The globalization of technology in emerging markets: a gravity model on the determinants of international patent collaborations

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ABSTRACT

This paper analyzes international technological collaborations among patents' inventors between emerging and advanced countries. It uses USPTO patents for eleven emerging economies and seven advanced countries (1990-2004) and a novel database that exploits information on companies' country of origin. Geographical distance and longitude affect international collaborations only when the applicant's ownership is in the emerging country. Fixed effect estimates show that stronger IPRs positively affect international collaborations when stemming from subsidiaries of multinational firms. In contrast the effect of IPRs is negative when the applicant's ownership is in the emerging country. Technological proximity and sharing a common language are also important.

Jel Codes: O30, O10, O11

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1. INTRODUCTION

Endogenous growth models have shown that commercially-oriented innovation efforts by profit-seeking firms promote technological progress and productivity growth (Romer, 1990; Aghion and Howitt, 1992) and international knowledge spillovers are key drivers of catching up and income convergence (Grossman and Helpman, 1991; Fagerberg, 1994). Recent empirical literature on international knowledge flows has made important progress and identifies different channels of knowledge spillovers: import flows, cross-border investments, and a disembodied direct channel of codified information. Most of this literature focuses on developed or OECD countries, however the literature shows that imports are a significant channel of technology diffusion (e.g. Coe et al. 1997; Keller, 2004). Some evidence suggests also that technical knowledge is transmitted through exports. Finally foreign direct investments (FDIs) from multinational corporations generate technology spillovers (in particular vertical spillovers), through the physical presence of the plant and labor turnover (Keller, 2010, Keller and Yeaple, 2009a). In particular, as emphasized by Keller's survey (2010), empirical evidence shows that geography and physical distance importantly shape the diffusion of technical knowledge.

The idea that international knowledge spillovers affect productivity growth enhancing technological adoption and innovation in developing countries (Keller, 2010; Montobbio and Sterzi, 2011) stimulates governments and international organizations to place the domestic dissemination of frontier knowledge high up on their policy agenda (e.g. World Bank, 2010). At the same time, recent empirical literature has also shown that knowledge spillovers tend to be localized[1] and require absorptive capacity (Cohen and Levinthal, 1989; Griffith et al., 2004). This is because technological knowledge includes not only materials and knowledge codified in blueprints, manuals, publications and patents but also know-how, routines and organizational capabilities, much of which is tacit in nature (Dosi, 1988; Cimoli et al., 2009). Tacit knowledge (e.g. related to technical know-how or non-standard production) is costly to transfer, and its transferability is limited by its embeddedness in individuals, teams and organizations.

As a consequence, knowledge diffuses more rapidly when inter-personal links in the form of joint research efforts and collaborations create opportunities for learning which go beyond the exchange of codified information. In particular, recent evidence underlines that research collaborations create social networks which can foster mutual learning and, as a result, individuals and companies that actively participate in a network of knowledge exchange (Singh, 2005; Hoekman et al., 2009; Breschi and Lissoni, 2009) are more innovative.

This paper therefore analyses international technological collaborations between patent inventors in a "North-South" gravity model looking at the interactions between *emerging* and *advanced* countries under the assumption that technological collaborations imply face-to-face interactions that are a key vehicle of knowledge spillovers. However, while scholars have been widely aware of the nature of globalization in terms of trade and financial openness, there is no clear consensus about the extent of globalization of technological activities.

Academics and international organizations acknowledge that R&D activity is increasingly done at the international level (OECD, 2008). A number of communications technologies, such as fiber optics, social networks, and satellite communications, facilitate international technological activity and, in parallel with the decrease in communications and transport costs, geographical distance should have a declining impact on technological collaborations and research ventures.

At the same time, some authors (Granstrand et al., 1992; Patel and Vega, 1999) show that the technological activities of the world's largest firms continue to be firmly embedded in their headquarters in the home countries. In parallel, Picci (2010), focusing on OECD countries, studies the degree of internationalization of innovative activities using patent data and finds a statistically significant impact of geographical distance. He shows that even if R&D internationalization is now more pronounced than it was 20 years ago there is a “lasting lack of globalization” that is surprising in the light of the abundant anecdotal evidence of both increased domestic R&D activities in emerging countries and offshoring R&D activities to countries such as China and India.

Moreover, the scale and scope of international technological collaborations are affected by the legislation on intellectual property rights (IPRs) which has changed rapidly in recent years after approval of the TRIPs (Trade-related aspects of intellectual property rights) agreement signed in 1994 and adopted and implemented by different countries at different points in time. One of the main economic justifications of the TRIPs agreement is that IPR reinforcement in emerging countries facilitates knowledge transfer and dissemination from advanced countries.[2] It is relevant then to control for the impact of IPR legislation on technology transfer and spillovers brought about by international technological collaborations between inventors.

In addition, the impact of geographical distance and IPR legislation on international technological collaborations – and, in turn, on knowledge transmission – depends upon the typology of firms involved in the innovative project. It is therefore important to distinguish whether international technological collaborations occur with the joint contribution of different companies in different countries or within the laboratory of a multinational corporation (MNC) located in an advanced or emerging country or, finally, within the laboratory of a company from an emerging country. This paper contributes to the literature, building a novel database that takes into account not only the residential address of inventors and assignees but also the *ownership* of companies and their nationality. In parallel, the specific composition of the international team of inventors and the relative weight of the different countries in the team is also taken into account. For example, if the international team of inventors contains a large majority of inventors from an advanced country and the patent is applied for by a company with an address in the advanced country, we can expect that the international collaboration is the result of a movement of skilled labor from the emerging to the advanced country. This type of international collaboration (and its determinants) is clearly different from a collaboration occurring in a laboratory of a MNC subsidiary located in the emerging country.

We use patent data from the US Patent and Trademark Office (USPTO) and we collect economic and institutional data from different sources. The sample covers 18 countries: a group of large emerging economies (Argentina, Brazil, India, Israel, China, South Korea, South Africa, Mexico, Malaysia, Singapore, and Turkey) and their relationship with seven advanced countries (USA, UK, Japan, Italy, Germany, France and Canada). In order to model the impact of geographical distance and the impact of IPR reinforcement on technological collaborations between emerging and advanced countries, we use a modified version of a gravity equation and different empirical specifications, using panel data and Poisson pseudo-maximum likelihood (PPML) in order to tackle various econometric problems.

Our main results are that geographical distance is not important *per se* and distance matters mostly through trade and cultural similarities. Results are slightly stronger for time zone differences. Technological proximity is a very important factor that favors collaboration. Fixed effects models show that countries experiencing an increase in IPRs protection tend to be more involved in international collaboration. This effect is greater for those countries that have stronger trade relationships, and is positive only in the emerging countries characterized by a very low level of IPR legislations before the TRIPs agreements.

Importantly, for a subset of countries, we show that these determinants of international technological collaboration vary according to the type of collaboration considered and country of origin (emerging vs. advanced) of the companies involved. For example, for collaborations deriving from laboratories of multinational subsidiaries, we have no effects of geographical distance and a positive effect of IPR reinforcement. On the contrary, for collaborations that involve only a company from the emerging market, communication and transport costs – proxied by geographical distance – turn out to be important and the effect of the reinforcement of IPRs is negative.

The paper is organized as follows. In Section 2 we present recent evidence on the geography of knowledge spillovers and discuss to what extent co-inventor relationships can be considered an indicator of knowledge flows. In Section 3 we present our model of weightless gravity used to study the determinants of international technological collaborations between emerging and advanced countries. In Section 4 we present data and the empirical model. Section 5 discusses the results of the econometric analysis. Finally, Section 6 concludes.

2. INTERNATIONAL TECHNOLOGICAL COLLABORATIONS AS SOURCE OF KNOWLEDGE FLOWS.

Technological diffusion is a major vehicle of technological change that in turn contributes importantly to productivity and economic growth. In particular the analysis of international technological diffusion is key to understand whether less-developed countries are able to catch up. Endogenous growth models typically consider technology as non-rival and underline that technological investments have both private and public returns. As a consequence technological activity creates external or spillover effects. However these external effects are not automatic as they require domestic investments in technology absorption (Cohen and Levinthal, 1989).

2(a) Diffusion of technology and tacit knowledge

In recent years substantial research effort has analyzed international technological diffusion (Keller, 2004; Keller, 2010). Keller (2004 and 2010) emphasizes that there are at least three important channels: international trade, foreign direct investment (FDI) and R&D. Recent evidence suggests that importing is associated with technology spillover. In addition there can be FDIs spillovers associated with physical presence of affiliate plants and mobility of human capital. Finally R&D spillovers depend upon the ability of countries of learning and adopting foreign technologies. For example substantial international knowledge spillovers are found by Griffith et al. (2004) who also show that technological learning requires absorptive capacity.

Keller (2004 and 2010) emphasizes also that international technological diffusion is shaped by geography. International trade is importantly affected by geographical distance because the diffusion of technology embedded in intermediate goods is affected by trade costs. Secondly it is also costly to communicate knowledge that is not incorporated in intermediate or capital goods (see footnote 1).

The main reason is that important pieces of knowledge are tacit and that learning is the product of experience (Polany, 1958). The transfer of knowledge is not automatic even when patents, publications and blueprints are freely available. Using Arrow's words (1962, p. 155): "Learning can only take place through the attempt to solve a problem and therefore only takes place during activity". In this respect many authors – including Keller (2010) and Keller and Yeaple (2009b) – have placed emphasis on the advantages provided by face-to-face interactions over other forms of communication like telephone calls or e-mails. Face-to-face interaction is a superior vehicle of knowledge communication because it is possible to have instantaneous feedback and direct correction of wrong interpretation.

Moreover, when people communicate face to face they convey information not only through words but also using body language, facial expression, and tone of voice that are tailored specifically to the receivers (Koskinen and Vanharanta, 2002). In sum, knowledge exchange is particularly fruitful when it is linked to specific problem-solving activities and when it takes place through face-to-face interactions. In addition, tacit knowledge is often linked to specific individuals and, typically, requires active participation in a specific network of knowledge exchange. This has been widely recognized in sociology of science (e.g. MacKenzie and Spinardi, 1995). Because tacit knowledge is transmitted person to person, there are great barriers to the diffusion of knowledge and in addition key scientific developments take often place within a restricted number of researchers rather than in the wider scientific community.

