNOLOGY ANALYSED WITH PATENT DATA[#]

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Abstract

This paper presents three new patent-based indicators of internationalisation of technology reflecting international co-operation in research and the location of research facilities of multinational firms. They witness both an increasing trend towards the globalisation of technology in the OECD area and large cross-country differences in the extent of internationalisation. An empirical analysis shows that the degree of technological internationalisation is higher for small countries and for countries with low technological intensity. Finally, two countries are more likely to collaborate if they are close to each other, if they have a similar technological specialisation and if they share a common language. Being member of the European Union involves more cross-border ownership but does not entail more research co-operation than it is implied by the above factors. Nordic countries have a particularly high propensity to collaborate together.

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1. **Introduction**

The internationalisation of research and development (R&D) and innovative activities is an important component of the ongoing trend towards globalisation of the economy. As industrial operation itself is increasingly conducted on a global basis (markets for goods and capital are more and more international in scale), technological activities are also involved in the globalisation trend, although they are probably somewhat lagging behind external trade of international investment in production facilities. At a high level of generality, the internationalisation of technology means that inventions, the people generating these inventions, and the ownership of these inventions tend to cross national borders more frequently. Technology invented in one country can be put in use in another country. Scientists and engineers born in one country graduate and get a job in another country, while possibly returning back to their home country after a while. Firms located in different countries set up alliances for research and development. Among the various dimensions of the internationalisation of technology this study focuses on two of them: cross border ownership of technology (an invention made in country A is owned by a firm based in country B), and the international generation of knowledge (co-operation between industrial R&D laboratories located in different countries).

An increasing share of technology is owned by firms from a different country than the one of the inventors (which mainly reflects the fact that companies have research facilities abroad). The importance of this phenomenon is not really new. Comparing US patents granted in 1969-72 and in 1983-86, Cantwell (1989) reported an increasing share of patents with the owner and inventor located in different countries. Data reported below show that this trend is continuing. Why do multinational firms have research facilities abroad? A first answer is that this is an accident, resulting from cross-borders mergers and acquisitions. When two firms of different nationalities, both equipped with research labs merge they end up with one firm owning research facilities abroad, even if there is no special technological strategy behind. This is apparently a common case (Patel, 1995). However, there may be also special purposes for a multinational firm to locate some of its research facilities abroad (Niosi, 1999). First is the will to adapt its products to local markets and to provide technological support to local subsidiary. Such technology transfer benefits first the recipient country. Second is the will to monitor new technology developments occurring in foreign countries, to “tap” foreign technology. It is not enough to read technical journals to keep pace with advancing technology, it is also necessary to be part of researchers networks, which means to be active in research in the areas of interest. By going directly to the places with more expertise in a given technological field the firm is able to penetrate at a lower cost such networks. Third is an attempt to develop special technology in which the recipient country has comparative advantage and which complements the firm’s core technology. The second and third mechanisms are also some kind of technology transfer, from the recipient country to the investing one. While the first two mechanisms have found some empirical confirmation, the third one has not (see Patel and Vega (1999), Dunning and Wymbs (1999) and Lichtenberg and van Pottelsberghe (forthcoming)).

However internationalisation of technology is not restricted to ownership and transfers: it further extends to the very generation of knowledge, as researchers based in different countries co-operate on the same projects and jointly invent new devices.[1] It is widely accepted that, as a public good, knowledge diffuses across borders: but its generation is also increasingly organised on an international basis. Thanks to decreasing communication costs the cost of networking is reduced, and due to increasing specialisation of researchers the benefits from networking are getting bigger. International co-operation facilitates the convergence of various sources of knowledge that is necessary to generate new technology in many fields (e.g. biotech, which requires both biology and computer science), as specialised expertise is often available in different countries.

This study explores measurement and analytical issues relating to the internationalisation of technology, based on patents data. We present and analyse three new patent-based indicators of internationalisation of technology. These indicators are calculated at the level of countries, for each of the 29 OECD member countries. They relate to the research activity abroad of domestic multinational firms, to the domestic activity of foreign multinational firms and to international co-operation in research. We are primarily concerned with the following issues: What are the advantages and drawbacks of these indicators?

Are they different from other indicators of internationalisation of technology (e.g. R&D abroad of multinational firms) or do they convey consistent messages? Has the internationalisation of technology increased over the past 15 years? Does it affect all countries to a similar extent?

This paper also analyses the factors that affect the degree and the pattern of internationalisation of technology: Does the size (GDP) and technological intensity of a country affect its degree of internationalisation? Which countries are relatively open (closed) to foreign technology when other factors are controlled for? Does technological proximity, geographical distance, and other country specific factors affect the geographical distribution of internationalisation (i.e. with which partner will a country have more linkages?).

The country level approach taken in this study complements the company level approach taken in most of the literature in this field. The company approach is able to capture aspects such as the industry to which the concerned actors belong, it is non ambiguous on the nationality of the patentee (the firm) at one point in time. Hence, the country level approach cannot address issues such as how does internationalisation relates to the corporate strategy (e.g. is multinational firms' research abroad related to their core activities or to complementary activities?), which is treated in depth in certain firm level studies (e.g. Zander (1995) or Cantwell and Jane (1999)). On the other hand, the country approach is exhaustive, as all patents are treated, whoever the patentee, instead of a selection of large companies. It further allows to cover more countries and to give for each country a more complete picture of internationalisation. Moreover, the boundaries of countries are generally stable over time, contrary to those of firms, which facilitates time consistency in the treatment of the nationality of patentees.

The study has been performed on a data base of patents applied to the European Patent Office (EPO) over the periods 1985-1987 and 1993-1995. A few tests reported below show that results are similar when based on patents granted by the USPTO . The next section defines the various concepts of internationalisation and presents their trends at the OECD wide level. Section 3 describes the country patterns of internationalisation of technology and compares the patent-based indicators with other indicators of internationalisation. Sections 4 and 5 evaluate empirically the determinants of the extent of

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[1] See Archibugi and Iammarino (1999) for a useful taxonomy of the globalisation of innovation.

internationalisation and of the geographical distribution of internationalisation, respectively. Concluding remarks are reported in section 6.

