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

Fabio MONTOBBIO

University of Turin
&
KITES, Bocconi University, Milan

Valerio STERZI

GREThA, CNRS, UMR 5113
Université de Bordeaux
&
KITES, Bocconi University, Milan

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GRETHA UMR CNRS 5113
Université Montesquieu Bordeaux IV
Avenue Léon Duguit - 33608 PESSAC - FRANCE
Tel : +33 (0)5.56.84.25.75 - Fax : +33 (0)5.56.84.86.47 - www.gretha.fr

La globalisation de la technologie dans les marchés émergents: un modèle gravitaire sur les déterminants des collaborations internationales sur les brevets

Résumé

Cet article analyse les déterminants des différents types de collaborations internationales technologiques entre les inventeurs de brevets issus des pays émergents et avancés. Les collaborations technologiques produisent des circulations de connaissances entre les inventeurs par des contacts interpersonnels et des rencontres en face-à-face.
Nous utilisons les brevets USPTO (Office américain des brevets) déposés de 1990 à 2004 sur un panel de onze économies émergentes et sept pays avancés et une base de données originale qui exploite les informations sur le pays d'origine des titulaires des brevets. Nous estimons l'impact de la distance géographique et de diverses variables économiques et institutionnelles par la méthode PPML (Poisson Pseudo-Maximum Likelihood). Les estimations montrent que les résultats varient selon le type de collaborations considéré et selon le pays d'origine (émergent vs. avancé) des entreprises.
La distance géographique affecte les collaborations technologiques internationales seulement quand les titulaires des brevets sont dans un pays émergent. Les estimations obtenues à partir d'un modèle à effets fixes montrent qu'un système de brevet plus fort affecte positivement les collaborations technologiques internationales seulement lorsqu'elles proviennent de filiales d'entreprises multinationales.

Mots-clés : Circulation de connaissances, Pays émergents; Brevets; Inventeurs; Droits de propriété intellectuelle

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Abstract

This paper analyzes the determinants of different types of international technological collaborations among patents' inventors between emerging and advanced countries. Technological collaborations generate knowledge flows between inventors through interpersonal and face to face contacts. We use US Patent and Trademark Office (USPTO) patent applications for a panel of eleven emerging economies and seven advanced countries (90-04) and a novel database that exploits information on companies' country of origin. We estimate the impact of geographical distance and various economic and institutional variables using the Poisson pseudo-maximum likelihood (PPML) and show that results vary according to the type of collaborations considered and to the country of origin (emerging vs. advanced) of the involved companies. Geographical distance affects international technological collaborations only when the applicant's ownership is in the emerging country. Fixed effect estimates show that stronger IPRs positively affect international technological collaborations only when stemming from subsidiaries of multinational firms.

Keywords: Knowledge flows, Emerging Countries, Patents, Inventors, Intellectual Property Rights

JEL: O30, O10, O11

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1. Introduction[1]

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). The 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 Coe et al. (1997) show that R&D stock in advanced countries significantly affects Total Factor Productivity on developing countries via machinery and equipment import, in particular for countries with higher levels of human capital.

The idea that international knowledge spillovers affects productivity growth enhancing technological adoption and innovation in developing countries (Keller, 2009; Montobbio, Sterzi 2011) stimulate governments and international organizations to place the domestic dissemination of frontier knowledge high up in their policy agenda (e.g. World Bank, 2010). At the same time the recent empirical literature has also shown that knowledge spillovers tend to be localized (e.g. Bacchiocchi, Montobbio, 2010; Bottazzi and Peri, 2003; Jaffe et al., 1993; Keller, 2002; Maruseth and Verspagen, 2002; Peri 2005) 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; Arora, 2008; 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 (Breschi and Lissoni, 2009, Singh, 2005; Hoekman et al. 2008) are more innovative.

This paper therefore analyses international technological collaborations at the inventor level 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

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(OECD, 2008). A number of communications technologies, such as fiber optics, social networks, and satellite communications, facilitate international technological activity and suggest that, 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 anedoctical evidence of both increased domestic R&D activities in emerging countries and off-shoring 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 is changing rapidly in recent year after the approval of 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 IPRs reinforcement in emerging countries facilitates knowledge transfer and dissemination from advanced countries[2], it is relevant then to control for the impact of IPRs 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 residence address of inventors and patent applicants but also the *ownership* of companies and its 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 results of a movement of skilled labor from the emerging to the advanced country. This type of international collaborations (and their determinants) is clearly different from a collaboration occurring in a laboratory of a MNC’s 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, Turkey) and their relationship with seven advanced countries (USA, UK, Japan, Italy, Germany,

[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”.

France and Canada). In order to model the impact of geographical distance and the impact of IPRs 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 different econometric problems.

Our main results are that geographical distance is not important *per se* and distance matters mostly via trade and cultural similarities. Results are slightly stronger for time zone differences. Technological proximity is a very important factor that favors collaborations. Fixed effects models find that countries experiencing an increase in the IP laws tend to be more involved in international collaborations. 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 collaborations vary according to the type of collaboration considered and country of origin (emerging vs. advanced) of the involved companies. For example for collaborations deriving from laboratories of multinational subsidiaries we have no effects of geographical distance and a positive effect of IPRs 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 the 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 the 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.

