# Internationalized R&D Activities and Technological Specialization: An Analysis of Patent Data

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This version: 11 November 2012

## Abstract

Using patent data, we study the relationship between countries' technological specialization profiles and the internationalization of inventive activities from 1990 to 2006. We document an increase in internationalization across all technologies, with only a modest impact of compositional effects on the aggregate. Technological specialization has not increased in the last two decades, thus interrupting a trend that other studies had discovered.

The specialization profiles that we observe in the production of national inventions tend to be reflected, but amplified, when we look at international inventive activities. Some countries have relatively many firms inventing abroad with foreign inventors, compared to inventors at home working for foreign firms. These countries also tend to be less technologically specialized than average. We argue that MNEs technological diversification at the firm level favors the technological specialization of overseas locations by building on their comparative advantage. The relevance of home-base augmenting motivations for internationalization has not changed in time. Looking at the role of technological proximity in influencing the level of international collaborations, we find great variations of results across sectors.

Our results overall suggest that in explaining the internationalization of inventive activities we should distinguish between system-specific and sector-specific motives.

**JEL classification**: O31; O34; F21; F23; F29.

*Keywords*: Patents; R&D; Internationalization; Specialization; Technological Sectors; Gravity Model.

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## 1. Introduction

More than twenty years ago Patel and Pavitt (1991) identified the internationalization of inventive activity as an area of economic endeavour which is "far from globalised". Lately this opinion has been challenged and there is a widespread perception that R&D internationalization has made considerable inroads over the last two decades (Patel and Vega, 1999; Le Bas and Sierra, 2002; for wireless telecommunications, Di Minin and Bianchi, 2011; pharmaceuticals, Bennato and Magazzini, 2009; Penner-Hahn and Shaver, 2005; biotech, Shan and Song, 1997; semiconductors, Almeida, 1996; for an overall assessment, Picci, 2010).[2] Parallel to the increase in internationalization, other studies have documented an increase in the technological specialization of countries. These two phenomena may well be linked. Archibugi and Pianta (1992) and Cantwell and Vertova (2004), for example, besides showing that the technological specialization of countries has increased from the mid-60s to the late 80s, also suggest explicitly that this might be due to the greater internationalization of multinational enterprises (MNEs), which leads overseas locations to focus on sectors where they have a technological comparative advantage. National profiles of technological specialization, then, would be reinforced by the presence and action of foreign firms.

These two processes, however, can hardly be characterized as a steady and homogenous progress in time. For example, Gerybadze and Reger (1999) identify three main periods in the evolution of the management of international R&D: from the late 70s to the early 80s, where multinational enterprises (MNEs) supported overseas subsidiaries with complementary R&D; from 1985 to 1995, when there was an increasing trend in the transnational organization of R&D; and in the mid-90s, where the R&D function was restructured to reduce the over-dispersion of innovation, which had resulted in excessive organizational complexities. With respect to countries' technological specialization, the existing accounts are somehow dated, and do not tell us whether its observed deepening is still ongoing. Moreover, and most importantly, we lack a coherent picture

[2] There has been a spur in media coverage on multinational enterprises setting up R&D labs. Consider as an example this excerpt from The Economist (2010): "The world's biggest multinationals are becoming increasingly happy to do their research and development in emerging markets. Companies in the *Fortune* 500 list have 98 R&D facilities in China and 63 in India. Some have more than one. General Electric's health-care arm has spent more than $50m in the past few years to build a vast R&D centre in India's Bangalore, its biggest anywhere in the world. Cisco is splashing out more than $1 billion on a second global headquarters—Cisco East—in Bangalore, now nearing completion. Microsoft's R&D centre in Beijing is its largest outside its American headquarters in Redmond".

shedding light on the relationships between the internationalization of innovative activities and technological specialization. Providing one, and bridging the gap between the debate on internationalization and the debate on specialization, is the main objective of this paper.

The motivations for technological specialization and for internationalization of R&D are likely connected. A well-known taxonomy (Kuemmerle, 1997) distinguishes between "home-base augmenting" motivations, aimed at obtaining abroad strategic assets that are complementary with those already available, as opposed to "home-base exploiting" motivations, whose goal is to exploit already developed assets, delivering inventions that are mostly of the adaptive type.[3] While Kummerle's is a useful framework that we also adopt, the debate on motivations has provided contrasting results. This might be so because the classification, in its simplicity, leaves out important aspects of the problem and, as such, oversimplify it (von Zedtwitz and Gassmann, 2002). In this paper we argue that the "home-base augmenting" and "home-base exploiting" motives should be explored through specific lenses. In particular, technological specialization matters: MNEs might either expand their R&D activities abroad in sectors where the home-base country is already strong or augment their know-how by tapping into sectors where foreign locations have a technological advantage. Also, internationalization strategy is likely to be sector specific (Archibugi and Michie, 1995) and, we argue, to depend on the profiles of technological specialization both of the national and of the foreign economy.

To study these issues empirically we identify inventions with patent applications, by using the Patstat database (European Patent Office, 2009a and 2009b), which we analyse by means of an innovative approach that draws on the filings to all the (at least marginally significant) patent offices in the world (De Rassenfosse et al., 2013). In this way, although with the known caveats that pertain the use of patent data in such a contest, we obtain a comprehensive view on the production of inventions at the world level. We distinguish "national" patents (those produced by inventors and applicants from the same country) from "international" ones (those where at least one inventor, or one applicant, is from a country different from that of the others). This approach has several antecedents, such as Guellec and van Pottelsberghe de la Potterie (2001), OECD (2008), and Picci (2010). For the first time in the literature we carry out the analysis at the level of (five) technological sectors, that we identify by adopting WIPO's International Patent Classification (IPC)[4]. To quantify the relevant phenomena we use Picci's (2010) set of fractional measures, which

[3] Patel and Vega (1999) and Le Bas and Sierra (2002) provide evidence in support of this perspective. See also Vernon (1966) for an early product-cycle rationale of this argument.

[4] Their detailed definition, in terms of the IPC taxonomy, is in Appendix A. The use of the word "sector" is made purely out of convenience, and has no relation with the concept of industrial sector, as

we supplement by introducing a new metric, the "applicant surplus", measuring the relative importance of applicants (typically, MNEs) relative to inventors, within countries and technologies.

Using these data, we first draw a picture not suffering from the shortcomings existing in the literature – what we may call a set of stylized facts. This is needed for two reasons. First, case studies have shed light on the ongoing intensification and transformation of R&D internationalization but, by their selective nature, they come short of providing a much desired overall picture. Moreover, the type of anecdotal evidence that makes it to the pages of the specialized press tends to suffer from a selection bias: what obtains visibility are the big events in R&D internationalization, while the less-glamorous inventive activities risk of being under-reported. We find that indeed there has been an increase in internationalization that, for the most, is not driven by the presence of compositional effects, but that is observable across the technological spectrum. We also provide stylized facts on technological specialization, and in doing that for the first time we distinguish between national and international inventions, a discrimination that plays a key role in our analysis.

With respect to technological specialization, we tackle the issue from three distinct angles: the role of technological similarity between pairs of countries in internationalization, the strategic aspect of technological revealed comparative advantages, and the evolution of specialization across countries, contrasting national and international patents. Our results show that the specialization of technological profiles has not increased since 1990, thus interrupting a trend that had been documented two decades ago by Archibugi and Pianta (1992), who found that countries have been increasingly specializing from the mid-70s to the late 80s (see also Cantwell and Vertova, 2004 and Archibugi and Michie, 1995). We also find that technological profiles of international inventive activities are correlated with those prevailing at the national level and, in addition, that they tend to amplify them: if a country is relatively specialized in producing national patents in, say, chemistry, it will tend to be even more specialized in chemistry when we look at its international patents. Furthermore, the technological profile of a country's international applicant pool is systematically different from that of international inventions produced by that country's inventors, thus suggesting that MNEs seek abroad assets that they do not master at home.

Throughout the paper, we consider separately patent-based measures that count inventors from those counting applicants (in most cases, multinational firms) – what is called, respectively, "inventor" and "applicant" criterion. When looking at inventive activities, in some cases adopting one criterion or the other is inconsequential. When considering international patents, however, it is

incarnated, for example, by the NACE code system. There is no direct link between the NACE code of a firm, and the IPC code of its patent application. See Schmoch et al. (2003).

not: for example, the United States have relatively many more firms that do patents by employing inventors abroad, than foreign firms doing patents by employing inventors residing in the United States. We measure this contrast by means of a new measure, that we call the "applicant surplus", and we find that countries which contribute relatively many inventors (countries displaying an "applicant deficit") tend to be more specialized than the average. We interpret this result as indicating that the international inventive activities of MNEs abroad tend to reinforce the patterns of technological specialization that they find in the host country.

To sharpen our understanding of the relationship between internationalization and technological specialization we use a gravity model – an empirical model familiar in the literature on international trade. First, we find confirmation that, once countries' technological profiles are controlled for, home-base augmenting motives play an important role. In contrast with expectations, we do not find evidence that home-base augmenting motives have become more important in recent years. Interestingly, this result parallels the finding that country technological specialization has not increased over the time period under consideration. We also show that bilateral trade ties help explain international collaborations in inventive activities, a fact which we interpret as evidence that home-base exploiting motives are also relevant.

The gravity model also allows us to look from yet another angle at the relation between technological specialization and internationalization. Firms source technologies from other countries, and firm-level technology matching aggregates up to the country level. We show that countries with an overall similar technology profile tend to collaborate more in the aggregate, but not for all technologies. When we consider technological similarities *within* broad technological families, results vary even more. Overall, the results of the gravity model reinforce our conclusion that the "home-base augmenting/exploiting" taxonomy is more useful when we contrast system-related motivations with technology-specific motivations.

Finally, a note on the organizational characteristic of those MNEs which are responsible for most of the internationalized innovative activities that we observe at the aggregate level. Case studies in the literature show that the R&D management may differ substantially across technological sectors (Gerybadze and Reger, 1999), and also evolve in time. While our analysis is at the aggregate country level, and does not identify the firms' patents portfolio – currently, it would be prohibitively expensive to do so – it is however instructive also in the wake of R&D management literature addressing the changing "charter" of MNEs subsidiaries (Birkinshaw and Hood, 1998, and the literature that it inspired) and appropriability issues in general (Teece, 1986, 2006).

Such organizational aspects, in particular, have to be considered when crafting innovation policies aiming at modifying firms' behaviour with respect to international R&D. The differences that we find at the sectoral levels lead us to conclude that a one-size policy does not fit all. The distinction that we propose between "system-related" versus "sector-related" motivations will hopefully prove to be useful in policy-making practice, supplying a tool to steer innovation policy either towards increasing the capabilities of the system or towards more specific sectoral incentives.

The paper proceeds as follows. In Section 2 we present the theoretical framework where we fit our analysis. Section 3 presents the data and the measures that we use. Section 4 analyses the relations between technological specialization and internationalization, and Section 5 presents the results of the estimation of a gravity model. An overall discussion of the results follows.

## 2. Views on internationalization

Kuemmerle (1997) contrasts two alternative motives for carrying out R&D activities internationally: the intent may be "home-base exploiting", aiming at leveraging on existing R&D expertise in new markets abroad, or "home-base augmenting", whereby firms seek knowledge available only in specific and far-away locations. Within home-based exploiting internationalization, the logical centre of the innovation process of the MNE is the R&D lab (a single corporate lab, or possibly a plurality of decentralized labs) residing in the home country, and the R&D lab abroad plays an ancillary role. Home-base augmenting internationalization, on the other hand, taps at new knowledge in foreign locations, where the R&D labs abroad participates to the firm's innovation process by contributing original assets and adding to the firm's knowledge base (Song et al. 2011).[5] A number of researches found evidence of a shift from home-base exploiting R&D activities to home-base augmenting ones (e.g. Song et al. 2011; Kuemmerle, 1999; Almeida, 1996). Other studies support the view that home-base exploiting motives are still important (Patel and Vega, 1999; Le Bas and Sierra, 2002). In fact, the two motives may coexist and interact in complex ways. For example, studying a sample of Japanese pharmaceutical industries, Penner-Hahn and Shaver (2005) find that even though firms operate R&D activities in

[5] The distinction between home-base exploiting and home-base augmenting motives for the internationalization of R&D echoes a debate on the nature of FDI, which is "asset-based" when the international expansion hinges upon existing technological advantage, and "asset-seeking" when it is a mean to access new localized knowledge. This specific local knowledge may be acquired from different sources, ranging from research labs to customers (e.g. in user-based innovation) and competitors (Leiponen and Helfat, 2010; Penner-Hahn and Shaver, 2005).

foreign countries to tap into local knowledge, these investments are effective only if the MNE already masters the underlying technology. Even within the same firm, different R&D units can be deployed to target both augmentation and exploitation (Chiesa, 1996). The extant literature in general provides insights on the problem that, while useful, are not easily amenable to generalization. This suggests that the basic theoretical framework proposed by Kummerle (1997) needs to be supplemented with further considerations.