2(b) Technological collaborations and knowledge exchanges

When inventors and scientists collaborate they exchange knowledge. The characteristics and the density of the community of inventors and the networks arising among them play therefore a relevant role in the innovative process. Research collaborations create social networks which can foster mutual learning. Actually, joint research efforts and collaborations create opportunities for learning which go beyond the exchange of formalized and codified information and knowledge. Participation or exclusion from given research networks not only affects the innovative performance of the country, the region, the firm or the individual in question, but also affects the set of possibilities for learning routines and practices.

Some papers have analyzed knowledge diffusion across regions through collaborations, mainly in the European context. The first group of papers studies R&D collaborations between firms, universities and public research centers using data from the EU Framework Programmes[3]. A second group of papers analyses research collaborations using publication data in different European organizations. EU organizations tend to collaborate with physically proximate partners (Hoekman et al. 2009). At the same the effect of national borders seem to decrease over time in parallel with the process of European integration (Hoekman et al. 2010)[4]. Scherngell and Hu (2011) study research collaboration between Chinese regions and find a strong effect of technological proximity together with a weaker effect of physical distance.

Other papers have used patents and patent citations data to analyze inventors' networks and knowledge diffusion. Singh (2005) analyzes if and how interpersonal networks determine knowledge diffusion patterns in terms of geographic localization and intra-firm transfers using USPTO data since 1975. He explores direct and indirect network ties between inventors, using past co-signed patents and finds that the social links between inventors are associated with a greater probability of knowledge flow (measured by patent citations), with the probability decreasing as the social 'distance' between inventors increases. Breschi and Lissoni (2001, 2009) show that inventors' mobility and the co-invention network are crucial determinants of knowledge diffusion.

This paper studies international technological collaborations between inventors as listed in patent data at country level. Each patent represents the output of an inventive project and co-inventorship can be used as a proxy of knowledge flows generated by interpersonal and social links deriving from the collaboration in the inventive project. In particular, co-inventorship can be used to track the transfer of non-codified knowledge (e.g. technical know-how, non-standardized production procedures etc.) which, at least periodically, requires face-to-face interactions which have a positive impact on technological learning and, finally, make technology transfer more effective.

However the claim that international patent collaborations measure knowledge flows has to be qualified. Actually international co-operations may be the results of different types of activities and therefore they measure different types of knowledge flows. In particular inventors may be listed in patent data because of activities that are different from R&D projects or for reasons that depend on specific features of the patent systems. Bergek and Bruzelius (2010) study ABB, a Swiss-Swedish multinational and have interviewed Swedish inventors of 53 ABB international patents. They find that 60% of the patents considered are really the result of international collaborations, that half of them are the result of international R&D activities and only one third are joint R&D projects. Activities different from R&D include maintenance, service or helping out the patent application procedures. Most of the remaining 40% are the result of inventor movements. This is another form of knowledge flow that we discuss at length in the empirical part of the paper.

2(c) International technological collaborations and emerging countries.

This paper examines collaboration between emerging and advanced countries. If knowledge spillovers are important for advanced countries where most of the technological activity takes place, they are even more relevant for emerging and developing countries where many new technical advances are either not available or not adopted. If technological collaborations are effective channels of knowledge spillovers, they can also be considered an important element in catching up processes. The fact that technological knowledge cannot be considered a pure public good has important implications for the growth path and for economic convergence because it limits the geographical reach of knowledge spillovers.

As an example, Montobbio and Sterzi (2011), based on data for Argentina, Brazil, Chile, Colombia and Mexico, estimate that international knowledge spillovers from the G-5 countries are a significant determinant of inventive activity during the period 1988-2003. Moreover, they find that controlling for US-driven R&D effects, bilateral patent citations and face-to-face relationships between inventors are both important additional mechanisms of knowledge transmission.

To a great extent, inadequate access to the informal or practical knowledge network that integrates the codified portion of technical change[5] could generate a slower pace of new technology adoption. In this vein, this paper provides a first attempt to estimate the determinants of international technological collaborations in emerging countries using a gravity model.

3. THE WEIGHTLESS GRAVITY OF INTERNATIONAL TECHNOLOGICAL COLLABORATIONS

The empirical evidence discussed in the previous section shows that seemingly weightless technological knowledge could follow the law of gravity. Only a few papers address the issue of technological collaborations in a gravity context and are mainly focused on developed or OECD countries. Guellec and van Pottelsberghe de la Potterie (2001) study different patent-based indexes of technological internationalization of the OECD countries and show that small and low tech countries are more open. They also find that technological collaboration depends upon technological proximity and the presence of both a common language and a common border.

Maggioni et al. (2007) study collaborations among inventors in EPO patents between 109 European regions from 1998 to 2002 and find a strong effect of geographical and technological distance. Picci (2010) studies international collaboration using co-inventors and co-applicants of a set of patent applications at the European national patent offices and at the EPO and studies the increased level of technological collaborations of the European countries. He finds that distance, common language and common borders explain a substantial part of the variation in bilateral collaborations.

Our main assumption is that firms incur costs to communicate and exchange knowledge because a substantial part of it is tacit and requires face-to-face contacts. These costs depend upon transport and communication costs that arise from geographical distance. In addition, if the knowledge is sophisticated and the content technically complex, the tacit component is particularly important and therefore we can expect higher communication costs. However, if the marginal benefit of the technological collaboration is higher, companies will be prepared to incur higher costs and in principle to collaborate with companies that are geographically further away. To address this issue, we model technological collaborations in a gravity framework where international knowledge flows between inventors in two different countries are assumed to depend upon a constant, a set of country specific attractors, geographical and technological distance between the two countries, a set of link variables and a set of policy variables.

3(a) Dependent variable

We observe international technological collaborations between an emerging country (*i*) and an advanced country (*j*) at the individual inventor level. We identify a technological collaboration when a patent is co-signed by at least one inventor resident in country *i* and at least one inventor resident in country *j*.[6] Note that, differently from gravity models in the trade literature, our dependent variable is a *non-directed* measure of international technological collaborations. However, we assume that the main knowledge flow is from G7 to emerging countries because patentable knowledge is mainly produced in the G7 countries and collaborations with emerging countries represent a negligible share of the total number of international collaborations of G7 countries. This is especially true whenever multinational companies seek new market opportunities in emerging countries, by locating their R&D facilities close to costumers, or when they are attracted by lower costs of R&D. However it is also possible that the multinational R&D location is driven by the access to high qualified R&D personnel in the emerging economy (Thursby and Thursby, 2006). In such case the exchange of knowledge takes place in both directions[7].

We look at the inventor level because we assume that knowledge spillovers pass through interpersonal links and, therefore, it is at the individual level that the real knowledge exchange takes place[8]. At the same time, the assignees' address and country of origin convey important pieces of information. In terms of knowledge spillovers, it makes a difference whether the assignee is from an emerging country (possibly a multinational subsidiary or a local company) or from an advanced country[9]. Accordingly, starting from the definition of collaborative *patent* given above, we observe three different possibilities:

(1) at least one of the assignees' addresses listed in the patent is a company located in the emerging country (i.e. at least one of the applicants is either a local company or the MNC subsidiary of a G7 country); (2) the assignee's address is in the advanced country (the applicant is either a foreign company or a MNC subsidiary which does not declare the R&D foreign laboratory in the patent); (3) the patent is co-owned by individuals from different countries (assignees of the patents are the inventors).

In case (1), taking the perspective of the emerging country, it is important to identify the country of origin of the assignee and distinguish whether the assignee is a local company (or institution) or a local subsidiary of a MNC. The composition of the international team of inventors in the patent can be generated either by a local company hiring a foreign inventor or by a MNC subsidiary working with both local and foreign inventors (presumably coming from the MNC's home country). In the former case, knowledge is transferred using a foreign skilled worker. In the latter, knowledge is transferred through the movement of R&D facilities from advanced countries (Keller and Yeaple, 2009b).

It is important to note that when looking at the assignee's address it is not possible to distinguish between a domestic organization (*DC*) and a multinational subsidiary (*MNC*); as a consequence, we have built a novel database in which, looking one by one at the assignees' names, we single out their country of origin. Considering all the assignees with an address in the emerging country *i* we call them *domestic* (DC), if the owner is from country *i* and *multinational* (MNC) if the owner is from an advanced country. More generally in our terminology, we take the perspective of the emerging countries and also collaborations are called *domestic* when the assignee's ownership is from the emerging country and *foreign* when the applicant firm's ownership is from the advanced country.

In case (2) when the assignee's address is in the advanced country, the presence of an international team of inventors is explained by two different possibilities: the first one is that there is temporary movement of an inventor from the emerging to the advanced country, that is an inventor from country *i* decides to move to advanced country *j* but still declares that her address is in the emerging country *i* and therefore maintains strong links with the home country[10]. The second possibility is that a MNC has a subsidiary in the emerging country but uses the legal address of the headquarters even if the patent is the result of a research activity that takes place in a foreign laboratory. To identify whether this collaboration originates in a multinational's R&D laboratory located in the emerging country or in R&D laboratories of firms located in advanced countries, we decide to look at the team of inventors and at their residential address. The idea is that if a patent is invented by the majority of individuals residing in country *i* we assume that the R&D laboratory is located in country *i* as well. In this vein, among collaborative patents whose applicant's address is in one of the G7 countries, we consider as *MNC* collaborative patents (i.e. a collaboration originating in the emerging country and owned by multinationals of advanced countries) those invented by teams where the number of inventors residing in one of the selected emerging countries is equal to or more than 50% of the total number of inventors in the team. Imposing these constraints reassures us that our dependent variable is measuring an international technological cooperation which occurs in the emerging country. Whenever the percentage of domestic inventors is lower than 50%, we consider those patents to originate in foreign companies located in the advanced country (*FC*).

Finally, in case (3), when the collaborative patent is co-owned by individuals from different countries it can safely be considered that an international exchange of knowledge has occurred, even though we are not able to assess whether it has originated in the emerging or in the advanced country.

In sum, collaborations may derive either from R&D laboratories located in emerging countries – and in such cases we distinguish between patents owned by domestic companies (*DC*) and multinational subsidiaries (*MNC*) – or from R&D laboratories located in advanced countries (*FC*), or from patents applied by individuals residing in different countries (*I*). Table 1 sums up the different types of collaborations considered.