2. Concepts and global trends

Patents are increasingly recognised as a rich source of information regarding technological performance.[2] Among the information available from patent files are the inventor and the applicant (the owner of the patent at the time of application) addresses, hence their countries of residence. When statistically elaborated, this information allows to map some aspects of the internationalisation process. The advantages of patents in this area are their broad availability (available for all countries in the world), international comparability (when a few sources of bias are dealt with), and possibilities to be matched with other types of data (e.g. firm level, country or industry level). Their major drawback is a difficulty to interpret, in some cases, the meaning of the indicators -i.e. which underlying activity is actually reflected in the patent.

Patents that are of interest for measuring internationalisation of technology are those with several applicants from different countries, or several inventors from different countries, or an applicant and inventor from different countries. Mapping these populations of patents and comparing them to other patents is the purpose of the indicators which are presented in the next paragraphs.

Cross-border ownership of inventions happens when at least one inventor and the applicant reside in different countries. It is deemed to reflect the location of R&D activities of multinational firms. For most EPO patents (a share usually estimated to be higher than 90%), the applicant is an institution (a firm, a university, a public laboratory). The inventor is always an individual, usually a researcher employed by the applicant. Most often, the address of the inventor is the address of the laboratory he/she works in. Then, when the inventor and the applicant of a patent don't reside in the same country, this reflects in a

[2] For the strengths and weaknesses of patents as indicator of innovative output, see Griliches (1990) and for the use of patent data as indicator of technological specialisation, see Archibugi and Pianta (1992).

huge majority of cases the fact that the patent protects an invention performed in a research facility abroad of a multinational firm. Two indicators have been calculated based on this data, which mirror each other:

- SHIA is the share for a given country of patents with a domestic inventor and a foreign applicant in the country's total domestic inventions. It reflects the extent to which foreign firms control (own) domestic inventions. Algebraically: PF_{ij}^{IA} is the number of patents[3] invented by the residents of country *i* and at least partly owned by the residents of country *j*. $PF_{i.}^{IA} = \sum_{j \neq i} PF_{ij}^{IA}$ is the total fractional number of patents invented by the residents of country *i* and controlled by foreign residents. $SHIA_i = PF_{i.}^{IA} / PFI_i$ is the share of patents controlled by foreign residents in the total fractional number of patents invented by residents (*PFI*).
- SHAI is the share for a given country of patents with a foreign inventor and a domestic applicant in the country's total domestic applications. It reflects the extent to which domestic firms control foreign inventions. Algebraically: PF_{ij}^{AI} is the number of patents owned by the residents of country *i* and at least partly invented by the residents of country *j*. $PF_{i.}^{AI} = \sum_{j \neq i} PF_{ij}^{AI}$ is the total number of patents controlled by the residents of country *i* and invented by foreign residents. $SHAI_i = PF_{i.}^{AI} / PFA_i$ is the share of patents invented by foreign residents in the total fractional number of patents controlled by residents (*PFA*).

International collaboration in science and technology takes place when a patent has several inventors residing in different countries. This kind of international collaboration between researchers can take place either within a multinational corporation (research facilities in several countries), or through a research joint venture between several firms. It is reflected by the following indicator.

[3] Patents are counted fractionnally: when a patent has several inventors residing in different countries, it is "shared" between these countries, each of which is attributed a fraction that corresponds to its share in the number of inventors. For instance, if a patent has two inventors from country A and three inventors from country B, then country A's number will be 0.4 and country B's will be 0.6.

- SHII is the share for a given country of patents with a foreign resident as co-inventor in the population of patents with a domestic inventor. Algebraically: P_{ij}^{II} is the number of patents co-invented by residents of country *i* and residents of country *j*. $P_{i.}^{II} = \sum_{j \neq i} P_{ij}^{II}$ is the total number of patents invented by the residents of country *i* in collaboration with foreign researchers. $SHII_i = P_{i.}^{II} / PI_i$ is the share of patents resulting from international research co-operation in the total number of patents invented by residents of a given country (*PI*).

Table 1 presents some illustrative examples of patents concerned with the three indicators. The four patents listed have been granted by the USPTO. They all represent a situation of cross-border ownership. The patents owned by Colgate Palmolive (United States) and Alcatel Alsthom CGE (France) witness a cross-border ownership of invention made by Belgian and German inventors, respectively. One example of both international co-operation between inventors and cross-border ownership is provided by the Microsoft patent, which was invented by researchers with residence in different countries (Franco-US collaboration). The fourth patent illustrates the three types of internationalisation altogether. It is co-owned by a US Hospital and a Belgian University (i.e., an international co-application) and has been invented by two researchers with a Belgian residence and one researcher with residence in the US.

***** Insert table 1 around here *****

These various indicators are not independent from each other. For instance, all patents with co-inventors residing in different countries will also have, for at least one of the concerned countries, a foreign applicant. As a consequence, any patent counted in SHII for a country will also be counted either in SHIA or in SHAI for this country. Analysing the share of co-inventions in the population of foreign owned patents allows to analyse the extent to which cross border ownership favours international circulation of knowledge. Another feature is that world wide SHIA is equal to SHAI. This fact does not preclude large differences between the two indicators at the country level.