In particular, issues regarding technological needs and specialization likely interact with the basic motivations for internationalization. Patel and Pavitt (1991) showed that MNEs source from abroad those technologies for which they do not enjoy a comparative advantage. Cantwell (1999) provides evidence that American MNEs in the United Kingdom shifted their interest from those sectors where they had their core technology to others where the British had a comparative advantage. These findings open important and not yet completely answered questions both with respect to MNEs' behaviours, to how sub behaviours aggregate to form national averages, and to the design of national innovation policies. At the national level, in particular, specialization could lead to locking-in to a particular technology and, more generally, to a technology portfolio implying insufficient risk diversification. There would then be something akin to an optimal upper bound for the level of technological specialization, eventually leading to the emergence of specialization cycles: an increase in specialization, possibly explained in part by MNEs strategies abroad, could be followed by periods when innovation systems re-organize and eventually broaden their focus to catch up with the best technological opportunities available. The historical account of Cantwell and Vertova (2004) shows indeed that the technological specialization which took place from the mid-70s to the late 80s was not part of a longer and continuous trend.

Intriguingly, the increase in countries' technological specialization was mirrored by an increase in technological *diversification* at the level of the firm, which has been witnessed by several studies, showing that this process has led to an increase in the productivity of R&D (Maria Garcia-Vega, 2006; Cantwell and Piscitello, 2000; Zander, 1997). This fact is often attributed to a perceived change in MNEs motivations for internationalization towards targeting the competitive advantages of overseas locations (Archibugi and Pianta, 1992; Dunning, 1994).

The home-base augmenting motivation then takes the form of a search for a comparative advantage in know-how, where one of the leading reasons for MNEs to offshore R&D activities is a "race for talents" to obtain technological expertise abroad (Lewin et al., 2009; Ito and Wakasugi, 2007; Griffith et al., 2006; Von Zedtwitz and Gassmann, 2002; Serapio and Dalton, 1999). Griffith et al. (2006), studying the specific relationship between the US and UK, find that the UK has benefited relatively more in terms of productivity from tapping into US inventors knowledge rather than the US firms accessing UK knowledge. In this paper we also exploit the idea that, when looking at bilateral relations, there may be asymmetries of this type. Most importantly, however, we develop a comprehensive picture of the sourcing of technology at the national level which, we hope, leads to a better overall understanding of the issues involved. Countries where firms race for talents abroad are not necessarily poor in terms of inventors in absolute terms, but possibly they are so in *relative* terms, that is, compared to the needs of their externally minded MNEs. Consider for example the United States, whose endowment of inventors is probably unparalleled, but that, as we will document, is relatively better endowed in MNEs inventing abroad than in national inventors working for foreign entities. At the opposite extremes of the spectrum there would be a country which only hosts applicants hunting for inventors abroad, and a country with no applicants busy abroad, but only inventors working for foreign MNEs. "Inventor" countries would have a drive to be more specialized, in order to be able to offer valuable assets to foreign firms, while "applicant" countries would tend to choose technological capabilities as they would pick the best cherries from a tree.[6] We would thus expect "inventor" countries to me more specialized on average than "applicant" countries.

Finally, the motivations behind internationalization may to some extent be technology-specific. For example, Gerybadze and Reger (1999) propose a taxonomy of four different types of internationalization activities depending on the underlying technology. The degree of technological interrelatedness between two countries plays an important role in determining the quality and quantity of their collaboration in invention, in ways that also may depend on the technological field (Cantwell and Vertova, 2004; Freeman and Perez, 1988).

The home-base exploiting vs. home-base augmenting dichotomy echoes the distinction between "market-driven" vs. "technology-driven" reasons for internationalization (von Zedtwitz and Gassmann, 2002). We suggest that technology-driven reasons should further distinguish between system wide and technological sector specific motivations. The former include all the factors of the overall technological environment which may make an innovation system a fertile soil for a foreign MNE: the relative presence of applicant and inventors, the similarity (or dissimilarity) of the local technological pattern of specialization with respect to that of the MNE's home country, and any relevant institutional factor. The latter depend on the factors which are specific to a given technological field, including the degree of specialization. These considerations hint at the presence interdependencies between policies aimed at the internationalization of innovative activities, and

[6] The degree of the technological specialization of countries may also be negatively correlated with their inventive size, as in Archibugi and Pianta (1992). However, in more recent years that seems not to be the case (Garcia-Vega, 2006; Cantwell and Vertova, 2004).

those industrial policies which affect the technological specialization profile of a country. Ignoring them when designing innovation policies would be a mistake. For example, countries providing relatively many inventors to foreign multinationals may encourage a transition towards a more balanced innovation environment, where their firms also are active innovating abroad. However, a policy aiming at this goal could contribute to technological de-specialization, leading in turn to a diminished attractiveness of the country to foreign MNEs. Implicit in this discussion is the evolution of the subsidiary "charter", as in Birkinshaw and Hood (1998), a theme that we will touch upon more explicitly in the concluding section of this work.

## 3. Data and measures

We use the Patstat database (European Patent Office, 2009a and 2009b) and we consider all priority applications of 40 countries filed at any of a group of 50 patent offices from 1990 to 2006, representing the virtual totality of worldwide patenting activity.[7] In what follows, whenever for simplicity we mention patents, in fact we always mean patent *applications*. We assign patent applications to countries either according to the nationality of the inventor ("inventor criterion") or of the applicant ("applicant criterion") and we define a patent as "national" if all its inventors and applicants are from the same country, and as "international" otherwise.[8] While inventors are always

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[7] Details on the methodology that we use are in De Rassenfosse et al. (2013). The methodology takes full advantage of the fact that Patstat allows to track multiple applications in different offices claiming the right to priority for the same invention, and to avoid double counting within patent families. Considering patent *applications*, instead of granted patents, allows for the analysis of more recent data (since the granting process may take several years). The 40 countries are: all 34 OECD countries; countries invited to open discussions for membership to the OECD: (Brazil, China, India, Indonesia, and South Africa); and Taiwan. The 50 patent offices that we consider are the national patent offices of the same countries, plus those of Bulgaria, Cyprus, Honk Kong, Latvia, Lithuania, Malta, Romania, Russia, Singapore, and the European Patent Office.

[8] Note that we use the term "international" (patent application) purely out of convenience, and with no reference to where the first filing occurred – nationally, to a regional office such as the European Patent Office, or via the so called "international route". Within the broader debate on internationalization, we thus focus on the "global generation of technology", according to Archibugi and Michie's (1995) taxonomy. While international collaborations may involve different actors (such as universities and the public sector), and in general do not generate global technology (inventions are generated still at the national level and without establishing subsidiaries abroad), the global generation of technology is a specific feature of MNEs, and its understanding thus provides important information on their evolution.

individuals, applicants may be firms, universities and other research institutions, governmental organizations, non-profit organizations and, finally, also individuals. Nevertheless, the type of internationalization of inventive activity which we observe is determined, by and large, by behaviours of MNEs, and we will interpret our results accordingly[9]. In our population of international patents we do not identify the nature of the applicant, because it would be prohibitively costly to do so.

Patent applications are assigned to one or more codes describing their technology according to the WIPO's International Patent Classification (WIPO, 2011). We adopt the taxonomy proposed by Schmoch (2008), who identifies 35 technologies that can be regrouped into five macro-technologies: electrical engineering (*Electr*), instruments (*Instr*), chemistry (*Chem*), mechanical engineering (*Mech*), and other fields (*Other*).[10]

We employ the most general measure of internationalization introduced by Picci (2010), $InvApp_{ijt}$. It is a (fully fractional) count of patent applications involving inventors of country $i$ and applicants of country $j$, in a given year $t$ (the year subscript is henceforth omitted for the sake of simplicity). Out of 10,940,242 priority applications filed at the selected patent offices (between 1990 and 2006)[11], 263,220, or 2.6%, are international according to the *InvApp* measure. Table 1 presents total patent counts (expressed as percentages of the world total) and one measure of internationalization for the most prolific patent applicants. The top positions are occupied by Japan, and China, the latter following an impressive surge during the last decade.[12] Their prominence is partly due to a higher propensity to patent (see, on Japan, Cohen et al. 2001; on Korea, Hu and Mathews 2005; on China, Hu, 2010). There follows the United States, whose share of world patents has declined over the last decade, notwithstanding its much hyped-about "patent inflation". Within Europe, Germany has the lion's share of patenting activity, followed at a distance by the UK and France. These countries together are responsible for over 90% of patents worldwide.

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9 Picci (2010) analyses a sample of 1000 such "international" patents to find that in 79% of cases, the applicant is a MNE's subsidiary or headquarter, and another 15% of cases involve firms which are not multinationals. Our population of patents is about 10% more numerous than in Picci (2010), since we consider additional (minor) patent offices.

10 These computations also are done fractionally, so that patents with multiple codes belonging to more than one macro-technology are counted appropriately. See Appendix A for a detailed description of the constituent technologies in terms of the IPC classification, and how they are aggregated to form the five macro-technologies.

11 See Table OL1 in the online appendix for the patent counts of a selection of countries in years 1990, 1998, 2006.

12 Figure OL1 in the online appendix shows the increase in internationalization for a selection of countries.

**[Table 1 about here]**

Since the total fractional count of patents may be measured either in terms of inventors or in terms of applicants, two alternative *relative* measures can be derived from the absolute measure *InvApp*. The first is derived by normalizing it by the total number of inventors of country *i* ($Inv_i$). We refer to this relative measure as *InvApp|Inv.*

$$InvApp \mid Inv \equiv InvApp_{ij|i} = \frac{InvApp_{ij}}{Inv_i} \cdot$$

*InvApp|Inv* expresses the relevance of national inventors and extra-national applicants, relative to national inventors. The *InvApp|Inv* measure can be usefully compared with another relative measure, *InvApp|App*:

$$InvApp \mid App \equiv InvApp_{ji|i} = \frac{InvApp_{ji}}{App_i} \cdot$$

This measure refers to the relevance of collaborations between extra-national inventors and national applicants, relative to national applicants ($App_i$). The above measures can be computed for patents covering all technologies, and also separately for different technologies, a fact that we exploit extensively in our analysis.

Despite being relatively small in size, the internationalization phenomenon has grown considerably in time, at least until the year 2000, as Table 1 shows for the *InvApp|Inv* measure. The degree of internationalization increased in most of the countries considered. For example, it more than doubled in the United States and it increased about 30% in the UK. In some smaller countries (results not reported) it augmented dramatically, such as in Finland, where it increased fivefold.[13] Smaller countries tend to be more internationalized than bigger ones, and Japan and China are characterized by a very low degree of internationalization. Picci (2010) and Thomson (2012) report similar results.

The increase in internationalization at the aggregate level went hand in hand with important technological sectoral shifts. In particular, in several countries the relative importance of *Electr*, which is more internationalized than average, grew considerably.[14] Thus, in principle, the aggregate growth in internationalization could be explained by the presence of compositional effects, that is,

[13] See Table OL2 in the online appendix for the calculations of the two measures for a selection of countries, across years.

[14] Figures OL2 and OL3 in the Online Appendix show this for selection of countries.

by the growth of the share of those sectors which are more internationalized.[15] In Figure 1 we show, for a selection of countries, the relative role of compositional effects in determining the observed increase in internationalization (see Appendix B for details on how these results were obtained). Compositional effects only played a modest role in the observed increase in internationalization: in other words, the aggregate increase in internationalization which we observe reflects an overall increase across the technological spectrum.

**[Figure 1 about here]**

We argue that differences between the two relative measures of internationalization are quite instructive. An example serves to illustrate this point. Panel a) in Figure 2 displays both metrics for France, Germany, and the US at the aggregate level. *InvApp|App* is always higher than *InvApp|Inv* for the US, while the opposite holds for France. These differences can be interpreted as evidence of the pre-eminence of US national applicants in internationalized R&D activities. The case of Germany is more complex, since the gap between the two measures is relatively small and its sign varies over time. Such a result for Germany is the aggregate expression of contrasting sectoral realities, as Panel b) in Figure 2 shows. For example, while in the *Chem* sector the *InvApp|App* measure dominates, the opposite happens in *Electr*. The traditional strength of the German chemical sector, in other words, is accompanied by an important role of German applicants abroad, while other macro-technologies may display a more important role for foreign applicants employing German inventors.

**[Figure 2 about here]**

To systematically compare the two measures of relative internationalization we introduce a novel indicator that we call “Applicant surplus”:

$$AppSur_{ij} = \left(1 - \frac{InvApp|App}{InvApp|Inv}\right) \cdot 100 .$$

It is expressed in percentage points for country couples (*i,j)*, and is positive when country *i* contributes with relatively more applicants than inventors relative to country *j*, considering all joint

15 The construct of compositional effect is very well known and plays an important role in the international economics literature; see e.g. Berthelon and Freund (2008).

international patent applications. In other words, a positive $AppSur_{ij}$ means that country *i* contributes with relatively many applicants, and country *j* with relatively many inventors. When it is negative, the opposite is true, reflecting a situation where MNEs from country *i* employ in country *j* many inventors of that country. $AppSur_{ij}$ is thus a bilateral measure and it is an index of the relative balance of applicants and inventors between one country and another. Obviously, one country's applicant surplus (or inventor deficit) is another country's applicant deficit (or inventor surplus).