[TABLE 1 NEAR HERE]

It is relevant to stress that all cases concern to some extent the transfer of knowledge from the advanced to the emerging country, and we start the analysis using as a dependent variable simply the number of all technological collaborations (x_{ijt}) in a given year between two countries (*i* and *j*) (Section 5(a)). We also argue that the different types of international collaboration outlined above may be explained by different determinants and therefore we decompose our dependent variable following the taxonomy in Table 1 (Section 5(c)). We estimate the impact of geographical distance and other determinants on the expected value of x_{ijt} using a standard gravity model[11] represented by the following equation[12]:

$$E[x_{ijt}]= A^{\alpha}_{it}A^{\beta}_{jt}D^{\theta}_{ij}\exp(\lambda L_{ij}+ \delta T_{ijt})\ M_{ijt}{}^{\nu}IPR^{\gamma}_{it}e^{\tau t} \qquad (1)$$

3(b) Distances

D_{ij} is the geographical distance between the emerging *(i)* and the advanced country *(j)*, θ is the "distance effect", that is, the (negative) elasticity of international technological collaborations with respect to geographical distance. We consider three different measures of geographical distance: $Distance_{ij}$ uses latitude and longitude of the most populated cities; $Distance(capital)_{ij}$ the latitude and longitude of capital cities; and $Distance(weighted)_{ij}$ is a weighted (by the share of country population) measure of the distances of the most populated cities[13].

Some scholars have also argued that it is important to distinguish between latitude and longitude (Stein and Daude, 2007). Simple distance does not capture the transaction costs of frequent interactions in real time between the parties: "provided that telephone, e-mail and videoconference communication are close substitutes for face-to-face interaction, North-South distance should not be such a large problem. In contrast, differences in time zones can matter even given today's easy and low-cost communications, for the obvious reason that people at night usually prefer to sleep" (Stein and

Daude 2007, p. 97). So geographic distance can be considered a proxy of face-to-face interaction cost and time zone difference a proxy of virtual interaction cost that can substitute direct personal contacts. The variable $TimeZoneDifference_{ij}$ measures the time difference in hours between the capital cities of countries *i* and *j*. This variable ranges from 0 to 12.

Moreover, other distances related to cultural and historical differences are taken into account: these variables usually refer to common language or past colonial links. Accordingly, L_{ij} is a vector of *time-constant* 'link' indicators that may affect both technological collaboration and knowledge flow. These dummies indicate whether county *i* and country *j* share a common official language ($Language_{ij}$) and whether they have had a colonial relationship since 1945 ($Colony_{ij}$).

We also consider technological distance. The probability to observe a technological collaboration between two countries is higher if companies and institutions in the two countries are active in a similar set of technological fields. Technological distance can also be result of the different level of development of the manufacturing sector in the emerging countries. Accordingly, T_{ijt} is the *technological proximity* between countries *i* and *j* and is measured by the un-centered correlation of the two countries' vectors of patents across 30 technological classes (OST, 2004) at time *t* (P_{it} and P_{jt}), as follows: $TP_{ijt}=P_{it}P'_{jt}/[(P_{it}P'_{it})(P_{jt}P'_{jt})]^{1/2}$. This indicator typically ranges between 0 and 1 for all pairs of countries. It is equal to one for the pairs of countries with identical distribution of technological activities; it is equal to zero if the distributions are orthogonal (Jaffe, 1988).

3(c) Attractors

A^{α}_{it} and A^{β}_{jt} measure specific characteristics of countries *i* and *j*, in particular the number of patents and the size of the labor force. In our gravity framework we assume that the probability to collaborate between two countries depends upon the size of their innovative activities and the size of the economy. Therefore, we substitute the masses of the law of gravity with the total number of patent applications and labor force ($Patents_{it}$, $Patents_{jt}$, $LaborForce_{it}$, and $LaborForce_{jt}$ respectively for country *i* and country *j,* at time *t*). These indicators control for the absorptive capacity of the countries and their technological infrastructure and dimension.

More innovative and larger countries ($LaborForce_{it}$) are expected to collaborate more. The greater the population, the higher the probability that foreign companies cooperate (*demand effect*). In addition if demand is large in an emerging economy, foreign firms (including MNCs) could be willing to adapt their technologies to that given market. This could lead them to collaborate with domestic inventors. Finally, a larger domestic demand may decrease the geographic distance impact on collaborations because the costs related to face-to-face communication decrease (i.e. airfare is cheaper). However, from the emerging country point of view, the dimension in terms of labor force ($LaborForce_{it}$) may have counter-intuitive effects: the greater the population, the lesser the probability that local companies seek expertise and highly-skilled workers abroad (*supply effect*).

There are other reasons that can affect the probability for collaboration at a technological level between two countries (vector M_{ijt} in Equation 1). M_{ijt} is made up of $Trade_{ijt}$ which is the value of country *i* imports[14] from country *j* at time *t*, and FDI_{it} which is the total inflow of foreign direct investments (FDI_{it}) into country *i* at time *t*.[15]

3(d) IPR Policy

Finally, we control for IPR policy in the emerging country. In recent years, emerging countries have significantly expanded the strength of their IPR legislations to comply with TRIPS requirements[16]. The adoption of TRIPS and the consequent increase in IP protection could affect co-inventorship and, as a result, bilateral knowledge flows. Stronger IPRs in emerging countries should increase their economic openness via FDIs, imports and joint ventures and, in turn, technological collaborations. New harmonized legislation and stricter enforcement generate greater incentives to disclose technological knowledge, especially when technological spillovers are linked to the imports of goods because the strengthening of IP reduces the imitation risk and favors the export mode (Helpman, 1993; Glass and Saggi, 2002).

In principle, the strength of IPRs in an emerging country should reassure multinational companies willing to invest and develop technologies in these countries. In particular, Branstetter et al. (2006) study how IPR reforms affect technology transfer among U.S. multinational firms. Their firm-level data show that in 12 countries after IPR reforms there is a growth of royalty payments to affiliates, affiliate R&D expenditures and total levels of foreign patent applications. Moreover, we can expect the positive effect of IPR reinforcement on international technological collaboration to be stronger when companies already have the opportunity to know the emerging market. This is facilitated for those emerging countries that are closer in terms of GDP and GDP per capita to the G7 countries or that have substantial trade relationships with advanced countries (Qian, 2007).

On the other side, strong IPRs generate a monopoly power, limiting competition and the possibility of cooperation among firms. As a consequence, stronger IPRs and stricter enforcement may generate less international knowledge flows through imitation and adoption and the closing down of infringing activities[17]. Finally, worries have also been expressed that stronger IPRs generate higher costs of access to imported technologies and difficulties in accessing basic scientific knowledge (Mazzoleni and Nelson, 1998; McCalman, 2001).

We measure the general strength of the domestic intellectual property system (IPR_{it}) using the Ginarte and Park index (Ginarte and Park, 1997; Park and Wagh, 2002; Park, 2008)[18]. This index ranges from zero to five and its value is the un-weighted sum of five sub-indexes that range from 0 to 1: (1) extent of coverage (subject matter and types of invention); (2) membership of international treaties; (3) duration of protection; (4) absence of restrictions on rights (e.g. degree of exclusivity); and finally, (5) statutory enforcement provisions (e.g. preliminary injunctions).[19] Table 2 shows the IPR index in the eleven emerging countries for available years.

4. DATA AND METHODOLOGY

4(a) Data description

Our database starts from the 26 countries included in the MSCI Emerging Market Index[20]. We collected all the patent applications[21] at the US Patent and Trademark Office (USPTO) signed by at least one inventor from all these countries during the period 1990-2004 and we took out European transition economies and those countries with less than 50 USPTO patent applications at the beginning of our sample between 1990 and 1995. We were then left with the following 11 emerging economies: Argentina, Brazil, China, India, Israel, South Korea, Malaysia, Mexico, South Africa, Singapore, and Turkey. The advanced countries are: Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. In addition, we also collected information on bilateral imports (source: STAN/OECD database), FDIs (UNCTAD), geographical and cultural distance (CEPII), and the IPR index (Park, 2008). Table A1 in the Appendix describes data sources and gives descriptive statistics.

The patent dataset contains 119,309 patent applications with at least one inventor residing in one of the selected emerging economies, of which 14,684 (12%) identify international collaborations between inventors in emerging and advanced countries[22]. Table 2 shows high heterogeneity among emerging countries in terms of patenting activity. South Korea and Israel are leading countries (in terms of number of patents) with 70,467 and 18,447 patent applications respectively during the period 1990-2004, while Argentina and Turkey have only 928 and 392 patent applications respectively. In terms of patenting intensity, China and India are ranked last with around 13 and 17 patent applications respectively per millions of workers. Countries characterized by a high level of patent productivity are also those with a higher level of IP regime at the beginning of the 1990s (see Column (e)).

[TABLE 2 NEAR HERE]

In seven countries (Argentina, Brazil, China, India, Malaysia, Mexico, and Singapore) the share of international collaborations in the total number of patents is around 30%. Nevertheless high heterogeneity appears when considering South Korea with just 3% of collaborative patents compared to Turkey with 64%.

Table 2 also shows that emerging countries have reinforced their regimes of intellectual property, due to the TRIPS agreement signed in 1994. Columns (e) and (f) display the value of the Ginarte and Park index for two sub-periods. The index grows particularly in countries such as Turkey, India and Mexico, whose IPR index was very low at the beginning of the 1990s. Moreover, standard deviation shows that, as a consequence of the TRIPS agreement, differences in terms of IPR protection decreased over time.

In terms of knowledge spillovers, as discussed in Section 3(a), it can make a difference whether the assignee is a multinational subsidiary located in the emerging country, a local company or a foreign company. In order to assign the country of origin of the assignee (in terms of ownership) we look one by one at all the assignee declaring their address in one of the emerging countries, with the exception of Korea and Israel[23]. This allows us to disentangle the international technological collaborations into four different categories according to different types patent applicants' ownership (see Table 1): collaborations derive either from R&D laboratories located in emerging countries – and in such cases we distinguish between patents owned by domestic organizations (*DC*) and multinational subsidiaries (*MNC*) – or from R&D laboratories located in advanced countries (*FC*), or from patent applications by individuals residing in different countries (*I*).

Table 3 shows how frequently each particular collaboration category occurs in the data. Collaborations involving companies located in one of the G7 countries (*FC*) are the most frequent in all the cases: they range from 82% for Brazil to 45% for Singapore. This basically means that a consistent part of knowledge exchange between advanced and emerging economies occurs abroad, possibly via the international labor mobility of skilled people. On the other hand, Singapore and South Africa have the highest share of collaborations which originate from own R&D laboratories, as they are the countries (not considering Israel and Korea) with the highest patent intensity.

[TABLE 3 NEAR HERE]

4(b) Model and econometric issues

The gravity model in Equation 1 can be estimated using different econometric techniques. Santos Silva and Tenreyro (2006) show that a log linear model provides biased estimates of mean effects when the errors are heteroschedastic. To address this problem they recommend a Poisson Pseudo Maximum Likelihood (PPML) estimator as a tractable and robust alternative[24].