An indicator similar to SHAI has been proposed by the University of Reading, relying on patent count data obtained from the Science Policy Research Unit (SPRU; see especially Patel and Pavitt (1991, 2000), Dunning (1994) and Dunning and Wymbs (1999)).This indicator has been computed with data on the patents registered in the US by 727 of the world's largest firms. It reflects the share of US patents filed by these firms attributable to research in foreign locations (outside the home country of the parent company). Contrary to SPRU, we use all patents (including those filed by small firms, large domestic firms, public institutions, universities, etc….), which means that the degree of internationalisation of a country is represented more completely. However, identifying the owner firm as SPRU does -and as we don't- allows to identify the actual owner of the patent, beyond the direct owner: hence, foreign affiliates of multinational firms can be identified and treated as such, which is not the case in our approach.[4]

The indicators proposed here should be considered as lower-bounds indicators of internationalisation of technology. A major factor of under-estimation of actual internationalisation in our data is related to the increasing tendency, since the early 1980s at least, of cross-border mergers and acquisitions (M&A). As underlined by Dunning (1994), an important *raison d'être* for the growing share of these M&As is to acquire the innovative capacity of the targeted firms. Patent databases do not register such changes in ownership of patents.

What do these indicators tell us? The time trends of the indicators of internationalisation of technology at the OECD-wide level are pictured in graph 1. Over the 1980-1995 period, the degree of international R&D collaboration (SHII, the share of patents involving at least two inventors from different countries) has more than doubled, from 2.1% in 1980 to 4.7% in 1995. That is, almost 5 out of 100 patented inventions in the OECD area are the fruit of international research collaboration. However, the cross country average share of patents co-invented with foreign residents in OECD countries is almost 10% (the cross country average share is higher than the OECD-wide share since in the latter case there is some clearing: each patent co-invented in several countries is counted once only whereas in the former case it is counted *in each country*).

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[4] It is worth mentioning that the cross country and cross industries differences observed with the SPRU indicator are

***** Insert Graph 1 around here *****

The share of cross-border ownership (at the OECD-wide level SHIA is equal to SHAI by construction) has been quite stable in the 1980s, fluctuating around 8.5% of the OECD patents. From 1990 onwards, cross-border ownership of inventions has grown steadily to reach a share of 12% of OECD patents. In other words, more than one out of 10 patent applied to the EPO is subject to cross-border ownership. That is less than the share of foreign affiliates of multinational firms in R&D expenditure, which averages about 15% OECD-wide: but it still high, and moreover it is increasing rapidly.

3. Country patterns of internationalisation of technology

Beyond these global trends, countries display various patterns of internationalisation, as reported in table 2. Four observations can be drawn from this table.

First, there is a striking heterogeneity across countries. Very few inventions made in Japan are controlled by foreign firms, invented in co-operation with foreign researchers, or controlled jointly with foreign applicant. Similarly, only few inventions controlled by Japanese residents are invented abroad. With the exception of Japan, it is clear that a significant proportion of patents are subject to cross-border ownership and international collaboration. Amongst the largest countries, the United Kingdom is characterised by a relatively high degree of internationalisation of its technology, with ratios ranging from 11 to 20 per cent. Smaller countries (such as Belgium, Austria and Ireland) and/or less developed countries (Turkey, Mexico, Poland) are highly internationalised. It is already well known that small economies are more internationalised than large one in terms of trade as well as foreign direct investment. It turns out that this applies to technology as well. The "technological size" of a country (measured for instance by the number of patents with a domestic inventor or applicant) seems to have a close relationship with its degree of internationalisation. Concerning the share of research co-operation, this may partly be explained by the

similar to the those observed with SHAI.

fact that each researcher from a small country has fewer local colleagues in the field and must therefore look abroad for collaboration.

Second, in most countries the share of domestic inventions owned by foreign firms (SHIA) is substantially higher than the share of foreign inventions in total domestic applications (SHAI). The reverse is true for only eight countries. This is due to concentration of ownership of cross-border patents in the hands of a few countries. Actually, three countries are the largest owners of patents covering foreign inventions: the United States (although, because of its size, the *share* of foreign inventions is just above the OECD average: but the *level* is high), the Netherlands, and Switzerland. These are also countries with well-known, strong multinational firms.

***** Insert Table 2 around here *****

Are these observations specific to EPO patents, or do they apply to other types of patents? A test on patents granted by the USPTO (see the last three columns of table 2) shows that overall the country patterns are similar. Cross-country correlation between USPTO and EPO indicators is 0.65 (SHIA), 0.95 (SHAI) and 0.74 (SHII). However there seems to be a systematic bias between the two sources. Patents filed by residents from European countries are much more internationalised at the USPTO than at the EPO. For instance, almost 20 per cent of patents invented by residents of the European Union and granted by the USPTO are controlled by non-EU residents, against less than 7 per cent with EPO applications. The reverse holds for residents from the United States, Canada, Korea and Mexico. There may be two reasons for this: the higher "proximity" of the EPO (USPTO) to European (non-European) countries leads them to patent there their purely domestic inventions to a larger extent than in other patent offices ("home advantage"). It may also happen that patents resulting from co-operation between US residents and non-US/non-European residents are more often patented at the USPTO than at the EPO.

Cross industries differences[5] are reported in table 3. The variance is significantly lower across industries than across countries, suggesting that the internationalisation of technology is more related to country peculiarities than to technological ones. Four sectors are nevertheless highly internationalised:

Chemicals, Oil refining, Drugs, and Food and beverages. Shipbuilding and Aerospace, two sectors generally considered to be subject to special government attentions are the least internationalised. These differences across industries confirm the findings of Dunning and Wymbs (1999). Their survey of the world largest multinationals shows that pharmaceutical firms obtain more of their competitive advantage from foreign sources than other sectors, whereas firms from the aerospace sector rely the most on domestic sources.

***** Insert Table 3 around here *****

To which extent does cross-border ownership of patents reflect the circulation of knowledge or, instead, "purely financial" relationship? One way of addressing this question is to analyse the population of internationally owned patents from the point of view of co-inventions and co-applications. The underlying assumptions are that co-inventions reflect circulation of knowledge, whereas co-applications are more on the financial side. The breakdown of internationally owned patents shows that more than 40 % involved international research co-operation in 1995, against 30% in 1985. That is, international ownership increasingly involves international circulation of knowledge.