As in international trade bilateral flows aggregate into national trade accounts, bilateral $AppSur_{ij}$ measures aggregate into country measures. This is the case when $j= - i$, where $- i$ stands for "Rest Of the World" (*ROW*, henceforth).[16] The country measure expresses the overall applicant surplus for a country, deriving from the aggregation of all bilateral measures, with *i* fixed and *j* spanning all the countries collaborating with country *i* to produce international patents. We notate the applicant surplus of country *i* $AppSur_{i,ROW}$. Country measures represent the relative overall predominance, for a country, of applicants vs. inventors in the production of the international patents. A positive $AppSur_{i,ROW}$ indicates that a given country has relatively many MNEs with R&D labs abroad, and relatively few inventors at home working for foreign R&D labs. For illustrative purposes we compute the "national" measure of applicant surplus for a small selection of countries, that we show in Table 2.

**[Table 2 about here]**

The United States presents, in all sub-periods, an important applicant surplus, deriving from the fact that its *InvApp|App* measure is consistently greater than the corresponding *InvApp|Inv*. A positive applicant surplus is present in all US technologies. However, while during the period 1990-1994 *Electr* and *Instr* presented an applicant surplus larger than the one for all technologies, in later years it is *Mech* and *Other* which display an applicant surplus above the country's average. Germany and Taiwan are the only other countries (among those considered) showing an overall applicant surplus, but with important variation across technologies. The UK, France, and Italy

[16] This measure is not to be confused with the case where $i=j$, where $AppSur_{ii}$ reduces to $(App_i-Inv_i)/App_i$, i.e. the difference with one country's applicant and inventors, weighted by applicants. Thomson (2012) measure of net R&D offshoring is a special case of our *AppSur* index (weighted over $Inv_i$ instead of $App_i$). Our measure has the advantage that it does not depend on the choice of either applicant or inventors as weight, and allows for both bilateral and country measures.

present applicant deficits, both overall and for most technologies. Most countries present important sectoral variations.

## 4. Technological specialization and internationalization

To clarify how country profiles of technological specialization relate to the internationalization of inventive activities, we proceed in three steps. First, we study the relationship between profiles of technological specialization that apply to the production of national inventions, and those relevant for international inventions. Second, at the level of technological sectors, we consider the difference between measures of internationalization according to the inventor criterion with the analogous measure computed according to the applicant criterion. Third, we use the measure of "applicant surplus" and consider how it relates to country profiles of technological specialization.

We compute the Krugman (1991) specialization index, which expresses the degree by which the country shares of the different technologies differ with respect to the shares prevailing in the rest of the world. For country *i* the index equals:

$$TecSpec_i = \sum_{s=1}^{5} abs(Sh_{s,i} - Sh_{s,ROW}),$$

where *abs* indicates the absolute value, $Sh_{s,i}$ is the share of technology *s* (*s=1,2,…5* in our case) in country *i* and $Sh_{s,ROW}$ is the share of technology *s* in the rest of the world. It is easy to show that $0 \leq TecSpec_i \leq 2$. At its lower bound, the technological structure of a country is the same as the rest of the world. At its upper bound, the country does not share any technology with the rest of the world.

We compute *TecSpec* separately for national and for international inventions and, in order to appreciate changes in time, for four distinct time periods. Also, we compute this measure separately for the inventor and the applicant criterion. Table 3 shows the world average of the *TecSpec* index.

**[Table 3 about here]**

Considering national inventions (Columns a and b), the average technological concentration remained roughly constant over the time period 1990-2006, and on average, applicants are only slightly more specialized than inventors. Archibugi and Pianta (1992) had reached a different conclusion looking at an earlier period. Besides finding that in smaller countries technological specialization tends to be higher, they also noted that it had on average increased over the period

1975-1988. They explained their results as a consequence of "increased international competition, which leads firms and countries to expand their technology-based advantages and building on their already existing strengths", and also saw in this an amplifying role of "specific government technology policies, which are an essential requirement for international strength in sectors where public procurement plays a crucial role". Cantwell and Vertova (2004), analysing the period 1890-1990, reached similar conclusions and motivate their results along similar lines. Our data indicate that this process of specialization deepening did not last into the 1990s. Later, in the concluding section, we argue in favour of the presence of long-run alternating waves of increasing/constant specialization.

The literature on measures of technological specialization has made no distinction between national and international inventions. We do so, and we show that the difference matters. Columns (c) and (d) of Table 3 report the *TecSpec* index for international inventions, using respectively the inventor and the applicant criterion. Considering the former, the world average technological concentration is roughly similar in the production of national or international inventors. However, when we look at applicants, the production of international inventions is characterized by a significantly higher technological concentration. Also for international inventions, we do not detect important changes in time. The main conclusion of this exercise, then, is that when we consider applicants, we find that countries are sensibly more specialized in producing international inventions, than national ones.

Within countries, we would expect the four measures of technology specialization (according to the inventor and to the applicant criterion; for national and for international inventions) to be positively correlated, since they should all reflect an underlying country profile of technological specialization.

**[Table 4 about here]**

Table 4, where such correlations are shown for the whole period under consideration, indicates however a nuanced reality. Considering national inventions, country's specialization profiles are almost the same regardless of whether we consider inventors or applicants (the correlation of the two measures is equal to 0.94). The measures of specialization that refer to *international* inventions, while being strongly and significantly correlated with the overall country profile of technological specialization, also show systematic differences, as indicated by correlation coefficients that are between 0.47 and 0.57.

Interestingly, in the production of international inventions country's technological profiles differ significantly when looking at inventors or at applicants, the correlation between the two measures being equal to 0.28. This last result indicates that those firms that, in a given country, are busy producing international inventions have, as a group, a technological specialization profile that is significantly correlated, but also systematically different from the overall specialization profile of the international inventions produced by national inventors (and foreign firms)[17].

While the *TecSpec* index is helpful to understand the dissimilarity of a country's technological structure with respect to rest of the world, it is silent regarding countries' comparative technological strength. In particular, we wish to understand whether patterns of specialization in national inventions are amplified in international collaborations, a possibility that, we discussed, could derive from the action of MNEs sourcing technologies from countries where those technologies already enjoy an advantage. We investigate this point by means of the index of Technological Revealed Comparative Advantage (TRCA). The index considers a country's worldwide patenting share in one sector relative to the total share of its patenting activity. Using the same notation employed in Section 3, we can thus write:

$$TRCA_{si} = \frac{Inv_{s,i} / \sum_{i} Inv_{s,i}}{\sum_{k} Inv_{s,i} / \sum_{k} \sum_{i} Inv_{s,i}}.$$

$TRCA_{si}$ is greater than 1 if country $i$ is relatively specialized in sector $s$, and below 1 otherwise.[18] We compute this specialization index separately for national and for international inventions, and both using the inventor and the applicant criteria.

To test whether the comparative advantage in a given sector is amplified when focusing on internationalized patents we look at two quantities. First, we compute the correlations between the TRCA indexes obtained separately for national and for international inventions. These are shown in the top panel of Table 5, they are all statistically significant and indicate that a country that is relatively specialized in a given technological sector in the production of national inventions, tends to also be specialized in that sector when producing international inventions. This shows that specialization patterns in producing international inventions reflect those which we observe in the production of national inventions.

[17] In results not reported we compute these correlations separately for each time period considered. We find that the correlation between the Inv and App measure of technological specialization in international innovative activities decreases in time, and is not significantly different from zero in periods 3 and 4.

[18] For previous applications and discussion of the properties of this index see, among others, Patel and Pavitt (1991) and Archibugi and Pianta (1992).

**[Table 5 about here]**

The lower panel of Table 5 shows the ratio of the standard deviation of the TRCA measures computed for international (numerator) and for national inventions (denominator). With few exceptions (e.g. inventors in the chemical technologies), the standard deviation of the former is greater than the standard deviation of the latter.

The results of Table 5 indicate that indeed, within countries, patterns of specialization for the production of international inventions tend to reflect (top panel) and amplify (lower panel) those which we observe in the production of national inventions. Moreover, they indicate that the amplification effect, as measured by the ratio of standard deviations, is non-increasing over time, and possibly slightly decreasing. This tendency indicates that, as the relative share of international patents increase, in terms of technological specialization they become more similar to national ones.

Previous works, such as Cantwell and Vertova (2004), suggest that re-organization of MNEs has led them to prefer sourcing of technologies abroad in those sectors where foreign countries have a relative advantage. This would then reinforce and increase the patterns of national technological specialization. We research this possibility by considering jointly $AppSur_{i,ROW}$, our country measure of the applicant surplus (see Section 3) and the *TecSpec* measure of overall technological specialization. As explained, the *AppSur* country measure represents the overall predominance of national applicants of that country. We would expect countries which are mainly a source of inventors to have a higher degree of specialization with respect to countries with an applicant surplus. In other terms, *AppSur* would be negatively related with the overall degree of specialization of a country. This, in turn, may be the case not only for international inventions, but also for national ones, since there would be an incentive for the whole local system deriving from being an inventor's source**.**

Spearman rank correlations between *AppSur* and *TecSpec* are negative and always statistically significant.[19] For international inventions they are about the same regardless of whether we consider inventors (-0.156) or applicants (-0.163). Correlations are more pronounced for national inventions, and equal to -0.270 for inventors, and -0.356 for applicants. Negative estimated correlations indicate that countries which are relatively rich in inventors tend to be specialized relative to the rest of the world, while the technological profile of countries having an applicant

[19] The Spearman Rank correlation is to be preferred to Pearson's in this case, since *TecSpec* is bounded. Estimated Pearson's coefficients (not reported) are slightly smaller in magnitude, but always positive and significantly different from zero.

surplus tend to be similar to that of the other countries (rest of the world). The estimated correlation coefficients are relatively modest, but they are always significant at least at the 1% level.

Estimated correlations are higher for national patents than for international ones. This supports the idea that having an inventor deficit may have positive effects on one nation's differentiation, as foreign firms manifest their interests for the domestic assets with capabilities in the technologies for which the home country is already relatively specialized.

Our analysis has highlighted a series of important regularities regarding the relationship between country profiles of technological specialization and the internationalization of inventive activities, but so far has remained silent regarding two aspects which we wish to address now: the determinants of the degree of internationalization, in terms of the degree of technological matching between pairs of countries, and of broad motivations behind the decision of MNEs. To this task we now turn using appropriate econometric tools.

## 5. Technological matching and the motivations for internationalization

We account for the factors that favour (or hinder) internationalization by means of a gravity model where bilateral collaborations are explained by several variables. The gravity model has been successful in explaining bilateral trade and other types of interactions between countries. In a context similar to the present one, the gravity model has been used by Picci (2010), Bennato and Magazzini (2011), Montobbio and Sterzi (2012), and Thomson (2012). The dependent variable is $InvApp^{s}_{ijt}$ , where to the notation of Section 3 we add the *s* superscript to indicate that we will estimate the model separately for all technologies (in which case, *s* = 0) and for the five macro-technologies in our taxonomy (*s*=1,..,5), so as to appreciate any difference that there may be across sectors. We estimate the following model:

$$InvApp^{s}_{ijt} = \beta_0 + \beta_1 \ln(A^{s}_{it}) + \beta_2 \ln(A^{s}_{jt}) + \beta_3 \ln(T_{ij}) + \beta_4 L_{ijt} + \varepsilon_{ijt}$$

where *ln* is the natural log; *A* is the "inventive mass" of country *i* or *j*, that we proxy with measures of total country patent portfolio in sector *s*; *T* includes bilateral imports and exports, and *L* is a vector of other conditioning variables. We estimate the model using the Poisson estimator (see the considerations in Santos Silva and Tenreyo, 2006).

In *A* we consider total counts of patents according to both the inventor and the applicant criteria, both in the home country and abroad. We indicate "all technologies" with the subscript 0. When we estimate the model for all technologies, these variables are: $Inv_{i0}$, $Inv_{j0}$ (total country portfolios according to the inventor criterion, respectively at home and abroad), and $App_{i0}$, $App_{j0}$ (the same, but counts are according to the applicant criterion). When we estimate the model on one of the technological sectors, the same variables will refer only to that sector, as indicated by the appropriate subscript.

We estimate the basic model using data on pairwise collaborations between countries that are directly computed from our set of about 263 thousands international patents. We compute all bilateral ties for a total of 40 countries, that together produce the vast majority of world patents, and the virtual totality of the international ones.

Table 6 shows the Poisson estimates of the gravity model for all technologies ($InvApp^0$) and then for each macro-technology separately ($InvApp^1$ to $InvApp^5$). We first consider the impact of technology matching on the level of internationalization of innovative activities, a question on which the literature is silent. We employ two different measures of technological proximity. The first, which we call *Tech*, is a measure of broad similarities in technological specialization between two countries. It is equal to the correlation of total applications in each one of the 35 technologies of our taxonomy (see Appendix A). The second, which we call $Techsec_s$, measures technological similarity between two countries within each one of the five broad technologies, and equals the correlation of total patent applications in each of the constituent technologies within one of the broad technologies. So for example, *Instr* has five constituent technologies: *Optics*, *Measurement*, *Analysis of biological materials*, *Control*, *Medical technology*. Suppose that the shares of the number of applications in each of these five technologies in country A are exactly the same as in country B. Then $Techsec_2$ for *Instr* would be equal to 1. $Techsec_s$ may thus be interpreted as a measure of overall technological similarity between two countries for each one of the five broad technologies.

