International Centre for Innovation Technology and Education

Solvay Brussels School Economics & Management

ULB

GLOBALIZATION OF INNOVATION PRODUCTION:

A PATENT-BASED INDUSTRY ANALYSIS

Author

Jérôme Danguy, Université Libre de Bruxelles, ECARES - iCite – SBS-EM

iCite Working Paper 2014 - 009

iCite - International Centre for Innovation, Technology and Education Studies
Université Libre de Bruxelles – CP 146
50, avenue F.D. Roosevelt – B-1050 Bruxelles – Belgium
www.solvay.edu/iCite

Globalization of Innovation Production: A Patent-Based Industry Analysis*

Jérôme DANGUY

Université libre de Bruxelles

Solvay Brussels School of Economics and Management (ECARES and iCite)

jdanguy@ulb.ac.be

February 2014

Abstract

Using patent-based indicators, this paper aims at explaining to what extent the production of innovation is globalized. Firstly, it provides evidence – over time, across countries and across industrial sectors – on the patterns in international technological collaboration and in cross-border ownership of innovation. Secondly, a fractional logit model is estimated for a unique panel dataset covering patent information of 21 industries in 29 countries from 1980 to 2005. The results show that countries tend to be more globalized in industrial sectors in which they are less technologically specialized. It suggests that globalization of innovation is more driven by home-base augmenting determinants than home-base exploiting ones. The empirical findings also indicate that the intensity of globalization of innovation is higher in multidisciplinary country-industry pairs and in those which compete internationally in trade.

Keywords: internationalization, R&D collaboration, patent statistics, industrial sectors

JEL classification: F21, F23, O14, O30

*I am grateful to Michele Cincera, Gaétan de Rassenfosse, Julien Gooris, Malwina Mejer, Pierre Mohnen, Carine Peeters, Lorenzo Ricci, Russell Thomson, Bruno van Pottelsberghe and Nicolas van Zeebroeck for helpful comments and discussions. This paper has also benefited from the comments of the participants of the 2012 Offshoring Research Network International Conference (Milan), the 7th EPIP Annual Conference (Leuven) and the Third Asia Pacific Innovation Conference (Seoul). I also acknowledge financial support from the Fonds National de la Recherche Scientifique (FNRS).

1 Introduction

At the crossroads of the rising importance of knowledge economy and the increasing international integration of economic activities, the globalization of innovation is a major concern. Compared to the globalized markets of goods and services, the technology production has been often described as "far from globalized" (Patel and Pavitt, 1991) and mainly concentrated in the home country (Belderbos et al., 2011) of multinational enterprises (MNE). However, international organizations recognize that research & development (R&D) activities are increasingly performed across borders (UNCTAD, 2005; OECD, 2008; UNESCO, 2010).

Various evidences illustrate this strong increasing trend in international collaboration in the innovation production. In a world of science which is becoming multipolar (Veugelers, 2010) – with the rise of emerging countries such as China and India – the increasing importance of teams in the production of knowledge is undeniable (Wuchty et al., 2007). In view of the complexity and interdisciplinarity of research, innovative firms collaborate more to access complementary resources from beyond their boundaries (Miotti and Sachwald, 2003; Cassiman and Veugelers, 2006). International technological collaborations matter to enhance the diffusion of relevant knowledge required to innovate in many technological fields but often available in different locations. These worldwide collaborations are thus a key channel of knowledge spillovers (Singh, 2005; Montobbio and Sterzi, 2012).

This paper aims at explaining, using patent-based indicators, to what extent the production of innovation is globalized. Firstly, it provides evidence – over time, across countries and across industrial sectors – on the patterns in the internationalization of innovation for two patent count indicators. Rich patent data allow us to distinguish between several types of internationalization in the production of innovation[1], looking into the trends not only in terms of international technological collaboration, but also concerning the cross-border ownership of innovation. Secondly, a fractional logit model is estimated – using a unique panel dataset covering 21 industries in 29 countries over 25 years – to investigate empirically the importance of two main opposing motives explaining the internationalization of innovation: home-base augmenting and home-base exploiting strategies (Kuemmerle, 1997).

Many studies have explored those questions within a firm level approach mainly focusing on a restricted sample of multinational firms (Patel and Pavitt, 1991; Cantwell, 1995; Patel and Vega, 1999; Cantwell and Janne, 1999; Kumar, 2001; von Zedtwitz and Gassmann, 2002; Narula and Zanfei, 2005; Cantwell and Piscitello, 2005; Fernández-Ribas and Shapira, 2009; Athukorala and Kohpaiboon, 2010; Schmiele, 2012). In my study, I opt for a more general approach aggregating information contained in a large patent database. This kind of approach is more exhaustive, as all patented inventions are treated, whoever the owner. Although it prevents us to take into consideration drivers of globalization that are firm-specific, it allows us to give a more complete picture of internationalization of innovation by covering more countries and more industries.

While most global approach studies were restricted on differences across countries (Guellec

[1] As suggested by Archibugi and Iammarino (2002), I consider that internationalization of innovation represents a "wide-range of forces" which concern not only the cross-border ownership or diffusion of technology but also the global generation of knowledge.

and van Pottelsberghe de la Potterie, 2001, 2004; Ma and Lee, 2008; Picci, 2010; Thomson, 2013), this paper is – to the best of my knowledge – the first study to take also into account a systematic industry perspective. The relevance of industry-level analyses has been shown by several results in the literature indicating that – in addition to the differences in the so-called propensity to patent across industries[2] – the globalization of innovation is industry-specific. For instance, Florida (1997) and Breschi (1999, 2000) have shown that the geographical concentration and the spatial organization of the innovative processes may differ remarkably across industrial sectors. In the same vein, Hagedoorn (2002) and Narula and Duysters (2004) have observed that R&D partnerships are sector-specific. Furthermore, a recent study by Picci and Savorelli (2012) has indicated that a strong heterogeneity exists in internationalization across technological fields. In addition to control for differences across industrial sectors, industry-level data enable us to investigate empirically the relationship between revealed technological advantages of countries across industries and globalization of innovation.

The first part of this paper highlights some stylized facts in the internationalization of innovation. This patent-based analysis confirms a strong growth in the intensity of globalization of innovation from 1980 to 2005. This worldwide trend is observed not only in terms of cross-border ownership of innovation, but also in terms of international technological collaborations. More interestingly, I show heterogeneity of globalization across countries and industries. First, more innovative countries (or industries) do not have more a globalized innovation footprint. Second, although the location of innovation is increasingly dispersed across the world, its ownership is still strongly concentrated in a few countries.

The estimation results show that the degree of internationalization of innovation is negatively related to the revealed technological advantage of countries across industries. Countries have a tendency to be more globalized in industrial sectors in which they are less technologically specialized. The empirical findings suggest also that countries with multidisciplinary technological knowledge are more likely to take part in international co-inventions of new technologies and to be attractive for foreign innovative firms. This aggregated patent-based analysis provides additional evidence that globalization of innovation is a means of acquiring competences abroad that are lacking at home, suggesting that home-base augmenting motives matter in the globalization of innovation production. By contrast, the internationalization of innovation does not seem to be purely market-driven since large economies are not the target of foreign innovative firms and international patenting is more related to international competitiveness of country-industry pairs than to the direction of trade flows.

The rest of the paper is structured as follows. The next section introduces the theoretical framework, which is based on the dichotomous motives of the globalization of innovation. Section 3 presents the internationalization patent-based indicators used in this paper. The extent to which innovation production is globalized is illustrated in section 4 – distinguishing the trends over time, across countries and industries. The empirical approach is described in section 5 and the results are presented in section 6. Last section concludes and puts forward ideas for further research.

[2] See for instance Cohen et al. (2000) and Danguy et al. (2013).

2 Theoretical framework

A large body of literature exists on this topic[3] and usually highlights several motives behind the internationalization of R&D. In particular, two main opposing strategies are often compared (Kuemmerle, 1997, 1999; Patel and Vega, 1999; Le Bas and Sierra, 2002; Narula and Zanfei, 2005).

First, firms set up R&D laboratories abroad in order to exploit their already developed assets. Their foreign R&D activities mainly support the entry in new markets overseas by adapting the products or the processes to the local conditions. These demand-oriented innovative activities aim at modifying products to make them more appropriate to the local market and to support manufacturing activities of local subsidiaries. In this context, the main objective of the globalization of innovation is to exploit their technological advantage created within the home country. It thus consists mainly in an extension of R&D work already undertaken at home. This first kind of internationalization strategy was referred to as 'asset-exploiting' by Dunning and Narula (1995) or as 'home-base exploiting' by Kuemmerle (1997).

Second, beyond the exploitation of domestic strengths, other motives can explain the globalization of innovation. Innovative firms can be motivated to cross borders to track or access overseas new technology development, to improve existing assets or alleviate technological weaknesses at home and to tap into knowledge around the world. This second strategy is reflected in 'asset-augmenting' (Dunning and Narula, 1995) or 'home-base augmenting' (Kuemmerle, 1997) international R&D activities. According to this strategy, the main objective of firms is to augment their knowledge base combining their own abilities with new foreign technological capabilities. They internationalize their innovation production to obtain abroad strategic assets that are complementary with those already available at home. Their international innovative activities aim to serve their global value chain in order to generate entirely new products from a global network of dispersed locations. As a result, they strengthen their technological competences and their global innovative performance.

While the home-base exploiting strategy has been initially recognized as dominating (Lall, 1979; Mansfield et al., 1979), the home-base augmenting strategy has received more empirical confirmation (Florida, 1997; Kuemmerle, 1999; Ambos, 2005)[4].

However, empirical papers investigating this set of dichotomous motives were often restricted to firm-level data. For instance, Kuemmerle (1999) studied the foreign direct investment in R&D laboratories of 32 MNE in pharmaceutical and electronics industries and confirmed the key role played by home-base augmenting motives. Patel and Vega (1999) focused on US patenting activities of a subset of 220 firms. Analyzing the technological profile of countries, they suggested that adapting products to local market and supporting overseas manufacturing

[3] See for instance the survey performed by Narula and Zanfei (2005) or Hall (2011).

[4] In addition to these strategies of internationalization for innovative activities, Lewin et al. (2009) have argued that the recent R&D offshoring strategies are increasingly 'home-base replacing'. In particular, this practice concerns companies that tend to locate innovative activities in lower labor-cost countries. However, the aggregate empirical approach of this paper enables to test if countries are more globalized in sectors in which they are strong or weak, which does not inform on the replacement of domestic innovative capabilities by foreign ones. Therefore, this paper does not aim to test empirically the home-base replacing strategy.

are major determinants of the internationalization of technology. Le Bas and Sierra (2002) confirmed the main findings of the previous study by considering the patenting activity in Europe of 245 MNE. Cantwell and Piscitello (2005) examined patents granted in the US to large industrial firms for inventions performed at the regional level of four European countries. Their results showed that the location of foreign-owned research is driven by the potential to capture various sources of spillovers, such as intra-industry, inter-industry or science-technology spillovers.

The main empirical contribution of this paper is to test the home-base augmenting and exploiting motives with aggregate patent-based indicators. It aims to deepen previous firm-level evidence with a unique panel dataset covering 21 industrial sectors in 29 countries. More importantly, industry-level data are at the core of the identification of these two strategies. Indeed, I test the relationship between technological specialization of countries across industries and their intensity of globalization of innovation. In other words, it is expected that countries are relatively more globalized in industrial sectors in which they are technologically strong if home-base exploiting strategy dominates. By contrast, countries which tend to augment their home knowledge base are expected to be relatively more globalized in industrial sectors in which they are technologically weak.

Two additional industry-level variables also enable the identification of home-base augmenting and exploiting strategies. First, a positive relationship between cross-border innovative activities and international trade would indicate the predominance of home-base exploiting motives (Picci and Savorelli, 2012). Indeed, if the internationalization of innovation is mainly driven by the desire to adapt the product to the local market, the intensity of globalization of innovation is more likely to be correlated with foreign sales. Second, the home-base augmenting strategy reflects a diversification of the home country into new technological areas. In this context, inter-industry spillovers, diversity externalities and multidisciplinary competences are key drivers of the internationalization of technology development (Cantwell and Piscitello, 2005; Narula and Zanfei, 2005; Fernández-Ribas and Shapira, 2009). A positive relationship between the intensity of globalization of innovation and the multidisciplinarity of country-industry pair – due to patenting activities in a large number of different technologies – would therefore reflect more the home-base augmenting strategy.