How similar to each other are the three patent-based indicators of internationalisation of technology? And are they similar to other indicators of internationalisation? In other words, do the different dimensions of internationalisation go together, so that certain countries are more opened than others in all respects -or conversely, are the different dimensions of internationalisation substitute to each other, allowing different patterns of internationalisation to exist? Table 4 reports cross-country correlation between these indicators. All pairs of indicators related to the internationalisation of inventions are significantly correlated with each other. The highest correlation (0.83) is for the pair SHII/SHIA: the higher a country's share of domestic inventions controlled by foreign companies, the more it collaborates with foreign countries.

***** Insert table 4 around here *****

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[5] We used the OST/MERIT concordance table between IPC, the international patents classification, and ISIC/rev 2, the international standard industry classification.

The three indicators (especially SHIA) are highly correlated with the share of production by affiliates of foreign owned firms in total domestic production. Only SHIA and SHII have a significant correlation with the share of foreign affiliates in total domestic R&D expenditure. That is, international collaboration and foreign ownership of domestic inventions are closely related to the innovative activities of foreign affiliates.

The share of technology payments in GDP is also significantly correlated with the three patents indicators, and especially with the share of foreign inventions in total applications by residents (SHAI). The higher the share of foreign inventions in applications owned by residents from a given country, the larger the technology payments of this country (which probably correspond to various types of funding of inventors). All patent-related indicators are positively correlated with openness to external trade (imports and exports relative to GDP). The only indicators that do not seem to provide similar pictures of internationalisation are FDI (both inward and outward) and technology receipts.

Finally, the last row of table 5 shows that SHII and SHIA are negatively correlated with the *number* of patents invented by residents (the number of patents reflects the *level* of technological activity). The smaller the "technological basis" of a country, the higher the share of this basis which is controlled by foreign applicants, and the more this country's residents are likely to collaborate with foreign researchers. This "size effect" probably increases the correlation of patents indicators with openness to trade: smaller countries are generally more internationalised on all aspects of their economy. A small size involves a relatively narrow range of activities (higher specialisation), therefore a deeper insertion in international division of labour. The next section partly tackles this issue within an econometric analysis.

4. The determinants of technological internationalisation of countries

What are the common determinants of the openness of countries to foreign technology? The few studies on the determinants of internationalisation of technology have essentially focused on the share of foreign R&D, at the firm level (see the survey by Granstrand et al. (1992)). The major determinants are the age of the firm, its size, its stage of corporate development and its international pattern of manufacturing. We shall focus on two main factors for each country: the relative level of technological endowment, proxied by the research intensity (GERD/GDP ratio), and the size of the country (GDP). Both variables are taken in logarithmic form, in order to capture non linear effects. The empirical model has the following form:

$$SHXX_i = c + \beta \log\left(GDP_i\right) + \alpha \log\left(IRD_i\right) + e_i \qquad (1)$$

where SHXX (XX = IA, AI, II) is the indicator of internationalisation , *c* is an intercept, *e* is the error term, α and β are the parameters to be estimated, *i* is the country index. Table 5 reports the econometric estimates for each of the three indicators (with EPO patents). The first part of the table shows the results with 27 OECD countries and the second part with the 21 countries with at least 150 patents invented over the period 1993-95. The third part of table 5 presents similar estimates for the period 1985-87. In all cases, the withdrawal of 6 countries from the sample and the consideration of an earlier period do not affect substantially the sign and significance of the parameters, which witnesses the robustness of the estimates. Similar regressions have been run on USPTO patents, with almost identical results (Annex table A1). These results lead to the following observations (focusing mainly on the first part of Table 5).

***** Insert Table 5 around here *****

The three estimations are of uneven statistical quality: The various types of internationalisation do not seem to respond to the same determinants. However, in all cases the effect of GDP is negative (although not always significant), showing that smaller countries are more internationalised than larger ones *ceteris paribus*, as expected. Similarly, R&D intensity has a negative impact on SHII and SHIA, a positive one on SHAI. The extent of collaboration with foreign researchers (SHII) is very well explained (adjusted R2 = 0.66) by the model. The higher (lower) the R&D intensity of a country, the less (more) its researchers enter into collaboration with foreign colleagues. Low R&D intensity and small countries rely more on external co-operation due to their weaker own capabilities, thus benefiting from knowledge flows from abroad.

SHIA (which is also quite well explained by the model, with an adjusted R2 equal to 0.36) tends to decrease with R&D intensity: the higher (lower) the relative R&D spending of a country, the lower (higher) is the share of its residents' invention that is controlled by multinational firms. In other words, national control over domestic inventions increases with domestic inventive effort. There is only a small (statistically insignificant) negative effect of GDP. SHAI is less well explained by the model. The size of a country is a negative and significant determinant of the extent to which it controls foreign inventions, whereas its technological intensity is a positive but not significant determinant. The smaller a country is, the higher is the share of inventions it owns that are invented abroad. This asymmetry between SHIA and SHAI was even more pronounced in the mid eighties, when a higher technological level was synonymous with a larger amount of foreign inventions controlled domestically. In a nutshell, the more a country is intensive in research, the less its own inventions are controlled by foreign firms and the less it enters into international research co-operation. The larger the country, the lower is its share of patent applications that have been invented abroad and the lower is its propensity to enter into international co-operation.

The asymmetry between SHIA and SHAI tend to confirm the idea that the firms based in leading edge countries exploit their technological advantage more through foreign acquisition (cross border ownership), i.e. through SHAI. The negative sign of the relationship between SHIA and R&D intensity does not support the argument that leading edge countries are being "techno-sourced", at least not through foreign ownership of their own invention facilities.

When size and technological intensity are controlled for, differences remain across countries in their degree of internationalisation. Some are more internationalised than predicted by the model, others are less. Other country specific factors seem to be at work. Table 6 reports for SHII and SHIA the countries whose actual degree of internationalisation is well above (or under) the predicted values[6]. Results are fragile for countries with few patents and are not reported.

***** Insert Table 6 around here *****

[6] Predicted values result from simulating the model with each country's actual variables (GDP, R&D intensity).