**[Table 6 about here]**

Block A of Table 6 shows the results. *Tech* has a positive and significant impact overall, but at the level of technological sectors we find that the impact is positive and significant in two cases, and negative and significant in one case. The estimated effects of $Techsec_s$ vary considerably across sectors. The effect is positive for *Chem* and *Mech*, negative for *Electr* and *Other*, and non significant for *Instr*.

While the results are sector specific, contrasting the estimates of *Tech* and $Techsec_s$ highlights interesting patterns. For *Electr*, *Instr*, and *Other* we observe a positive effect of the similarity of the innovation system, and a negative effect at the similarity at the level of the sub-technologies. This suggests that in these sectors internationalization is favored by the similarity of the innovation environments, but where MNEs tap into specific technological knowledge which is not available in the home country. This pattern is reversed for *Mech*.

Overall, we find that when we look at similarities in country's technological profiles, different sectors are led by different motivations for internationalization, a finding consistent with those studies asserting that R&D strategies (internationalization being one of them) are technology-dependent (e.g. Gerybadze and Reger, 1999). A negative estimated coefficient on either *Tech* or $Techsec_s$ indicates that firms in sourcing technology from abroad privilege those countries which are relatively different in terms of technological profiles – either overall – the *Tech* measure, or within each one of the five broad technologies – the $Techsec_s$ measure. This may occur when firms, motivated by home-base augmenting motives, seek abroad technologies that they cannot muster at home. But more generally, the interpretation of these results can only in part be framed within the "home base augmenting" vs. "home base exploiting" debate. While there may be motivations for internationalization that are, in a sense, system wide as in the original Kummerle (1992) taxonomy, our results indicate the importance of carrying out the analysis separately for different technologies, and with explicit considerations of issues of technological specialization and technological matching.

The gravity model does allow reaching a better understanding of the relevance of those general motivations – home-base augmenting vs. home-base exploiting – for internationalization, with the advantage that, with our data, such an analysis may also be carried out also separately for each technology. We do this by means of an appropriate choice of variables, that in the empirical model above are indicated by the *A* and *T* blocks. To motivate our choice, we consider as an example the model explaining internationalization in a given technology, say, technology n. 3 (*Chem*). The dependent variable then is $InvApp_{ij3}$, representing international collaborations in chemistry where inventors are from country *i*, and applicants from country *j*. *A* includes $Inv_{i3}$, $Inv_{j3}$, $App_{i3}$, and $App_{j3}$. If the reason for internationalization is of the home-base augmenting type, a MNEs would find attractive countries where there is suitable innovative potential by local inventors, as indicated by the production of many inventions in chemistry, and we would expect $Inv_{i3}$ to have a positive effect.

The presence of many inventions in *Chem* in the country where the applicants are from ($Inv_{j3}$) could discourage them to seek collaborations abroad, particularly so when their motivation is primarily of the home-base augmenting type. We then expect $App_{j3}$ to have a positive effect, because if country *j*'s applicants produce many inventions in their own country, they are better placed to also collaborate with country *i* inventors.

The presence of many inventions in *Chem* by applicants in country *i* ($App_{i3}$) could discourage applicants from country *j* to invent in country *i* using country *i* inventors, since they would compete for the same pool of inventors. This would be particularly true if the internationalization is home-base augmenting.[20]

We estimate a strong and positive impact of inventions according to the inventor's criterion in country *i* ($Inv_{i0}$) and a negative and almost as strong effect of $Inv_{j0}$. This is what we would expect under home-base augmenting motivations for R&D internationalization, where applicants from country *j* have an incentive to internationalize to country *i* if inventors there produce many patents, and the more so, the fewer patents are produced by inventors in country *j*. We observe that this conclusion applies in general, and also to each one of the technological sectors, but the first of the two effects is particularly strong for the residual *Other* sector, and the second is stronger for *Mech*.

The impact of $App_{i0}$ is estimated to be negative, as we would expect in a situation where country *i* and *j* applicants compete in country *i* for a given pool of local inventors. On the other hand, $App_{j0}$ is estimated to have a positive effect, as expected. The same qualitative results apply for all technological sectors. These results confirm the importance of the home-base augmenting motive for internationalization

To test whether the relative weight of the two motivations for internationalization have changed over time, we estimate the same model in two sub-periods, so as to assess any change in time in the effects of a subset of variables of interest. The first sub-period extends from 1990 until 1998, and the second from 1999 until 2006.[21] Table 7 shows the estimated coefficients for the variables included in *A* (and in *T*, which we will discuss later). Most estimated coefficients are remarkably stable across time: overall, we do not find evidence that home-base augmenting motivations have become more relevant in recent years. If anything, we observe that the impact of $Inv_i$, that we associate with home-base augmenting motives, slightly decreases, both in the aggregate and across most technologies.

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20 Part of international inventions of the *InvApp* type includes the collaboration of applicants from two different countries (or, in other words, some *InvApp* inventions are also of the *AppApp* type). For these inventions, by contrast, the presence of inventive applicants in country *i* is a precondition, so that the effect should be positive. Nevertheless, *AppApp* inventions represent a small fraction of the broader *InvApp* category (see Picci, 2010) so that, in the aggregate, we expect this effect to be tiny.

21 The cut-off date has been chosen mostly out of convenience, in order to have a comparable number of observations in both sub-periods; however, it also arises as a fairly natural choice, since it corresponds to a reasonable conventional date for the change of pace of the patenting surge.

**[Table 7 about here]**

To refine our analysis, we conjecture that the degree of internationalization in a particular technological sector might also be influenced by the entity of patent assets in the other technological sectors, at home and abroad. For example, it may be the case that invention in instruments (sector 2) is stimulated by the research in other sectors that may deliver complementary inventions – so-called "embedded systems" provide an example. To capture any spillover effects that there may exist among technologies, when we estimate the model for each technological sector, we include in *A* also patent counts for the other technological sectors. Continuing our example for technological sector number 3 (*Chem*), we include $Inv_i^{no3}$, $Inv_j^{no3}$, $App_i^{no3}$, and $App_j^{no3}$, where the upper script "*no*" preceding the "3" means that patent counts are relative to all technologies excluding *Chem*.

The effect of these variables is a priori ambiguous: the presence of numerous patents in other sectors may be an index either of a fertile national innovation system or of de-specialization. In the first case we expect positive spillovers and thus a positive effect on international collaborations. In the second case we expect a negative effect given that de-specialization may be a signal of lack of comparative advantage. For example, assume that applicants from country *i* desire to produce in country *j* inventions that include technologies from two fields – say, *Chem* and *Elect*. Assume further that country *j* is strong in electronics, but weak in chemistry. Then, while the impact of $Inv_{j3}$ (*Chem*) could be negative, indicating that applicants in country *j* are induced to seek abroad for inventors in *Chem*, $Inv_j^{no3}$, that includes inventions in *Electr*, could affect the dependent variable with a positive sign, since the two technologies, in our example, would be complements.

The estimated coefficients for the patent counts on all other technologies ($Inv_j^{no,s}$ and $App_j^{no,s}$) vary considerably across sector. In a few cases, the effect is opposite in sign to the one detected for the corresponding variable computed for a given technology sector. Interestingly, in sector 2 (*Instr*), unlike for the other technological sectors, the coefficients are positive, possibly due to the complementary nature of these technologies, that make it positively influenced by the presence of patent portfolios in the other technological macro-sectors.

The variables included in *A* are expected to affect international collaborations if home-base augmenting motives are important. On the other hand, in *T* we include bilateral trade flows – imports to, and exports from, country *i*, that we expect to be relevant if home-base exploiting motives play a role. These variable are meant to capture the market-oriented, or home-base exploiting, motivations for internationalization. If the home-country *i* imports much from country *j*, then country *j* applicants have an incentive in collaborating with country *i* inventors, particularly if the purpose is to adapt their inventions to the local market. However, we note that trade flows also proxy for overall economic ties between two countries, which could be a significant factor in internationalization decisions even when motivations are other than of the home-base augmenting type. Moreover, in a world of delocalized production, exports of country *i* to country *j* could be of intermediate goods to be assembled in country *j*, or outright exports of final goods produced on behalf of country *j's* MNEs. In this case, a country *j*'s MNE decision to locate a R&D lab in country *i*, regardless of its motivation, would be favored by the presence of production facilities there. The *export* variable, then, could be relevant under both types of motivations for internationalization.

We find that imports to country *i* have a positive and significant impact, for all technologies, with elasticities ranging from 12% to 41%. Exports from country *i* are also important, but comparatively less. These results indicate the relevance of home-base exploiting motivations for internationalization, subject to the caveats above. Furthermore, Table 7 shows that the impact of imports to the home country, that we associate with home-base exploiting motives, in the aggregate is practically unchanged over time.[22]

To summarize, when we break down home-base exploiting and home-base augmenting motives in more narrow constituent parts we find that they can coexists, but that they act through specific channels depending on the technological sectors. In addition, our analysis suggests that the home-base augmenting / exploiting debate could be reframed in terms of innovation environment versus sector specific motivations. This would allow to single out market-driven factors (such as exports and imports) from technology-driven factors (such as the technological proximity and the applicant and inventor pool of two countries). Finally, we also find no evidence that the relevance

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[22] The model includes a battery of other variables. They are collectively indicated by *L* and are as follows. *Dist:* the distance between the capital cities of pairs of countries computed with the great circle formula; *Border*: a dummy indicating the presence of a common border between pairs of countries; *Com lang*: indicates the presence of a common language. Two measures are meant to proxy for cultural distance: *Lang sim* takes higher values for languages sharing more common "branches", and *Religion sim* is computed as the probability that two persons in different countries share the same broad religious group. A measure of protection of Intellectual Property Rights, $Ipr_{i,j}$, is from Park (2008). We also considered measures of foreign direct investment, but then did not include them in the final regressions, since in almost all cases the estimated coefficients were not significant. We report the whole set of results in the online appendix in Table O4 and Table O3, together with further details on some of these variables. Last, we also include time and country-specific fixed effects, within a specification that is quite flexible, including all possible fixed effects short of estimating a Fixed-Effects panel model. The presence of a year dummy interacted with the country dummies is coherent with the discussion in Baldwin and Taglioni (2006).

of home-base augmenting has increased in more recent years. In the past sections we observed that home-base augmenting motives would lead overseas location to focus on their technological comparative advantage. The halt in the process of increased specialization, which we witnessed in the previous section, is coupled with a non-increasing influence of home-base augmenting motives over time.

## 6. Discussion and conclusions

The main focus of our research has been the interrelation between countries' technological profiles and the internationalization of innovative activities, as seen through the analysis of a very rich dataset of patent applications. As a first step, we established a few stylized facts. We confirmed that internationalization has increased since 1990, and we found that such an increase has occurred across the technological spectrum, so that compositional effects only played a modest role in driving increases in aggregate internationalization.

Technological specialization, occurring during the 1970s and the 1980s did not continue into the 1990s. We showed that the profiles of technological specialization which we observe for the production of national inventions differ, sometimes markedly, from those that are relevant for the production of international ones. The latter, in particular, tends to reflect but also to amplify the former – countries that are relatively specialized in a given technology in the production of their national inventions tend to be even more specialized in that technology in the production of international ones.

When looking at internationalization through the lenses of patent applications, distinguishing between inventors and applicants makes an important difference. To study such a difference we introduced the measure of "applicant surplus", which is positive when one country contributes to the production of international inventions relatively more applicants (mostly, firms) than inventors. We showed that countries differ widely in this respect. Also, we found that countries that have an inventor surplus tend to be relatively specialized in terms of technology. We interpreted this as evidence in favour of the hypothesis that, when sourcing technology from another country, national MNEs tend to reinforce the relative technological specialization of that country.

The relationship between applicant surplus and country profiles of technological specialization may be seen as a part of an evolutionary process. In a first phase, the creation of new international links leads some countries (e.g. emerging countries) to further specialize. In a second phase, established positions of comparative advantage may be enhanced as countries reach a maturity that allows their firms to be proactive, as applicants abroad, in the production of internationalized inventions. For those countries, at some point we would observe a halt and a possible reversal to the deepening of technological specialization, and eventually the shift from an applicant deficit to a surplus.

Innovation policies may target the internationalization of inventive activities, as it happens for example in the European Union "Framework Program", which favours collaborations in applied research among organizations residing in different member states. The motivations behind the internationalization of R&D have long been known as an important determinant of innovation policies (Dunning, 1994). Policy makers seem to share two opposite worries when discussing the internationalization of R&D. On the one hand, countries that attract many foreign R&D labs are preoccupied that they benefit too little in terms of local spillovers or, in slightly different terms, that they only play a minor role within a value chain which is governed from abroad. To counteract this situation, these countries may seek to shape policies aimed either at increasing the local spillovers of the activities carried out by the subsidiaries of foreign MNEs, or by encouraging local firms to become more active in R&D, both at home and abroad.