Moreover, the number of technological cooperations between two countries in some years is zero. However, zeros are not the results of the rounding up errors that can be typically found in trade data and the PPML estimator solves this problem as it is "*a natural way to deal with the zero values of the dependent variable*" (Santos Silva and Tenreyro, 2006, p. 641). In addition, in our case the problem is not as relevant as in the trade gravity equations because the share of zeros is less than 30%, while for example the same share in datasets involving disaggregate trade flows is frequently much higher (e.g. Baldwin and Harrigan, 2007; Helpman et al., 2008).

Finally, this estimator is also particularly suitable because our dependent variable is a count and its distribution is highly skewed. So, as suggested by Santos Silva and Tenreyro (2006), we started estimating the model using PPML with the classical Huber and White sandwich estimator of variance (Huber, 1967, White, 1980). Moreover, because observations in pairs of countries are likely to be dependent across years, robust standard errors are clustered to control for error correlation in the panel (Cameron and Golotvina, 2005).

5. RESULTS

In what follows we present three sets of regressions. In the first set we consider different specifications to estimate distance effects. We use panel data with source and destination country dummies and interact time dummies to control whether the estimated collaboration elasticity to distance changes over time. However, there is the possibility that country *i* would exchange different levels of knowledge with two different countries even though the two countries have the same level of *LaborForce*$_j$ and *Patents*$_j$ and of the other control variables, being at the same time equidistant from country *i*. One possible reason could be that they share similar historical, cultural or political factors that are difficult to observe and are only partly addressed by our control variables.

Accordingly in the second set of regressions, we control for unobservable time invariant individual effects where the individual is the specific bilateral relation between countries *i* and *j*. In so doing, the fixed effect analysis shifts the focus onto the impact of time variant variables like technological proximity, trade and IPRs.

Finally, in the third set of regressions we disentangle international technological collaborations by identifying where (in emerging or advanced country) they take place and the applicants' ownership (domestic, MNCs or individuals), as described in Section 3(a). We argue that international technological collaborations can be the result of decisions by individuals to move abroad or by MNCs to internationalize their R&D activities and to cooperate with a foreign knowledge base. These decisions are subject to different explanatory factors.

5(a) The effect of geographical, cultural and technological distances

Table 4 reports the estimates of the distance elasticity of international technological collaborations for different specifications[25]. All regressions contain a full set of time dummies that are used to control for time varying unobservable factors that are common across countries. Country dummies (both for country *i* and *j*) control for differences between countries – such as macroeconomic stability, particularly government policies, human capital and other non-observable factors – that might affect the number of collaborations.

In column (1) we estimate a non-augmented gravity model by considering distance and mass; we find that both have significant explanatory power. In particular, our gravity model is asymmetric because the masses measured by patenting activity have a positive and significant effect only in the case of patent applications by emerging countries (*Patents*$_{it}$) and not for patent applications from advanced countries ($Patents_{jt}$)[26]. $LaborForce_{it}$ in the emerging country is negative and significant. This may suggest that smaller countries seek expertise and highly-skilled workers abroad to compensate for the shortage in the local market.

[TABLE 4 NEAR HERE]

Column (1) suggests that $Distance_{ij}$ is significantly negative and that therefore communication and transportation costs might play a significant role in determining the geographical scope of technological collaborations. However, what we observe in column (1) is both the *direct* and the *indirect* effect (through trade) of distance on collaborations. According to trade literature in fact distance significantly affects trade flows and so, by omitting trade in the model, we capture both effects. However, Poisson results also show that the estimated distance elasticity is no more significant once we use a broader set of variables in columns (2) to (4). In particular, controlling for trade cancels out the effects of geographical distance. In columns (2)-(4) we estimate the *direct* effect and Poisson results show that controlling for trade (and other broader set of variables) geographical distance is no more significant. Moreover, in columns (2)-(4) different measures for geographical distances are considered, but in all the cases they are not significant (even though negative as expected). Our first result therefore is that the impact of geographical distance *per se* on international technological collaboration is hardly relevant. However it is important to note that distance still plays a role on international collaborations through bilateral imports as we find a distance elasticity with respect to trade of about -0.84.

Other forms of distance like similarity in the technological distribution of the inventive activity and language similarity have a positive effect still controlling for trade relationship. In addition, using the specification in column (2), we have interacted time dummies with distance to estimate the effect of distance in different calendar years. Figure 1 shows that its magnitude does not decrease over time.

[FIGURE 1 NEAR HERE]

As a general result, therefore, geographical distance does not significantly matter once controlling for trade and, at the same time, there is no trend towards a reduction of the impact of distance over the years because, if any, the distance elasticity of international technological collaborations increases over time. This result is also in line with the "missing globalization puzzle" (e.g. Brun et al., 2005) in the gravity model of bilateral trade.

As discussed in Section 3(b), Stein and Duade (2007) find that differences in time zones have a negative and significant effect on the location of FDI and, to a lesser extent, on trade. Moreover, they find that the longitudinal effect has increased over time. In Columns (5) and (6) we show two regressions in which the $TimeZoneDifference_{ij}$ variable is added: our results, in line with their findings for trade, show that its coefficient is negative and significant. In particular, an additional hour is associated with a 7% decrease in the number of patent collaborations (column (5)). Moreover $TimeZoneDifference_{ij}$ is still negative and significant when controlling for geographical distance (column (6)).

Cultural and historical ties, respectively, are captured by dummies which are equal to one if two countries share a common official language ($Language_{ij}$) and the two countries have ever had a colonial link ($Colony_{ij}$). Our results confirm the hypothesis as corroborated in Picci (2010): sharing a common language facilitates collaborations. Also, the colonial relationship variable is positively correlated with international technological collaborations even though this effect is not statistically different from zero[27].

We observe a positive, large and statistically significant coefficient for technological proximity ($TechnlogyProximity_{ijt}$)[28]. The effect of technological proximity is much larger than trade (bilateral imports). Countries which share similar technological composition have more chances to collaborate. The quantitative significance of the estimated impact of technological proximity is substantial: for a standard deviation increase in the technological proximity (which is equal to 0.14, see Table A1 the

Appendix), the mean number of expected collaborations between country *i* and country *j* increases by a factor of 1.23 (or 23.4%), holding other variables constant.

Concerning *Trade*, we always find a positive estimated coefficient that is not statistically different from zero. In principle, the probability of observing a technological collaboration is higher between trading partners but this effect, if it exists, is weak. The total amount of FDIs received is negatively but not significantly correlated with collaborations. Note however that this measure, differently from trade, is not bilateral (but when we use bilateral FDIs on a subset of countries[29] we obtain similar results) and that many FDIs do not occur in high tech sectors and therefore it is plausible that there is no correlation with technological collaborations.

Finally, IPRs do not affect the level of technological collaboration between countries. However, we suspect that the lack of significance of the coefficient is mainly due to the heterogeneity of countries and the effect of IPRs may vary according to the intensity of economic relationship between two countries and according to the level of GDP per capita. We explore this issue more in depth in the next section.

5(b) The effect of IPRs

Simple Poisson models presented in Table 4 show a non-significant role of IPRs on international patent collaborations. However, in order to better understand the role of IPR strengthening, we use a fixed effects (FE) Poisson ML estimator which, with a dummy for each pair of countries, captures all the observable and non-observable factors which characterize the country-pairs and may have an impact on the propensity to collaborate (Westerlund and Wilhelmsson, 2009). Column (1) in Table 5 displays the Poisson estimates for the FE case, which basically is the analogous of Column (2) in Table 4 but with 76 individual pair-dummies (11 emerging countries by seven advanced countries, with the exclusion of one dummy)[30].

The FE model shows that the IPR effect is positive and significant. It means that, overall, countries experiencing an increase in the IP index tend to be more involved in the international network of collaborations[31]. Moreover, looking at level of protection in 1990, we note that six countries show an index higher than 1.50: South Africa, South Korea, Malaysia, Israel, Singapore, and Argentina. The other five countries show an index lower than 1.50: Brazil, India, China, Mexico and Turkey. The latter group includes countries among the highest in terms of IPR index growth (see Table 2).

[TABLE 5 NEAR HERE]

It is important to note that we find that a stronger level of IPRs has a positive effect only for this latter group of countries (see column (2)). In addition, the effect of IPRs is negative for those countries that at the beginning of the period had a relatively higher level of IPR protection (column (3)). This suggests that the relationship between patent collaborations and the strength of intellectual property rights may be different according to the different levels of intellectual property protection in different countries. This result is in line with other evidence on the non-linear relations between innovation and IPRs (e.g. Qian, 2007). Altogether, these results may suggest that the strengthening of IPRs could facilitate technological collaborations only if a country starts from a very weak level of IPR protection. However, a further reinforcement beyond a certain threshold could have a negative effect leading to monopoly power and higher cost of access to imported technologies.

We study whether the impact of IPRs varies with different levels of trade or per capita GDP. According to some authors (Lapan and Bardhan, 1973; Cohen and Levinthal, 1989) knowledge flows between countries are greater when emerging countries are characterized by high levels of absorptive capacity, which are highly correlated with the per capita GDP. However, our results indicate the opposite: stronger IPRs have a negative effect on the intensity of international collaborations for high levels of per capita GDP. The interaction term of IPRs and per capita GDP is negative and statistically significant (see column (4)). This effect is similar to that outlined in column (3). Countries with a higher GDP per capita are those that for the whole period already have a high level of IPR protection. As a consequence, further reinforcement does not have a positive effect on international technological collaborations[32].

Finally, we observe a positive sign of the interaction term between IPRs and Trade. The effect is positive and significant (only at 90% level). Stronger IPRs in the emerging countries stimulate international technological collaborations between countries that also have increasing trade relationships. Following this view, the strengthening of IPR facilitates the creation of international technological collaborations to the extent that it is supported by the market for goods.

Note that multicollinearity could increase the standard errors of the estimated coefficients in the case of IPRs, Trade and FDIs[33]. In the correlation table in the Appendix we show that the correlation between Trade and IPRs is only 0.17. The problem is a little stronger for FDIs where the correlation is 0.28. A possible concern regards also the fact that IPR decisions could be endogenous to the extent that they could be explained by previous patenting and collaborating strategies of multinational companies. However, in the period under scrutiny in the paper (1990-2004) emerging and developing countries expanded significantly the strength of their IPR legislations to comply with TRIPS requirement. By requiring that WTO member nations enact and enforce laws on copyrights and patents to protect intellectual property, the TRIPS agreement could be partially seen as exogenous policy changes.