Finally, the large panel dataset used in this paper distinguishes between several types of globalization. Beyond the foreign location of R&D activities (at the core of most papers in the literature, e.g. Kuemmerle, 1999; Cantwell and Piscitello, 2005; Picci and Savorelli, 2012; Thomson, 2013), this paper contributes also to the literature by analyzing both the international technological collaborations (e.g. co-inventions) and the cross-border ownership of innovation for a large panal dataset of country-industry pairs.

Before investigating this question in an empirical model, the next two sections present the internationalization patent-based indicators and provide new descriptive evidence on the globalization of innovation over time, across countries and across industries.

3 Data: internationalization patent-based indicators

3.1 Patent as indicator of innovation

Patent data are widely used as indicator of innovation (for a discussion, see Griliches, 1990) because they are easily available and contain rich information. In particular, despite some well-known limitations[5], patents are extensively used as an indicator of the location of foreign inventive activities because they offer the most accessible and internationally comparable information for innovative activities across countries and technological fields. Moreover, systemic and detailed data on the location of R&D expenditures are neither collected for similar aggregates nor comparable for a large set of countries and industrial sectors (as pointed out by Hall, 2011).

In order to measure the globalization of innovation production, I have developed patent-based indicators. These indicators are computed using the EPO worldwide patent statistical database (PATSTAT, April 2009) which covers records on patent applications filed at more than 70 patent offices around the world. Among the rich information contained in a patent, I use mainly two of them. Firstly, the country of inventors and applicants provides geographical information on inventorship and ownership. Even though the PATSTAT database contains a large number of information, it should be noticed that the coverage of information remains not perfect. Therefore, I use an algorithm similar to the one described by de Rassenfosse et al. (2013)[6] recovering missing country information in order to obtain more accurate patent information for a larger sample of countries. Secondly, I express patent indicators not only by country – of inventor and applicant – but also by industry. Indeed, counts per industrial sector are derived by matching technological information contained in patents, International Patent Classification (IPC) codes, and industry, International Standard Industry Classification (ISIC, Rev 3), using the concordance table provided by Schmoch et al. (2003)[7].

This study relies also on two types of patent count indicators. The first indicator is a corrected count of priority filings[8] (PF, a worldwide inventiveness indicator recently introduced by de Rassenfosse et al., 2013). It captures all the patents filed by the inventors (or applicants) based in a country, regardless of the patent office of application. This methodology assures the best match between R&D expenditures and patent applications at the country level. For instance, the count for Austria as country of inventor (and similarly for applicant) is thus equal to the number of priority filings with inventors (applicants) based in Austria and filed at the Austrian patent office plus the priority filings with inventors (applicants) based in Austria but directly filed at other patent offices. The inclusion of these priority filings filed abroad allows

[5]For instance, the so-called patent propensity varies across countries and industries since all inventions cannot be patented and all patentable inventions are not patented.

[6]I thank Gaétan de Rassenfosse for helping me on this issue.

[7]The same methodology is used by the OECD to build the patent segment of their STAN database (for more details, see OECD, 2009). In this paper, the counts per industry are not fractional. A patent related to multiple industries is thus taken into account equally for each industry. Note that the coverage of industries offered by the concordance table of Schmoch et al. (2003) is nearly completed. Only 4% of EPO applications (less than 3% in terms of priority filings) contained in PATSTAT have a IPC technological class which is not taken into consideration by this concordance table.

[8]A prioirty filing is the first patent application protecting an invention.

reducing for the bias against small countries which file a high share of their patents abroad. Moreover, PF does not suffer from geographical bias[9] related to single-office-based indicators (i.e. the home-country bias due to the fact that inventors have a tendency to file relatively more in their own country), since it is based on all patent offices information. The second indicator is the number of patent applications filed at the European Patent Office (EPO). More precisely, this EPO patent count indicator encompasses first and subsequent patent applications which have been filed directly at EPO and those which have reached EPO during the regional phase of a PCT application.

Combining these two indicators provides a more global overview on the globalization of innovation. It also helps to test the robustness of the results since each patent metric has its own interpretation and drawbacks (see among others, Dernis et al., 2001; OECD, 2009). Priority filings are first filings of patents made usually at national patent offices and potentially extended to regional offices. In particular, they are known to present a skewed distribution with a large number of low value patents; compared to regional patents which have a larger geographical scope and are more expensive for applicants (due to higher fees and intermediary costs in terms of translation or attorneys for instance).

3.2 Internationalization patent-based indicators

Using patent data, one can gauge the globalization of innovation production[10]. First of all, I define an international patent for country *i* as being a patent with a least one resident of country *i* and at least one resident of any other country. Based on the measures of internationalization presented by Guellec and van Pottelsberghe de la Potterie (2001) and on the country information contained in patents, I now define four types of internationalization in Table 1.

Table 1: Four types of internationalization of innovation

(1)	**co-invention (II)**: patent with *inventors* from different countries
(2)	**co-ownership (AA)**: patent with *applicants* from different countries
(3)	**foreign ownership of domestic innovation (IA)**: patent with domestic *inventors* and foreign *applicants*
(4)	**domestic ownership of foreign innovation (AI)**: patent with domestic *applicants* and foreign *inventors*

[9] See de Rassenfosse et al. (2013) or van Zeebroeck et al. (2006) for discussion on this issue.

[10] Globalization of innovation production means that the analysis focuses on the globalization of the innovation process itself without looking at determinants of globalization of patent protection (such as the decision to protect a same invention in several countries). The patent filing strategy, across countries, is out of the scope of this paper.

I measure co-invention when a patent has several inventors residing in different countries, illustrating that those researchers based in different countries co-operate on the same project and jointly invent. This kind of international collaboration between researchers can take place either within a multinational enterprise (research facilities of a same company located in several countries), or through a research joint program between several institutions. The co-ownership measure is similarly defined by considering applicants located in different countries. The two other types are identified when at least one inventor and at least one applicant reside in different countries. For most patents, the applicant is an institution (a firm, a university or a public institute of research) and the inventor is an individual. For instance, the patent can protect an invention performed in a research facility abroad of a multinational firm. These two measures reflect thus the extent to which foreign (domestic) firms control domestic (foreign) innovation. Within these four types of internationalization, the first two dimensions concern more the globalization of innovation in terms of international technological collaboration, whereas the last two are more closely related to the cross-border ownership of innovation.

The total count of patents corresponding to each type could be computed to measure the extent to which and how innovation production is globalized. However, what matters more is to consider not only the absolute counts, but also the relative measures in order to better understand the intensity of internationalization. This kind of measures in terms of globalization intensity was proposed by Guellec and van Pottelsberghe de la Potterie (2001). In this paper, I extend their analysis, which was limited to a cross section of countries, with a more general framework across industrial sectors and over time.

Four patent-based internationalization indicators are computed to evaluate the intensity of globalization across industries, countries and over time. For each industry k in a country i at priority year t, these variables of interest are expressed as the share of international patents in the total number of patents (see equations (1) to (4)):

- **SHII** is the share of patents with a foreign resident as co-inventor in the population of patents with a domestic inventor:

$$SHII_{i,k,t} = \frac{patent\ II_{i,k,t}}{patent\ I_{i,k,t}} \tag{1}$$

- **SHAA** is the share of patents with a foreign resident as co-applicant in the population of patents with a domestic applicant:

$$SHAA_{i,k,t} = \frac{patent\ AA_{i,k,t}}{patent\ A_{i,k,t}} \tag{2}$$

- **SHIA** is the share of patents with a domestic inventor and a foreign applicant in the total domestic inventions:
$$SHIA_{i,k,t} = \frac{patent\ IA_{i,k,t}}{patent\ I_{i,k,t}} \quad (3)$$
- **SHAI** is the share of patents with a domestic applicant and a foreign inventor in the total domestic applications:
$$SHAI_{i,k,t} = \frac{patent\ AI_{i,k,t}}{patent\ A_{i,k,t}} \quad (4)$$

In addition to have a simple interpretation, those relative measures have one main advantage. They allow us to focus on the globalization per se – being relatively independent of the determinants of patenting decision which are out of the scope of this paper. In particular, it means that these measures are robust to the strong differences in the propensity to patent observed across countries and industries. This reasoning is based on the assumption that there is no difference in the propensity to patent within a same industry-country pair between all patent and international ones.

Nevertheless, one can argue that those patent-based internationalization indicators have limitations and do not reflect all types of international innovation experience which presents strong variations across firms. For instance, the case of a MNE that prefers to register, as applicant, the name and the location of its local subsidiary where the invention was developed – rather than those of its headquarters – would not be counted as international innovation experience according to previous definitions. We can thus expect that results would be under-estimates of the true globalization intensity. This underestimation is mainly due to the fact that the country of residence of a firm is not always its nationality.[11] As shown by Cincera et al. (2006) for the case of Belgium, we can indeed compare the direct foreign ownership of innovation (as measured by SHIA) and the indirect foreign ownership when we have the information about the foreign control of applicant (when it is a subsidiary of a foreign firm). The empirical evidence illustrated by the authors seems to confirm that patent information under-estimates the real level of globalization of innovation production. However, they have also indicated that the global trend over time is more explained by the patents that are "directly owned by foreign applicants" (p 501). Even though all firm level ownership information – consolidated for the headquarter and its various subsidiaries (which is available only for a restricted number of cases) – would provide the complete picture, patent information is satisfactory enough to have a larger view on the globalization of innovation phenomenon.

[11] In the same vein, OECD (2009) has highlighted that the attribution of a country to a company is a problem for all indicators of internationalization and is thus not limited to the patent-based indicators used in this research.

4 Patterns in the globalization of innovation production

The first part of this research aims at providing global evidence on internationalization of innovation production; focusing first on the worldwide trends over time and then on cross-countries and cross-industries variations. It is based on an unique panel dataset that is composed of 21 manufacturing industries (2-digit ISIC classification from 15 to 36, see Appendix Table A.1) in 29 countries (OECD economies)[12] covering the period (defined by the priority date of the patent filing) from 1980 to 2005.

4.1 Over time

To introduce the topics, it is interesting to examine globally the evolution over time of the internationalization of innovation. Since making averages across countries or industries would lead to some bias, this worldwide representation is computed with all information contained in PATSTAT considering distinct applications – preventing from multiple counting of the same patent. The international shares indicators are thus equal to the ratio of distinct international patent applications of each type of internationalization divided by the total number of distinct patent applications per priority year.

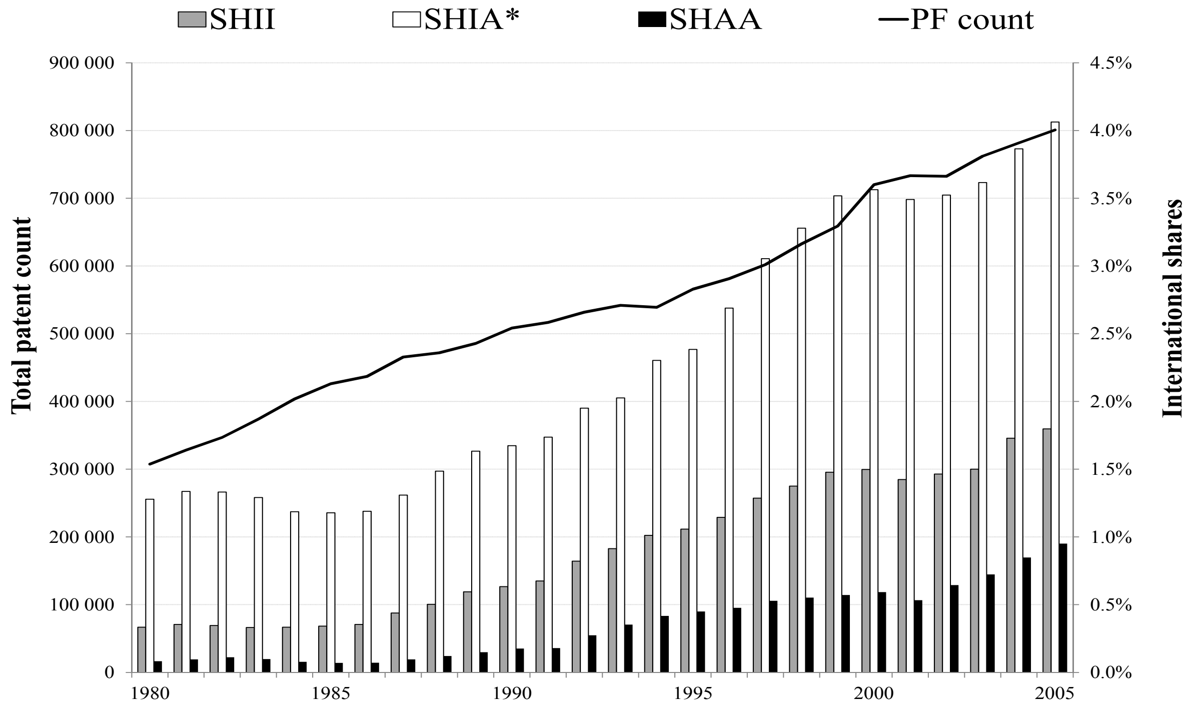
Figures 1 and 2 represent, respectively for PF and EPO, first on the black curve the annual patent count (see the left axis) and second on the bars the share of international patents (see the right axis). The white ones are the cross-border ownership, the gray the co-invention and the black the co-ownership.