However, host countries policies of this type may be at odds precisely with those incentives that are leading MNEs to internationalize their R&D function. Teece (2006) and Di Minin and Bianchi (2011) show that the level of appropriability of inventions, i.e. their commercial exploitation potential, plays an important role in MNEs' internationalization decisions. There is a risk that MNEs are confronted with local innovation policies which, for example by encouraging spillovers through inventing around or imitations, have a negative impact on MNE's appropriability. This in turn would diminish their incentives to internationalize, the more so, the higher is the risk of spillovers of crucial information to competitors (Sanna-Randaccio and Veugelers, 2007). Low appropriability may arise from the poor interaction between researchers and the IP management function. For example, studying the wireless industry, Di Minin and Bianchi (2011) suggest that an important determinant in the commercial success of an invention is the close relationship between the inventors and the IP management staff. IP management tends to be centralized, and this plays against R&D decentralization. Host countries policies could then favour those MNEs that not only decentralize their R&D laboratories, but also the management of the intellectual property rights generated abroad.

If host countries are worried that spillovers are too low, countries having many MNEs owning R&D labs abroad are anxious precisely that the opposite occurs, eventually leading to a "hollowing-out" of the core assets of their firms. Both worries implicitly assume, either with hope or with fear depending on the point of view, the presence of a dynamic process whereby spillovers of various types generated by R&D labs abroad, together with a maturing of the receiving economy, eventually create the condition allowing for a reversal of an applicant deficit into a balance and, eventually, a surplus. Policies targeting the internationalization of inventive activities implicitly aim at tinkering with such a presumed dynamic process. Our results not only suggest that such policies should be technology specific, but also that, when narrowly minded, they could backfire. For example, countries experiencing an applicant deficit could adopt policies aiming at broadening their technological portfolio so as to reduce lock-in and dependence from abroad. However, in the process, they would become less attractive to foreign MNEs seeking technological excellence, and specialization, abroad.

Countries experiencing an applicant deficit also could attempt to increase local spillovers by encouraging "charter" changes of local foreign MNEs subsidiaries. Charter changes are best seen as in Birkinshaw and Hood (1998), who consider a MNE's subsidiary as an entity with some degree of autonomy which is constrained by two main factors: the required targets of the home-base and the challenges and opportunities of the local environment. Subsidiaries are characterized by *capabilities*, i.e. the ability to exploit their resource and endowments, and by a *charter*, i.e. the elements of the business that the MNE considers to be in charge of the subsidiary, for example the mastered technology. Not necessarily the charter and the underlying capabilities move in accord, and therefore the subsidiary evolution depends on both factors. Innovation policies could then aim at spillover-augmenting charter changes of the local subsidiaries of foreign MNEs, for example by encouraging a shift from home-base exploiting to more valuable home-base augmenting inventive activities. In the case of green field investments from abroad, the same policies could gauge incentives with an eye on the degree and quality of the R&D activities that the new entity would carry. Policies of this type, however, should also take into consideration the issues of technological specialization which we have addressed. Host country's resources aimed at upgrading foreign-led R&D through changes in the charter of foreign subsidiaries may be wasted, when they are dedicated to technological sectors where the host country does not enjoy a comparative advantage.

These considerations echo those of Gerybadze and Reger (1999), who argued that the overdispersion of resources which accompanies an unspecialized technology portfolio may result in the depletion of the existing capabilities. The re-organization of R&D labs in the 90s might thus have mainly operated on the side of strengthening and sharpening the capabilities of subsidiaries, rather than on changing the charter status. This guess is in line also with Cantwell and Vertova (2004), who view that an innovative system should have some degree of diversification, and with our finding that the technological profile of applicants is more diversified than that of inventors.

Even though our analysis does not provide micro data at firm level, our measure of applicant surplus may be used to monitor aggregate changes in subsidiary's charters. For example, an aggregate average gain in the charter of a country's subsidiaries may be mirrored in our data in a shift from an applicant deficit to an applicant surplus. Also for this reason, we believe and we hope that the utility of the applicant surplus measure, which we introduced and used in this paper, will exceed the boundaries of the present research.[23]

Using a gravity model we inquired into two broad factors that we expect to affect the degree of internationalization. On the one hand, technology matching: we found that broad similarities between countries favour collaborations, but with important differences across technological fields. Also, the gravity model allows us to discriminate between home-base exploiting and home-base augmenting motives for internationalization. Here too we found important variations in results across technologies. Considering effects that are aggregate across the technology spectrum at best results in an estimate of average effects, which may hide important variations, including the possibility of not rejecting key null hypotheses because significant but opposite effects cancel out in the aggregate. At worst, for certain types of analysis, the results may be vitiated by the presence of compositional effects of various type. The presence of dissimilarities in results across technological fields reinforces our conclusion that policies addressing the internationalization of innovative activities, inasmuch as they are informed by the knowledge of the relevant conditioning factors, also should be crafted cognizant of sector-specific differences.

At the most general level, the main message of this paper is that we needed a coherent picture shedding light on the relationships between the internationalization of innovative activities and technological specialization. We believe that future research should aim at improving such an understanding that we have now provided. One limit of our data is the lack of identification of patent applications with the entities filing them. This knowledge, in turn, would allow being much more precise about the micro behaviours that form the aggregate results which we observe. While we underline that the present exercise has implied a considerable computational burden, it also should be noted that name matching algorithms, together with business registries, would allow today to solve the problem even on a grand scale, albeit at a considerable cost.

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[23] However, our applicant surplus measure hides the sometimes nuanced details of any evolution in the organizational set-up of IP management, whose understanding requires in-depth studies at the firm level. Consider the case of Motorola, whose foreign R&D subsidiaries rely on local committees dealing with the patenting process and subsequent management of the patents' portfolio, but not managing intellectual property rights for the purpose of commercial exploitation, a priority which is still centralized (Di Minin and Bianchi, 2011).

**Acknowledgements**

We would like to thank for useful comments and insights the audience of the EPIP 2011 conference, Brussels; the 2012 Workshop “Competition, innovation and competition policy”, University of St Andrews; the 2011 Workshop “The output of research activities: harnessing the power of patent data”, JRC-IPTS, European Commission, Sevilla; and seminar’s participants at the University of St Andrews.

## **Appendix A - Taxonomy of technologies (Schmoch, 2008)**

*Electr* (Electrical engineering)

1 - Electrical machinery, apparatus, energy: F21#, H01B, H01C, H01F, H01G, H01H, H01J, H01K, H01M, H01R, H01T, H02#, H05B, H05C, H05F, H99Z.

2 - Audio-visual technology: G09F, G09G, G11B, H04N-003, H04N-005, H04N-009, H04N-013, H04N-015, H04N-017, H04R, H04S, H05K.

3 - Telecommunications: G09F, G09G, G11B, H04N3, H04N5, H04N9, H04N13, H04N15, H04N17, H04R, H04S, H05K, H04W, G08C, H01P, H01Q, H04B, H04H, H04J, H04K, H04M, H04N1, H04N7, H04N11, H04Q, H04W.

4 - Digital communication : H04L.

5 - Basic communication processes: H03.

6 - Computer technology: G06 (but not G06Q), G11C, G10L.

7 - IT methods for management: G06Q.

8 - Semiconductors: H01L.

*Instr* (Instruments)

9 - Optics: G02, G03B, G03C, G03D, G03F, G03G, G03H, H01S.

10 - Measurement: G01B, G01C, G01D, G01F, G01G, G01H, G01J, G01K, G01L, G01M, G01N, G01N33G01P, G01R, G01S, G01V, G01W, G04, G12B, G99Z.

11- Analysis of biological materials: G01N33.

12 - Control: G05B, G05D, G05F, G07, G08B, G08G, G09B, G09C, G09D.

13 - Medical technology: A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, H05G.

*Chem* (Chemistry)

14 - Organic fine chemistry: C07B, C07C, C07D, C07F, C07H, C07J, C40B, A61K8, A61Q.

15 - Biotechnology: C07G, C07K, C12M, C12N, C12P, C12Q, C12R, C12S.

16 - Pharmaceuticals: A61K, A61K8, A61P (added, not present in WIPO document).

17 - Macromolecular chemistry, polymers: C08B, C08C, C08F, C08G, C08H, C08K, C08L

18 - Food chemistry: A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, C12C, C12F, C12G, C12H, C12J, C13D, C13F, C13J, C13K.

19 - Basic materials chemistry: A01N, A01P, C05, C06, C09B, C09C, C09F, C09G, C09H, C09K, C09D, C09J, C10B, C10C, C10F, C10G, C10H, C10J, C10K, C10L, C10M, C10N, C11B, C11C, C11D, C99Z.

20 - Materials, metallurgy: C01, C03C, C04, C21, C22, B22.

21 - Surface technology, coating: B05C, B05D, B32, C23, C25, C30.

22 - Micro-structure and nano-technology: B81, B82.

23 - Chemical engineering: B01B, B01D0, B01D1, B01D2, B01D, B01D41, B01D5 (added, not clear in WIPO document), B01D8 (added, not clear in WIPO document), B01D9 (added, not clear in WIPO document), B01D43, B01D57, B01D59, B01D6, B01D7, B01F, B01J, B01L, B02C, B03, B04, B05B, B06B, B07, B08, D06B, D06C, D06L, F25J, F26, C14C, H05H.

24 - Micro-structure and nano-technology: A62D , B01D45 , B01D46 , B01D47 , B01D49 , B01D50 , B01D51 , B01D52 , B01D53, B09, B65F, C02, F01N, F23G, F23J, G01T, E01F8, A62C.

*Mech* (Mechanical engineering)

25 - Handling: B25J, B65B, B65C, B65D, B65G, B65H, B66, B67.

26 - Machine tools: B21, B23, B24, B26D, B26F, B27, B30, B25B, B25C, B25D, B25F, B25G, B25H, B26B.

27 - Engine pumps, turbines: F01B, F01C, F01D, F01K, F01L, F01M, F01P, F02, F03, F04, F23R, G21, F99Z.

28 - Textile and paper machines: A41H, A43D, A46D, C14B, D01, D02, D03, D04B, D04C, D04G, D04H, D05, D06G, D06H, D06J, D06M, D06P, D06Q, D99Z, B31, D21, B41.

29 - Other special machines: A01B, A01C, A01D, A01F, A01G, A01J, A01K, A01L, A01M, A21B, A21C, A22, A23N, A23P, B02B, C12L, C13C, C13G, C13H, B28, B29, C03B, C08J, B99Z, F41, F42.

30 - Thermal processes and apparatus: F22, F23B, F23C, F23D, F23H, F23K, F23L, F23M, F23N, F23Q, F24, F25B, F25C, F27, F28.
31 - Mechanical elements: F15, F16, F17, G05G.
32 - Transport: B60, B61, B62, B63B, B63C, B63G, B63H, B63J, B64.

*Other* (Other fields)
33 - Furniture, games: A47, A63.
34 - Other consumer goods: A24, A41B, A41C, A41D, A41F, A41G, A42, A43B, A43C, A44, A45, A46B, A62B, B42, B43, D04D, D07, G10B, G10C, G10D, G10F, G10G, G10H, G10K, B44, B68, D06F, D06N, F25D, A99Z.
35 - Civil engineering: E02, E01B, E01C, E01D, E01F1, E01F3, E01F5, E01F7, E01F9, E01F1, E01H, E03, E04, E05, E06, E21, E99Z.

## Appendix B – The decomposition of the aggregate growth in the internationalization rate

We show the formula used to decompose the growth rate in internationalization into a "growth" and a "compositional" component for the special case of two technological sectors, that we identify with *A* and *B*.

Let's call $Int_{i,t}$ the rate of internationalization of sector *i* at time *t*. We call $Sh_{s,t}$ the share of sector *s* at time *t* over all technologies, equal to the total number of patents of technology *i*, divided by the total number of patents of all technologies. In our computations we use the inventor criterion. The overall rate of internationalization is equal to the weighted sum of the rates of internationalization of the two technologies:

$$Int_{TOT,t} = Sh_{A,t} \cdot Int_{A,t} + Sh_{B,t} \cdot Int_{B,t}$$

where $0 \leq Int_{i,t} \leq 1$ and $0 \leq Sh_{i,t} \leq 1$. Let's consider the growth index $Int_{TOT,t} / Int_{TOT,t-1}$ and *t*=1. After simple manipulations, we obtain:

$$\frac{Int_{TOT1}}{Int_{TOT0}} = \frac{(Sh_{A1} - Sh_{A0})Int_{A1}}{Sh_{A0}Int_{A0} + Sh_{B0}Int_{B0}} + \frac{(Sh_{B1} - Sh_{B0})Int_{B1}}{Sh_{A0}Int_{A0} + Sh_{B0}Int_{B0}} + \frac{Sh_{A0}Int_{A1} + Sh_{B0}Int_{B1}}{Sh_{A0}Int_{A0} + Sh_{B0}Int_{B0}}$$

The first term represents the compositional effect due to sector *A*, the second term the compositional effect due to sector *B*, and their sum the overall compositional effect. The last term is the pure growth effect, equal to the sum of the contributions of each one of the two sectors.