5(c) Companies' country of origin and patent collaborations

In Section 3(a) we built up a taxonomy of international technological collaborations based on the country of origin and country of residence of the assignees. In our terminology we take the perspective of the emerging countries and collaborations are called *domestic* when the assignee's ownership is from the emerging country and *foreign* when the assignee's ownership is from the advanced country. International patent collaborations derive from R&D laboratories of either multinational subsidiaries located in the emerging country (*MNCs*) or *foreign* companies located in one of the advanced countries (FCs) or *domestic* organizations in the emerging country (*DCs*) or, finally, from patents applied for by individuals residing in different countries (*I*) (see Table 1). In Section 3(a) we have explained why this taxonomy implies different types of collaboration.

[TABLE 6 NEAR HERE]

[TABLE 7 NEAR HERE]

Table 6 and Table 7 shows Poisson estimates (with and without pairs fixed effects) for these different types of collaborations (see Table 1). The coefficient for geographical distance is always negative but not significant, confirming the results displayed in Table 4 with one important exception. Geographical distance becomes negative and significant when we consider the *domestic* collaborations (DCs_x_{ijt}): communication and transport costs are relevant when the collaborative project is owned by a company from an emerging country. This is probably because they often have tighter financial constraints or higher marginal communication costs due to a lower integration in the international network of knowledge production. In this case companies manage to access knowledge that is physically closer because it is more costly to communicate and exchange knowledge that is tacit and requires face-to-face contacts. The same argument is valid also for collaboration between individuals. The value of the estimated is particularly high even of not statistically significant. Interestingly when we add time zones to the regressions we find that longitude is important for the same two types of collaborations: DCs_x_{ijt} and Is_x_{ijt}.

International patent collaborations are less affected by communication and interaction costs (face-to-face or virtual) when they derive from R&D laboratories of either multinational subsidiaries located in the emerging country (*MNCs*) or *foreign* companies located in one of the advanced countries (FCs).

Sharing a common language is an important driver of international technological collaborations when these involve a mobility decision at the individual level: the presence of common language

(*Language*$_{ij}$) is positively associated only with *FCs_x*$_{ij}$ collaborations, that is for collaborations involving the mobility of individuals of emerging country to advanced country, and with *DCs_x*$_{ijt}$ collaborations, where the mobility of individuals is in the opposite direction. On the other hand, having a colonial link (*Colonial*$_{ij}$) is positively correlated with the number of collaborations stemming from MNC subsidiaries.

It is important to note that the importance of sharing a common language might not be related just to the mobility decision at the individual level but to the cost of searching for partners. MNCs are expected to be indifferent to language as they are searching within the boundaries of the group and they are all likely to speak English. This possibly does not occur in the case for FCs and DCs collaborations. In this case probably inventors are looking for partners outside their companies.

The effect of technological proximity (*TechnlogyProximity*$_{ij}$) is positive and significant only for the collaborations of subsidiaries (*MNCs_x*$_{ijt}$) and *domestic* organizations (*DCs_x*$_{ijt}$): the relative attraction of an emerging country for multinationals and highly skilled workers from abroad positively depends upon the local scientific and technological infrastructure. This result suggests that multinationals seeking profits and searching for technologies abroad prefer, ceteris paribus, countries whose technological composition is similar to that of their own country. However, these factors do not play any role in decisions at an individual level as the international mobility of highly skilled workers of emerging economies is affected by the cultural relationship and dimension of the labor market.

Dividing collaborations by country of origin we are also able to better understand the nature of the overall positive effect of IPRs on the number of international patent collaborations, as shown in the previous section (Table 6 and 7). First of all, the number of collaborations originating from multinational subsidiaries increases with the strength of the patent regime in the emerging country: the coefficient of IPRs is positive and significant both with and without country-pair fixed effects. Stronger IPRs, by reducing the imitation risk faced by potential investors in the advanced country and by creating a market for technologies in the emerging country, reduce the transaction costs (such as informational asymmetry and non-excludability property of knowledge) of collaborations and increase the investor's rent share (e.g. Markusen, 1995).

This in turn raises the incentive of MNC subsidiaries to locate part of the innovative process abroad and to cooperate with the local knowledge base. This result is in line with Branstetter et al. (2006) and corroborates the finding of Lee and Mansfield (1996) who found a positive relationship between the level of the IPR system in developing countries as perceived by a sample of 100 US firms and their foreign direct investments. Also, the IPR coefficient for the collaborations originating from foreign companies abroad (FCs_x_{ij}) is positive and significant in the FE case showing that foreign companies located in one of the G7 countries are more inclined to cooperate with inventors from emerging countries as the fear of being imitated decreases with the higher level of IPRs. Finally, Table 6 and 7 suggest that IPRs also positively affect collaborations brought about by individuals (Is_x_{ij}). The strength of the patent regime in the emerging country seems to encourage cooperation with foreign inventors.

Interestingly, the effect of IPRs is negative for collaborations stemming from the R&D laboratories of domestic companies (DCs_x_{ijt}): the coefficient of IPRs (columns 3 and 4 in Table 6 and column 2 in Table 7) is negative and significant both with and without country-pair fixed effects. So IPR reinforcement facilitates international technological collaborations when (with the perspective of the emerging countries) foreign companies are directly involved in the R&D project. At the same time, it does not facilitate collaborations when the innovative project is owned by a *domestic* company. So access to foreign knowledge in the form of technological collaborations for domestic companies seems more difficult when there are stronger IPRs.

Finally, some other results in Table 4 are also confirmed in Table 6 and 7. The asymmetry of the gravity model is evident for all types of patent collaborations. The masses measured by patenting activity have a positive and significant effect only in the case of patent applications of emerging countries ($Patents_{it}$) and not for patent applications of advanced countries ($Patents_{jt}$). Moreover, as expected, the coefficient is greater for collaborations originating from the R&D laboratories of domestic organizations (DCs_x_{ijt}). However, the dimension of the emerging country ($LaborForce_{it}$) has a positive effect on the collaborations originating in the emerging country ($MNCs\_x_{ijt}$ and DCs_x_{ijt}) but negative on the foreign collaborations (FCs_x_{ijt}): on the one hand, bigger countries are able to attract more MNC subsidiaries and highly skilled workers from abroad to cooperate with, and on the other hand, for what concerns the FCs_x_{ij} collaborations, it makes sense that highly skilled workers have more incentives to leave their own country when they find fewer opportunities in terms of employment. This reasoning is reinforced by the positive role played by the dimension of the G7 country ($LaborForce_{jt}$) which positively affects the international mobility of highly skilled people (FCs_x_{ijt}).

6. CONCLUDING REMARKS

There is a growing body of literature that underlines that face-to-face contacts and personal interactions are a crucial vehicle of knowledge transfer and spillovers. In emerging countries, access to foreign technologies, in particular, via collaborations with foreign counterparts, both in the domestic country and abroad is a hot political issue. As scientific research increasingly involves international teams and mobility of researchers is on the rise, it is possible to ask whether collaborative links with foreign laboratories rely more on relational and capability proximity than on geographical distance. Also, multinationals are increasingly delocalizing R&D activities in host countries, spurring a debate on what are the conditions under which the local community of researchers and firms can learn by tapping into foreign collaborative networks.

Taking these issues as a point of departure, this paper analyzes international technological collaborations among inventors in emerging and advanced countries using USPTO patent applications and asks to what extent they are affected by a decrease in communication and transport costs (that are a function of geographical distance). In addition, it studies the effects of a set of economic and institutional variables like technological proximity, sharing a common language or a colonial link, and, finally, the recent reinforcement of IPRs brought about by the TRIPs agreement.

This paper uses a novel database that considers not only the residence of inventors and assignees but also the companies' country of origin (in terms of ownership). In addition, the specific composition of the international team of inventors and the relative weight of the different countries in the team are taken into account. An important point of the paper is that results depend upon the type of collaboration considered and it makes a substantial difference whether the collaboration stems from a multinational company from an advanced country or a company from an emerging country.

Overall, geographical distance seems to have a modest effect on international collaborations when controlling for trade relationships, technological and cultural distances. However, differences arise when we consider the origin and the nature of such collaborations. In particular, we observe that distance affects international collaborations only when they originate in laboratories of companies from the emerging countries. On the contrary, geographical distance in itself is not important for those collaborations originating in MNC subsidiaries or via the international mobility of inventors from an emerging to an advanced country. If simple geographical distance has no strong (and negative) impact on international collaborations, time zone differences, to some extent, do.

We also find that technological proximity is an important factor in explaining international technological collaborations. Sharing a common language is also always significant in the main models. This effect is mainly driven by the collaborations generated by the international mobility of highly skilled workers from the emerging countries or from companies from the emerging countries. Sharing a common language has no significant impact for collaborations within MNC subsidiaries.

Our paper contributes also to the policy debate on the effects of IPR reinforcement and our evidence suggests that there may be some positive effects on knowledge flows generated by the reinforcement of IPRs for those economies which started at the beginning of the 1990s with a low level of IPR protection. However, these results have to be taken with extreme care because the impact of the IPR regime is extremely complex and can vary from sector to sector and country to country. Importantly, we also show that the impact of IPR reinforcement varies according to the type of collaboration considered and country of origin (emerging vs. advanced) of the companies involved. For collaborations deriving from laboratories of multinational subsidiaries we have a positive effect of IPR reinforcement. On the contrary, for collaborations that involve only a company from the emerging market the effect of the reinforcement of IPRs is negative. Finally, our additional results show that a positive result may be confined to pairs of countries that are close trade partners and to those countries with a lower level of per capita GDP.