There is a substantial evidence that knowledge spillovers tend to be geographically localized[3]. For example Peri (2005), using patent citations at the US Patent and Trademark Office in a gravity framework, finds that knowledge flows go much farther than trade flows even if knowledge flows remain highly localized. He estimates that only 20% of knowledge comes from outside the region of origin, and only 9% from outside the country of origin. Keller (2002) looks at the impact of R&D on total factor productivity at the sectoral level in a subset of OECD countries and shows that R&D effects are halved in 1200 kilometers. Also Maruseth and Verspagen (2002) and Bottazzi and Peri (2003), using patent citations at the European Patent Office (EPO), show that spillover are localized at the regional level and mainly occur within 300 km.

At the same time the literature emphasizes the presence of international knowledge spillovers, in particular among OECD countries, and shows that many activities that generate international knowledge transfer are observable. As a consequence the economic literature has studied in depth international knowledge spillovers through MNCs foreign direct investments (FDIs) and trade (in particular import)[4].

[3] Many papers have addressed this issue, see for example, Jaffe et al., (1993); Keller, (2002); Bottazzi and Peri, (2003) and Peri (2005); Maruseth and Verspagen, (2002); Bacchiocchi, Montobbio (2010).
[4] A detailed survey can be found in Keller (2009).

Substantial international knowledge spillovers are found by Griffith et al. (2004) who also show that technological learning requires absorptive capacity[5] (Cohen and Levinthal, 1989).

The evidence that technological spillovers tend to be localized, that are embedded in trade goods or investments and that learning depends upon the previous accumulation of knowledge suggest that important pieces of knowledge are tacit and that learning is the product of experience. 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 (2009) and Keller and Yeaple (2009) - have placed emphasis on the advantages provided by face-to-face interactions over other forms of communications like telephone calls or e-mails. Face-to-face interaction is a superior vehicle of knowledge communication because it is possible to have instantaneous feedbacks and direct corrections of wrong interpretations. Moreover when people communicate face-to-face they convey information not only by words but also using body language, facial expression, and tone of voice that are tailored specifically to the receivers[6].

In sum knowledge exchange is particular fruitful when 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. As a result personal contacts in technological collaborations can be considered as a key vehicle of knowledge spillovers.

This paper studies international technological collaborations between inventors as listed in patent data, 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 requires, at least periodically, face-to-face interactions which have a positive impact on technological learning and, finally, make technology transfer more effective.

This paper studies collaborations between emerging and advanced countries. If technological collaborations are effective channel 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.

[5] Griffith et al. (2004) interact R&D expenditures at industry level for twelve OECD counties with distance from the technological frontier and look at the impact on Total Factor Productivity.

[6] Koskinen and Vanharanta (2002) describe at length how tacit knowledge is acquired and transferred. A survey of managers in Forbes (2009) shows that eight executives out of ten like face-to-face contacts more than virtual ones because "they build stronger, more meaningful relationships" thanks to "the ability to 'read' another person, and greater social interaction." (p. 2)

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 and 2009) show that inventors' mobility and the co-invention network are crucial determinants of knowledge diffusion.

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.

If these considerations 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 advancements are either not available or not adopted.

To a great extent, inadequate access to the informal or practical knowledge network that integrates the codified portion of technical change[7] could generate a slower pace of adoption of new technologies. In this vein this paper provides the first attempt to estimate the determinants of international technological collaborations in the 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 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. 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 rise in geographical distance. In addition if the knowledge is sophisticated and the content is 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

[7] Kerr (2008) shows that knowledge diffusion is importantly affected by interpersonal links within the same ethnic community.

that are geographically farther. 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.

3.1 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*[8]. Note that, differently from gravity models in trade literature, our dependent variable is a *non-directed* measure of international technological collaborations. However 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.

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. At the same time applicants' address and their country of origin convey important pieces of information. In terms of knowledge spillovers, it makes a difference whether the applicant is from an emerging country (possibly a multinational's 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 applicants' addresses listed in the patent is in the emerging country (i.e. at least one of the applicants is either a local company or a MNC's subsidiary of a G7 country), (2) the applicant's address is in the advanced country (the applicant is either a foreign company or a MNC's subsidiary which does not declare the R&D foreign laboratory in the patent), (3) the patent is co-owned by individuals from different countries.

In case (1), taking the perspective of the emerging country, it is important to identify the country of origin of the applicant and distinguish whether the applicant 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's 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 case knowledge is transferred through the movement of R&D facilities from advanced countries (Keller and Yeaple, 2009).

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

[8] If a patent is signed by three inventors from three different countries in our sample, we consider three bilateral collaborations.

[9] Note that applicants can be companies, universities, public research organizations, governmental institutions other forms of organizations (e.g. foundations, associations etc. etc.) and individuals.

collaborations are called *domestic* when the applicant firm'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 applicant'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 a 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 use 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 residence address. The idea is that if a patent is invented by the majority of individuals residing in the country *i* we assume that the R&D laboratory is located in the country *i* as well. In this vein, among collaborative patents whose applicant's address is in one of 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 country is more or equal than 50% of the total number of inventors in the team. Imposing these constraints reassures 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 originated 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 if it is 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 case we distinguish between patents owned by domestic companies (*DC*) and multinational's 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.