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# Tables

## Table 1. Patents applications and degree of internationalization.

| | 1990 | | 1998 | | 2006 | |
|---|---|---|---|---|---|---|
| **Country** | **Patents %** | ***InvApp/Inv*** | **Patents %** | ***InvApp/Inv*** | **Patents %** | ***InvApp/Inv*** |
| JP | 65.7 | 0.15 | 57.3 | 0.30 | 42.4 | 0.44 |
| CN | 1.1 | 0.39 | 2.0 | 0.88 | 14.7 | 0.83 |
| KR | 1.2 | .33 | 6.5 | 0.20 | 14.4 | 0.12 |
| US | 12.2 | 1.42 | 12.2 | 3.16 | 9.2 | 3.68 |
| DE | 5.3 | 2.66 | 6.8 | 4.30 | 6.1 | 7.32 |
| RU | 0.0 | 8.88 | 0.1 | 16.63 | 3.4 | 16.75 |
| UK | 3.7 | 12.85 | 3.3 | 16.63 | 2.4 | 16.75 |
| FR | 2.3 | 4.20 | 2.2 | 8.84 | 2.1 | 11.56 |
| TW | 0.2 | 2.61 | 1.2 | 1.48 | 2.0 | 8.98 |
| IT | 1.6 | 8.30 | 1.5 | 10.79 | 1.6 | 13.33 |
| World total | 492593 | 6.60 | 592842 | 9.44 | 740623 | 11.56 |

Note: World totals are (rounded) total counts of patent applications, and median of *InvApp/Inv* over the group of 40 countries considered.

**Table 2.** ***$AppSur_{i,ROW}$*** **: Country Applicant surplus (inventor deficit). Percentage points.**

| Period | Country | Technology | | | | | |
|---|---|---|---|---|---|---|---|
| | | **All tech** | Electr | Instr | Chem | Mech | Other |
| 1990-1994 | JP | **-16.70** | -23.40 | 6.18 | -28.35 | 8.43 | -7.75 |
| 1995-1999 | | **-12.68** | -8.88 | 11.92 | -30.24 | -4.88 | -10.66 |
| 2000-2004 | | **1.00** | 24.08 | -12.96 | -24.88 | -10.16 | -17.18 |
| 2005-2006 | | **-1.63** | 6.87 | -1.37 | -11.10 | -11.63 | -29.83 |
| 1990-1994 | CN | **-46.68** | -60.43 | -74.75 | -34.65 | -41.55 | 3.88 |
| 1995-1999 | | **-75.82** | -74.36 | -23.64 | -69.00 | -93.66 | -60.94 |
| 2000-2004 | | **-73.54** | -79.70 | -51.60 | -82.14 | -59.48 | -44.16 |
| 2005-2006 | | **-60.70** | -61.67 | -57.23 | -61.10 | -62.00 | -41.97 |
| 1990-1994 | US | **174.45** | 258.73 | 268.75 | 135.65 | 125.30 | 169.83 |
| 1995-1999 | | **172.36** | 145.68 | 257.26 | 187.92 | 188.50 | 249.98 |
| 2000-2004 | | **91.58** | 48.92 | 90.74 | 164.74 | 216.10 | 173.42 |
| 2005-2006 | | **151.73** | 117.77 | 103.07 | 160.50 | 353.30 | 298.53 |
| 1990-1994 | DE | **21.18** | 1.38 | 19.35 | 62.50 | 5.88 | -4.13 |
| 1995-1999 | | **7.52** | -17.32 | -6.86 | 71.66 | -5.18 | 2.18 |
| 2000-2004 | | **11.58** | -12.58 | -5.82 | 78.28 | 10.96 | 1.14 |
| 2005-2006 | | **-4.87** | -9.97 | -23.30 | 51.63 | -12.67 | -21.53 |
| 1990-1994 | UK | **-32.08** | -56.88 | -35.65 | -19.68 | -23.58 | -25.28 |
| 1995-1999 | | **-32.40** | -60.74 | -41.28 | -8.46 | -19.62 | -11.94 |
| 2000-2004 | | **-31.58** | -60.42 | -19.12 | -6.06 | -19.64 | 31.58 |
| 2005-2006 | | **-30.40** | -48.13 | -24.87 | -13.50 | -28.33 | 63.17 |
| 1990-1994 | FR | **-54.40** | -52.18 | -68.98 | -37.85 | -55.15 | -71.20 |
| 1995-1999 | | **-46.80** | -39.94 | -47.42 | -32.52 | -60.20 | -64.28 |
| 2000-2004 | | **-41.08** | -14.14 | -41.32 | -28.82 | -74.26 | -72.00 |
| 2005-2006 | | **-43.07** | -12.47 | -58.23 | -20.73 | -73.33 | -80.13 |
| 1990-1994 | TW | **487.30** | 440.83 | 640.38 | 74.40 | 806.38 | 1001.78 |
| 1995-1999 | | **415.68** | 499.68 | 266.72 | 201.20 | 567.34 | 483.60 |
| 2000-2004 | | **274.02** | 425.10 | 359.22 | 51.42 | 188.62 | 131.76 |
| 2005-2006 | | **2.47** | 14.37 | 40.37 | -53.63 | -15.10 | -18.63 |
| 1990-1994 | IT | **-26.88** | -37.33 | -32.55 | -31.45 | -23.63 | 3.00 |
| 1995-1999 | | **-27.58** | -27.04 | -38.32 | -55.80 | 22.06 | 0.16 |
| 2000-2004 | | **-38.86** | -52.00 | -43.92 | -53.84 | -6.64 | -24.54 |
| 2005-2006 | | **-30.57** | -37.40 | -20.47 | -34.63 | -14.87 | -37.93 |

**Table 3. World average of the four measures of the *TecSpec* index. 1990 – 2006.**

| **Period** | **National** | | **International** | |
|---|---|---|---|---|
| | **(a)Inv** | **(b)App** | **(c)Inv** | **(d)App** |
| 1990-1993 | .399 | .410 | .368 | .618 |
| 1994-1998 | .370 | .384 | .355 | .577 |
| 1999-2002 | .368 | .398 | .385 | .555 |
| 2003-2007 | .386 | .413 | .355 | .682 |

**Table 4.Correlation of the *TecSpec* index of technological specialization: Inv vs. App, National vs. International, 1990 - 2006.**

| | | Nat | | Int | |
|---|---|---|---|---|---|
| | | **Inv** | **App** | **Inv** | **App** |
| **Nat** | **Inv** | 1.00 | | | |
| | **App** | 0.94 | 1.00 | | |
| **Int** | **Inv** | 0.57 | 0.52 | 1.00 | |
| | **App** | 0.48 | 0.47 | 0.28 | 1.00 |

**Table 5. Correlation between $TRCA_{int}$, $TRCA_{nat}$, and ratio of their standard deviations.**

| | Corr ($TRCA_{int}$, $TRCA_{nat}$) INV | | | | | | Corr ($TRCA_{int}$, $TRCA_{nat}$) APP | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **Electr** | **Instr** | **Chem** | **Mech** | **Other** | **AVG** | **Electr** | **Instr** | **Chem** | **Mech** | **Other** | **AVG** |
| 1990-2006 | 0.471 | 0.310 | 0.246 | 0.484 | 0.218 | | 0.557 | 0.193 | 0.467 | 0.223 | 0.304 | 0.557 |

| | $StDev(TRCA_{int})/StDev(TRCA_{nat})$ INV | | | | | | $StDev(TRCA_{int})/StDev(TRCA_{nat})$ APP | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990-1993 | **1.86** | **3.51** | 0.83 | **1.44** | **1.65** | 1.86 | **1.59** | **5.51** | 0.99 | **7.81** | **5.97** | 4.37 |
| 1994-1998 | **1.43** | **2.17** | 0.57 | **1.80** | **1.26** | 1.45 | 1.18 | **2.74** | 1.16 | **5.44** | **2.72** | 2.65 |
| 1999-2002 | 1.20 | **1.46** | 0.86 | **1.81** | 1.21 | 1.31 | **1.42** | **4.10** | 0.90 | **3.18** | **1.79** | 2.28 |
| 2003-2006 | 1.01 | **1.43** | 0.93 | **1.63** | 0.90 | 1.18 | **1.47** | **2.65** | **1.68** | **3.39** | **4.45** | 2.73 |
| Total | **1.42** | **2.04** | 0.80 | **1.70** | **1.27** | | **1.40** | **3.69** | **1.31** | **5.12** | **4.08** | |

Notes.

Test of the null hypothesis that the ratio of standard deviations is smaller than one.

In bold: null hypothesis rejected at the 5% significance level.

Underscored: ratio of standard deviations is smaller than 1 (null hypothesis always rejected).

## Table 6. Poisson regression results of the gravity model.

| | VARIABLES | Dependent variable | | | | | |
|---|---|---|---|---|---|---|---|
| | | *InvApp*$^0$ All technologies | *InvApp*$^1$ Electrical | *InvApp*$^2$ Instruments | *InvApp*$^3$ Chemistry | *InvApp*$^4$ Mechanical | *InvApp*$^5$ Other |
| A | *Tech* | 0.667*** | 1.034*** | 0.795*** | 0.0274 | -0.284*** | 0.109 |
| | | (0.0176) | (0.0336) | (0.0542) | (0.0424) | (0.0432) | (0.0751) |
| | *Techsec* s=1…,5 | | -0.0848*** | -0.0139 | 0.427*** | 0.406*** | -0.253*** |
| | | | (0.0312) | (0.0419) | (0.0250) | (0.0353) | (0.0275) |
| B | ln($Inv_{is}$), s=0,1…,5 | 3.877*** | 2.000*** | 3.248*** | 3.135*** | 3.369*** | 6.905*** |
| | | (0.0802) | (0.0510) | (0.162) | (0.120) | (0.173) | (0.309) |
| | ln($Inv_{js}$), s=0,1…,5 | -3.122*** | -2.297*** | -2.110*** | -1.937*** | -3.807*** | -2.854*** |
| | | (0.0675) | (0.0539) | (0.161) | (0.125) | (0.159) | (0.173) |
| | ln($Inv_i^{no,s}$), s=1…,5 | | 2.356*** | -0.335 | 0.321*** | -0.0591 | 0.792** |
| | | | (0.176) | (0.282) | (0.118) | (0.169) | (0.325) |
| | ln($Inv_j^{no,s}$), s=1…,5 | | 0.439** | -1.444*** | 0.484*** | 0.0310 | -0.873*** |
| | | | (0.195) | (0.256) | (0.112) | (0.162) | (0.248) |
| | ln($App_{is}$), s=0,1…,5 | -2.888*** | -1.363*** | -2.969*** | -2.389*** | -1.941*** | -6.379*** |
| | | (0.0799) | (0.0458) | (0.147) | (0.109) | (0.173) | (0.299) |
| | ln($App_{js}$), s=0,1…,5 | 3.353*** | 2.601*** | 2.704*** | 2.305*** | 4.435*** | 2.953*** |
| | | (0.0695) | (0.0534) | (0.162) | (0.123) | (0.163) | (0.169) |
| | ln($App_i^{no,s}$), s=1…,5 | | -2.091*** | 1.080*** | -0.170 | -0.449*** | -0.437 |
| | | | (0.177) | (0.273) | (0.109) | (0.163) | (0.323) |
| | ln($App_j^{no,s}$), s=1…,5 | | -0.414** | 1.103*** | -0.581*** | -0.470*** | 0.722*** |
| | | | (0.206) | (0.269) | (0.102) | (0.157) | (0.255) |
| T | ln(*import*) | 0.295*** | 0.409*** | 0.362*** | 0.118*** | 0.278*** | 0.289*** |
| | | (0.00681) | (0.0108) | (0.0206) | (0.0153) | (0.0164) | (0.0263) |
| | ln(*export*) | 0.197*** | 0.0933*** | 0.136*** | 0.398*** | 0.230*** | 0.380*** |
| | | (0.00672) | (0.0107) | (0.0196) | (0.0148) | (0.0164) | (0.0266) |
| | | | | | | | |
| | Pseudo-$R^2$ | 0.899 | 0.876 | 0.839 | 0.831 | 0.841 | 0.733 |
| | Observations. | 16,084 | 15,460 | 15,852 | 16,030 | 16,024 | 15,802 |

Notes.
*ln*($Inv_{is}$), s=0,1…,5 is ln($Inv_{i0}$) for sector 0 (all sectors, Column 1), ln($Inv_{i1}$)for sector 1 (Electrical eng., Col. 2), etc.
*ln*($Inv_i^{no,s}$), s=1…,5 is the log of the sum of $Inv_i$ for all technological fields excluding the one indicated by the *s*-number.
$Techsec_s$ , s=1…,5 is $Techsec_1$ for sector 1 (Electrical eng., Col. 2), $Techsec_2$ for sector 2 (Instruments, Col. 3), etc.
Column 1: all technologies, all available observations.