Over those 25 years, the number of patents has strongly increased. The increase was even stronger for international patents since we observe a strong increase in the internationalization intensity, especially from the beginning of the 90's. However, the share of internationalization – compared to all patenting activity – remains quite limited. In 2005, only 2% of PF (8% for EPO) were subject to international co-invention; less than 5% represented cross-border ownership of innovation (18% for EPO); and only 1% of PF (2% for EPO) were subject to international co-ownership. Note that SHIA is larger than SHII because, by construction, II is a sub-sample of IA.[13] As soon as you have two inventors coming from two different countries, at least one of those will come from a different country than the applicant's one.

[12]The sample is mainly restricted to OECD countries to guarantee enough availability of explanatory variables at the industry level. Own calculation illustrates that this sample of countries represents on average, over our time period of analysis, about 90% of the worldwide patenting activities. Note that our sample focuses on 29 countries but considers international collaboration with all the countries in the PATSTAT database.

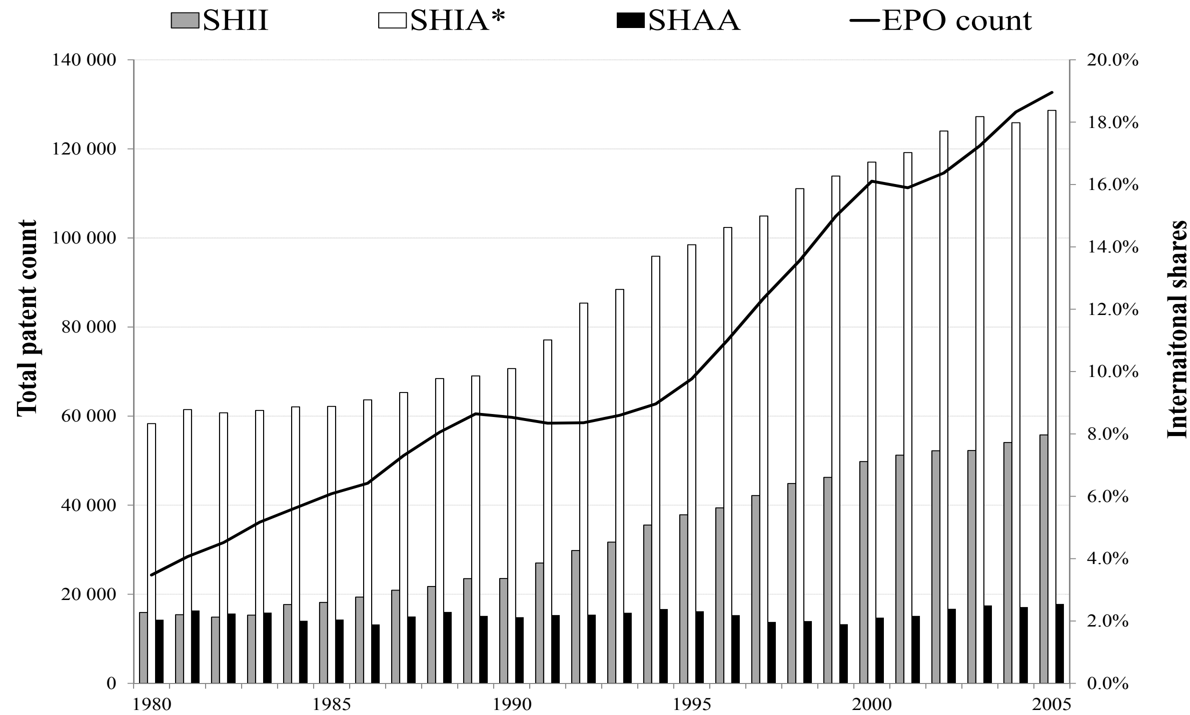
[13]This characteristic is valid for the worldwide and industry representations. Note also that SHIA is equal to SHAI for these two representations.

Figure 1: Worldwide trends for Priority Filings (PF)



Source: own calculations based on PATSTAT database (April 2009)
Note: * SHIA is equal to SHAI in the worldwide representation.

Figure 2: Worldwide trends for EPO filings



Source: own calculations based on PATSTAT database (April 2009)
Note: * SHIA is equal to SHAI in the worldwide representation.

Comparing Figure 1 with Figure 2, we observe that only a restricted fraction of priority filings are subject to a protection in a regional patent office. In 2005, about 15% of worldwide priority filings were also applied at EPO. Within this smaller number of patent applications, however, the share of international patents is largely higher, illustrating that regional filings are more likely to be subject to international technological collaboration and to cross-border ownership.[14] These first figures seem thus to confirm a strong growth in the intensity of globalization in innovation (OECD, 2008). This worldwide trend is observed not only in terms of cross-border ownership of innovation but also in terms of international technological collaborations. Obviously, a world level analysis is not enough to understand the determinants of this internationalization of innovation. Yet, it requires looking at the country-level and industry-level differences.

4.2 Country-level

Table 2 exhibits the four indicators of internationalization intensity per country in average over our 25 year time period of analysis. They are expressed in percentage points since they are simply computed – as expressed in equations (1) to (4) – by dividing the count of international applications by the total number of applications for each country.

Beyond the absolute counts of patent applications (see Appendix Table A.2), the relative internationalization indicators presented in Table 2 show three insightful results. First, the increasing worldwide trend of the globalization of innovation seems to be balanced by a strong heterogeneity across countries. In particular, it shows that country-size in patenting does not reflect the degree of internationalization since the largest innovative countries (such as US and Germany in Appendix Table A.2) are not the most globalized ones (about 5% of their priority filings are subject to co-invention while less than 8% of their innovation portfolio reflects cross-border ownership). Indeed, smaller countries such as Belgium or Netherlands have the highest degree of globalization of their innovations (their shares of international patents are more than the double of those of largest innovative countries).

[14]One can also argue that EPO applications correspond to high-value inventions since the total cost of patent application at EPO is high. The links between the globalization of technology and the value of inventions is an interesting question to tackle in further research, but this is out of the scope of the current thesis.

Table 2: Internationalization intensity per country (1980-2005) [%]

Country	PF				EPO			
	SHII	SHIA	SHAI	SHAA	SHII	SHIA	SHAI	SHAA
Australia*	2.2	3.8	1.8	1.5	16.0	23.3	10.8	3.9
Austria	13.2	25.7	11.5	5.0	20.3	33.1	21.6	13.8
Belgium	19.5	30.4	14.7	6.6	30.0	41.9	27.7	9.4
Canada	9.6	14.5	9.8	3.1	26.3	34.3	26.0	5.3
Czech Republic	9.8	11.4	6.4	3.8	39.9	50.0	27.7	10.0
Denmark*	9.3	12.2	9.3	4.2	17.5	20.9	18.2	5.2
Finland	4.4	4.5	9.2	2.3	11.8	10.5	21.1	1.7
France	5.9	8.7	6.0	2.0	11.9	18.9	14.6	6.0
Germany	5.0	6.3	5.6	1.5	9.6	13.2	10.7	4.0
Greece	2.5	3.3	0.9	0.8	29.5	35.9	9.6	6.8
Hungary	2.4	3.5	1.4	1.1	21.8	31.0	8.1	4.1
Iceland	21.5	28.5	15.0	6.9	39.3	51.6	37.4	8.0
Ireland*	6.8	10.2	8.4	2.6	31.1	38.6	47.3	8.3
Italy	3.1	6.0	2.0	1.2	8.1	16.3	5.4	2.5
Japan	0.2	0.3	0.3	0.1	2.7	3.8	3.4	1.2
Luxembourg	29.5	33.9	58.6	8.1	46.5	52.3	79.6	6.3
Mexico	7.7	12.2	3.8	2.0	44.7	60.8	16.0	13.2
Netherlands	12.2	20.1	24.9	8.1	13.2	19.5	34.3	16.9
New Zealand	4.9	7.1	3.9	3.2	20.5	26.6	12.6	5.5
Norway	6.5	8.5	6.7	2.9	19.4	23.6	20.4	3.9
Poland	1.5	1.4	1.0	0.5	38.4	47.9	14.5	12.4
Portugal	9.2	12.6	8.7	3.0	31.1	42.7	31.5	7.3
Rep. of Korea	0.8	0.4	1.2	0.3	5.5	5.2	6.3	1.7
Slovakia	12.4	11.9	8.6	5.0	54.2	61.8	31.0	12.3
Spain	6.9	9.6	4.2	1.7	18.7	29.2	8.0	4.2
Sweden	5.5	7.4	10.7	2.7	13.0	17.1	23.6	4.0
Switzerland	17.3	18.3	30.0	5.9	25.8	21.5	43.8	8.2
United Kingdom	5.0	10.3	4.5	2.8	16.6	33.0	18.2	12.4
United States	4.0	4.2	7.5	1.5	9.2	10.7	15.1	2.3

Source: own calculations based on PATSTAT database (April 2009)
Notes: See Appendix Table A.2 for the absolute counts of patents per inventor/applicant country and for the absolute counts of international patents according to the different types of internationalizaiton of innovation. * indicates countries that suffer from a coverage problem, concerning the PF indicators, identified by de Rassenfosse et al. (2013, p 734). Those countries were not taken into account in the empirical model for PF.

Second, the share of international co-invention (SHII) is always lower than the share of foreign ownership of domestic innovation (SHIA). Although it can be partly explained by the construction of the indicators (see above), note that this difference is sometimes significantly high. This underlines that countries may have a stronger tendency to participate in cross-border ownership of innovation than to take part in pure technological collaborations. Third, a comparison across countries and across both types of cross-border ownership of innovation highlights that SHIA is higher – for most countries – than SHAI. It means that the percentage of patents invented in those countries and assigned abroad is higher than the percentage of patents owned by those countries and invented abroad. It confirms that most countries are net exporter of innovation (indicated by negative net R&D offshoring ratio in Thomson, 2013). Only few countries (such as US, Switzerland or Netherlands) seem to have an "applicant surplus" (as shown by Picci and Savorelli, 2012), presenting higher number of domestic applicants with foreign inventors than domestic inventions owned by foreigners. Those countries control relatively more inventions abroad than their own ones are controlled by foreigners. They are also known to be the headquarters of strong multinational firms.

Even though the production of innovation is increasingly globalized (its location is more dispersed across the world), its ownership is still strongly concentrated. It thus confirms the worldwide concentration of ownership of international patents, already pointed out by Guellec and van Pottelsberghe de la Potterie (2001). Note also that all countries have a more international footprint in their regional patent application (EPO) than in their priority filings.

4.3 Industry-level

Similar indicators were computed per industrial sectors. In addition to present strong differences in their patenting activities (see Appendix Table A.3), Table 3 shows that industries exhibit differences in the average intensity of globalization of their innovation.

Three findings can be drawn from this table. First, the manufacturing of coke, petroleum producs and nuclear fuel (PETR[15]), and the manufacturing of chemicals products (CHEM) are the industries which are globally the more international ones across the four types of internationalization and for both patent count indicators. About 2% of PF (10% of EPO) are co-invented and 4% (17%) are subject to cross-order ownership in both industries. Second, like for the country case, it confirms that size in patenting is not reflected in the degree of internationalization. Industries with a large number of patent applications (see machinery and equipement, MACH; radio, television and communication equipement, COMM in Appendix Table A.3) present a relatively small share of international patents. By contrast, industries with a low number of applications (food products and beverages, FOOD; textiles, TEXT) have a relatively higher degree of internationalization. Third, comparing high-tech with low-tech, we observe that high-tech industries (in particular the industries related to Information and Communication Technologies, such as office, accounting and computing machinery, COMP; COMM; and electrical machinery and apparatus, ELEC) are not, on average, the most globalized ones compared to some low-tech industries[16] (such as FOOD) – particularly in terms of EPO filings.

[15]See Appendix Table A.1 for the description of the industry abbreviations used in the main text and in the tables.

[16]Similar evidence has been observed by Dunning (1994) in terms of US registered patents of foreign affiliates of MNEs.