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[1] There is substantial evidence that knowledge spillovers tend to be geographically localized (among many papers on this issue see for example the following surveys: Breschi and Lissoni, 2001; Keller, 2002 and Keller, 2010).
[2] Article 7 of the TRIPS Agreement claims that "The protection and enforcement of intellectual property rights should contribute to the promotion of technological innovation and to the transfer and dissemination of technology". Moreover, Article 66.2 asks developed WTO Members to "provide incentives to enterprises and institutions in their territories for the purpose of promoting and encouraging technology transfer".
[3] R&D collaborations in Europe are significantly affected by technological and geographical distance (Balland, 2011; Scherngell and Barber, 2009 and 2011). At the same time other factors affect R&D collaborations like the specific position of the company in the network of collaborations, past experience in collaborations (Autans-Bernard, 2007 in micro and nanotechnologies), being part of the same group (organizational proximity) and, finally, having a similar institutional form (institutional proximity) (Balland, 2011 in the Global Navigation Satellite System).
[4] Institutional proximity plays an important role mitigating the effect of geographical distance (Pond et al. 2007).
[5] Kerr (2008) shows that knowledge diffusion is importantly affected by interpersonal links within the same ethnic community.
[6] If a patent is signed by three inventors from three different countries in our sample, we consider three bilateral collaborations.
[7] Consider an emerging country researcher who has not access to the needed infrastructure to develop the technology. He has the option to collaborate either with a G7 lab in the emerging country (if there exists) or with a company abroad. In both cases the researcher in the emerging country would benefit from the (technological) competences of the advanced country and, at the same time, the G7 country would benefit too from the (scientific) competences of the researcher.
[8] Note that we are assuming that workload and skills are the same across inventors. As shown by Bergek & Bruzelius (2010) this is not always the case.
[9] Note that applicants can be companies, universities, public research organizations, governmental institutions or other forms of organizations (e.g. foundations, associations etc.) and individuals. Whenever a patent is co-owned by two or more companies, one from an emerging and the other from a foreign country, we categorized it as "domestic" in so far as we believe that this case reflects a R&D activity located in the emerging country.
[10] This phenomenon would be associated with knowledge flows and possibly categorized as international labor mobility.
[11] Gravity models have been widely used in explaining trade flows (see Baldwin and Taglioni, 2006 and De Benedictis and Taglioni, 2011). Disdier and Head (2008) show that the negative impact of distance on trade flows began to rise after the 1950s and remains high. Taking into account in their meta-analysis of approximately 1400 distance effects estimated in 103 different econometric papers, they show that the mean bilateral trade flow elasticity to distance is equal to 0.9 and challenge significantly the idea that distance is becoming less relevant as globalization and international integration increase.
[12] In Equation 1 we estimated the number of collaborations in year *t* as function of attributes of the country pairs in the same year. However a patent application could be seen as the outcome of R&D activities performed in the years prior to *t*. For this reason we estimated several gravity equations where the correlates are evaluated in the year t-1, t-2 and moving 2-year average over (t-2) to (t - 1) and we obtained similar results (available upon request).
[13] Data come from the CEPII dataset, further details at http://www.cepii.fr/francgraph/bdd/distances.htm. The weighted measure is the distance between the biggest cities of those two countries, those inter-city distances being weighted by the share of the city in the overall country population.
[14] Bilateral imports are both expressed in millions of US dollars at current prices; however the inclusion of a full set of time dummies makes it unnecessary to use constant prices (Picci, 2010).
[15] Official data (OECD) on bilateral FDIs have many missing observations. Nonetheless, we have controlled our results also using bilateral FDI data. Results do not change.
[16] TRIPS agreements require WTO member nations to enact and enforce laws on copyrights, trademarks and patents to protect intellectual property. Rights expanded in many fields such as computer software, publications of various types, and pharmaceuticals.
[17] Helpman (1993) underlines the risk that a tighter IPR in developing countries could provoke a reduction of FDI and an increase of imports which in turn would have deterred innovation because of monopoly pricing and a higher dependence on imports.
[18] This is the most widely used IPR index. Legislation-based indexes have some limitations that are discussed in the literature (e.g. Hamdan-Livramento, 2009). The main limitation is that it does not take into account how in practice IPRs legislation is enforced.
[19] Data are available for an average of 1960-1990, from 1995, 2000 and 2005. Following Picci (2010), for the years 1990, 1991 and 1992, the 1960-1990 average has been used. The years 1993, 1994, 1996 and 1997 are set equal to the observation for 1995. The observation for the year 2000 is also used for the years 1998, 1999, 2001 and 2002. Lastly, the observation for the year 2005 is also used for the years 2003 and 2004.
[20] An index created by Morgan Stanley Capital International (MSCI) that is designed to measure equity market performance in global emerging markets.
[21] A patent application is a legal document filed with the USPTO when applying for patent protection, which includes an abstract, a specification (claims), an oath or declaration, and usually at least one drawing. Other available information in the

patent applications are the names and country of inventors, name and country of assignees, filing date, references to the prior knowledge, and technological classes.

[22] An example of collaborative patent between USA and Brazil is the following: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=4&f=G&l=50&d=PTXT&S1=4950848&OS=4950848&RS=4950848

[23] We used data developed in Malerba et al. (2011) which categorized by ownership the assignees for Brazil, Russian Federation, India, China, Mexico and South Africa. Here we updated the data to Singapore, Turkey, Argentina, but we have been not able to accurately categorize all collaborations for Korea and Israel.

[24] In their simulation study designed to assess the performance of different econometric methods, they find that PPML estimators are less subjected to have biases form heteroschedasticity.

[25] Throughout the paper we consider all patenting collaborations to be of similar value. However, it is plausible that attractors and frictions may have different impacts according to the value of the collaborations. Given the typical skewed distribution in the technological and economic value of the inventions, we weight them using standard value indicators like forward patent citations and in such case our measure of collaborations becomes a weighted sum of patent collaborations by pairs and year, where the weights are the number of citations received in the first three years after the priority date. The results are not reported to save space but are available upon requests and are very similar to the results displayed in Table 4: the only difference is that differences in time zones have no negative effect on the international patenting collaborations. This could suggest that as far as two countries are able to produce a novel and worthwhile innovation, the effects of transportation and communication costs are negligible.

[26] We estimate a gravity model to the extent that there is no overlap between home countries (i) and source countries (j) which represent two distinct sets of countries in terms of economic and patenting activity.

[27] Interestingly, past colonial relationship (COLONY ij) remains not significant even without controlling for language similarity (LANGUAGE ij).

[28] Note that technology proximity could hide other factors like the similarities in the demand side and in the stage of development.

[29] We mainly lack bilateral information for Canada (and also for Italy and Japan): the number of observations falls to 929 and the FDI bilateral estimate is positive but not significant. The results for the other variables are confirmed and are available upon request.

[30] FE models clearly cancel out the time-constant variables like geographical distance. Notice also that the technological proximity ($TechnlogyProximity_{ij}$) is no more significant: the reason is the variance of this index is high between countries but very low within pairs of countries.

[31] Branstetter et al. (2002) found a similar effect of IPR reforms on international technology transfer measured by royalty payments between affiliates.

[32] This suggests two other possible interpretations of this phenomenon: (1) by developing their economies, emergent countries build up competences which allow them to create new knowledge without the help of more advanced countries; (2) for high levels of development, with stronger IPRs, multinational companies might prefer licensing and exporting their technological goods rather than collaborating with domestic laboratories.

[33] Even if some results are still mixed, the available empirical evidence tends to suggest that trade responds to IPRs reinforcement even if there are some contrasting results (e.g. Maskus and Penubarti, 1995 and Co, 2004).

FIGURES

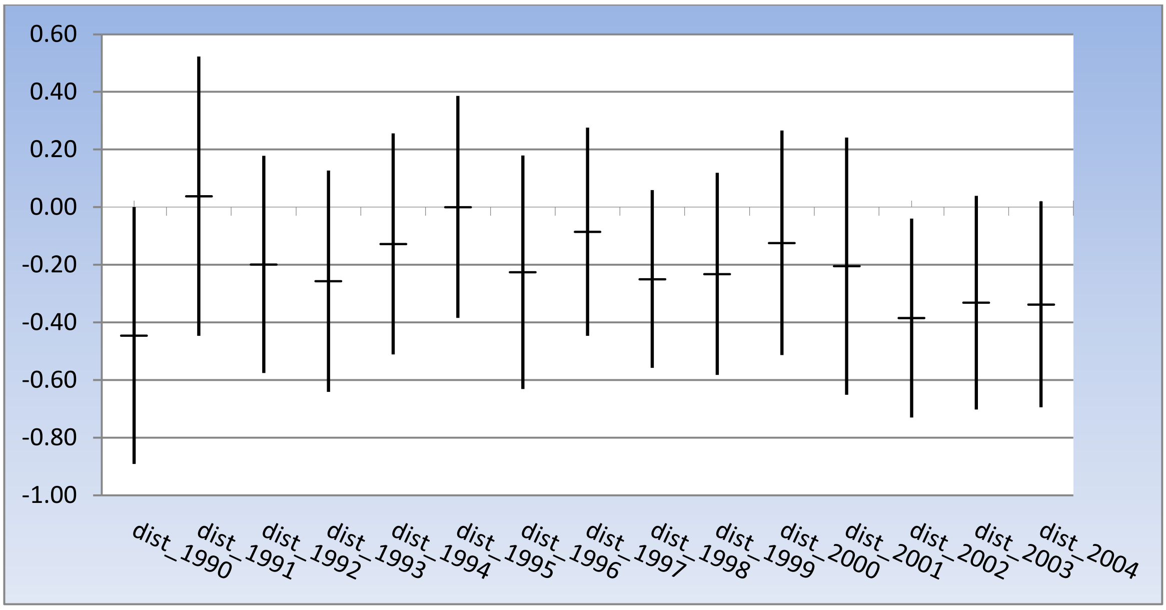

Figure 1.
The effect of distance over time.

Coefficients are the estimates of interaction between distance and dummy years in the augmented version of the gravity model (column (2), Table 2).

TABLES

Table 1.
Collaborations by patent applicants' ownership and assignee's address.

<table>
<tr><td colspan="3" rowspan="2"></td><td colspan="2">Assignee's address</td></tr>
<tr><td>Emerging [E]</td><td>Advanced [A]</td></tr>
<tr><td rowspan="3">Patent Applicants' Ownership</td><td>INDIVIDUALS</td><td></td><td>I</td><td>I</td></tr>
<tr><td rowspan="2">FIRMS</td><td>Emerging [E]</td><td>DC</td><td rowspan="2">MNC (if no less than 50% of inventors reside in E), FC (if less than 50% of inventors reside in E)</td></tr>
<tr><td>Advanced [A]</td><td>MNC</td></tr>
</table>

Collaboration is defined as a patent with inventors residing both in emerging and advanced country. In the terminology we take the perspective of the emerging country. We consider four types of collaborations. A domestic collaboration (DC) is when the assignee is a domestic institution (firm, university or public research center) which is located in the emerging country; a subsidiary collaboration (MNC) is when the patent is applied for by a G7 MNC subsidiary located in the emerging country; a foreign collaboration (FC) is when the patent applicant country of origin is from one of the G7 countries and is not located in the emerging country; finally I is when the patent is applied for by individuals residing either in emerging country or in G7 country, or both. Whenever a patent is co-applied for by two or more companies, we adopted the following rule: whenever there is a DC we categorized it only as DC. Then, in the case of multiple co-applications between MNC,FC and I we categorized it as MNC. The residual category is I.