It is relevant to stress that all cases concern to some extent the transfer of knowledge from the advanced to the emerging country, 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 5.1). We also argue that the different types of international collaborations outlined above may be explained by different determinants and therefore we decompose our dependent variable following the taxonomy in Table 1 (Section 5.3). We estimate the impact of geographical distance and other determinants on the expected value of x_{ijt} using a standard empirical implementation[11] according to which the gravity equation can be represented in the following equation:

[10] This phenomenon would be associated to 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 get deeper.

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

Table 1 - Collaborations by patent ownership and applicant's address.

<table>
<tr><td colspan="3" rowspan="2"></td><td colspan="2">Applicant's address</td></tr>
<tr><td>Emerging [E]</td><td>Advanced [A]</td></tr>
<tr><td rowspan="3">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 more than 50% of inventors reside in E),
FC (if no more 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 advance 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 patent applicant is a domestic institution (firm, university or public research centre) which is located in the emerging country; a subsidiary collaboration (MNC) is when the patent is applied by a G7 MNC's subsidiary located in the emerging country; a foreign collaboration (FCs) is when the patent is applied by a organization from one of the G7 country which is not located in the emerging country; finally I is when the patent is applied by individuals residing either in emerging country or in G7 country, or both.

3.2 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 country population) measure of the distances of the most populated cities[12].

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

[12] Data come from 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's population.

2007, p. 97). In this line, the variable $TimeZoneDifference_{ij}$ measures the time difference in hours between the capital cities of country *i* and *j*. This variable ranges from 0 to 12.

However other distances related to cultural and historical differences are taken into account: these variables usually refer to common language, past colonial links or common legal origin. Accordingly L_{ij} is a vector of *time-constant* 'link' indicators that may affect both technological collaborations and knowledge flows. These dummies indicate whether county *i* and country *j* share a common official language[13] ($Language_{ij}$) and whether they have had a colonial relationship since 1945 ($Colony_{ij}$).

Then we consider also technological distance. The probability to observe a technological collaboration between two countries is higher if in the two countries companies and institutions are active in a similar set of technological fields. Accordingly T_{ijt} is the *technological proximity* between country *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).

3.3 Attractors

A^{α}_{it} and A^{β}_{jt} measure specific characteristics of country *i* and *j*, in particular the number of patents and the size of the labour 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 ($Patents_{it}$, $Patents_{jt}$, $LabourForce_{it}$, and $LabourForce_{jt}$ respectively of 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 are expected to collaborate more. However, from the emerging country point of view, the dimension in terms of labor force ($LabourForce_{it}$) may have counter-intuitive effects: on one side the grater the population, the higher the probability that foreign companies cooperate with (*demand effect*); on the other side, the greater the population, the lesser the local companies seek expertise and high-skilled workers abroad (*supply effect*).

There are other reasons that can affect the probability to collaborate at the technological level between two countries (vector M_{ijt} in eq. 1). M_{ijt} is composed by $Trade_{ijt}$ 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}) in county *i* at time *t*[15].

3.4 IPR Policy

Finally we insert in the model a control for the IPR policy in the emerging country. In recent years emerging countries expanded significantly the strength of their IPR legislations to comply with TRIPS

[13] Language might be a factor limiting the scope of international knowledge flows as evidenced by Jaffe and Trajtenberg (1999).
[14] Bilateral imports are both expressed 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 using also bilateral FDI data, results do not change.

requirement[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 a emerging country should reassure multinational companies willing to invest and develop technologies in these countries. Moreover we can expect that the positive effect of IPRs reinforcement on international technological collaboration is stronger when companies have already the opportunity to know the emerging market. This is facilitated for those emerging countries that are closer in term of GDP and GDP per capita to the G7 countries or have substantial trade relationships with advanced countries.

On the other side strong IPRs generate a monopoly power, limiting the competition and the possibility of co-operations 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 cost of access to imported technologies and difficulties in accessing basic scientific knowledge (McCalman, 2001; Grossman and Lai, 2004; Mazzoleni and Nelson 1998).

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). 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 in 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)[18].

4 Data and Methodology

4.1 Data description

Our database starts from the 26 countries included in the MSCI Emerging Market Index[19]. We have collected all the patent applications at the US Patent and Trademark Office (USPTO) that are signed by at least one inventor from all these countries in the period 1990-2004 and we have taken 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 are then left with the following 11 emerging economies: Argentina, Brazil, China, India, Israel, South Korea, Malaysia, Mexico, South Africa, Singapore, and

[16] TRIPS agreements require that WTO member nations 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 of imports.

[18] The 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 year 2000 is also used for the years 1998, 1999, 2001 and 2002. Last, the observation for year 2005 is also used for the years 2003 and 2004.

[19] An index created by Morgan Stanley Capital International (MSCI) that is designed to measure equity market performance in global emerging markets. A discussion on the choice of emerging and developing markets can be found also in Bascavusoglu (2005).

Turkey. The advanced countries are: Canada, France, Germany, Italy, Japan, United Kingdom, and United States. In addition, we collected also information on bilateral imports (source: STAN/OECD database), FDIs (UNCTAD), geographical and cultural distance (CEPII), and the IPR index (Park, 2008). Table A1 in Appendix describes data sources and gives descriptive statistics.

The patent dataset contains 119,309 patent applications with at least an inventor residing in one of the selected emerging economies, of which 14,684 (12%) identify international collaborations between inventors in emerging and advanced countries . 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 respectively 70,467 and 18,447 patent applications in 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 respectively around 13 and 17 patent applications per millions of workers. Countries characterized by a high level of patent productivity are also those with higher level of IP regime at the beginning of the 90s (see Column (e)).