Table 3: Internationalization intensity per industry (1980-2005) [%]

Industry		**PF**			**EPO**		
	Tech*	**SHII**	**SHIA/AI**	**SHAA**	**SHII**	**SHIA/AI**	**SHAA**
FOOD	LOTE	1.17	2.61	0.44	10.11	21.89	5.43
TOBA	LOTE	1.28	2.63	0.60	4.38	12.24	0.66
TEXT	LOTE	1.34	3.03	0.42	7.81	16.75	2.19
WEAR	LOTE	0.57	1.63	0.21	3.93	10.45	0.66
LEAT	LOTE	1.03	3.49	0.40	3.92	15.17	0.98
WOOD	LOTE	0.35	0.95	0.15	2.69	7.77	0.68
PAP	LOTE	0.74	1.74	0.26	5.30	12.13	1.38
PETR	MLTE	2.10	4.11	0.72	7.82	17.44	4.17
CHEM	MHTE	1.92	3.61	0.64	9.23	17.65	2.97
RUBB	MLTE	0.81	2.39	0.35	4.41	13.67	2.00
MINE	MLTE	0.77	1.75	0.30	5.05	12.49	1.90
META	MLTE	0.83	1.58	0.31	5.57	11.63	2.06
FABM	MLTE	0.65	1.94	0.22	3.21	10.24	1.01
MACH	MHTE	0.71	1.91	0.27	3.86	11.07	1.45
COMP	HTE	0.76	2.23	0.28	3.87	12.84	1.80
ELEC	MHTE	0.69	1.99	0.21	3.43	11.18	1.41
COMM	HTE	0.85	2.45	0.36	4.49	14.81	2.11
INST	HTE	0.98	2.36	0.36	5.28	13.35	2.07
AUTO	MHTE	0.72	2.02	0.23	3.34	10.13	1.52
TRAN	MHTE	0.81	1.77	0.28	3.01	6.88	0.91
MISC	LOTE	0.45	1.39	0.24	2.64	8.83	1.18

Source: own calculations based on PATSTAT database (April 2009)
Notes: see Appendix Table A.1 for the description of the industries. See also Appendix Table A.3 for the absolute counts of patents per industry and for the absolute counts of international patents according to the different types of internationalizaiton of innovation. * Based on the OECD technological classification. LOTE, MLTE, MHTE, and HTE stand for low technology, medium-low technology, medium-high technology, and high technology, respectively.

In addition to analyze the differences in the average intensity of globalization across countries and industries, the trends over time provide interesting insights. Table 4 exhibits the compound annual growth rates (CAGR) per country and per industry. It shows that the worldwide increasing trends in international patenting activities (observed in Figures 1 and 2) are shared among most of the countries and all industries. This growth in globalization of innovation was undeniable with worldwide annual growth rates that were equal, for PF, to 7% in international co-invention and 5% in cross-border of innovation. Concerning the industries related to the ICT, while Table 3 reports a relatively low average level of internationalization over the 25 years, Table 4 shows that internationalization has more strongly increased in those particular industries (such as COMP and COMM) than in low-tech industries (such as FOOD)[17].

[17] Additional descriptive evidence (available upon request) illustrates that the international shares in these ICT industries have especially increased from the beginning of the 90's; to reach similar degree of internationalization as CHEM at the end of the time period.

Table 4: CAGR of internationalization of innovation (PF)

(a) Per country

Country	SHII	SHIA	SHAI	SHAA
Australia*	8%	7%	10%	16%
Austria	6%	5%	8%	11%
Belgium	11%	8%	13%	14%
Canada	8%	6%	8%	11%
Czech Republic	2%	0%	-6%	-7%
Denmark*	5%	6%	5%	14%
Finland	11%	7%	11%	13%
France	8%	8%	9%	11%
Germany	7%	6%	6%	10%
Greece	12%	11%	16%	15%
Hungary	18%	19%	17%	15%
Iceland	2%	2%	4%	-2%
Ireland*	13%	13%	13%	18%
Italy	9%	7%	8%	14%
Japan	10%	8%	8%	14%
Luxembourg	7%	8%	3%	8%
Mexico	4%	3%	1%	9%
Netherlands	7%	2%	5%	9%
New Zealand	9%	8%	8%	8%
Norway	8%	7%	9%	9%
Poland	21%	19%	26%	24%
Portugal	10%	10%	12%	9%
Rep. of Korea	4%	5%	6%	1%
Slovakia	1%	1%	-2%	-8%
Spain	13%	11%	14%	19%
Sweden	9%	7%	10%	14%
Switzerland	6%	3%	5%	11%
United Kingdom	7%	4%	6%	10%
United States	8%	8%	5%	11%
World	7%	5%	5%	10%

(b) Per industry

Industry	SHII	SHIA/AI	SHAA
FOOD	5%	2%	6%
TOBA	6%	8%	1%
TEXT	7%	5%	11%
WEAR	5%	5%	1%
LEAT	2%	1%	6%
WOOD	7%	4%	7%
PAP	5%	2%	8%
PETR	7%	4%	6%
CHEM	6%	4%	9%
RUBB	9%	5%	13%
MINE	10%	5%	11%
META	5%	4%	6%
FABM	7%	3%	10%
MACH	7%	4%	9%
COMP	11%	7%	10%
ELEC	9%	6%	10%
COMM	9%	7%	10%
INST	7%	6%	8%
AUTO	8%	6%	9%
TRAN	5%	3%	6%
MISC	4%	2%	10%
World	7%	5%	10%

Source: own calculations based on PATSTAT database (April 2009)
Note: The compound annual growth rates were computed over the longest time period available between 1980 and 2005.

5 Empirical approach

5.1 Fractional logit model

Beyond these stylized facts, the second objective of this paper is to better understand the determinants of the globalization of innovation using an econometric model. To explain the intensity of globalization of innovation production in our panel dataset, estimating a classical linear model is not convenient since our dependent variables ($SHII, SHIA, SHAI, SHAA$) are shares. These variables of interest vary, by definition, between 0 and 1. As pointed out in the econometric literature[18], using a linear model for such fractional data would suffer from the same weaknesses as using a linear model for binary choice models. In particular, the predicted values from a classical OLS regression are not necessarily restricted in the unit interval.

I have prefered to use a fractional response model proposed by Papke and Wooldridge (1996)[19] and suited to proportions data:

$$E(y|x) = G(x\beta) \tag{5}$$

where $G(.)$ is a known function satisfying $0 < G(z) < 1$ for all $z \in \mathbb{R}$. It simply consists in considering a function $G(.)$ in the relation between y and x. This function $G(.)$ is chosen to satisfy the conditions that guarantee that the predicted y will be restricted to the unit interval for all values of the regressors. It is typically chosen to be a cumulative distribution function. In this case, I took the logistic function, $G(z) = \frac{exp(z)}{1+exp(z)}$, and I thus estimated a fractional logit model. The authors have proposed a particular quasi-maximum likelihood estimator (QMLE) based on the Bernoulli log-likelihood function, given by:

$$l_i(\beta) = y_i log[G(x_i\beta)] + (1 - y_i)log[1 - G(x_i\beta)] \tag{6}$$

This method takes into account the bounded nature of the dependent variable and the possibility of observing values at the boundaries. Equation (6) corresponds to the familiar log-likelihood of the Logit model, except that y_i is continuous in the unit interval. Estimates of β are obtained from the maximization problem: $max_\beta \sum_{i=1}^{N} l_i(\beta)$. As pointed out by the authors, since equation (6) is a member of the linear exponential family, the QMLE estimate is consistent and $\sqrt{N}$-asymptotically normal regardless of the distribution of y_i conditional on x_i. In particular, y_i could be a continuous variable or a discrete variable.

The following fractional logit model is estimated for our panel dataset composed of country-industry pairs over time:

$$E(y|x) = G\left(\alpha_i + \alpha_k + \alpha_t + \beta_1 RTAc + \beta_2 TRADE + \beta_3 MULTI. + \beta_4 R\&D\ Int. + \beta_5 SIZE\right) \tag{7}$$

The dependent variables – $y = \{SHII, SHIA, SHAI, SHAA\}$ – are the four types of internationalization indicators based on the two alternative patent counts – PF and EPO. They vary between 0 (if the patents of a country-industry pair list only domestic residents) and 1 (if all patents of a country-industry pair reflect international inventive activities).[20]

[18] For a discussion, see among others Kieschnick and McCullough (2003) or Ramalho et al. (2011).

[19] For examples using this estimation technique in applied economics papers, see for instance Wagner (2001, 2003) and Czarnitzki and Kraft (2004).

[20] See Appendix Table A.5 for descriptive statistics.

5.2 Explanatory variables[21]

To deepen our understanding of the globalization of innovation, five explanatory variables are taken into account in the main econometric specifications. First, an indicator of the revealed technological advantage of countries across industrial sectors is defined as in equation (8).

$$RTAc_{i,k,t} = \frac{rta_{i,k,t} - 1}{rta_{i,k,t} + 1} \in [-1, 1] \text{ where } rta_{i,k,t} = \frac{Patent_{i,k,t} / \sum_k Patent_{i,k,t}}{\sum_i Patent_{i,k,t} / \sum_{i,k} Patent_{i,k,t}} \tag{8}$$

where $Patent_{i,k,t}$ is the fractional count of patents of country i in industry k at priorirty year t.

This kind of index was initially built for trade literature to compute the so-called revealed comparative advantage. Based on patent counts[22], it is computed for each country-industry pair as being the ratio between the share of industry k in the country i patents and the share of the same industry in all worldwide patents. We thus point out a revealed technological advantage of country i in a particular industry if the share of this industry is higher in country i compared to the average in other countries. We point out a revealed disadvantage for the opposite case. This ratio (*rta*) is normalized[23] to obtain a symmetric measure (*RTAc*) between -1 and 1, with positive values representing a revealed technological advantage and negative values a revealed technological disadvantage. In other words, positive values of RTAc indicate a technological specialization of a country in a particular industry.

This first variable is the key factor which helps us to distinguish between the home-base augmenting and home-base exploiting motives in internationalization of innovation (see discussion in section 2). Indeed, it allows us to evaluate if countries are relatively more globalized in industries in which they are technologically either strong or weak. Positive or negative effects can be expected according to the prevalence of each strategy. The home-base augmenting strategy suggests a negative relationship between RTAc and internationalization intensity. By contrast, if firms primarly go abroad to exploit the technological strenghts of their home country, a positive relationship between RTAc and internationalization intensity is more likely. This last interpretation was highlighted by Patel and Vega (1999) and Le Bas and Sierra (2002) in their descriptive analysis of patenting activities of samples of MNE's in US for the former and in Europe for the latter. They indeed concluded that in a large manjority of cases, firms tend to locate their technoloigy abroad in their core areas in which they are strong at home.

A second set of variables is taken into account to investigate the relationship between international trade in goods and international patenting activities across industrial sectors. A strong relationship with the absolute series of trade flows would indicate that internationalization of R&D is demand driven (Lall, 1979; Mansfield et al., 1979). In the same vein, Picci and Savorelli

[21] See Appendix Table A.4 for more details on the variables, see Appendix Table A.5 for the descriptive statistics and see Appendix Table A.6 for correlation matrix.

[22] A similar measure has been introduced by Soete (1987) and then has been largely used (see for instance, Dunning, 1994; Cantwell, 1995; Patel and Vega, 1999; Le Bas and Sierra, 2002; Frietsch and Jung, 2009; Frietsch and Schmoch, 2010). Note also that this revealed comparative advantage is evaluated for both patent counts indicators (PF or EPO) based either on the country of inventor (RTAc inv) or the country of applicant (RTAc app).

[23] This kind of normalization has been proposed by Laursen (1998) and then has been applied by Dalum et al. (1999), Begg et al. (1999), Brusoni and Geuna (2003), Schubert and Grupp (2011) or D'Agostino et al. (2013).

(2012) interpreted the strong relationship between bilateral trade and international collaborations in inventive acitvities as evidence that home-base exploiting motives are relevant. In addition to the impact of import and export, I also analyze the relationship between the internationalization of innovation and two relative measures of international competitiveness: the revealed comparative advantage based on exports series (RCAc) and the net trade ratio of countries across industries (Net trade). A positive impact is expected since international competitive innovative countries are more likely to be more effective in performing research abroad and to be more attractive for international technological collaboration (Kumar, 2001). Moreover, openness to international trade (Furman et al., 2002) and international competitiveness in trade (Danguy et al., 2013) have been recognized as closely related to international patenting experience.