## Table 7. Poisson regression: time variation in the role of country patent portfolios.

| | | Dependent variable | | | | | |
|---|---|---|---|---|---|---|---|
| | VARIABLES | $InvApp^0$ All technologies | $InvApp^1$ Electrical | $InvApp^2$ Instruments | $InvApp^3$ Chemistry | $InvApp^4$ Mechanical | $InvApp^5$ Other |
| $\ln(Inv_{is})$ s=0,1…,5 | **a.** 1990-1998 | 4.860*** | 1.953*** | 4.611*** | 3.215*** | 5.859*** | 9.087*** |
| | | (0.221) | (0.112) | (0.333) | (0.168) | (0.369) | (0.664) |
| | **b.** 1999-2006 | 4.267*** | 1.895*** | 4.030*** | 3.173*** | 5.550*** | 10.15*** |
| | | (0.186) | (0.0896) | (0.304) | (0.160) | (0.318) | (0.608) |
| $\ln(Inv_{js})$ s=0,1…,5 | **a.** 1990-1998 | -4.721*** | -2.755*** | -1.584*** | -1.996*** | -4.341*** | -3.786*** |
| | | (0.182) | (0.164) | (0.231) | (0.210) | (0.341) | (0.353) |
| | **b.** 1999-2006 | -4.550*** | -2.258*** | -1.563*** | -2.114*** | -4.103*** | -3.976*** |
| | | (0.162) | (0.123) | (0.207) | (0.198) | (0.290) | (0.335) |
| $\ln(App_{is})$ | **a.** 1990-1998 | -3.987*** | -1.092*** | -3.936*** | -2.655*** | -5.149*** | -8.298*** |
| | | (0.217) | (0.101) | (0.334) | (0.154) | (0.363) | (0.641) |
| | **b.** 1999-2006 | -3.441*** | -0.953*** | -3.789*** | -2.578*** | -4.745*** | -9.299*** |
| | | (0.181) | (0.0834) | (0.307) | (0.147) | (0.314) | (0.578) |
| $\ln(App_{js})$ | **a.** 1990-1998 | 4.887*** | 2.962*** | 2.361*** | 2.214*** | 4.936*** | 4.460*** |
| | | (0.191) | (0.153) | (0.233) | (0.212) | (0.340) | (0.365) |
| | **b.** 1999-2006 | 4.636*** | 2.410*** | 2.226*** | 2.436*** | 4.837*** | 4.444*** |
| | | (0.168) | (0.116) | (0.211) | (0.202) | (0.292) | (0.343) |
| ln(*import*) | **a.** 1990-1998 | 0.339*** | 0.622*** | 0.303*** | 0.280*** | 0.202*** | 0.0356 |
| | | (0.0129) | (0.0232) | (0.0389) | (0.0255) | (0.0276) | (0.0451) |
| | **b.** 1999-2006 | 0.334*** | 0.578*** | 0.377*** | 0.248*** | 0.224*** | 0.0861** |
| | | (0.0116) | (0.0200) | (0.0350) | (0.0233) | (0.0254) | (0.0416) |
| ln(*export*) | **a.** 1990-1998 | 0.218*** | 0.133*** | 0.164*** | 0.286*** | 0.275*** | 0.612*** |
| | | (0.0124) | (0.0242) | (0.0370) | (0.0241) | (0.0270) | (0.0466) |
| | **b.** 1999-2006 | 0.210*** | 0.100*** | 0.0893*** | 0.326*** | 0.288*** | 0.533*** |
| | | (0.0113) | (0.0210) | (0.0336) | (0.0221) | (0.0251) | (0.0428) |

# Figures

**Figure 1. Breakdown in compositional and pure growth effects.**
Growth rate of internationalization, *InvApp*|Inv metric for a selection of countries from 1990.

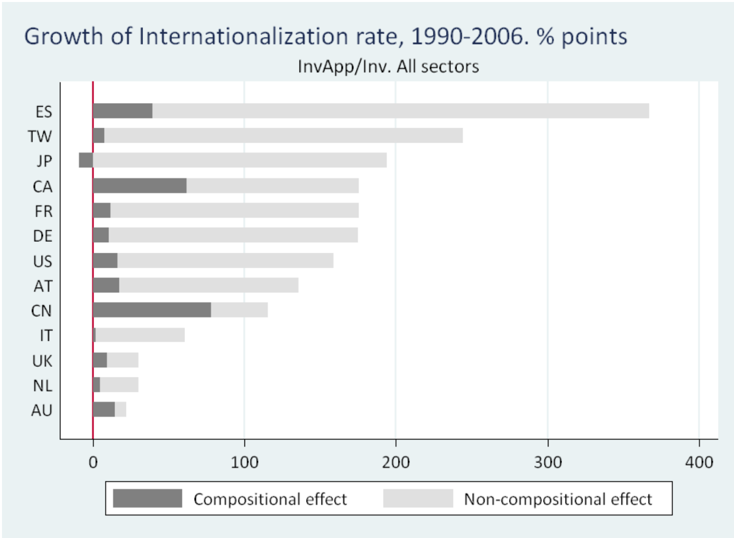
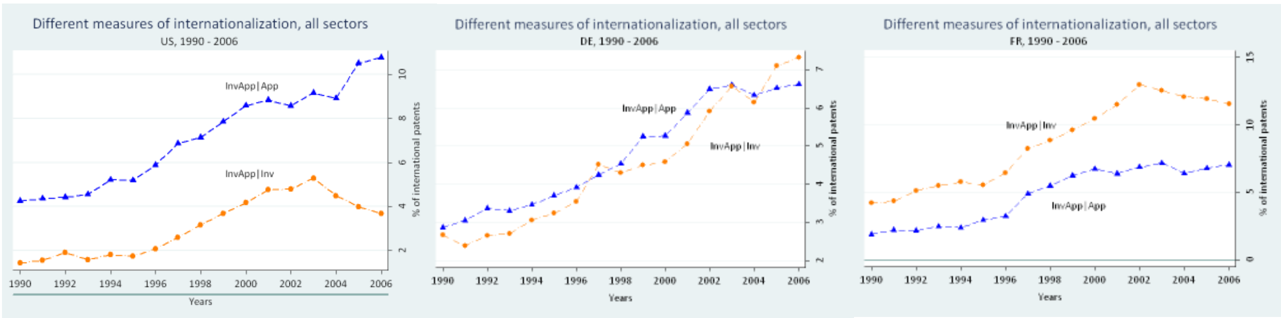
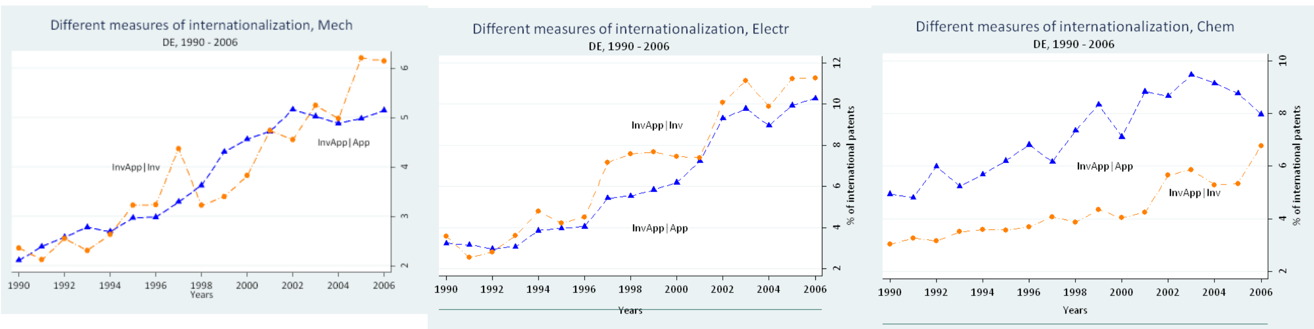



**Figure 2. Comparison between different measures of internationalization. 1990 – 2006.**




a) Aggregate. *InvApp*|Inv and *InvApp*|App metrics for the USA, France, and Germany.




b) By macro-technological sector. *InvApp*|Inv and *InvApp*|App metrics for Germany for the chemical, electrical, and mechanical sectors.

## Additional Online Materials

## Tables

### Table OL1. Patents applications around the world

| Country | 1990 | % | 1998 | % | 2006 | % |
|---|---|---|---|---|---|---|
| JP | 324180 | 64.8 | 339863 | 56.5 | 314157 | 40.6 |
| CN | 5315 | 1.1 | 12096 | 2.0 | 108823 | 14.0 |
| KR | 5910 | 1.2 | 38729 | 6.4 | 106744 | 13.8 |
| US | 60104 | 12.0 | 72277 | 12.0 | 67864 | 8.8 |
| DE | 26008 | 5.2 | 40264 | 6.7 | 45067 | 5.8 |
| RU | 14 | 0.0 | 768 | 0.1 | 24894 | 3.2 |
| UK | 18449 | 3.7 | 19495 | 3.2 | 17952 | 2.3 |
| FR | 11517 | 2.3 | 13238 | 2.2 | 15306 | 2.0 |
| TW | 1100 | 0.2 | 7166 | 1.2 | 15207 | 2.0 |
| IT | 7835 | 1.6 | 9047 | 1.5 | 11913 | 1.5 |
| CA | 3442 | 0.7 | 4900 | 0.8 | 5220 | 0.7 |
| NL | 2493 | 0.5 | 3677 | 0.6 | 5076 | 0.7 |
| BR | 2329 | 0.5 | 2533 | 0.4 | 3919 | 0.5 |
| AU | 3396 | 0.7 | 8318 | 1.4 | 3096 | 0.4 |
| CH | 2331 | 0.5 | 2823 | 0.5 | 3007 | 0.4 |
| SE | 3344 | 0.7 | 4651 | 0.8 | 2711 | 0.3 |
| AT | 1790 | 0.4 | 1954 | 0.3 | 2601 | 0.3 |
| FI | 2136 | 0.4 | 2533 | 0.4 | 2516 | 0.3 |
| ES | 1970 | 0.4 | 1775 | 0.3 | 2384 | 0.3 |
| IN | 553 | 0.1 | 414 | 0.1 | 2004 | 0.3 |
| BE | 821 | 0.2 | 1424 | 0.2 | 1577 | 0.2 |
| DK | 1339 | 0.3 | 1196 | 0.2 | 1510 | 0.2 |
| IL | 1212 | 0.2 | 1750 | 0.3 | 1494 | 0.2 |
| ZA | 1284 | 0.3 | 1387 | 0.2 | 938 | 0.1 |
| NO | 845 | 0.2 | 1378 | 0.2 | 872 | 0.1 |
| TOT a | 489715 | 97.9 | 593655 | 98.7 | 766853 | 99.0 |
| TOT b | 500238 | 100.0 | 601445 | 100.0 | 774609 | 100.0 |

Notes.
%: percentage of world patent
TOT a: sum of reported countries; TOT b: world total
World: 50 countries
Total number of patents worldwide, 1990-2006: 10940242 (countries for which we have intern. measures)
11,242,777 (50 countries)

## Table OL2. Measures of relative internationalization. Percentage points.

| | *1990* | | *1998* | | *2006* | |
|---|---|---|---|---|---|---|
| **Country** | ***InvApp*/Inv** | ***InvApp*/App** | ***InvApp*/Inv** | ***InvApp*/App** | ***InvApp*/Inv** | ***InvApp*/App** |
| JP | 0.153 | 0.135 | 0.299 | 0.342 | 0.436 | 0.466 |
| CN | 0.387 | 0.189 | 0.881 | 0.328 | 0.833 | 0.408 |
| KR | 0.333 | 1.548 | 0.205 | 0.436 | 0.121 | 1.243 |
| US | 1.421 | 4.253 | 3.157 | 7.14 | 3.68 | 10.776 |
| DE | 2.663 | 2.868 | 4.301 | 4.539 | 7.325 | 6.628 |
| UK | 12.854 | 8.885 | 16.629 | 11.565 | 16.755 | 11.829 |
| TW | 2.61 | 6.143 | 1.483 | 5.875 | 8.985 | 4.87 |
| FR | 4.199 | 1.871 | 8.844 | 5.485 | 11.559 | 7.041 |
| IT | 8.298 | 6.131 | 10.793 | 7.511 | 13.331 | 9.239 |
| CA | 6.911 | 4.324 | 9.41 | 12.76 | 19.04 | 7.47 |
| NL | 10.946 | 16.059 | 14.295 | 18.625 | 14.217 | 22.091 |
| AU | 8.627 | 7.581 | 14.252 | 12.256 | 10.517 | 7.502 |
| CH | 12.497 | 28.365 | 12.682 | 32.999 | 11.723 | 43.101 |
| SE | 6.532 | 7.469 | 6.931 | 11.842 | 16.721 | 21.915 |
| AT | 10.349 | 3.513 | 13.593 | 5.285 | 24.397 | 10.914 |
| FI | 1.856 | 2.376 | 4.291 | 9.784 | 11.299 | 14.319 |
| ES | 1.532 | 1.962 | 8.761 | 3.692 | 7.152 | 6.726 |
| IN | 4.952 | 1.125 | 19.441 | 3.879 | 32.369 | 5.021 |
| BE | 20.385 | 12.136 | 24.596 | 16.046 | 30.181 | 29.202 |
| DK | 6.675 | 3.147 | 12.513 | 10.773 | 19.218 | 11.739 |
| NO | 11.036 | 9.874 | 15.617 | 14.704 | 19.292 | 14.952 |
| HU | 0.471 | 0.622 | 4.106 | 1.903 | 10.921 | 5.853 |
| NZ | 17.684 | 13.942 | 10.9 | 7.271 | 7.705 | 5.419 |
| CZ | 13.158 | 8.333 | 4.323 | 2.537 | 9.211 | 4.215 |