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 intensity (a)/(c)	(e) 1990-1992	(f) 2003-2004	(g) IPR growth (e)-(f)
Argentina	928	237	*26%*	*15,03*	61,74	1,6	3,98	2,38
Brazil	2345	754	*32%*	*75,61*	31,01	1,22	3,59	2,37
China	9427	2464	*26%*	*712,37*	13,23	1,33	4,08	2,75
India	6264	2229	*36%*	*371,28*	16,87	1,03	3,76	2,73
Israel	18447	3432	*19%*	*2,22*	8309,46	2,76	4,13	1,37
Korea	70467	2303	*3%*	*21,75*	3239,86	2,55	4,13	1,58
Malaysia	1332	444	*33%*	*8,82*	151,02	1,7	3,03	1,33
Mexico	1613	568	*35%*	*36,57*	44,11	1,19	3,88	2,69
Singapore	5740	1631	*28%*	*1,90*	3021,05	1,64	4,01	2,37
South Africa	2354	371	*16%*	*14,28*	164,85	2,94	4,25	1,31
Turkey	392	251	*64%*	*2,76*	142,03	1,16	4,01	2,85
All sample	*119309*	*14684*	*12%*	*116,60*	1023,23	*(s.d.: 0.69)*	*(s.d.: 0.34)*	

** Ginarte and Park index: the source of data, available for 1990, 1995, 2000, 2005 is Park (2008); ** average values: 1990-2000*

In seven countries (Argentina, Brazil, China, India, Malaysia, Mexico, and Singapore) the share of international collaborations on the total number of patents is around 30%. Nevertheless high heterogeneity appears when considering South Korea with just 3% of collaborative patents and, on the other side, 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 in particularly in countries such as Turkey, India and Mexico, whose IPR index was very low at the beginning of the Nineties. Moreover standard deviation shows that, as a consequence of the TRIPS agreement, differences in terms of IPRs protection decreased over time.

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 advance country. In the terminology we take the perspective of the emerging country. A domestic collaboration (DC) is when the patent applicant is a domestic institution (firm, university or public research centre) which is located in the emerging country; a subsidiary collaboration (MNC) is when the patent is applied by a G7 MNC's subsidiary located in the emerging country; a foreign collaboration (FCs) is when the patent is applied by a organization from one of the G7 country which is not located in the emerging country; finally I is when the patent is applied by individuals residing either in emerging country or in G7 country, or both.

4.2 Model and Econometric issues

The gravity model in Eq. 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 – as a tractable and robust alternative - a Poisson Pseudo Maximum Likelihood (PPML) estimator[20].

Moreover, the number of technological cooperations between two countries in some years is zero. However zeros are not the results of the rounding errors that can be typical 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 particular suitable also 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).

[20] In their simulation study designed to assess the performance of different econometrics methods, they find that PPML estimators is less subject to have biases form heteroschedasticity.

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 a country *i* would exchange different levels of knowledge with two different countries even though the two countries have the same level of $LabourForce_i$ and $Patents_i$ 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 on 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 their ownership (domestic, MNCs or individuals), as described in Section 3.1. We argue that international technological collaborations can be the results of the decisions of individuals to move abroad or that of MNCs to internationalize their R&D activities and to cooperate with foreign knowledge base. These decisions are subject to different explanatory factors.

5.1 The Effect of geographical, cultural and technological distances

Table 4 reports the estimates of the distance elasticity of international technological collaboratioons for different specifications. All regressions contain a full set of time dummies that are used to control for time varying un-observables factors that are common across countries. Country dummies (both for country *i* and *j*) control for differences between countries – such as macroeconomic stability, particular 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 ($Patents_{jt}$)[21]. $LabourForce_{it}$ in the emerging country is negative and significant. This may suggest that smaller countries seek abroad expertise and high-skilled workers to compensate the shortage of local market.

[21] We estimate a gravity model to the extent that there is not overlapping between home countries (i) and source countries (j) which represent two distinct set of countries in terms economic and patenting activity.

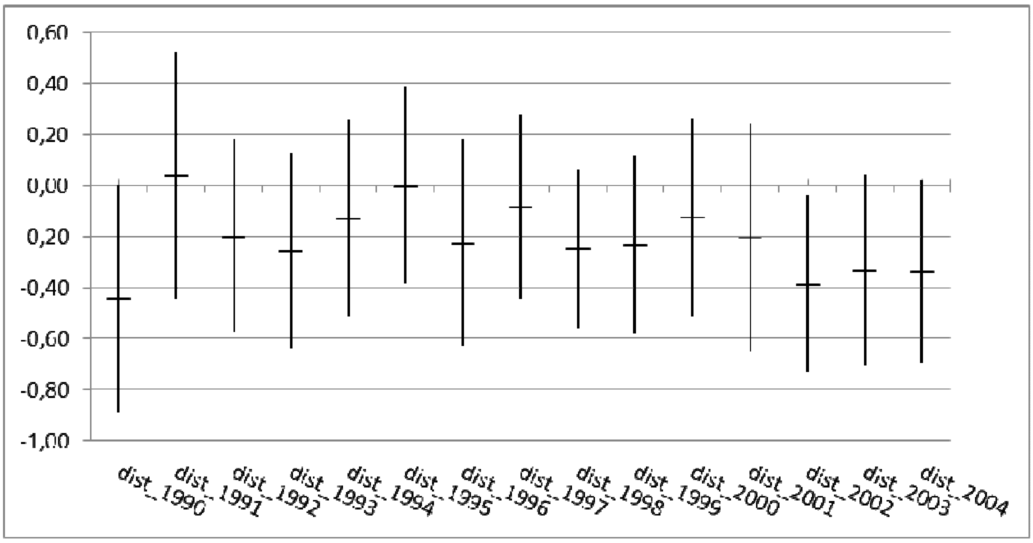
Table 4 - The Role of the Distance. Poisson estimates