Third, I estimate the effect of the multidisciplinarity of innovation performed by country-industry pair. This is evaluated with a new patent-based indicator, which corresponds to the number of distinct 4-digit IPC classes – outside the scope of the industry defined by the concordance table of Schmoch et al. (2003) – listed on patents. For instance, consider a country with two patents: $Patent_i$ listing $\{IPC_A, IPC_B, IPC_C\}$ and $Patent_j$ listing $\{IPC_A, IPC_B, IPC_D\}$. For industry k defined by IPC_A in the concordance table, the multidisciplinarity indicator is based on 3 distinct IPC classes – $\{IPC_B, IPC_C, IPC_D\}$ – for this country-industry pair. Multidisciplinary innovation is evaluated for each country-industry pair considering either the country of inventor (Multi. inv) or the country of applicant (Multi. app). Its expected impact is positive, particularly if home-base augmenting strategy dominates. Multidisciplinary country-industries pairs present strong inter-industry spillovers and can thus be more attractive for foreign innovative firms that desire to augment and diversify their home knowledge base (Cantwell and Piscitello, 2005; Fernández-Ribas and Shapira, 2009).

While the previous variables were expressed for each country-industry pair, I also include variables that vary only across countries. Indeed, I control for differences, across countries, in terms of the intensity of R&D expenditures (R&D Int.) and in terms of the economic size measured by the GDP (Size). For both variables, positive or negative impact can be expected. Technological intensity contributes to the absorptive capacity of countries such that they can benefit more from the sourcing of knowledge abroad but strong technological capabilities may also mean less incentives to cross borders to find additional knowledge assets (Song and Shin, 2008). Concerning the size of country, R&D collaboration literature (Guellec and van Pottelsberghe de la Potterie, 2001; Narula and Duysters, 2004) suggests that smaller countries collaborate more to compensate for the lack of home capabilities; whereas papers on international R&D location (Kumar, 1996; Cantwell and Piscitello, 2005) demonstrate that larger countries are more attractive for the location of foreign R&D facilities, especially if internationalization of innovation is market-oriented (Kuemmerle, 1999). Finally, I control for unobserved heterogeneity in our panel dataset by including country (α_i), industry (α_k) and time (α_t) dummies.

6 Results and discussion

The main estimation results of the fractional logit model[24] of equation (7) are presented in Table 5 for EPO patent applications[25]; distinguishing between the four types of internationalization (see Table 1 and equations (1)–(4) for more details).

Table 5: Main fractional logit estimation results for EPO patent applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. var.	**SHII**	**SHII**	**SHIA**	**SHIA**	**SHAI**	**SHAI**	**SHAA**	**SHAA**
RTAc inv	-1.111***	-1.119***	-0.770***	-0.767***				
	(0.0791)	(0.0793)	(0.0738)	(0.0737)				
RTAc app					-0.181**	-0.191**	-0.750***	-0.761***
					(0.0875)	(0.0886)	(0.139)	(0.137)
Net trade	0.257***		0.195***		0.172**		0.299**	
	(0.0676)		(0.0657)		(0.0695)		(0.138)	
RCAc		0.260***		0.172***		0.179**		0.297**
		(0.0660)		(0.0646)		(0.0704)		(0.121)
Multi. inv	0.120***	0.114***	0.0866**	0.0826**				
	(0.0365)	(0.0363)	(0.0348)	(0.0350)				
Multi. app					0.00175	-0.00267	0.137**	0.131**
					(0.0401)	(0.0403)	(0.0628)	(0.0632)
R&D Int.	-0.592***	-0.595***	-0.638***	-0.639***	0.307**	0.309**	0.314	0.310
	(0.132)	(0.133)	(0.136)	(0.136)	(0.139)	(0.140)	(0.249)	(0.250)
Size	-0.331	-0.306	-0.643**	-0.629**	-0.00555	0.00821	-0.782	-0.775
	(0.211)	(0.215)	(0.252)	(0.253)	(0.260)	(0.262)	(0.595)	(0.603)
Country FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Industry FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Year FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Pseudo LL	-2955	-2954	-3601	-3602	-2935	-2935	-1566	-1555
Observations	10,043	10,043	10,043	10,043	9,789	9,789	9,789	9,789

Notes: Robust standard errors in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The rows "country FE", "industry FE", and "year FE" report the significance levels of the joint effect of these fixed effects.

First, RTAc variables have a strongly significant and negative coefficient over the different specifications. It means that the intensity of globalization of innovative activities is higher in industrial sectors in which countries present a revealed technological disadvantage; i.e. in which they are relatively weak. By contrast, countries which present a revealed technological advantage seem to keep it relatively more within their national borders and their innovative firms are less likely to collaborate with foreigners. This effect is observed not only in terms of international

[24]The same model was also estimated by OLS and Tobit. Appendix Tables A.7 and A.8 show that these additional econometric specifications confirm the results of the fractional logit.

[25]Results for priority filings are in Appendix Table A.9. These results are globally similar although the impact of multidisciplinarity and size variables are less significant. Note that the samples for PF estimations are smaller since de Rassenfosse et al. (2013) have noticed a coverage problem for few countries which were not taken into account in the estimation for PF.

co-invention and co-ownership of patents (SHII and SHAA) but also in terms of cross-border ownership of innovation (SHIA and SHAI). The negative relationship between RTAc and the dependent variables suggests that firms do not extend their R&D internationally to replicate research in the industrial sectors in which their country is already strong, but rather to acquire the knowledge which is lacking at home (as suggested by Archibugi and Michie, 1997). It thus reflects the dominance of the home-base augmenting strategy, in comparison with the home-base exploiting strategy.

These results for our panel dataset confirm the conclusions of Almeida (1996) for the semi-conductors case, the illustrative evidence of Cantwell (1995) for American electrical and German chemical firms, and the results of the analysis of the German innovation survey performed by Schmiele (2012). Concerning foreign ownership of domestic innovation (SHIA), Cantwell and Piscitello (2005) have also suggested that strong domestic specialization[26] acts as an entry barrier against foreign firms. Since foreign and domestic firms compete for a given pool of resources (e.g. the inventors), foreigners may have more difficulties to access the market where residents are relatively strong.

Concerning trade variables, the main impact comes from both measures of international competitiveness (Net trade and RCAc, which are illustrated in Table 5; whereas results of absolute series of export and import are in Table 6). Related estimates show positive values, as expected, and significant. It illustrates that international competitive country-industry pairs present higher intensity of internationalization of their innovation. Countries that compete internationally in trade are more involved in international technological collaboration and cross-border ownership of patents, underlying the close relationship between the openness to trade and the globalization of innovation.

However, the internationalization of innovation does not seem to be strongly correlated to overseas trade. Indeed, results in terms of export and import (see Table 6) show less significant coefficients, suggesting that international patenting does not follow totally the flows of international trade of goods. If the internationalization of innovation was strongly demand-driven or market-oriented, one would expect that foreign ownership of domestic innovation (SHIA) – domestic ownership of foreign innovation (SHAI) – to be particularly more related to import than export – export than import, respectively. This distinction between the two types of cross-border ownership of innovation does not take place significantly, which suggests that international innovative activities are poorly driven by home-base exploiting motives. This provides also evidence that the international competitiveness of the country-industry pair matters more than the direction of the trade flows in explaining the internationalization of innovation.

[26] In addition to measure this specialization in terms of inventors (see columns concerning SHIA in Table 5), I tested the same model controlling for specialization in terms of applicants (RTAc app). These robustness results are the same, see Appendix Table A.10. Unlike Cantwell and Piscitello (2005), our database does not allow us to focus precisely on domestic owned firms.

Table 6: Estimation results for EPO patent applications with trade flows variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. var.	**SHII**	**SHII**	**SHIA**	**SHIA**	**SHAI**	**SHAI**	**SHAA**	**SHAA**
RTAc inv	-1.085***	-1.035***	-0.751***	-0.709***				
	(0.0803)	(0.0783)	(0.0748)	(0.0738)				
RTAc app					-0.190**	-0.128	-0.729***	-0.659***
					(0.0874)	(0.0793)	(0.136)	(0.126)
Export	0.0629**		0.0511*		0.0724***		0.0864*	
	(0.0289)		(0.0266)		(0.0267)		(0.0481)	
Import		-0.00883		0.00955		0.0654		-0.00286
		(0.0606)		(0.0528)		(0.0564)		(0.0957)
Multi. inv	0.120***	0.130***	0.0852**	0.0922***				
	(0.0364)	(0.0368)	(0.0352)	(0.0354)				
Multi. app					-0.00276	0.00470	0.136**	0.148**
					(0.0403)	(0.0408)	(0.0633)	(0.0643)
R&D Int.	-0.609***	-0.583***	-0.654***	-0.632***	0.288**	0.308**	0.290	0.322
	(0.135)	(0.132)	(0.136)	(0.135)	(0.141)	(0.140)	(0.250)	(0.253)
Size	-0.380*	-0.328	-0.682***	-0.646**	-0.0557	-0.0606	-0.859	-0.788
	(0.216)	(0.215)	(0.255)	(0.256)	(0.264)	(0.267)	(0.601)	(0.603)
Country FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Industry FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Year FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Pseudo LL	-2957	-2958	-3603	-3604	-2935	-2936	-1566	-1567
Observations	10,043	10,043	10,043	10,043	9,789	9,789	9,789	9,789

Notes: Robust standard errors in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The rows "country FE", "industry FE", and "year FE" report the significance levels of the joint effect of these fixed effects.

The opposite effect of RTAc and RCAc (see Table 5) could be considered as confusing. Nevertheless, these results indicate that specialization in technological innovation is not necessarily related to export performance. These two set of variables may reflect different phenomena, particularly as determinants of the globalization of innovation. While RTAc measures the performance in the development of patentable inventions, exports based indicators are more related to the business exploitation of patented technologies. The results show in fact that country-industries which present better performance on the former dimension collaborate less than those which better perform in the latter one.

The third variable of interest, the multidisciplinarity (Multi. inv and Multi. app), has a positive and significant coefficient (except for SHAI), confirming the importance of home-base augmenting strategy. On the one hand, it indicates that multidisciplinary country-industry pairs are more likely to be involved in international collaboration (SHII and SHAA). On the other hand, it shows that country-industry pairs with more diverse patenting activities – across a larger number of different technologies – are more attractive for foreign applicants (SHIA). It confirms the positive impact of diversity externalities, observed by Cantwell and Piscitello (2005) (for a sample of MNE across European regions). These multidisciplinary country-industry pairs reflect a higher potential for inter-industry spillovers. As shown by Fernández-Ribas and Shapira (2009) in the case of nanotechnology, it also suggests that the inter-disciplinary and diversified knowledge in the host country matters for the location of R&D facilities abroad. Nevertheless, this positive impact is not observed for SHAI, suggesting that multidisciplinary country-industry pairs do not seem to own more foreign inventions.

The results of the last two variables (R&D Int. and Size), varying only across countries and over time, confirm mainly the findings of Guellec and van Pottelsberghe de la Potterie (2001, 2004) based on a cross-section of countries for EPO, USPTO and triadic patents[27].

Concerning the technological intensity of countries, we can distinguish between the different types of internationalization. First, the R&D intensity has a negative and significant impact on SHII and SHIA. The more a country is intensive in research and development, the less its inventors take part in international co-invention. In other words, inventors in countries with higher technological capacities – i.e. a larger home knowledge base – do not need as much as others collaboration with foreign researchers. It thus reinforces the results of RTAc and reflects that researchers cooperate with abroad to fulfill their weak innovative environment. Moreover, the higher the technological intensity of a country, the lower foreign applicants control its inventions. Indeed, Guellec and van Pottelsberghe de la Potterie (2001) concluded that leading innovative countries are not being "techno-sourced, at least not through foreign ownership of their inventions." Second, the impact of technological intensity on SHAI is positive and significant. It illustrates that companies in countries with higher R&D intensity have a higher tendency to own foreign innovation; it can be explained by a higher absorptive capacity of the knowledge flows related to these foreign locations of R&D (Cohen and Levinthal, 1989; Song and Shin, 2008).

Finally, the size variable has globally a negative impact, although poorly significant. It seems to reflect that firms in smaller countries do not only collaborate relatively more in patenting with foreigners but they also "participate relatively more in global sourcing of innovation" (as suggested by Thomson, 2013 for home and host country of R&D offshoring). In the same vein, these empirical findings indicate that internationalization of innovation is not purely market driven since large economies are not the target of foreign applicants in international patenting experiences (see columns (3)-(4) for SHIA).

[27] Patent families applied in Europe, the US and Japan.