Table 2.
Patent and IPR summary statistics

Country	**Patent data**					**IPR data***			
	(a) Total patent applications	(b) Collaborative patent applications	(%)	(c) *Labour Force** (Millions)*	(d) Patent productivity (a)/(c)	(e) Average 1960–1990	(f) 1995	(g) 2000	(h) 2005
Argentina	928	237	*26%*	*15.03*	61.74	1.6	2.73	3.98	3.98
Brazil	2345	754	*32%*	*75.61*	31.01	1.22	1.48	3.59	3.59
China	9427	2464	*26%*	*712.37*	13.23	1.33	2.12	3.09	4.08
India	6264	2229	*36%*	*371.28*	16.87	1.03	1.23	2.27	3.76
Israel	18447	3432	*19%*	*2.22*	8309.46	2.76	3.14	4.13	4.13
Korea	70467	2303	*3%*	*21.75*	3239.86	2.55	3.89	4.13	4.33
Malaysia	1332	444	*33%*	*8.82*	151.02	1.7	2.7	3.03	3.48
Mexico	1613	568	*35%*	*36.57*	44.11	1.19	3.14	3.68	3.88
Singapore	5740	1631	*28%*	*1.90*	3021.05	1.64	3.88	4.01	4.21
South Africa	2354	371	*16%*	*14.28*	164.85	2.94	3.39	4.25	4.25
Turkey	392	251	*64%*	*2.76*	142.03	1.16	2.65	4.01	4.01
All sample	*119309*	*14684*	*12%*	*116.60*	1023.23	*(s.d.: 0.69)*	*(s.d.: 0.87)*	*(s.d.: 0.62)*	*(s.d.: 0.27)*

* Ginarte and Park index**:** is Park (2008); ** average values: 1990-2000

Table 3.
Patent collaborations frequency by applicant type.

	DCs_x_{ijt}	$MNCs\_x_{ijt}$	FCs_x_{ijt}	Is_x_{ijt}
Argentina	2%	26%	64%	8%
Brazil	5%	9%	82%	4%
China	3%	16%	74%	7%
India	3%	17%	77%	3%
Malaysia	2%	44%	52%	2%
Mexico	4%	22%	66%	8%
Singapore	20%	32%	45%	2%
South Africa	15%	6%	62%	16%
Turkey	3%	21%	72%	4%

Collaboration is defined as a patent with inventors residing both in emerging and advanced country. In the terminology we take the perspective of the emerging country. We consider four types of collaborations. A domestic collaboration (DC) is when the assignee is a domestic institution (firm, university or public research center) which is located in the emerging country; a subsidiary collaboration (MNC) is when the patent is applied for by a G7 MNC subsidiary located in the emerging country; a foreign collaboration (FC) is when the patent applicant country of origin is from one of the G7 countries and is not located in the emerging country; finally I is when the patent is applied for by individuals residing either in emerging country or in G7 country, or both. Whenever a patent is co-applied for by two or more companies, we adopted the following rule: whenever there is a DC we categorized it only as DC. Then, in the case of multiple co-applications between MNC,FC and I we categorized it as MNC. The residual category is I.

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Table 4.
The Role of the Distance. Poisson estimates

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Collaborative patents	Collaborative patents	Collaborative patents	Collaborative patents	Collaborative patents	Collaborative patents
Estimation method	PPML	PPML	PPML	PPML	PPML	PPML
Distance *ij*	-0.54***	-0.24				0.25
	(0.15)	(0.16)				(0.36)
Distance (capital) *ij*			-0.21			
			(0.16)			
Distance (weighted) *ij*				-0.24		
				(0.15)		
Time zone difference *ij*					-0.073***	-0.11*
					(0.027)	(0.062)
Labor Force *it*	-1.48*	-0.80	-0.78	-0.79	-0.96	-1.03
	(0.82)	(0.89)	(0.89)	(0.90)	(0.89)	(0.88)
Labor Force *jt*	0.71	1.02	1.01	1.00	1.30	1.37
	(1.33)	(1.60)	(1.60)	(1.61)	(1.62)	(1.63)
Patents *it*	0.72***	0.69***	0.68***	0.69***	0.70***	0.70***
	(0.061)	(0.070)	(0.070)	(0.070)	(0.070)	(0.069)
Patents *jt*	0.60	0.22	0.21	0.23	0.30	0.31
	(0.45)	(0.41)	(0.42)	(0.41)	(0.42)	(0.43)
Technology Proximity *ijt*		1.48***	1.50***	1.51***	1.33***	1.25***
		(0.50)	(0.50)	(0.50)	(0.48)	(0.47)
Trade *ijt*		0.13	0.14	0.12	0.032	0.020
		(0.095)	(0.097)	(0.096)	(0.097)	(0.098)
FDI *it*		-0.020	-0.021	-0.020	-0.016	-0.017
		(0.037)	(0.037)	(0.037)	(0.035)	(0.035)
IPR *it*		0.10	0.10	0.11	0.14	0.15
		(0.12)	(0.12)	(0.12)	(0.12)	(0.12)
Colony *ij*		0.19	0.20	0.16	0.27	0.41
		(0.24)	(0.24)	(0.24)	(0.18)	(0.29)
Language *ij*		0.40**	0.41**	0.42**	0.49***	0.52***
		(0.18)	(0.18)	(0.18)	(0.16)	(0.15)
Constant	8.34	-9.10	-9.40	-8.90	-13.2	-15.3
	(27.8)	(31.4)	(31.4)	(31.3)	(31.6)	(32.1)
Observations	1155	1155	1155	1155	1155	1155
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Country *i* dummy	Yes	Yes	Yes	Yes	Yes	Yes
Country *j* dummy	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudo-likelihood	-2924.46	-2742.96	-2745.72	-2740.56	-2720.63	-2715.63

All explanatory variables except *Technology proximity* and *Time zone difference*, are in logs. Country *i* is the home (emerging) country, country j is the foreign (G7) country. Country-pair clustered robust standard errors are reported in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 5.
The role of IPR. Poisson Fixed effect estimations

	(1)	(2)	(3)	(4)
	All countries	Low IPR countries	High IPR countries	All countries
Dependent variable	Collaborative patents	Collaborative patents	Collaborative patents	Collaborative patents
Estimation method	POISSON FE	POISSON FE	POISSON FE	POISSON FE
Labor Force $_{it}$	-1.83***	-0.52	-2.03***	-1.75***
	(0.37)	(0.99)	(0.47)	(0.38)
Labor Force $_{jt}$	0.042	3.45***	-1.75**	-0.11
	(0.56)	(0.93)	(0.72)	(0.57)
Patents $_{it}$	0.67***	0.65***	0.59***	0.66***
	(0.035)	(0.064)	(0.060)	(0.04)
Patents $_{jt}$	0.65***	0.38	0.94***	0.70***
	(0.21)	(0.34)	(0.27)	(0.21)
Technology Proximity $_{ijt}$	-0.061	0.16	-0.37	-0.06
	(0.19)	(0.27)	(0.30)	(0.19)
Trade $_{ijt}$	-0.082*	0.27***	-0.28***	-0.22***
	(0.049)	(0.088)	(0.055)	(0.08)
FDI $_{it}$	-0.017	0.019	-0.046*	-0.02
	(0.019)	(0.049)	(0.024)	(0.02)
IPR $_{it}$	0.30***	0.22*	-0.38**	-1.09***
	(0.066)	(0.13)	(0.18)	(0.39)
IPR $_{it}$ *Trade $_{ijt}$				0.07*
				(0.04)
IPR $_{it}$ *GDP_per capita $_{it}$				-0.06***
				(0.01)
Observations	1155	525	630	1155
Year dummy	Yes	Yes	Yes	Yes
Log pseudo-likelihood	-2044.54	-872.92	-1122.90	-2035.01

All explanatory variables except *Technology proximity* and *Time zone difference*, are in logs. Country *i* is the home (emerging) country, country j is the foreign (G7) country. High IPR countries are those which show an IPR index higher than 1.50 in 1990; they are: South Africa, South Korea, Malaysia, Israel, Singapore, and Argentina. Countries with an IPR index lower than 1.50 are: Brazil, India, China, Mexico and Turkey. Country-pair clustered robust standard errors are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 6.

Collaborations by patent applicants' ownership. Poisson estimates

	Subsidiaries *MNCs_x_{ijt}*		Domestic *DCs_x_{ijt}*		Foreign *FCs_x_{ijt}*		Individuals *INDIVIDUALSs_x_{ijt}*	
	PPML	PPML	PPML	PPML	PPML	PPML	PPML	PPML
	(1)	(2) §	(3)	(4) §§	(5)	(6) §§§	(7)	(8) §§§§
Distance *ij*	-0.31	0.19	-0.64*	1.35	-0.15	0.69	-0.44	1.44
	(0.27)	(0.49)	(0.38)	(0.84)	(0.16)	(0.45)	(0.29)	(0.88)
Time zone difference *ij*		-0.087		-0.39**		-0.15**		-0.32**
		(0.083)		(0.17)		(0.074)		(0.13)
Labor Force *it*	3.46**	3.28**	12.8***	11.9***	-2.38**	-2.52**	-1.25	-1.43
	(1.64)	(1.62)	(2.95)	(2.80)	(1.10)	(1.08)	(2.72)	(2.77)
Labor Force *jt*	0.54	0.51	8.99*	8.27**	5.70***	5.68***	4.55	3.88
	(4.36)	(4.39)	(4.74)	(3.92)	(1.76)	(1.82)	(3.32)	(3.20)
Patents *it*	0.79***	0.78***	1.55***	1.53***	0.66***	0.67***	0.45**	0.46**
	(0.12)	(0.12)	(0.20)	(0.21)	(0.085)	(0.085)	(0.21)	(0.21)
Patents *jt*	-0.47	-0.44	0.96	0.85	-0.16	-0.15	-0.34	-0.31
	(0.91)	(0.92)	(1.08)	(1.06)	(0.57)	(0.57)	(1.50)	(1.51)
Tech. Prox. *ijt*	1.46*	1.19	2.39**	1.45	0.68	0.46	-0.54	-0.81
	(0.81)	(0.75)	(1.05)	(1.04)	(0.64)	(0.58)	(1.05)	(1.01)
Trade *ijt*	0.068	0.050	0.15	-0.0010	0.20**	0.16*	0.32	0.23
	(0.17)	(0.18)	(0.29)	(0.27)	(0.090)	(0.094)	(0.20)	(0.19)
FDI *it*	-0.040	-0.043	0.037	0.053	0.021	0.019	-0.13	-0.13
	(0.082)	(0.082)	(0.097)	(0.084)	(0.047)	(0.046)	(0.089)	(0.087)
IPR *it*	0.45**	0.48**	-1.11***	-1.01***	0.19	0.20	1.02**	1.04***
	(0.22)	(0.20)	(0.34)	(0.33)	(0.19)	(0.19)	(0.40)	(0.40)
Colony *ij*	0.69**	0.69*	0.55	0.45	-0.17	-0.16	1.29**	1.09*
	(0.34)	(0.35)	(0.66)	(0.59)	(0.54)	(0.54)	(0.61)	(0.63)
Language *ij*	-0.15	-0.027	1.23***	1.98***	0.51**	0.73***	0.69	1.23***
	(0.28)	(0.30)	(0.34)	(0.52)	(0.22)	(0.23)	(0.43)	(0.46)
Constant	-66.4	-67.2	-371***	-359***	-59.3*	-63.7*	-54.2	-55.9
	(76.6)	(78.4)	(76.9)	(74.3)	(31.6)	(33.5)	(75.3)	(74.6)
Observations §	945	945	945	945	945	945	945	945
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country i dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country j dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudo-likelihood	-908.58	-908.56	-479.62	-479.58	-1616.65	-1616.54	-447.12	-447.11