Dependent variable Estimation method	(1) Collaborative patents PPML	(2) Collaborative patents PPML	(3) Collaborative patents PPML	(4) Collaborative patents PPML	(5) Collaborative patents PPML
Distance *ij*	-0.54***	-0.24			
	(0.15)	(0.16)			
Distance (capital) *ij*			-0.21		
			(0.16)		
Distance (weighted) *ij*				-0.24	
				(0.15)	
Time zone difference *ij*					-0.073***
					(0.027)
Labour Force *it*	-1.48*	-0.80	-0.78	-0.79	-0.97
	(0.82)	(0.90)	(0.90)	(0.90)	(0.90)
Labour Force *jt*	0.71	1.03	1.02	1.01	1.31
	(1.33)	(1.61)	(1.61)	(1.62)	(1.63)
Patents *it*	0.72***	0.69***	0.68***	0.69***	0.70***
	(0.061)	(0.070)	(0.070)	(0.070)	(0.070)
Patents *jt*	0.60	0.22	0.21	0.23	0.30
	(0.45)	(0.41)	(0.42)	(0.41)	(0.42)
Technology Proximity *ijt*		1.48***	1.50***	1.50***	1.33***
		(0.50)	(0.50)	(0.51)	(0.48)
Trade *ijt*		0.13	0.14	0.12	0.032
		(0.095)	(0.097)	(0.096)	(0.097)
FDI *it*		-0.020	-0.021	-0.020	-0.016
		(0.037)	(0.037)	(0.037)	(0.035)
IPR *it*		0.10	0.10	0.11	0.14
		(0.12)	(0.12)	(0.12)	(0.12)
Colony *ij*		0.19	0.20	0.16	0.27
		(0.24)	(0.24)	(0.24)	(0.18)
Language *ij*		0.40**	0.41**	0.42**	0.49***
		(0.18)	(0.18)	(0.18)	(0.16)
Constant	8.34	-9.23	-9.53	-9.04	-13.3
	(27.8)	(31.5)	(31.4)	(31.4)	(31.7)
Observations	1155	1153	1153	1153	1153
Year dummy	Yes	Yes	Yes	Yes	Yes
Country *i* dummy	Yes	Yes	Yes	Yes	Yes
Country *j* dummy	Yes	Yes	Yes	Yes	Yes
Log pseudo-likelihood	-2924.46	-2741.204	-2743.96	-2738.79	-2718.89

All explanatory variables, but 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 parenthesis, *** p<0.01, ** p<0.05, * p<0.1.*

Column (1) suggests that $Distance_{ij}$ is significantly negative and that therefore communications and transportation costs might play a significant role in determining the geographical scope of technological collaborations. However, Poisson results also show that the estimated distance elasticity is no more significant once we use a broader set of variables in columns from (2) to (4). In particular controlling for technological distance and language similarity cancels out the effects of the geographical distance. In column (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. Other forms of distance like similarity in the technological distribution of the inventive activity have a stronger effect. In addition we have interacted - using the specification in column (2) – 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 - 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).

As a general result therefore geographical distance does not significantly matter and, at the same time, there is not a trend towards a reduction of the impact of distance over the years because, if any, distance elasticity of international technological collaborations is increasing over time. This result is also in line with the ‘‘missing globalization puzzle’’ (Soloaga and Winters, 2001, Brun et al., 2005) in the gravity model of bilateral trade.

As discussed in Section 3.2, 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 longitude effect has increased over time. In Column (5) we show a regression 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.

Culture 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.

We observe a positive, large and statistically significant coefficient for technological proximity ($TechnlogyProximity_{ijt}$). The effect of technological proximity is much larger than trade (bilateral imports) or FDI. Countries which share similar technological composition have more chances to collaborate. For what concern *Trade* we always find a positive estimated coefficient that is not statistically different from zero. In principle the probability to observe a technological collaboration is higher between trading partner but this effect, if it exists, is very weak. FDI results are confirmed also when we use bilateral FDIs on a subset of countries[22]. However 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 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 enquire this issue more in depth in the next Section.

5.2 The effect of IPR

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 IPRs strengthening, we use a fixed effects (FE) Poisson ML estimator which captures, with a dummy for each pair of countries, 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 2006). Column (1) in Table 5 displays the Poisson estimates for the FE case, which basically is the analogous of Column (3) in Table 5 but with 76 individual pair-dummies (11 emerging country by 7 advanced countries, with the exclusion of 1 dummy)[23].

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[24]. 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 last group includes countries among the highest ones in terms of IPR index growth (see Table 2).

It is important to note that we find that a stronger level of IPRs have 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 IPRs protection (column (3)). This suggests that relationship between patent collaborations and the strength of intellectual property rights has a typical “inverted U” shape, analogous to the relationship between innovation and IPR (Gallini 1992, Qian 2007). Altogether these results may suggest that the strengthening of IPRs could facilitate technological collaborations only if a country start from a very weak level of IPRs 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.