7 Conclusions

In a world in which geographical borders are less and less relevant for production, trade and research, this paper aims at better understanding the globalization of innovation production. Using patent-based indicators, I firstly provide evidence on the extent to which the production of innovation takes place internationally. While most studies in the literature were carried out on a limited number of firms (mainly MNEs) or at cross-country level only, I prefer to use a more aggregated approach based on a unique panel dataset composed of 21 industries in 29 countries over 25 years. It allows us not only to better control for differences across industries, across countries and over time, but also to evaluate the relationship between the specialization of countries across industrial sectors and their internationalization of technology. Secondly, a fractional logit model is estimated to highlight main determinants behind the intensity of four types of globalization of innovation production: (1) co-invention (patent with inventors from different countries) (2) co-ownership (patent with applicants from different countries); (3) foreign ownership of domestic innovation (patent with domestic inventors and foreign applicants) and (4) domestic ownership of foreign innovation (patent with domestic applicants and foreign inventors).

Although the amplitude of globalization remains quite limited in the production of innovation, the patterns described in the first part of this paper confirm a strong growth in the intensity of internationalization of innovation – in addition to the so-called patent explosion. For instance, between 1980 and 2005, the intensity of co-invention in PF has been multiplied by 5 while the intensity of cross-border ownership of patents has known a growth rate superior to 200%. More importantly, the descriptive evidence shows still strong differences across countries and industries. First, the size of innovative effort of countries (or industries) is not necessarily reflected in the degree of internationalization of their patents. Second, the ownership of innovation remains still strongly geographically concentrated whereas the location of innovation is spread across borders.

The empirical findings of this paper indicate that globalization of innovation production is driven by home-base augmenting motives. Indeed, taking an industry perspective shows that the degree of internationalization of innovation is negatively related to the revealed technological advantage of countries across industries. Countries have a tendency to be more globalized in industrial sectors in which they are less technologically specialized. Additional results also provide evidence suggesting that international patenting is a way to compensate for technological weaknesses at home, rather than to exploit home technological strenghts in large foreign markets. In fact, the intensity of globalization of innovation is higher for small economies and for countries with low intensity of R&D expenditures, both indicating a smaller technological knowledge base. Strong innovative performance reduces the incentives to collaborate with foreigners in order to co-invent new technology. Countries with stronger research and development acitvities and large economies have also a lower risk that their domestic inventions are controlled by foreigners. By contrast, higher R&D intensity seems to stimulate the cross-border ownership of foreign innovation.

Concerning the relationship with international trade of goods, the impact is more ambiguous.

On the one hand, the impact of export and import – particularly concerning the cross-border ownership of innovation (SHIA and SHAI) – does not seem to confirm that globalization of R&D is largely market oriented. On the other hand, the international competitiveness (in terms of trade) of country-industry pairs positively affects the degree of globalization of innovation.

Finally, I show that the multidisciplinarity of research matters to explain internationalization of innovation. Again, it reinforces the argument saying that globalization is a mean to find complementary assets abroad. The more complex and interdisciplinary the technological development, the more likely you would need to collaborate on an international basis to find the necessary competences. Moreover, this positive impact suggests that country-industry pairs presenting more diverse patenting efforts – across a larger number of different technologies – are more attractive for foreign applicants.

However, these conclusions require further research. In particular, similar patent-based indicators can be used not only to measure the globalization of innovation of country with the rest of the world but also to study more precisely who collaborates with whom in the globalized production of innovation. Focusing on the bilateral relationships (with a same global approach, across countries, industries and over time) would allow us to control more precisely about home and host characteristics and especially to investigate the effects of distance factors (such as geographical distance, institutional differences or technological proximity) on international patenting experience. This kind of methodology would help to better understand where country-industry pairs are going to compensate for their weak technological environment.

Appendix Tables

Table A.1: Industry definition

ISIC Rev 3.		Industry description
FOOD	**15**	Manuf. of food products and beverages
TOBA	**16**	Manuf. of tobacco products
TEXT	**17**	Manuf. of textiles
WEAR	**18**	Manuf. of wearing apparel; dressing and dyeing of fur
LEAT	**19**	Tanning and dressing of leather; Manuf. of luggage, handbags, saddlery, harness and footwear
WOOD	**20**	Manuf. of wood and of products of wood and cork, except furniture; Manuf. of articles of straw and plaiting materials
PAP	**21**	Manuf. of paper and paper products
PETR	**23**	Manuf. of coke, refined petroleum products and nuclear fuel
CHEM	**24**	Manuf. of chemicals and chemical products
RUBB	**25**	Manuf. of rubber and plastics products
MINE	**26**	Manuf. of other non-metallic mineral products
META	**27**	Manuf. of basic metals
FABM	**28**	Manuf. of fabricated metal products, except machinery and equipment
MACH	**29**	Manuf. of machinery and equipment n.e.c.
COMP	**30**	Manuf. of office, accounting and computing machinery
ELEC	**31**	Manuf. of electrical machinery and apparatus n.e.c.
COMM	**32**	Manuf. of radio, television and communication equipment and apparatus
INST	**33**	Manuf. of medical, precision and optical instruments, watches and clocks
AUTO	**34**	Manuf. of motor vehicles, trailers and semi-trailers
TRAN	**35**	Manuf. of other transport equipment
MISC	**36**	Manuf. of furniture; manufacturing n.e.c.

Table A.2: Total count of patent applications per country (1980-2005)

Country	PF INV[1]	PF APP[2]	PF II	PF AA	PF IA	PF AI	EPO INV[1]	EPO APP[2]	EPO II	EPO AA	EPO IA	EPO AI
Australia*	163978	160764	3648	2446	6295	2815	15931	13246	2541	522	3714	1436
Austria	49709	40978	6543	2029	12799	4711	23273	19157	4723	2643	7703	4130
Belgium	44002	34869	8563	2307	13363	5137	28096	20702	8419	1937	11781	5744
Canada	113941	105713	10896	3254	16492	10378	27413	21931	7218	1166	9405	5702
Czech Republic	8820	8220	867	309	1002	525	1089	711	434	71	545	197
Denmark*	32967	31168	3072	1308	4034	2898	14564	13157	2542	686	3044	2395
Finland	59310	61129	2632	1392	2689	5609	18511	19368	2192	320	1942	4088
France	327671	314903	19353	6428	28461	19035	148540	139089	17688	8315	28067	20314
Germany	912523	887729	45368	13666	57236	49671	390360	368160	37465	14573	51459	39537
Greece	17770	17354	440	146	579	151	1177	825	347	56	422	79
Hungary	40182	39306	968	419	1417	566	2788	2059	609	85	864	167
Iceland	808	662	174	46	230	99	440	286	173	23	227	107
Ireland*	21808	21183	1476	553	2214	1784	3574	3682	1112	306	1380	1741
Italy	212617	203466	6539	2368	12714	3984	70301	61652	5687	1531	11433	3348
Japan	7908626	7903434	15958	10623	25274	22336	318504	315324	8527	3749	12076	10810
Luxembourg	2940	4105	866	331	998	2404	1594	2720	742	170	833	2165
Mexico	8339	7609	644	150	1016	287	852	394	381	52	518	63
Netherlands	87467	91368	10654	7362	17573	22716	74898	90510	9866	15333	14586	31051
New Zealand	15691	15160	765	488	1111	590	2350	1894	482	104	626	238
Norway	27566	26687	1805	766	2348	1787	6363	5709	1232	223	1500	1166
Poland	87376	86697	1274	463	1252	839	1258	759	483	94	603	110
Portugal	3133	2973	287	89	395	259	721	578	224	42	308	182
Rep. of Korea	774179	776358	5912	2121	3169	9002	22318	22202	1229	387	1155	1393
Slovakia	3504	3288	433	164	417	282	306	155	166	19	189	48
Spain	51323	47772	3553	836	4930	1989	13248	10031	2472	417	3874	806
Sweden	109928	111852	6095	3070	8124	11924	38656	39614	5010	1581	6594	9336
Switzerland	99513	106050	17215	6239	18192	31822	61511	72105	15900	5895	13227	31556
United Kingdom	478639	448436	23833	12496	49520	20316	115950	95246	19204	11793	38309	17322
United States	1666469	1695302	66181	25849	70129	126878	527881	528581	48697	12054	56627	79783

Source: own calculations based on PATSTAT database (April 2009)

Notes: * indicates countries that suffer from a coverage problem, concerning the PF indicators, identified by de Rassenfosse et al. (2013, p 734). Those countries were not taken into account in the empirical model for PF. [1] Total count of patent applications based on inventor criterion. [2] Total count of patent applications based on applicant criterion.

Table A.3: Total count of patent applications per industry (1980-2005)

Industry	PF				EPO			
	COUNT	II	AA	IA/AI	COUNT	II	AA	IA/AI
FOOD	196275	2295	872	5120	27581	2788	1498	6037
TOBA	9389	120	56	247	1805	79	12	221
TEXT	66233	887	280	2006	15317	1196	336	2566
WEAR	27718	159	57	453	3664	144	24	383
LEAT	19084	196	76	666	3876	152	38	588
WOOD	61622	213	92	586	4838	130	33	376
PAP	141871	1056	365	2470	22169	1174	306	2690
PETR	61213	1288	442	2514	14354	1123	598	2504
CHEM	1649839	31624	10536	59601	465107	42929	13820	82073
RUBB	604055	4871	2084	14411	99997	4414	1999	13674
MINE	531458	4070	1606	9308	69969	3532	1329	8739
META	445355	3715	1371	7036	49652	2766	1023	5776
FABM	502937	3266	1113	9775	73015	2344	734	7477
MACH	3149820	22429	8348	60084	422627	16320	6131	46804
COMP	2086155	15845	5909	46480	218321	8449	3930	28036
ELEC	808823	5573	1728	16066	105438	3615	1483	11789
COMM	2683105	22706	9574	65620	324360	14560	6852	48024
INST	1870777	18394	6720	44074	329007	17367	6799	43933
AUTO	905974	6561	2099	18336	134038	4475	2033	13572
TRAN	180800	1465	511	3202	29745	895	272	2045
MISC	393262	1787	926	5451	39636	1046	466	3498

Source: own calculations based on PATSTAT database (April 2009)
Note: see Appendix Table A.1 for the description of the industries.

Table A.4: Description of variables

Variable	Description
Dependent Variables *[i,k,t]*	
EPO SHII EPO SHIA EPO SHAI EPO SHAA	Share of international patents in the total number of patents, see equations (1) to (4) considering counts of patent applications at the European Patent Office (EPO)
PF SHII PF SHIA PF SHAI PF SHAA	Share of international patents in the total number of patents, see equations (1) to (4) considering counts of priority filings (PF)
Explanatory variables	
RTAc EPO inv *[i,k,t]* RTAc EPO app *[i,k,t]* RTAc PF inv *[i,k,t]* RTAc PF app *[i,k,t]*	Indicator of Revealed Technological Advantage described in equation (8) counting either EPO or PF based on inventor (inv) or applicant (app).
Export *[i,k,t]*	export of goods (in log)
Import *[i,k,t]*	import of goods (in log)
RCAc *[i,k,t]*	Same formula as equation (8) replacing patent counts by export of goods
Net trade *[i,k,t]*	$\frac{Export_{i,k,t} - Import_{i,k,t}}{Export_{i,k,t} + Import_{i,k,t}}$
Multi. EPO inv *[i,k,t]* Multi. EPO app *[i,k,t]* Multi. PF inv *[i,k,t]* Multi. PF app *[i,k,t]*	Number of distinct 4-digit IPC classes (in log) – outside the scope of the industry k defined by the concordance table of Schmoch et al. (2003) – listed on patents (EPO or PF) of industry k in country i (inv or app) at priority year t
R&D Int. *[i,t]*	log of the ratio of R&D expenditures divided by the GDP of country i at year t
Size *[i,t]*	log of the GDP of country i at year t

Sources: own calculation based on PATSTAT April 2009 database for patent-based variables; OECD STAN Database for Structural Analysis for Trade series; OECD Main Science and Technology Indicators 2011 for R&D. Int.; and OECD National Accounts data files for Size.