Among larger patenting countries, the United Kingdom, Belgium, Canada and the United States have a higher than predicted share of their domestic inventions owned by foreigners, the reverse being true for Finland, Korea, Italy and Japan. For international co-operation in research, the United States, Switzerland and Canada rank much higher than their size and R&D intensity would have lead to predict, whereas Italy, Finland and Japan are below their predicted value. The estimated parameters have been applied to the aggregate R&D intensity and GDP of the European Union. The predicted value of SHII is well above its actual value, which means that Europe as a whole (net of intra-zone collaboration) is less opened that its size and technological intensity would lead one to predict. Finally, Japan, although still shown as little internationalised in this analysis, does not appear as the most insulated OECD country as it is when size and R&D intensity are not controlled for: being a big and R&D intensive country contributes to Japan's low degree of openness, although it does not explain it entirely.

5. Who mates with whom?

This section addresses the geographical distribution of the internationalisation of technology: with which partners do each country tend to co-operate more, and less? For instance, regarding the patents invented by residents and owned by foreign applicants (SHIA), the share of US residents is higher in non-European countries, except Ireland and the United Kingdom. The share of Japan is higher in Korea, Australia and the United States (but this is partly a statistical artefact since the United States is not partner to… the United States, which tends to inflate the share of all countries in the United States as compared to their share in other countries). In European countries (except the United Kingdom, Ireland and Luxembourg), the highest share of foreign owned patents goes to other European countries. Similar patterns appear for SHAI and SHII.

In order to control for the size effect (i.e. the United States is the largest partner to all countries, simply because it is the biggest patenting country of all) an index of "revealed geographical distribution" (RGD) has been computed for each of the three indicators of internationalisation of technology. This index is similar, in spirit, to "revealed comparative advantages" that international economists are familiar with. Basically, it is country *j*' share in country *i*'s foreign relationships relative to its share in OECD. For instance, it is the share of German residents in French inventors' patents owned by foreigners, divided by German's residents share in total OECD foreign owned patents. Algebraically, we have :

- The RGD of foreign ownership of domestic inventions is equal to the share of country *j* in country *i*'s patents owned by foreign residents divided by the share of country *j* in the world wide patents subject to cross-border ownership: $RGD\_IA_{ij} = \left[PF_{ij}^{IA} \big/ PF_{i.}^{IA}\right] * \left[PF_{.j}^{IA} \big/ PF_{..}^{IA}\right]$.
- The RGD of domestic ownership of foreign inventions is equal to the share of country *j* in country *i*'s patents owned by foreign resident divided by the share of country *j* in the world wide patents subject to cross-border ownership: $RGD\_AI_{ij} = \left[PF_{ij}^{AI} \big/ PF_{i.}^{AI}\right] * \left[PF_{.j}^{AI} \big/ PF_{..}^{AI}\right]$. By construction, *RGD_AI* is the transposed matrix *RGD_IA.*
- The RGD of international co-inventions is equal to the share of country *j* in a country *i*'s patents owned by foreign divided by the share of country *j* in the world wide patents subject to cross-border ownership: $RGD\_II_{ij} = \left[P_{ij}^{II} \big/ (P_{i.}^{II} - P_{ij}^{II})\right] * \left[(P_{.j}^{II} - P_{ij}^{II}) \Big/ (\sum_i P_{i.}^{II} - P_{i.}^{II} - P_{.j}^{II})\right]$

These indicators have been calculated for each pair of countries, resulting in three 29X29 matrices.

We identified and tested five factors that may explain the revealed geographical distribution of the different indicators of internationalisation of technology. The first one is the technological proximity (*TP*) between pairs of countries. To measure the proximity of countries *i* and *j*, we use the uncentered correlation of the two countries' distribution vectors of patents across 30 technological classes in 1992-95 (*Fi* and *Fj*), as follows [7] :

$TP_{ij} = F_i F_j' \, / \, [(F_i F_j') \, (F_{ji})]^{1/2}$.

[7] This indicator is similar to Jaffe (1986)'s indicator of technological proximity between US firms.

This indicator is equal to one for the pairs of countries whose technological specialisations are identical, it is equal to zero for pairs of countries whose vectors are orthogonal, and it is bounded between 0 and 1 for all other pairs of countries.

The second explanatory factor is the geographical distance (*DGD*), proxied by a dummy variable taking the value one if countries *i* and *j* have a common border, and 0 otherwise. Then come two particular dummy variables reflecting the fact that countries *i* and *j* are member or not of the European Union (*DEU, included 12 countries for the two sub-periods*), whether they are both Nordic countries (*DNORD*) and whether the they share a common language (*DLANG*), be it English, Spanish or German. These dummies aim at testing whether the common membership to the European Union or common languages (and hence cultural and historical similarities) increase the propensity of firms from two different countries to collaborate with each other. The estimated model has the following form :

$$RGD\_XX_{ij} = c + \beta\ TP_{ij} + \alpha\ DGD_{ij} + \delta\ DEU_{ij} + \psi\ DNORD_{ij} + \rho\ DLANG_{ij} + e_{ij} \qquad (2)$$

where *XX* represents either *IA* (cross-border ownership) or *II* (international co-inventions).[8]

Estimates of the five parameters of interest of equation (2) are reported in table 7 for two sub-periods (1993-95 and 1985-87). They provide fairly good results that lead to the following observations. First, technological proximity matters. The closer two countries are in their technological specialisation, the more they co-operate in research and own patents invented by researchers of the other country. Second, the geographical distance has also a significant effect, for the two types of internationalisation of technology. Countries with a common border enter into cross-border ownership and co-operate more. In the age of globalisation, geography still matters (along with history, which is more shared between closer countries). The common history and relatively weak cultural differences that characterise the Nordic countries is probably the main explanation of the positive and significant parameter associated with *DNORD*.