Finally we study whether the impact of IPRs varies with different levels of trade or per capita GDP. Some authors argue that the knowledge flows between countries are greater when emerging countries are characterized by a high level 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 level 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 the one outlined in

[22] We manly miss bilateral information for Canada (and to 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.

[23] 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 countries.

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

column (3). Countries with a higher GDP per capita are the ones that for the whole period have already a high level of IPRs protection. As a consequence a further reinforcement does not have a positive effect on international technological collaborations[25].

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

	(1)	(3)	(4)	(2)
	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*	-1.81***	-0.51	-2.00***	-1.74***
	(0.37)	(0.99)	(0.47)	(0.38)
Labor Force *jt*	0.023	3.46***	-1.81**	-0.13
	(0.56)	(0.93)	(0.72)	(0.57)
Patents *it*	0.67***	0.65***	0.59***	0.66***
	(0.035)	(0.064)	(0.060)	(0.035)
Patents *jt*	0.65***	0.38	0.93***	0.70***
	(0.21)	(0.34)	(0.27)	(0.21)
Technology Proximity *ijt*	-0.063	0.16	-0.37	-0.063
	(0.19)	(0.27)	(0.30)	(0.19)
Trade *ijt*	-0.083*	0.27***	-0.28***	-0.22***
	(0.049)	(0.088)	(0.056)	(0.075)
FDI *it*	-0.016	0.020	-0.046*	-0.016
	(0.019)	(0.049)	(0.024)	(0.019)
IPR *it*	0.30***	0.22*	-0.38**	-1.10***
	(0.066)	(0.13)	(0.18)	(0.39)
IPR*Trade				0.066*
				(0.038)
IPR*GDP_per capita				-0.059***
				(0.014)
Observations	1153	524	629	1153
Year dummy	Yes	Yes	Yes	Yes
Log pseudolikelihood	-2042,64	-872,75	-1120,82	-2033,00

*All explanatory variables, but 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 parenthesis, *** p<0.01, ** p<0.05, * p<0.1.*

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

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

international technological collaborations between countries that also have increasing trade relationship. Following this view, the strengthening of IPR facilitates the creation of international technological collaboration to the extent that it is supported by the market for goods.

5.3 Companies' country of origin and patent collaborations

In Section 3.1 we have built a taxonomy of international technological collaborations based on the country of origin and country of residence of the applicant firms. In our terminology we take the perspective of the emerging countries and collaborations are called *domestic* when the applicant firm's ownership is from the emerging country and *foreign* when the applicant firm's ownership is from the advanced country. International patent collaborations derive from R&D laboratories of either multinational's subsidiaries located in the emerging country (*MNCs*) or *foreign* companies located in one of the advanced country (FCs) or *domestic* organizations in the emerging country (*DCs*) or, finally, from patents applied by individuals residing in different countries (*I*) (see table 1). In section 3.1 we have explained why this taxonomy implies different types of collaboration.

Table 6 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 positive 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.

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 side having a colonial link ($Colonial_{ij}$) is positively correlated with the number of collaborations stemming from MNC subsidiaries.

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 high skilled workers from abroad positively depends upon the local scientific and technological infrastructure (see also footnote 22). This result suggests that multinationals seeking for 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 on the decisions at the individual level as the international mobility of high skilled workers of emerging economies is affected by cultural relationship and dimension of labor market.

Finally, in order to understand the nature of the overall positive effect of IPRs on the number of international patent collaborations, as shown in the previous section, we divide collaborations by country of origin. First of all, the number of collaborations originating from multinational subsidiaries increases with the strength of patent regime in the emerging country: the coefficient of IPRs (column 1 and 2) is positive and significant both with and without country-pair fixed-effects. Stronger IPRs, by reducing the imitation risk faced by the potential investors in the advanced country and by creating a market for technologies in the emerging country, reduce the transaction costs (such as the informational asymmetry and the non-excludability property of knowledge) of collaborations and increase the investor's rent share (Markusen 1995, Rugman 1986).