Table A.5: Descriptive statistics

Variable	Obs.	Mean	SE	Min	Max
Dependent Variables *[i,k,t]*					
EPO SHII	10043	0.165	0.202	0	1
EPO SHIA	10043	0.232	0.238	0	1
EPO SHAI	9789	0.167	0.201	0	1
EPO SHAA	9789	0.057	0.118	0	1
PF SHII	9481	0.082	0.120	0	1
PF SHIA	9481	0.123	0.159	0	1
PF SHAI	9402	0.086	0.134	0	1
PF SHAA	9402	0.027	0.060	0	1
Explanatory variables					
RTAc EPO inv *[i,k,t]*	10043	-0.014	0.321	-0.991	0.984
RTAc EPO app *[i,k,t]*	9789	-0.012	0.332	-0.986	0.985
RTAc PF inv *[i,k,t]*	9481	0.018	0.322	-0.928	0.977
RTAc PF app *[i,k,t]*	9402	0.020	0.329	-0.949	0.977
Export *[i,k,t]*	10043	21.410	1.756	7.467	25.651
Import *[i,k,t]*	10043	21.720	1.327	15.970	25.949
RCAc *[i,k,t]*	10043	-0.118	0.370	-1.000	0.981
Net trade *[i,k,t]*	10043	-0.118	0.390	-1.000	0.967
Multi. EPO inv *[i,k,t]*	10043	3.360	1.454	0	6.207
Multi. EPO app *[i,k,t]*	9789	3.355	1.449	0	6.209
Multi. PF inv *[i,k,t]*	9481	3.285	1.566	0	6.207
Multi. PF app *[i,k,t]*	9402	3.250	1.574	0	6.209
R&D Int. *[i,t]*	10043	0.458	0.533	-1.874	1.418
Size *[i,t]*	10043	26.593	1.405	22.406	30.042

Note: The number of observations per variable corresponds to the one of the largest sample used in the empirical approach.

Table A.6: Correlation matrix

		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]
[1]	EPO SHII	1																					
[2]	EPO SHIA	0.73	1																				
[3]	EPO SHAI	0.62	0.42	1																			
[4]	EPO SHAA	0.37	0.47	0.47	1																		
[5]	PF SHII	0.59	0.48	0.51	0.22	1																	
[6]	PF SHIA	0.45	0.60	0.40	0.23	0.78	1																
[7]	PF SHAI	0.41	0.29	0.67	0.21	0.74	0.56	1															
[8]	PF SHAA	0.33	0.35	0.36	0.37	0.57	0.59	0.55	1														
[9]	RTAc EPO inv	-0.10	-0.10	-0.10	-0.04	-0.06	-0.07	-0.04	-0.03	1													
[10]	RTAc EPO app	-0.13	-0.25	-0.02	-0.07	-0.09	-0.16	-0.01	-0.05	0.93	1												
[11]	RTAc PF inv	-0.10	-0.13	-0.07	-0.04	-0.17	-0.18	-0.12	-0.09	0.66	0.66	1											
[12]	RTAc PF app	-0.10	-0.17	-0.03	-0.04	-0.17	-0.26	-0.07	-0.11	0.65	0.68	0.97	1										
[13]	Export	-0.06	-0.02	0.00	0.03	0.02	0.05	0.02	0.03	0.07	0.05	0.06	0.05	1									
[14]	Import	-0.06	-0.01	-0.04	0.03	-0.01	0.03	-0.03	0.01	-0.12	-0.12	-0.10	-0.11	0.81	1								
[15]	RCAc	-0.01	-0.01	0.05	0.04	0.01	0.01	0.03	0.03	0.41	0.40	0.36	0.35	0.55	0.11	1							
[16]	Net trade	-0.03	-0.05	0.04	0.01	0.03	0.03	0.06	0.04	0.28	0.26	0.24	0.23	0.61	0.05	0.80	1						
[17]	Multi. EPO inv	-0.19	-0.16	-0.13	-0.06	-0.16	-0.13	-0.12	-0.11	-0.07	-0.09	-0.04	-0.05	0.63	0.67	0.06	0.19	1					
[18]	Multi. EPO app	-0.21	-0.20	-0.11	-0.06	-0.19	-0.19	-0.10	-0.11	-0.07	-0.07	-0.03	-0.03	0.61	0.65	0.05	0.18	0.99	1				
[19]	Multi. PF inv	-0.19	-0.16	-0.13	-0.06	-0.16	-0.13	-0.12	-0.11	-0.07	-0.09	-0.04	-0.05	0.63	0.67	0.06	0.19	1.00	0.99	1			
[20]	Multi. PF app	-0.21	-0.20	-0.11	-0.06	-0.19	-0.19	-0.10	-0.11	-0.07	-0.07	-0.03	-0.03	0.61	0.65	0.05	0.18	0.99	1.00	0.99	1		
[21]	R&D Int.	-0.22	-0.26	0.05	-0.09	-0.01	-0.05	0.15	-0.03	-0.16	-0.17	-0.11	-0.11	0.31	0.26	0.03	0.20	0.45	0.46	0.45	0.46	1	
[22]	Size	-0.29	-0.26	-0.23	-0.09	-0.25	-0.23	-0.23	-0.14	-0.09	-0.09	-0.03	-0.03	0.61	0.71	0.05	0.10	0.62	0.62	0.62	0.62	0.39	1

Table A.7: Main OLS estimation results for EPO patent applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. var.	**SHII**	**SHII**	**SHIA**	**SHIA**	**SHAI**	**SHAI**	**SHAA**	**SHAA**
RTAc inv	-0.152***	-0.152***	-0.139***	-0.138***				
	(0.0120)	(0.0121)	(0.0127)	(0.0127)				
RTAc app					-0.0198*	-0.0200*	-0.0384***	-0.0396***
					(0.0112)	(0.0115)	(0.00829)	(0.00828)
Net trade	0.0474***		0.0402***		0.0258***		0.0157**	
	(0.00785)		(0.00942)		(0.00813)		(0.00615)	
RCAc		0.0465***		0.0373***		0.0251***		0.0178***
		(0.00887)		(0.0105)		(0.00929)		(0.00649)
Multi. inv	0.0159***	0.0142***	0.0168***	0.0154***				
	(0.00496)	(0.00497)	(0.00586)	(0.00588)				
Multi. app					-0.00233	-0.00321	0.00800**	0.00736**
					(0.00526)	(0.00526)	(0.00320)	(0.00318)
R&D Int.	-0.0531***	-0.0525***	-0.0968***	-0.0961***	0.0334*	0.0338*	0.0148	0.0148
	(0.0168)	(0.0168)	(0.0226)	(0.0226)	(0.0173)	(0.0174)	(0.0131)	(0.0132)
Size	-0.0154	-0.0137	-0.0892**	-0.0879**	0.0380	0.0388	-0.0413*	-0.0407*
	(0.0332)	(0.0340)	(0.0433)	(0.0435)	(0.0463)	(0.0467)	(0.0242)	(0.0244)
Country FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Industry FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Year FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
R-squared	0.398	0.398	0.399	0.399	0.403	0.403	0.163	0.163
Obs.	10,043	10,043	10,043	10,043	9,789	9,789	9,789	9,789

Notes: Robust standard errors in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The rows "country FE", "industry FE", and "year FE" report the significance levels of the joint effect of these fixed effects.

Table A.8: Main Tobit estimation results for EPO patent applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. var.	**SHII**	**SHII**	**SHIA**	**SHIA**	**SHAI**	**SHAI**	**SHAA**	**SHAA**
RTAc inv	-0.164***	-0.164***	-0.137***	-0.134***				
	(0.0150)	(0.0153)	(0.0154)	(0.0155)				
RTAc app					-0.00304	-0.00305	-0.0383***	-0.0404***
					(0.0150)	(0.0155)	(0.0137)	(0.0138)
Net trade	0.0613***		0.0487***		0.0295***		0.0302***	
	(0.0106)		(0.0117)		(0.0105)		(0.0111)	
RCAc		0.0564***		0.0405***		0.0273**		0.0321***
		(0.0119)		(0.0127)		(0.0120)		(0.0113)
Multi. inv	0.0318***	0.0297***	0.0273***	0.0258***				
	(0.00676)	(0.00678)	(0.00737)	(0.00741)				
Multi. app					0.0106	0.00965	0.0316***	0.0305***
					(0.00722)	(0.00721)	(0.00672)	(0.00666)
R&D Int.	-0.0346	-0.0333	-0.0872***	-0.0859***	0.0876***	0.0886***	0.0583***	0.0588***
	(0.0211)	(0.0212)	(0.0260)	(0.0260)	(0.0226)	(0.0227)	(0.0222)	(0.0222)
Size	0.00869	0.0109	-0.0867*	-0.0852*	0.0708	0.0716	-0.0202	-0.0206
	(0.0385)	(0.0395)	(0.0492)	(0.0493)	(0.0518)	(0.0521)	(0.0453)	(0.0457)
Country FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Industry FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Year FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Pseudo LL	97.06	88.53	-556.8	-564.8	-174.5	-176.4	54.36	55.26
Obs.	10,043	10,043	10,043	10,043	9,789	9,789	9,789	9,789

Notes: Robust standard errors in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The rows "country FE", "industry FE", and "year FE" report the significance levels of the joint effect of these fixed effects.

Table A.9: Main fractional logit estimation results for Priority Filings (PF)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. var.	**SHII**	**SHII**	**SHIA**	**SHIA**	**SHAI**	**SHAI**	**SHAA**	**SHAA**
RTAc inv	-0.786***	-0.794***	-0.640***	-0.638***				
	(0.104)	(0.104)	(0.105)	(0.105)				
RTAc app					-0.00155	-0.0159	-0.616***	-0.603***
					(0.111)	(0.112)	(0.146)	(0.147)
Net trade	0.266***		0.318***		0.125		0.348***	
	(0.0847)		(0.0848)		(0.0783)		(0.111)	
RCAc		0.254***		0.275***		0.133*		0.250***
		(0.0764)		(0.0807)		(0.0752)		(0.0955)
Multi. inv	0.0336	0.0304	0.0425	0.0399				
	(0.0424)	(0.0421)	(0.0446)	(0.0446)				
Multi. app					0.0618	0.0603	0.0733	0.0736
					(0.0457)	(0.0458)	(0.0672)	(0.0670)
R&D Int.	-0.428**	-0.429**	-0.514***	-0.518***	0.389**	0.391**	0.435*	0.440*
	(0.174)	(0.174)	(0.157)	(0.157)	(0.191)	(0.191)	(0.263)	(0.262)
Size	0.215	0.143	0.315	0.228	-0.233	-0.270	-0.985	-1.054
	(0.392)	(0.395)	(0.430)	(0.433)	(0.345)	(0.347)	(0.642)	(0.643)
Country FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Industry FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Year FE	yes***	yes***	yes***	yes***	yes***	yes***	yes***	yes***
Pseudo LL	-1762	-1762	-2268	-2268	-1733	-1733	-835.8	-836.2
Observations	9,481	9,481	9,481	9,481	9,402	9,402	9,402	9,402

Notes: Robust standard errors in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The rows "country FE", "industry FE", and "year FE" report the significance levels of the joint effect of these fixed effects. The additional estimation results (presented for EPO applications in Table 6 and Appendix Tables A.7, A.8 and A.10) are also confirmed for PF and are available upon request.

Table A.10: Robustness results on SHIA for EPO patent applications

	(1)	(2)	(3)	(4)
Dep. var.	**SHIA**	**SHIA**	**SHIA**	**SHIA**
RTAc app	-1.273***	-1.173***	-1.271***	-1.279***
	(0.0671)	(0.0668)	(0.0674)	(0.0666)
Export	0.123***			
	(0.0248)			
Import		0.0467		
		(0.0508)		
Net trade			0.321***	
			(0.0658)	
RCAc				0.314***
				(0.0638)
Multi. inv	0.169***	0.186***	0.177***	0.168***
	(0.0320)	(0.0328)	(0.0319)	(0.0319)
R&D Int.	-0.472***	-0.431***	-0.440***	-0.441***
	(0.114)	(0.111)	(0.113)	(0.113)
Size	-0.360	-0.305	-0.261	-0.238
	(0.233)	(0.237)	(0.229)	(0.231)
Country FE	yes***	yes***	yes***	yes***
Industry FE	yes***	yes***	yes***	yes***
Year FE	yes***	yes***	yes***	yes***
Pseudo LL	-3282	-3289	-3283	-3283
Observations	9,772	9,772	9,772	9,772

Notes: Robust standard errors in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The rows “country FE”, “industry FE”, and “year FE” report the significance levels of the joint effect of these fixed effects.

References

Almeida, P. (1996). Knowledge sourcing by foreign multinationals: patent citation analysis in the semiconductor industry. *Strategic Management Journal 9*(1), 98–122.

Ambos, B. (2005). Foreign direct investment in industrial research and development: A study of German MNCs. *Research Policy 34*, 395–410.

Archibugi, D. and S. Iammarino (2002). The globalization of technological innovation: definition and evidence. *Review of International Political Economy 9*(1), 98–122.

Archibugi, D. and J. Michie (1997). The globalisation of technology: a new taxonomy. In D. Archibugi and J. Michie (Eds.), *Technology, Globalisation and Economic Performance*, Chapter 6, pp. 172–197.