All explanatory variables except *Technology proximity* and *Time zone difference*, are in logs. Country *i* is the home (emerging) country, country *j* is the foreign (G7) country. In this sample South Korea and Israel are not considered. Country-pair clustered robust standard errors are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 7.

Collaborations by patent applicants' ownership. FE Poisson estimates

	Subsidiaries *MNCs_x_ijt*	Domestic *DCs_x_ijt*	Foreign *FCs_x_ijt*	Individuals *INDIVIDUALSs_x_ijt*
	Poisson FE (1) §	Poisson FE (2) §§	Poisson FE (3) §§§	Poisson FE (4) §§§§
Labor Force *it*	2.80**	12.0***	-2.84***	-1.60
	(1.27)	(2.69)	(0.77)	(2.79)
Labor Force *jt*	-1.74	4.76	3.37***	1.38
	(1.76)	(3.30)	(0.96)	(3.56)
Patents *it*	0.67***	1.53***	0.65***	0.47**
	(0.096)	(0.19)	(0.053)	(0.19)
Patents *jt*	0.14	1.22	0.19	-0.16
	(0.66)	(1.15)	(0.35)	(1.30)
Tech. Prox. *ijt*	-0.68	0.46	-0.19	-0.053
	(0.50)	(1.07)	(0.28)	(1.02)
Trade *ijt*	0.30*	-0.40***	0.072	0.048
	(0.16)	(0.15)	(0.080)	(0.19)
FDI *it*	-0.083	0.16	0.013	-0.11
	(0.057)	(0.10)	(0.030)	(0.079)
IPR *it*	0.59***	-0.91***	0.27***	1.01**
	(0.20)	(0.35)	(0.10)	(0.42)
Observations	795	570	915	510
Year dummy	Yes	Yes	Yes	Yes
Pairs dummy (FE)	Yes	Yes	Yes	Yes
Log pseudo-likelihood	-691.77	-350.14	-1253.20	-339.37

All explanatory variables except *Tech. Prox ijt* are in logs. Country *i* is the home (emerging) country, country *j* is the foreign (G7) country. In this sample South Korea and Israel are not considered. §:10 groups (150 obs.) dropped because of all zero outcomes; §§: 25 groups (375 obs.) dropped because of all zero outcomes; §§§: 2 groups (30 obs.) dropped because of all zero outcomes; §§§§: 29 groups (435 obs.) dropped because of all zero outcomes. Country-pair clustered robust standard errors are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

APPENDIX

Table A1 . Definition and summary statistics

Variable	Definition and Source	Obs	Mean	Std. Dev.	Min	Max
Collaborative patents ijt	Number of patents with at least an inventor from the Emerging Country and an inventor from the Advanced Country (source: KITES/USPTO)	1155	12.71	40.81	0	508
Subsidiaries collaborative patents ijt	Number of patents with at least an inventor from the Emerging Country and an inventor from the Advanced Country applied by G7 subsidiaries (source: KITES/USPTO)	945	3.03	11.73	0	170
Domestic companies collaborative patents ijt	Number of patents with at least an inventor from the Emerging Country and an inventor from the Advanced Country applied by domestic (i) companies (source: KITES/USPTO)	945	0.63	1.88	0	18
Foreign companies collaborative patents ijt	Number of patents with at least an inventor from the Emerging Country and an inventor from the Advanced Country applied by foreign (j) companies (source: KITES/USPTO)	945	4.52	14.82	0	183
Individuals collaborative patent ijt	Number of patents with at least an inventor from the Emerging Country and an inventor from the Advanced Country applied by individuals (source: KITES/USPTO)	945	0.37	1.20	0	15
Distance ij	Km (in logarithm), simple distance which uses latitudes and longitudes of the most important cities/agglomerations (in terms of population). Source: CEPII dataset	1155	8.96	0.58	7.06	9.83
Distance (capital) ij	Km (in logarithm), simple distance which uses latitudes and longitudes of the capitals. Source: CEPII dataset	1155	8.95	0.56	7.06	9.82
Distance (weighted) ij	Km (in logarithm), distance between the biggest cities of those two countries, those inter-city distances being weighted by the share of the city in the overall country's population. Source: CEPII dataset	1155	8.97	0.58	6.86	9.81
Time Zone ij	Time Zone difference among countries capital cities	1155	5.52	3.39	0	12
Labor force it	Total (in logarithm), Source: World Bank	1155	17.05	1.76	14.26	20.46
Labor force jt	Total (in logarithm), Source: World Bank	1155	17.44	0.68	16.50	18.83
Patents it	Number of patent applications (in logarithm) with at least an inventor residing in country i (source: KITES/USPTO)	1155	5.18	1.63	0.69	9.60
Patents jt	Number of patent applications (in logarithm)with at least an inventor residing in country j (source: KITES/USPTO)	1155	9.12	1.29	7.15	11.80
Trade ijt	Bilateral imports, millions of US dollars, current prices (in logarithm). Stan database	1155	7.55	1.26	1.79	11.62
FDI it	Millions of constant US dollars (inward), year 2000 prices (in logarithm)	1155	8.09	1.67	0.00	11.01
IPR it	Ginarte and Park Index (in logarithm) (Ginarte and Park, 1997; Park 2008) [see Table 1]	1155	1.02	0.42	0.03	1.45
Technology Proximity ijt	Indicator of pairwise "inventive proximity"	1155	0.69	0.14	0.10	0.96
Colony ij	Dummy which equals to one if the two countries have ever had a colonial link. Source: CEPII dataset	1155	0.08	0.27	0	1
Language ij	Dummy which equals to one if two countries share a common official language. Source: CEPII dataset	1155	0.16	0.36	0	1
GDP _ Per capita it	Millions of constant US dollars (2000) over labor force (in logarithm)	1155	0.16	0.36	0	1

Table A2 . Correlations

		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]
Collaborative patents *ijt*	[1]	1																		
Subsidiaries collaborative patents ijt	[2]	0.98*	1																	
Domestic companies collaborative patents ijt	[3]	0.67*	0.64*	1																
Foreign companies collaborative patents ijt	[4]	0.98*	0.96*	0.69*	1															
Individuals collaborative patent ijt	[5]	0.66*	0.65*	0.71*	0.69*	1														
Distance *ij*	[6]	0.06*	0.07*	0.08*	0.07*	0.03	1													
Distance (capital) *ij*	[7]	0.07*	0.07*	0.08*	0.07*	0.03	0.99*	1												
Distance (weighted) *ij*	[8]	0.07*	0.07*	0.07*	0.07*	0.03	0.99*	0.99*	1											
Time Zone *ij*	[9]	0.18*	0.19*	0.16*	0.20*	0.16*	0.71*	0.73*	0.72*	1										
Labour force *it*	[10]	0.03	0.14*	0.05	0.17*	0.21*	-0.03	-0.04	-0.01	0.07*	1									
Labour force *jt*	[11]	0.46*	0.40*	0.44*	0.44*	0.42*	0.04	0.04	0.04	0.10*	0.00	1								
Patents *it*	[12]	0.30*	0.30*	0.27*	0.31*	0.23*	-0.01	-0.04	-0.04	0.14*	-0.03	0.02	1							
Patents *jt*	[13]	0.46*	0.39*	0.43*	0.43*	0.40*	0.08*	0.08*	0.06*	0.15*	0.01	0.93*	0.10*	1						
Trade *ijt*	[14]	0.21*	0.13*	0.14*	0.14*	0.17*	-0.15*	-0.17*	-0.16*	-0.20*	0.15*	-0.02	0.36*	0.01	1					
FDI *it*	[15]	0.36*	0.33*	0.36*	0.37*	0.35*	-0.33*	-0.34*	-0.36*	-0.13*	0.13*	0.68*	0.25*	0.63*	0.23*	1				
IPR *it*	[16]	0.11*	0.14*	0.11*	0.17*	0.14*	0.10*	0.10*	0.08*	0.19*	0.26*	0.01	0.19*	0.10*	0.17*	0.28*	1			
Technology Proximity *ijt*	[17]	0.15*	0.10*	0.12*	0.10*	0.06	-0.00	-0.00	-0.02	-0.01	-0.37*	0.02	0.51*	0.15*	0.23*	0.16*	0.18*	1		
COLONY *ij*	[18]	-0.02	-0.04	0.02	-0.05	-0.01	-0.17*	-0.17*	-0.18*	-0.12*	-0.11*	-0.05	0.11*	-0.08*	0.15*	0.10*	-0.10*	0.04	1	
Language *ij*	[19]	0.25*	0.19*	0.30*	0.20*	0.17*	0.19*	0.20*	0.22*	0.22*	-0.18*	0.04	0.14*	0.07*	0.16*	-0.11*	-0.200*	0.04	0.41*	1
GDP_per capita *it*	[20]	0.02	-0.12*	-0.03	-0.13*	-0.18*	-0.02	-0.01	-0.05	-0.08*	-0.90*	0.00	0.21*	0.02	-0.08*	-0.03	-0.09*	0.49*	0.05	0.06