[8] The 27*27 countries matrix of the revealed geographical distribution indexes of international co-inventions (II) is symmetric and therefore only half of the observations have been used. Regarding cross-border ownership, the matrix for IA (the share of domestic inventions controlled by non-residents) is the transposed of the matrix for AI (the share of patent controlled by residents that are invented abroad) and therefore all observations are used.

***** Insert table 7 around here *****

Third, countries that share a common language co-operate more with each other and have a higher propensity to enter into cross-border ownership. Finally, pairs of countries that are both members of the European Union have slightly more cross border ownership of patents, but not more research co-operation. This positive relationship between cross border ownership and European Union membership appeared between the mid-1980s and the mid-1990s. One interpretation would be that the policies fostering the European integration have stimulated a process of industrial and financial concentration (through M&As) between European firms. Such cross-border consolidation translates into more cross border ownership of patents, as the new firm owns research facilities in different countries. European countries co-operate more with each other than with non-European ones, but not more than their language similarity and their geographical and technological proximity would predict.[9] Hence, industrial and financial concentration has not yet resulted in closer research links: there is not yet real integration of European countries in the field of business R&D.

6. Concluding remarks

This paper presented and analysed three indicators of internationalisation of technology derived from information available in patent data. In accordance with the existing literature, these indicators witness an increasing trend towards the internationalisation of technology of OECD countries. However, there are large differences in the extent of internationalisation across countries. Internationalisation of a country's technological activities decreases with the level of its GDP and with its R&D intensity. Researchers in larger countries find more easily colleagues for partnering in their own country, and countries with higher technological level do not need as much as others co-operation with foreign researchers since their own knowledge base is large. This partly explains the relative insulation of Japan

[9] Other estimates, excluding the smaller patenting countries, led to similar results. For the European Union member countries, the proximity dummy variable accounts for 25% of the European Union dummy; i.e. about 25% of the pairs of EU Member countries share a common border.

for instance. On the other end, the United Kingdom and the United States seem to be more open than their size and research intensity would lead to predict. Language may be part of the explanation, as suggested in results concerning geographical patterns of international co-operation. Another insight from the study is that the major aim of multinational firms when establishing research facilities abroad is to adapt their products to local conditions rather than to "tap" foreign technology: actually, the major stream of R&D investment abroad come from highly R&D intensive countries to low intensive ones rather than the opposite (as it would be the case if technology sourcing was the dominant objective).

Who co-operates with whom is largely explained by geographical proximity and technological proximity (similar specialisation) of the partnering countries. In addition, sharing a common language fosters bilateral links in technology. Pairs of countries that are both members of the European Union have slightly more cross-border ownership than the average, but not more research co-operation than it is implied by their geographical and technological proximity.

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Table A1.
Cross-country analysis of the extent of internationalisation of technology; USPTO

Dependent variables :	USPTO – All countries (NOBS=26)						USPTO – Larger innovators (NOBS=21)					
	SHIA		SHAI		SHII		SHIA		SHAI		SHII	
Constant	1.00		0.65		0.80	*	0.81		1.29		0.65	*
	(2.02)		*(1.28)*		*(2.39)*		*(1.69)*		*(3.10)*		*(2.21)*	
Log (GDP)	-0.06	*	-0.04	*	-0.06	*	-0.5	*	-0.05	*	-0.04	*
	(-3.45)		*(-1.75)*		*(-3.97)*		*(-2.29)*		*(-2.85)*		*(-2.96)*	
Log (IR)	-0.13	*	-0.06		-0.12	*	-0.10	*	0.02		-0.08	*
	(-3.09)		*(-0.82)*		*(-4.04)*		*(-2.93)*		*(0.46)*		*(-3.10)*	
F-test	22.81	*	1.91		20.8	*	8.63	*	4.09	*	9.28	*
Adjusted R^2	0.46		0.07		0.62		0.21		0.20		0.44	

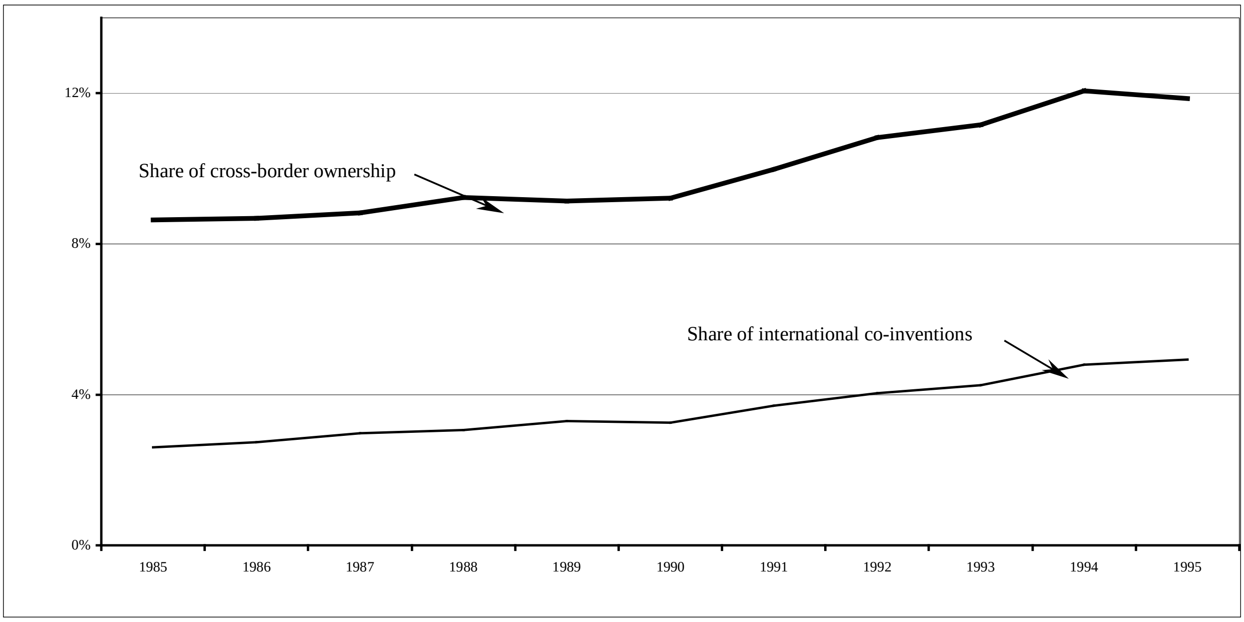
1. OLS estimates, with Heteroskedastic-consistent standard errors; *t-stat.* between parentheses; * indicates the parameters that are significantly different from zero at a 10% probability threshold. There are 26 observations corresponding to the OECD countries; Luxembourg is missing and Turkey and Iceland were dropped from the sample, due to a too small number of patents (8 and 16 patents invented during the 1993-95 period, respectively).