## Table OL3. Poisson regression: time variation in the role of distance.

| | VAR. | *InvApp⁰* All technologies | *InvApp¹* Electrical | *InvApp²* Instruments | *InvApp³* Chemistry | *InvApp⁴* Mechanical | *InvApp⁵* Other |
|---|---|---|---|---|---|---|---|
| **a.** 1990-2006 | ln(*dist*) | -0.274*** | -0.237*** | -0.232*** | -0.300*** | -0.311*** | -0.127*** |
| | | (0.00531) | (0.00917) | (0.0121) | (0.00888) | (0.00968) | (0.0157) |
| **b.** 1990-1998 | ln(*dist*) | -0.148*** | -0.131*** | -0.0747*** | -0.264*** | -0.155*** | 0.00492 |
| | | (0.00644) | (0.0123) | (0.0195) | (0.0130) | (0.0140) | (0.0235) |
| **c.** 1999-2006 | ln(*dist*) | -0.166*** | -0.120*** | -0.101*** | -0.272*** | -0.190*** | -0.0212 |
| | | (0.00593) | (0.0109) | (0.0181) | (0.0121) | (0.0132) | (0.0219) |
| Observations | (a | 16494 | 15957 | 16248 | 16374 | 16432 | 16128 |
| | b | 8742 | 8092 | 8496 | 8622 | 8680 | 8500 |
| | c) | 9734 | 9084 | 9488 | 9614 | 9672 | 9492 |

Note: ln(*dist*): log of distances between countries' capitals.

**Table OL4. POISSON regression results of the gravity model**

| VARIABLES | Dependent variable *InvApp*$^0$ All technologies | *InvApp*$^1$ Electrical | *InvApp*$^2$ Instruments | *InvApp*$^3$ Chemistry | *InvApp*$^4$ Mechanical | *InvApp*$^5$ Other |
|---|---|---|---|---|---|---|
| ln($Inv_{is}$), s=0,1…,5 | 3.877*** | 2.000*** | 3.248*** | 3.135*** | 3.369*** | 6.905*** |
| | (0.0802) | (0.0510) | (0.162) | (0.120) | (0.173) | (0.309) |
| ln($Inv_{js}$), s=0,1…,5 | -3.122*** | -2.297*** | -2.110*** | -1.937*** | -3.807*** | -2.854*** |
| | (0.0675) | (0.0539) | (0.161) | (0.125) | (0.159) | (0.173) |
| ln($Inv_i^{no,s}$), s=1…,5 | | 2.356*** | -0.335 | 0.321*** | -0.0591 | 0.792** |
| | | (0.176) | (0.282) | (0.118) | (0.169) | (0.325) |
| ln($Inv_j^{no,s}$), s=1…,5 | | 0.439** | -1.444*** | 0.484*** | 0.0310 | -0.873*** |
| | | (0.195) | (0.256) | (0.112) | (0.162) | (0.248) |
| ln($App_{is}$), s=0,1…,5 | -2.888*** | -1.363*** | -2.969*** | -2.389*** | -1.941*** | -6.379*** |
| | (0.0799) | (0.0458) | (0.147) | (0.109) | (0.173) | (0.299) |
| ln($App_{js}$), s=0,1…,5 | 3.353*** | 2.601*** | 2.704*** | 2.305*** | 4.435*** | 2.953*** |
| | (0.0695) | (0.0534) | (0.162) | (0.123) | (0.163) | (0.169) |
| ln($App_i^{no,s}$), s=1…,5 | | -2.091*** | 1.080*** | -0.170 | -0.449*** | -0.437 |
| | | (0.177) | (0.273) | (0.109) | (0.163) | (0.323) |
| ln($App_j^{no,s}$), s=1…,5 | | -0.414** | 1.103*** | -0.581*** | -0.470*** | 0.722*** |
| | | (0.206) | (0.269) | (0.102) | (0.157) | (0.255) |
| ln(*import*) | 0.295*** | 0.409*** | 0.362*** | 0.118*** | 0.278*** | 0.289*** |
| | (0.00681) | (0.0108) | (0.0206) | (0.0153) | (0.0164) | (0.0263) |
| ln(*export*) | 0.197*** | 0.0933*** | 0.136*** | 0.398*** | 0.230*** | 0.380*** |
| | (0.00672) | (0.0107) | (0.0196) | (0.0148) | (0.0164) | (0.0266) |
| ln(*dist*) | 0.115*** | 0.167*** | 0.149*** | 0.102*** | 0.103*** | 0.349*** |
| | (0.00677) | (0.0111) | (0.0207) | (0.0156) | (0.0163) | (0.0260) |
| *Border* | 0.104*** | 0.0694*** | 0.0137 | 0.0689*** | 0.302*** | 0.634*** |
| | (0.0114) | (0.0197) | (0.0346) | (0.0256) | (0.0243) | (0.0422) |
| *Com Lang* | -0.134*** | -0.158*** | -0.551*** | 0.106*** | 0.217*** | 0.108** |
| | (0.0151) | (0.0261) | (0.0485) | (0.0347) | (0.0324) | (0.0530) |
| *Tech* | 0.667*** | 1.034*** | 0.795*** | 0.0274 | -0.284*** | 0.109 |
| | (0.0176) | (0.0336) | (0.0542) | (0.0424) | (0.0432) | (0.0751) |
| *Techsec* s=1…,5 | | -0.0848*** | -0.0139 | 0.427*** | 0.406*** | -0.253*** |
| | | (0.0312) | (0.0419) | (0.0250) | (0.0353) | (0.0275) |
| $Ipr_i$ | -0.0561*** | 0.0166** | -0.0674*** | 0.00649 | -0.0597*** | -0.0979*** |
| | (0.00466) | (0.00776) | (0.0138) | (0.0101) | (0.0115) | (0.0206) |
| $Ipr_j$ | 0.00192 | 0.0246*** | 0.0454*** | 0.0323*** | -0.0335*** | -0.0213 |
| | (0.00517) | (0.00853) | (0.0158) | (0.0120) | (0.0115) | (0.0197) |
| *Lang sim* | 1.019*** | 1.494*** | 1.504*** | 0.0288 | 0.683*** | 0.638*** |
| | (0.0190) | (0.0280) | (0.0597) | (0.0522) | (0.0448) | (0.0678) |
| *Religion sim* | -0.277*** | -1.072*** | -0.441*** | 0.571*** | -0.113 | 1.118*** |
| | (0.0337) | (0.0637) | (0.104) | (0.0635) | (0.0719) | (0.111) |
| Pseudo-$R^2$ | 0.899 | 0.876 | 0.839 | 0.831 | 0.841 | 0.733 |
| Observations. | 16,084 | 15,460 | 15,852 | 16,030 | 16,024 | 15,802 |

ln($Inv_{is}$), s=0,1…,5 is ln($Inv_{i0}$) for sector 0 (all sectors, Column 1), ln($Inv_{i1}$)for sector 1 (Electrical eng., Col. 2), etc.
ln($Inv_i^{no,s}$), s=1…,5 is the log of the sum of $Inv_i$ for all technological fields excluding the one indicated by the *s*-number.
$Tech_{s,}$ s=1…,5 is $Tech_1$ for sector 1 (Electrical eng., Col. 2), $Tech_2$ for sector 2 (Instruments, Col. 3), etc.
Column 1: all technologies, all available observations.

## Table OL4 – Description of variables

*Com lang:* It is equal to 1 if two countries share the same language, 0 otherwise, and it takes fractional values for multilingual countries. For example, it is equal to one half between Belgium and France (the presence of a small German speaking minority in Belgium is ignored), and to one third for the pairs of Switzerland with Germany, France and Italy.
*Lang sim:* the similarity between couple of languages is computed using data from the Ethnologe Project (http://www.ethnologue.com/), as collected and organized by James Fearon (see Fearon, 2003). The similarity between two languages is based on the distance between "tree branches" ("for example [. . .] Byelorussian, Russian and Ukrainian share their first three classifications as Indo-European, Slavic, East Branch languages"; Fearon, 2003). Unlike in Fearon's work, who obtains his measure by dividing the number of branches that are in common by the maximum number of branches that any language has (which is equal to 15), we divide it by the maximum number of branches within each couple of language, so as to take into account that the granularity of the branch definition may be not the same across languages.
*Religion dist:* the probability that two persons in different countries belong to the same broad group of religions. The computation is based on data from the World Value Survey (http://www.worldvaluessurvey.org/), integrated with data from the CIA World Factbook for the countries not covered therein.

## Figures

**Figure OL1. Overall degree of internationalization from 1990 to 2006.**
*InvApp*|Inv metric, the United Kingdom, France, Germany, US, and Japan.

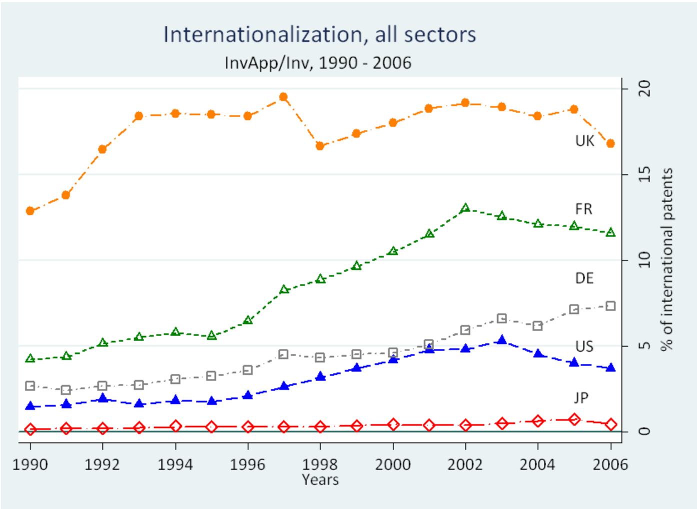



**Figure OL2. Patents' shares of technological sectors from 1990 to 2006.**
Inv. from the USA, China, Germany, and Japan.

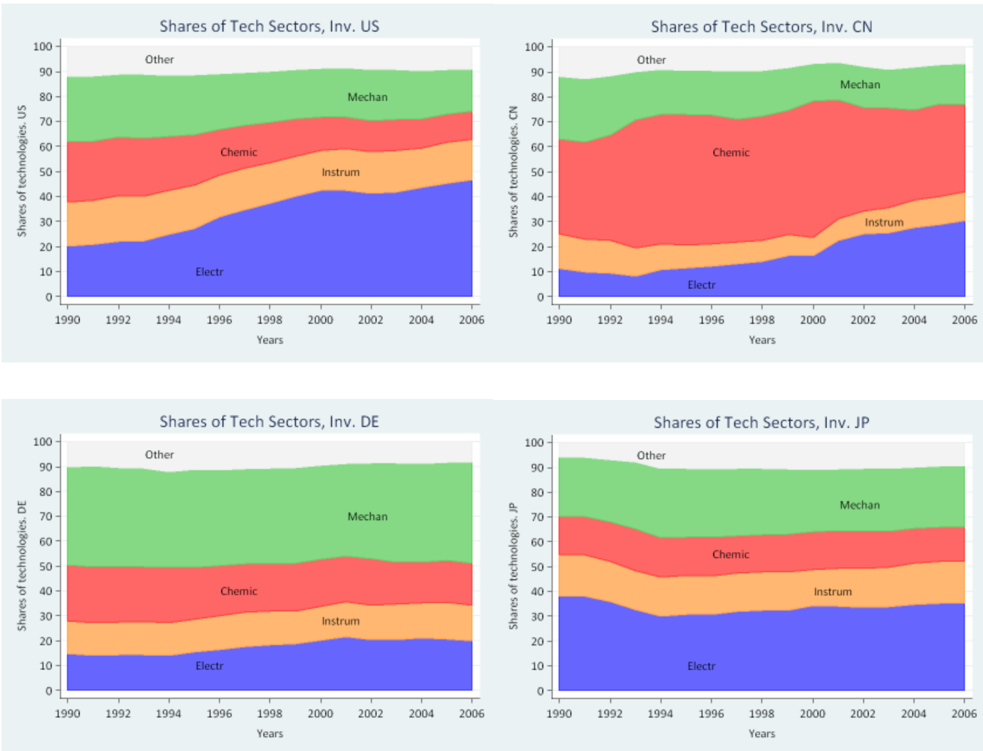


**Figure OL3. Shares of international patents by technological sector, from 1990 to 2006.** *InvApp*|Inv metric for the USA, China, Germany, France, the United Kingdom, and Japan.