Table 6 - Collaborations by ownership. Poisson estimates

	Subsidiaries *MNCs_x*		Domestic		Foreign		Individuals	
	*MNCs*_x_{ijt}		*DCs*_x_{ijt}		*FCs*_x_{ijt}		*INDIVIDUALSs*_x_{ijt}	
	PPML	Poisson FE	PPML	Poisson FE	PPML	Poisson FE	PPML	Poisson FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Distance *ij*	-0.31		-0.64*		-0.15		-0.44	
	(0.27)		(0.38)		(0.16)		(0.29)	
Labor Force *it*	3.47**	2.80**	12.8***	12.0***	-2.38**	-2.83***	-1.25	-1.60
	(1.64)	(1.27)	(2.94)	(2.69)	(1.10)	(0.77)	(2.72)	(2.79)
Labor Force *jt*	0.55	-1.74	9.00*	4.78	5.71***	3.37***	4.55	1.38
	(4.37)	(1.76)	(4.74)	(3.30)	(1.76)	(0.96)	(3.32)	(3.56)
Patents *it*	0.79***	0.67***	1.55***	1.53***	0.66***	0.65***	0.45**	0.47**
	(0.12)	(0.096)	(0.20)	(0.19)	(0.085)	(0.053)	(0.21)	(0.19)
Patents *jt*	-0.47	0.14	0.95	1.23	-0.16	0.19	-0.34	-0.16
	(0.91)	(0.66)	(1.08)	(1.15)	(0.57)	(0.35)	(1.50)	(1.30)
Tech. Prox. *ijt*	1.46*	-0.68	2.38**	0.45	0.68	-0.20	-0.55	-0.053
	(0.81)	(0.50)	(1.05)	(1.07)	(0.64)	(0.28)	(1.05)	(1.02)
Trade *ijt*	0.069	0.30*	0.15	-0.40***	0.20**	0.072	0.32	0.048
	(0.17)	(0.16)	(0.29)	(0.15)	(0.090)	(0.080)	(0.20)	(0.19)
FDI *it*	-0.039	-0.083	0.038	0.16	0.021	0.013	-0.13	-0.11
	(0.082)	(0.057)	(0.097)	(0.10)	(0.047)	(0.030)	(0.089)	(0.079)
IPR *it*	0.45**	0.59***	-1.12***	-0.91***	0.19	0.27***	1.02**	1.01**
	(0.22)	(0.20)	(0.34)	(0.35)	(0.19)	(0.10)	(0.40)	(0.42)
Colony *ij*	0.69**		0.55		-0.17		1.29**	
	(0.34)		(0.66)		(0.54)		(0.61)	
Language *ij*	-0.15		1.23***		0.51**		0.69	
	(0.28)		(0.34)		(0.22)		(0.43)	
Constant	-66.5		-371***		-59.5*		-54.3	
	(76.7)		(76.7)		(31.6)		(75.2)	
Observations	944	794	944	569	944	914	944	510
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country i dummy	Yes	No	Yes	No	Yes	No	Yes	No
Country j dummy	Yes	No	Yes	No	Yes	No	Yes	No
Pairs dummy (FE)	No	Yes	No	Yes	No	Yes	No	Yes
Log pseudolikelihood	-908.56	-691.77	-479.58	-350.14	-1616.54	-1253.20	-447.11	-339.37

All explanatory variables, but *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 parenthesis, *** p<0.01, ** p<0.05, * p<0.1.

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 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 G7 country are more inclined to cooperate with inventors from emerging countries as the fear of being imitating decreases with higher level of IPRs.Finally, columns (7) and (8) in Table 6 suggests that IPRs positively affects also collaborations brought about by insividuals (*Is*_x_{ij}). The strength of the patent regime in the emerging country seems to encourage the cooperation with foreign inventors.

Interestingly, the effect of IPRs is negative for collaborations stemming from R&D laboratories of domestic companies (*DCs*_x_{ijt}): the coefficient of IPR (column 3 and 4) is negative and significant both with and without country-pair fixed-effects. So IPRs 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 the 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. The asymmetry of 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 R&D laboratories of domestic organizations (*DCs*_x_{ijt}). However, the dimension of the emerging country ($LabourForce_{it}$) 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 high skilled workers from abroad to cooperate with, and on the other hand, for what concerns the *FCs*_x_{ij} collaborations, it makes sense that high 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 ($LabourForce_{jt}$) which positively affects the international mobility of high skilled people (*FCs*_x_{ijt}).

5.4 Robustness check: weighted collaborations

Till now we have considered all patenting collaborations as being of similar value. However it is plausible that attractors and frictions may have different impact 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[26]. 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. Table A2 in Appendix shows similar estimates found in the first set of regression (Table 4): the only difference is that the $TimeZoneDifference_{ij}$ is no more significant: differences in time zones have not a negative effect on the international patenting collaborations. This suggests 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] Forward patent citations have shown to be highly correlated with measures of the social value of the invention (Trajtenberg, 1990; Albert et al., 1991) as well as with its private value (Harhoff et al., 1999; Hall *et al.*, 2005).

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 rather than on geographical distance. Also, multinationals are increasingly delocalizing R&D activities in host countries, spurring a debate on which 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 patent applicants 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 not a strong (and negative) impact on international collaborations, time zone differences, to some extent, do.

We find also that technological proximity is an important factor 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 high skilled workers from the emerging countries or from companies from the emerging countries. Sharing a common language has not a significant impact for collaborations within MNCs 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 90s with a low level of IPR protection. However these results have to be taken with extreme care because the impact of IPRs regime is extremely complex and can vary from sector to sector and country to country. Importantly we show also that the impact of IPRs reinforcement vary according to the type of collaboration considered and country of origin (emerging vs. advanced) of the involved companies. For collaborations deriving from laboratories of multinational subsidiaries we have a positive effect of IPRs 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 the positive result might be confined to pairs of countries that are close trade partners and to those countries with a lower level of per capita GDP.