Table 1.
Examples of cross-border ownership and international co-operation.

Appl. No.	APPLICANT Name	APPLICANT Resid.	INVENTOR Resid.	SHIA SHAI	SHII
472,807	Microsoft Corporation	U.S.	France (2) U.S. (1)	X	X
859,431	Colgate Palmolive Comp.	U.S.	Belgium (2)	X	
828,191	Alcatel Alsthom CGE	France	Germany (2)	X	
463,418	General Hospital Corp. Rijksuniversiteit	U.S. Belgium	Belgium (2) U.S. (1)	X	X

Source : USPTO Webb site - http://www.uspto.gov/

Graph 1.
Global trends in the internationalisation of technology



Note: EPO applications, by date of priority.
Sources: OECD Secretariat

Table 2.
Three indicators of internationalisation of technology, by country, priority date 1993-95.

	EPO			USPTO [5]		
(%)	**SHIA [1]**	**SHAI [2]**	**SHII [3]**	**SHIA [1]**	**SHAI [2]**	**SHII [3]**
Australia	11.7	5.3	13.8	23.8	12.6	16.5
Austria	18.4	7.8	14.9	33.6	13.7	27.1
Belgium	31.7	11.8	21.3	51.7	17.6	30.4
Canada	24.0	15.3	19.9	20.8	18.1	15.5
Czech Republic	31.2	5.7	26.8	61.5	0	46.2
Denmark	10.8	9.3	16.1	28.3	21.5	27.0
Finland	5.2	7.6	8.0	8.7	16.3	11.3
France	8.3	5.3	7.9	19.5	9.3	13.0
Germany	6.3	4.5	6.6	15.2	10.2	11.6
Greece	13.1	4.2	22.6	52.0	66.7	52.0
Hungary	11.7	2.3	17.8	50.8	10.0	40.0
Iceland	92.3	16.7	37.1	42.9	0.0	14.3
Ireland	26.5	37.2	21.1	53.1	47.5	36.7
Italy	9.4	2.3	5.8	17.6	7.4	11.8
Japan	2.6	1.5	2.4	3.0	3.0	2.3
Korea	4.5	3.4	8.4	3.1	3.3	2.6
Luxembourg	42.7	80.3	31.7			
Mexico	48.1	9.2	40.4	41.2	20.0	35.3
Netherlands	12.2	30.9	12.6	61.9	44.7	25.1
New Zealand	18.1	8.8	21.1	24.8	10.0	14.0
Norway	12.6	14.2	15.3	21.2	29.6	25.7
Poland	35.5	7.8	34.7	64.1	0	64.1
Portugal	18.5	10.3	25.0	58.3	66.7	41.7
Spain	15.6	4.4	14.7	32.2	14.2	24.9
Sweden	8.4	9.4	9.9	18.4	19.5	14.8
Switzerland	12.4	26.9	18.0	34.7	41.7	30.1
Turkey	61.5	27.8	51.2	100	-	88.9
United Kingdom	20.0	10.7	11.9	38.8	18.9	22.6
United States	5.0	8.7	6.8	2.6	8.6	3.7
European Union	6.5	3.7	5.1	18.9	3.5	9.4
OECD	11.7	11.7	4.7	7.2	8.4	6.2

1. Share of patent applications at EPO (USPTO) owned by foreign residents in total patents invented domestically (%).
2. Share of patent applications at EPO (USPTO) invented abroad in total patents owned by country residents (%).
3. Share of patent applications at EPO (USPTO) with at least one foreign co-inventor in total patents invented domestically (%).
4. The figures for the USPTO correspond to the date of grant 1998 (approximately 1993-1996 for the date of priority).

Source: OECD Secretariat.

Table 3.
Three indicators of internationalisation of technology, by sector, 1993-95.

	SHIA & SHAI	SHII
Electric mach.,ex.electronics	7.2	5.0
Electronics	7.3	5.1
Chemistry, except pharmacy	10.7	12.6
Pharmacy	8.8	14.7
Oil refining	11.6	10.6
Ship building	3.0	1.4
Motor vehicles	6.4	4.6
Aerospace	2.0	1.2
Other transport	5.1	4.4
Ferrous basic metals	6.4	8.5
Nonferrous basic metals	3.7	6.0
Metal products, ex.machines	6.3	5.1
Instruments	6.5	6.4
Computers & office machines	5.6	3.5
Other machinery	6.9	5.9
Food, beverages, tobacco	11.9	15.1
Textiles, clothes, etc.	7.2	5.9
Rubber and plastic products	7.5	5.9
Stone, clay and glass products	8.0	8.0
Paper, printing and publishing	7.5	7.7
Wood and furniture	4.2	2.8
Other industrial products	6.8	5.5

Note. Cf. table 2 for definitions. Source: OECD Secretariat.