Athukorala, P.-c. and A. Kohpaiboon (2010). Globalization of R&D by US-based multinational enterprises. *Research Policy 39*(10), 1335–1347.

Begg, I., B. Dalum, P. Guerrieri, and M. Pianta (1999). The impact of specialization in Europe. In J. Fagerberg, P. Guerrieri, and B. Verspagen (Eds.), *The Economic Challenge for Europe: Adapting to innovation based growth*, pp. 21–45.

Belderbos, R., B. Leten, and S. Suzuki (2011). How Global is R & D ? Determinants of the Home Country Bias in R & D Investments. *Paper presented at the DIME Final Conference, Maastricht*.

Breschi, S. (1999). Spatial patterns of innovation: evidence from patent data. In A. Gambardella and F. Malerba (Eds.), *The Organization of Economic Innovation in Europe*, Volume 1999, pp. 71–102. Cambridge University Press.

Breschi, S. (2000). The geography of innovation : A cross-sector analysis. *Regional Studies 34*(3), 213–229.

Brusoni, S. and A. Geuna (2003). An international comparison of sectoral knowledge bases: persistence and integration in the pharmaceutical industry. *Research Policy 32*(10), 1897–1912.

Cantwell, J. (1995). The globalisation of technology : what remains of the product cycle model? *Cambridge Journal of Economics 19*, 155–174.

Cantwell, J. and O. Janne (1999). Technological globalisation and innovative centres: the role of corporate technological leadership and locational hierarchy. *Research Policy 28*, 119–144.

Cantwell, J. and L. Piscitello (2005). Recent Location of Foreign-owned Research and Development Activities by Large Multinational Corporations in the European Regions: The Role of Spillovers and Externalities. *Regional Studies 39*(1), 1–16.

Cassiman, B. and R. Veugelers (2006). In Search of Complementarity in Innovation Strategy: Internal R & D and External Knowledge Acquisition. *Management Science 52*(1), 68–82.

Cincera, M., B. van Pottelsberghe de la Potterie, and R. Veugelers (2006). Assessing the foreign control of production of technology: The case of a small open economy. *Scientometrics 66*(3), 493–512.

Cohen, W. M. and D. A. Levinthal (1989). Innovation and Learning: The Two Faces of R & D. *The Economic Journal 99*(397), 569–596.

Cohen, W. M., R. R. Nelson, and J. P. Walsh (2000). Protecting Their Intellectual Assets: Appropriability Conditions and Why US Manufacturing Firms Patent (or Not). *NBER Working Paper No. 7552*.

Czarnitzki, D. and K. Kraft (2004). Firm Leadership and Innovative Performance: Evidence from Seven EU Countries. *Small Business Economics 22*(5), 325–332.

D'Agostino, L., K. Laursen, and G. D. Santangelo (2013). The impact of R&D offshoring on the home knowledge production of OECD investing regions. *Journal of Economic Geography 13*(1), 145–175.

Dalum, B., K. Laursen, and B. Verspagen (1999). Does Specialization Matter for Growth? *Industrial and Corporate Change 8*(2), 267–288.

Danguy, J., G. de Rassenfosse, and B. van Pottelsberghe de la Potterie (2013). On the Origins of the Worldwide Surge in Patenting: An Industry Perspective on the R&D-patent Relationship. *Industrial and Corporate Change , forthcoming*.

de Rassenfosse, G., H. Dernis, D. Guellec, L. Picci, and B. van Pottelsberghe de la Potterie (2013). The worldwide count of priority patents: A new indicator of inventive activity. *Research Policy 42*(3), 720–737.

Dernis, H., D. Guellec, and B. van Pottelsberghe de la Potterie (2001). Using patent counts for cross-country comparisons of technology output. *OECD Science Technology and Industry Review 27*, 129–146.

Dunning, J. (1994). Multinational enterprises and the globalization of innovatory capacity. *Research Policy 23*(1), 67–88.

Dunning, J. H. and R. Narula (1995). The R&D activities of foreign firms in the United States. *International Studies of Management & Organization 25*(1/2), 39–74.

Fernández-Ribas, A. and P. Shapira (2009). Technological diversity, scientific excellence and the location of inventive activities abroad: the case of nanotechnology. *The Journal of Technology Transfer 34*(3), 286–303.

Florida, R. (1997). The globalization of R&D: Results of a survey of foreign-affiliated R&D laboratories in the USA. *Research Policy 26*, 85–103.

Frietsch, R. and T. Jung (2009). Transnational Patents: Structures, Trends and Recent Developments. *Studien zum deutschen Innovationssystem Nr 7-2009*.

Frietsch, R. and U. Schmoch (2010). Transnational patents and international markets. *Scientometrics 82*(1), 185–200.

Furman, J., M. Porter, and S. Stern (2002). The determinants of national innovative capacity. *Research Policy 31*(6), 899–933.

Griliches, Z. (1990). Patent Statistics as Economic Indicators: A Survey. *Journal of Economic Literature 28*(4), 1661–1707.

Guellec, D. and B. van Pottelsberghe de la Potterie (2001). The internationalisation of technology analysed with patent data. *Research Policy 30*(8), 1253–1266.

Guellec, D. and B. van Pottelsberghe de la Potterie (2004). Measuring the internationalisation of the generation of knowledge. In H. Moed, W. Glänzel, and U. Schmoch (Eds.), *Handbook of quantitative science and technology research*, Chapter 29, pp. 645–662.

Hagedoorn, J. (2002). Inter-firm R&D partnerships: an overview of major trends and patterns since 1960. *Research Policy 31*(4), 477–492.

Hall, B. H. (2011). The Internationalization of R&D. In A. Sydor (Ed.), *Global Value Chains: Impacts and Implications*.

Kieschnick, R. and B. D. McCullough (2003). Regression analysis of variates observed on (0,1): percentages, proportions and fractions. *Statistical Modelling 3*(3), 193–213.

Kuemmerle, W. (1997). Bulding Effecitve R&D Capabilites Abroad. *Harvard Business Review* (March/April), 61–70.

Kuemmerle, W. (1999). The Drivers of Foreign Direct Investment into Research and Development: An Empirical Investigation. *Journal of International Business Studies 30*(1), 1–24.

Kumar, N. (1996). Intellectual property protection, market orientation and location of overseas R&D activities by multinational enterprises. *World Development 24*(4), 673–688.

Kumar, N. (2001). Determinants of location of overseas R&D activity of multinational enterprises: the case of US and Japanese corporations. *Research Policy 30*(1), 159–174.

Lall, S. (1979). The International Allocation of Research Acitvity By US Multinationals. *Oxford Bulletin of Economics and Statistics 41*, 313–331.

Laursen, K. (1998). Revealed Comparative Advantage and the Alternatives as Measures of International Specialisation. *DRUID Working Paper No. 98-30*.

Le Bas, C. and C. Sierra (2002). Location versus home country advantages' in R&D activities: some further results on multinationals' locational strategies. *Research Policy 31*(4), 589–609.

Lewin, A. Y., S. Massini, and C. Peeters (2009). Why are companies offshoring innovation? The emerging global race for talent. *Journal of International Business Studies 40*(6), 901–925.

Ma, Z. and Y. Lee (2008). Patent application and technological collaboration in inventive activities: 1980-2005. *Technovation 28*(6), 379–390.

Mansfield, E., D. Teece, and A. Romeo (1979). Overseas Research and Development by US-Based Firms. *Economica 46*(182), 187–196.

Miotti, L. and F. Sachwald (2003). Co-operative R&D: why and with whom? An integrated framework of analysis. *Research Policy 32*(8), 1481–1499.

Montobbio, F. and V. Sterzi (2012). The globalization of technology in emerging markets : a gravity model on the determinants of international patent collaborations. *Dipartimento di Economica "S Cognetti de Martiis" Working Paper No. 08/2012*.

Narula, R. and G. Duysters (2004). Globalisation and trends in international R&D alliances. *Journal of International Management 10*(2), 199–218.

Narula, R. and A. Zanfei (2005). Globalization of Innovation: The Role of Multinational Enterprises. In J. Fagerberg, D. C. Mowery, and R. R. Nelson (Eds.), *The Oxford Handbook of Innovation*, pp. 318–345.

OECD (2008). The Internationalisation of Business R & D: Evidence, Impacts and Implications.

OECD (2009). *OECD Patent Statistics Manual*.

Papke, L. and J. Wooldridge (1996). Econometric methods for fractional response variables with an application to 401(K) plan participation rates. *Journal of Applied Econometrics 11*, 619–632.

Patel, P. and K. Pavitt (1991). Large firms in the Production of the World's Technology: An Important case of "Non-Globalisation". *Journal of International Business Studies 22*(1), 1–21.

Patel, P. and M. Vega (1999). Patterns of internationalisation of corporate technology: location vs. home country advantages. *Research Policy 28*(2-3), 145–155.

Picci, L. (2010). The internationalization of inventive activity: A gravity model using patent data. *Research Policy 39*(8), 1070–1081.

Picci, L. and L. Savorelli (2012). Internationalized R & D Activities and Technological Specialization : An Analysis of Patent Data. *SSRN Working Paper*.

Ramalho, E., J. Ramalho, and J. Murteira (2011). Alternative Estimating and Testing Empirical Strategies for Fractional Regression Models. *Journal of Economic Surveys 25*(1), 19–68.

Schmiele, A. (2012). Drivers for international innovation activities in developed and emerging countries. *The Journal of Technology Transfer 37*(1), 98–123.

Schmoch, U., F. Laville, P. Patel, and R. Frietsch (2003). Linking Technology Areas to Industrial Sectors Research. *Final Report to the European Commission, DG Research*.

Schubert, T. and H. Grupp (2011). Tests and Confidence Intervals for Economic, Scientometric, and Technological Specialisation Ratios. *Applied Economics 43*(8), 941–950.

Singh, J. (2005). Collaborative Networks as Determinants of Knowledge Diffusion Patterns. *Management Science 51*(5), 756–770.

Soete, L. (1987). The impact of technological innovation on international trade patterns: The evidence reconsidered. *Research Policy 16*, 101–130.

Song, J. and J. Shin (2008). The paradox of technological capabilities: a study of knowledge sourcing from host countries of overseas R&D operations. *Journal of International Business Studies 39*(2), 291–303.

Thomson, R. (2013). National scientific capacity and R&D offshoring. *Research Policy 42*(2), 517–528.

UNCTAD (2005). World Investment Report: Transnational Corporations and the Internationalization of R & D. *New York and Geneva*.

UNESCO (2010). UNESCO Science Report 2010: The current status of science around the world. *Paris*.

van Zeebroeck, N., B. van Pottelsberghe de la Potterie, and W. Han (2006). Issues in measuring the degree of technological specialisation with patent data. *Scientometrics 66*(3), 481–492.

Veugelers, R. (2010). Towards a multipolar science world: trends and impact. *Scientometrics 82*(2), 439–456.

von Zedtwitz, M. and O. Gassmann (2002). Market versus technology drive in R & D internationalization : four different patterns of managing research and development. *Research Policy 31*, 569–588.

Wagner, J. (2001). A Note on the Firm Size - Export Relationship. *Small Business Economics 17*, 229–237.

Wagner, J. (2003). Unobserved firm heterogeneity and the size-exports nexus: Evidence from German panel data. *Review of World Economics 139*(1), 161–172.

Wuchty, S., B. F. Jones, and B. Uzzi (2007). The increasing dominance of teams in production of knowledge. *Science 316*(5827), 1036–9.

WORKING PAPERS 2013

001 - Exploring europe's r&d deficit relative to the us: differences in the rates of return to r&d of young leading r&d firms - Michele Cincera and Reinhilde Veugelers

002 - Governance typology of universities' technology transfer processes - A. Schoen, B. van Pottelsberghe de la Potterie, J. Henkel.

003 - Academic Patenting in Belgium: Methodology and Evidence – M. Mejer.

004 - The impact of knowledge diversity on inventive performance at European universities – M. Mejer

005 - Cross-Functional Knowledge Integration, Patenting and Firm's Performance – M. Ceccagnoli, N. van Zeebroeck and R. Venturini.

006 - Corporate Science, Innovation and Firm Value, M. Simeth and M. Cincera

WORKING PAPERS 2014

007 - Determinants of Research Production at top US Universities – Q. David

008 - R&D financing constraints of young and old innovation leaders in the EU and the US – M. Cincera, J. Ravet and R. Veugelers

009 - Globalization of Innovation Production; A Patent-Based Industry Analysis – J. Danguy