Appendix 1 - 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	12.71342	40.81021	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 only by G7 multinational subsidiaries (source: KITES/USPTO) [South Korea and Israel are not considered]	945	3.027513	11.72583	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) [South Korea and Israel are not considered]	945	0.6328042	1.88369	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 in lab located in advanced country (source: KITES/USPTO) [South Korea and Israel are not considered]	945	4.520635	14.81917	0	183
Individuals collaborative patents 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)					
Labour force *it*	Total (in millions), Source: World Bank	1155	1.17E+08	2.15E+08	1555483	7.66E+08
Labour force *jt*	Total (in millions), Source: World Bank	1155	4.90E+07	4.08E+07	1.47E+07	1.52E+08
Patents *it*	number of patent applications with at least an inventor residing in country *i* (source: KITES/USPTO)	1155	723.0848	1735.078	2	14756
Patents *jt*	number of patent applications with at least an inventor residing in country *j* (source: KITES/USPTO)	1155	21906.17	31687.09	1276	132479
GDP *it*	Millions of constant US dollars, (year 2000 prices). Source: World Bank	1155	3.49E+05	2.96E+05	4.47E+04	1.72E+06
GDP *jt*	Millions of constant US dollars, (year 2000 prices). Source: World Bank	1155	2.75E+12	2.74E+12	5.32E+11	1.06E+13
Trade *ijt*	Bilateral imports, millions of US dollars, current prices. Stan database	1153	4617.568	10195.53	6	111710
FDI *it*	(inward) millions of constant US dollars, (year 2000 prices) UNCTAD Database	1155	8528.489	12050.53	1	60630
IPR *it*	Ginarte and Park Index (Ginarte and Park, 1997; Park 2008), [see Table 1]	1155	3.004	1.016692	1.03	4.25
Technology Proximity *ijt*	indicator of pairwise "inventive proximity"	1155	0.6929492	0.142299	0.0990354	0.9597085
Distance *ij*	Km, simple distance which uses latitudes and longitudes of the most important cities/agglomerations (in terms of population). Source: CEPII dataset	1155	8865.453	3686.174	1156.67	18549.61
Distance (capital) *ij*	Km, simple distance which uses latitudes and longitudes of the capitals. Source: CEPII dataset	1155	8754.817	3637.495	1156.67	18372.04
Distance (weighted) *ij*	Km, bilateral distances 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	8915.096	3652.584	951.7373	18310.16
Time Zone *ij*	Time Zone difference among countries capital cities	1155	5.519481	3.392099	0	12
COLONY *ij*	Dummy which equals to one if the two countries have ever had a colonial link. Source: CEPII dataset	1155	0.0779221	0.268165	0	1
Language *ij*	Dummy which equals to one if two countries share a common official language. Source: CEPII dataset	1155	0.1558442	0.3628647	0	1

Appendix 2 - Table A2: The Role of the Distance: collaborations weighted by forward citations

	(1)	(2)	(3)	(4)	(5)	(6)
Distance *ij*	-0.45***	-0.12	-0.12			
	(0.16)	(0.46)	(0.19)			
Distance (capital) *ij*				-0.080		
				(0.19)		
Distance (weighted) *ij*					-0.12	
					(0.17)	
Time zone difference *ij*						-0.037
						(0.030)
Labor Force *it*	-2.72***	-2.66***	-1.88**	-1.87**	-1.87**	-1.94**
	(0.99)	(0.90)	(0.94)	(0.94)	(0.94)	(0.95)
Labor Force *jt*	1.71	3.28	2.09	2.05	2.08	2.35
	(2.35)	(2.26)	(2.50)	(2.50)	(2.51)	(2.55)
Patents *it*	0.89***	0.92***	0.90***	0.90***	0.90***	0.91***
	(0.100)	(0.090)	(0.10)	(0.10)	(0.10)	(0.10)
Patents *jt*	0.79	0.62	0.52	0.51	0.52	0.55
	(0.85)	(1.02)	(0.85)	(0.85)	(0.85)	(0.85)
Technology Proximity *ijt*			1.45***	1.45***	1.46***	1.36***
			(0.50)	(0.50)	(0.50)	(0.53)
Trade *ijt*			0.15	0.17	0.15	0.100
			(0.12)	(0.12)	(0.11)	(0.13)
FDI *it*			-0.039	-0.039	-0.039	-0.038
			(0.056)	(0.056)	(0.056)	(0.056)
IPR *it*			-0.12	-0.12	-0.12	-0.10
			(0.14)	(0.14)	(0.14)	(0.14)
Colony *ij*			0.19	0.22	0.17	0.22
			(0.31)	(0.31)	(0.32)	(0.22)
Language *ij*			0.46***	0.45***	0.47***	0.50***
			(0.16)	(0.16)	(0.16)	(0.16)
Distance *1991		0.063 (0.46)				
Distance *1992		-0.36 (0.42)				
Distance *1993		-0.35 (0.37)				
Distance *1994		-0.23 (0.51)				
Distance *1995		-0.36 (0.50)				
Distance *1996		-0.34 (0.47)				
Distance *1997		-0.15 (0.32)				
Distance *1998		-0.42 (0.45)				
Distance *1999		-0.25 (0.39)				
Distance *2000		-0.26 (0.31)				
Distance *2001		-0.38 (0.29)				
Distance *2002		-0.63 (0.42)				
Distance *2003		-0.37 (0.42)				
Distance *2004		-0.51 (0.43)				
Constant	9.82	-18.8	-12.3	-12.1	-12.4	-16.6
	(45.2)	(37.0)	(46.5)	(46.4)	(46.6)	(46.8)
Observations	1155	1155	1153	1153	1153	1153
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	-6505.76	-6453.77	-6185.07	-6187.82	-6183.69	-6174.45

All explanatory variables, but *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 parenthesis, *** p<0.01, ** p<0.05, * p<0.1.

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33608 PESSAC - FRANCE
Tel : +33 (0)5.56.84.25.75
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