Table 4.
Cross country correlations between indicators of internationalisation

	#	SHIA	SHAI	SHII
Patent data				
SHIA	20		0.47 *	0.83 **
SHAI	20	0.47 *		0.55 *
SHII	20	0.83 **	0.55 *	
Activities of foreign affiliates				
Share of foreign output (SHFP)	12	0.86 **	0.83 **	0.83 **
Share of foreign R&D (SHFR)	11	0.90 **	0.56	0.89 **
Foreign direct investments				
Share of inward FDI (SHINF)	20	0.25	0.13	0.32
Share of outward FDI (SHOUF)	20	0.01	0.41	0.07
Technology balance of payments				
Share of TBP Receipts (SHINTBP)	17	0.42	0.33	0.41
Share of TBP payments (SHOTBP)	17	0.55 *	0.74 **	0.51 *
International trade				
Share of imports in GDP (MGDP)	20	0.76 **	0.69 **	0.72 **
Share of exports in GDP (XGDP)	20	0.69 **	0.75 **	0.66 **
Number of domestic inventions	20	-0.45 *	-0.24	-0.62 **

Note: Correlation across 20 OECD countries with at least 200 patents invented over the period 1993-95.
# indicates the number of available observations for each variable; SHIA the share of domestic inventions with foreign applicants; SHAI the share of domestic applications with foreign inventors; SHII the share of domestic inventions with at least one foreign inventor; SHFP the share of domestic output produced by foreign firms; SHFR the share of domestic R&D in foreign firms; SHINF the share of inward FDI in gross fixed capital formation; SHOUF the share of outward FDI in gross fixed capital formation; SHINTBP the share of technology receipts in GDP; SHOTBP the share of technology payments in GDP; MGDP the share of imports in GDP; and XGDP the share of exports in GDP; * indicates the coefficients that are significant at a 5% probability threshold; ** at a 1% probability threshold.

Table 5.
Cross-country analysis of the extent of internationalisation of technology; 1993-95, 27 countries.

	EPO, 1993/95 (nobs = 27)			EPO, 1993/95 (nobs = 21)			EPO, 1985/87 (nobs = 26)		
Dependent variables :	**SHIA**	**SHAI**	**SHII**	**SHIA**	**SHAI**	**SHII**	**SHIA**	**SHAI**	**SHII**
Constant	0.22	1.67 *	0.27	-0.25	0.85 *	0.07	0.04	1.81 *	0.14
	(0.46)	*(1.90)*	*(1.01)*	*(-0.95)*	*(2.37)*	*(0.30)*	*(0.10)*	*(2.13)*	*(0.84)*
Log (GDP)	-0.02	-0.06 *	-0.03 *	-0.01	-0.03 *	-0.02 *	-0.01	-0.07 *	-0.01 *
	(-1.41)	*(-1.74)*	*(-2.74)*	*(-1.14)*	*(-2.06)*	*(-2.52)*	*(-1.04)*	*(-1.9)*	*(-2.27)*
Log (IR)	-0.10 *	0.08	-0.09 *	-0.15 *	0.02	-0.11 *	-0.09 *	0.09 *	-0.06 *
	(-2.00)	*(1.57)*	*(-3.31)*	*(-5.03)*	*(0.77)*	*(-3.66)*	*(-2.32)*	*(2.33)*	*(-3.53)*
F-test	6.51 *	1.61	23.3 *	19.4 *	2.3	27.0 *	9.48 *	2.7 *	17.8 *
Adj-R^2	0.36	0.23	0.66	0.59	0.12	0.67	0.40	0.38	0.49

1. OLS estimates, with Heteroskedastic-consistent standard errors; *t-stat*. between parentheses; * indicates the parameters that are significantly different from zero at a 10% probability threshold. There are 27 observations corresponding to the OECD countries; Turkey and Iceland were dropped from the sample, due to a too small number of patents (8 and 16 patents invented during the 1993-95 period, respectively). During the period 1985/87, the Czech Republic had no patent filed at EPO.

Table 6.
Countries with degree of internationalisation above or under the predicted level.[1]

	SHIA	SHII
Above prediction	UK [0.96] Belgium [0.91] Luxembourg [0.83] Canada [0.73] Mexico [0.53] USA [0.43]	USA [1.57] Switzerland [0.50] Canada [0.49]
Under prediction	Finland [-0.66] Korea [-0.57] Greece [-0.57] Hungary [-0.55] Italy [-0.43] Japan [-0.43]	Italy [-0.63] Finland [-0.47] Japan [-0.39] (EU [-0.7])

1. The ratio of the error of prediction to the predicted value of the dependent variable is shown between bracket, computed from the results presented in table 5, with 27 countries. The countries listed are those for which the ratio is the highest or the lowest (0.4 was selected as a threshold value).

Table 7.
The determinants of the revealed geographical distribution of internationalisation.

	1993/95 RGD - IA				1993/95 RGD - II				1985/87 RGD – IA		1985/87 RGD - II	
Technological proximity	12.07	*	11.58	*	7.33	*	6.86	*	3.74	*	7.08	*
(TP)	*(4.62)*		*(4.33)*		*(3.34)*		*(3.14)*		*(5.06)*		*(4.75)*	
Common borders *(DGD)*	3.40	*	2.11	*	4.05	*	2.83	*	2.19	*	2.85	*
	(3.28)		*(1.87)*		*(4.52)*		*(2.99)*		*(6.65)*		*(4.00)*	
European Union *(DEU)*			1.47	*			0.06		0.10		-0.09	
			(1.68)				*(0.08)*		*(0.39)*		*(-0.16)*	
Nordic countries			5.78	*			7.65	*	3.72	*	4.60	*
(DNOR)			*(2.31)*				*(3.58)*		*(5.40)*		*(3.02)*	
Common language			2.52	*			3.12	*	1.77	*	2.13	*
(DLANG)			*(1.72)*				*(2.48)*		*(4.30)*		*(2.36)*	
Chi2 (4)	42.30	*	51.32	*	39.31	*	57.30	*	176.95	*	83.29	*
Observation number	676		676		351		351		600		325	
Number left censored	337		337		136		136		328		157	

Left-censored Tobit estimates (lower bound at zero); all regressions include an intercept. Include 27 OECD countries, Turkey and Iceland not included because less than 20 patents invented during the period 1993-95. * indicates the parameters that are significant at a 10% probability threshold.