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Papers in Innovation Studies

Paper no. 2014/25

Is Co-Invention Expediting Technological Catch Up? A Study of Collaboration between Emerging Country Firms and EU inventors

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This is a pre-print version of a paper that has been submitted for publication to a journal.

This version: November 2014

WP 2014/25

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JEL codes: O1, O3, O34, F63

Keywords: emerging countries, multinationals, technological catch up, patents, European Union

Is Co-Invention Expediting Technological Catch Up?

A Study of Collaboration between Emerging Country Firms and EU inventors

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Abstract

Firms from emerging countries such as Brazil, India, and China (BIC) are going global, and Europe is attracting around one-third of their direct outward investments. Growing internationalization constitutes an opportunity for technological catch up. In this paper we analyze BIC firms' cross-border inventions with European Union (EU-27) actors, during the period 1990-2012. Our results suggest that cross-border inventions represent an opportunity for BIC firms to accumulate technological capabilities, access frontier knowledge, and appropriate the property rights of co-inventions. This paper contributes to the understanding of the catching up process by emerging country firms, and offers some policy recommendations.

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Acknowledgments

We thank Fabio Montobbio for useful comments and suggestions. This paper is an output of the project “The challenge of globalization: Technology driven foreign direct investment (TFDI) and its implications for the negotiation of International (bi and multilateral) Investment Agreements” funded by the Riksbanken Foundation.

1. Introduction

Emerging countries such as Brazil, India, and China (hereafter BIC) have experienced recent rapid economic take-off, with several projections suggesting that the aggregate GDP of BIC and Russia, is catching up and may overtake the level of the industrialized economies (Michilova et al., 2013). The internationalization of BIC countries is also growing and their companies are increasingly involved in global value chains. Their share of world stock of Inward Foreign Direct Investment (IFDI) increased from 4.4% in 2000 to 7.5% in 2013, and from 1% to 4% respectively for Outward FDI (OFDI) (UNCTAD, 2014). Europe attracts more than a third of OFDI from BRICS (BIC plus Russia and South Africa), mainly searching for technological and commercial assets (UNCTAD, 2013).

This impressive economic dynamism has prompted scholars to ask whether and how BIC and their firms, are progressing from production to innovation (Altenburg et al., 2008) and improving their technological capabilities. This is a central issue in analyses of countries' catching up, because the degree to which BIC companies are able to generate valuable, new-to-the-world innovations may influence their future prospects for growth (Fu et al, 2011; Montobbio and Sterzi, 2013; Vivarelli, 2014). Data on innovation in BIC show increasing business R&D expenditures (especially in India and China), and exponential growth of patent applications (Branstetter al., 2013).[1] For example, the share of Chinese R&D expenditure in GDP increased from less than 1% in 2000 to almost 2% in 2012.[2] Moreover, recent studies provide evidence that companies from emerging economies are increasingly connected to international production and innovation networks (Branstetter al. 2013; Chen et al., 2013). In particular, cross-border R&D collaborations between emerging country firms and other international actors are attracting the attention of analysts in relation to the capacity of emerging country firms to spur production of joint patents (Picci, 2010).

International collaborations involving co-inventions (or cross-border inventions) are considered a valuable channel for the transfer of knowledge from developed to developing countries (Montobbio and Sterzi, 2011 and 2013) because they are often characterized by intensive knowledge sharing over extended periods of time (Alnuaimi et al., 2012), and by face-to-face interactions between inventors with different levels of technological competence, which facilitate international knowledge spillovers (Agrawal et al., 2006; Fleming et al., 2007a). Some studies show that patents derived from international collaboration among inventors are more valuable and more important than those produced by individual isolated inventors (Bercovitz and Feldman, 2011; Fleming et al. 2007b; Singh and Fleming, 2010), since collaboration brings knowledge variety and sparks creativity (Fleming et al., 2007b; Reagans and Zuckerman, 2001; Weitzman, 1998). This means that cross-border inventions may be a way for emerging economies to accumulate technological capabilities, and catch up with the advanced countries.

Despite their potentially positive developmental impact, cross-border inventions in the context of emerging economies have not been analyzed in depth. Most studies focus on R&D collaborations among firms and inventors in advanced countries (e.g. Leiponen and Helfat, 2011; Penner-Hahan and Saver, 2005), and almost exclusively on US patents and patentees (Breschi and Lissoni, 2009; Furman et al., 2005; Singh, 2008). There is very little evidence available on Europe. In studies that do include developing/emerging countries the focus is often on the operations of advanced country firms in these countries (Alnuaimi et al. 2012; Branstetter et al. 2013; Chen et al., 2013; Montobbio and Sterzi, 2011; 2013). There are no studies that investigate the nature of cross-border inventions from the perspective of developing/emerging country firms.

This paper addresses this gap in the literature by analyzing the extent to which BIC firms are involved in cross-border inventions with European Union (EU-27) actors. A focus on the EU is justified by the fact that it constitutes an important target for BIC OFDI. We compare the value and characteristics of BIC-EU cross-border inventions with those of a sample of analogous domestic patents by BIC firms over the period 1990-2012. We distinguish between BIC Multinational Companies (MNCs) and BIC domestic firms (DFs) (i.e. BIC firms with no foreign direct investments), and assess the differences in the value and characteristics of cross-border and domestic inventions between these two types of firms.

Our analysis reveals that cross-border inventions between BIC firms and EU actors are growing, though still small in absolute numbers. Also, cross-border inventions are more valuable than domestic ones (in terms of higher quality and higher impact on the generation of subsequent innovations across a variety of technological fields), suggesting that they represent an opportunity for BIC firms to accumulate technological capabilities, access frontier knowledge, and, not least, appropriate the property rights of collaborative inventions involving European actors. We find also that BIC MNCs benefit more from international collaborations than BIC DFs, explaining this difference as the better ability of MNCs to minimize coordination costs and combine the skills of diverse inventors around the globe. Overall, our findings contribute to understanding the role played by emerging economies in the global innovative landscape and provide recommendations for international development policy.

The paper is organized as follows: Section 2 outlines the conceptual framework; Section 3 explains the methodology; Section 4 presents the empirical evidence and Section 5 concludes with some policy implications.

2. International R&D Collaborations and Cross-border Inventions as a Source of Technological Catch Up for Emerging Countries

European countries are one of the most important targets for BIC firms keen to acquire technologies and other strategic assets (Giuliani et al., 2014; UNCTAD 2013). As a consequence, European stakeholders are worried about losing control of their strategic assets while for BIC this represents an unprecedented opportunity to catch up and to accumulate technological capabilities. Such investments generate international knowledge spillovers as demonstrated by earlier studies (Alnuaimi et al. 2012; Branstetter, 2006; Branstetter et al. 2013; Chen et al., 2013; Montobbio and Sterzi, 2011; 2013).

The literature on international knowledge flows has so far analyzed different channels of knowledge spillovers, particularly trade and FDI (Grossman and Helpman, 1991; Lee, 2006). Apart from some recent work on the growing involvement of emerging country firms in blue-sky innovative projects, and improved quality of their innovations, much less attention has been paid to international R&D collaborations between emerging country firms and other international actors (Chen et al., 2013; Picci, 2010). Yet the extent to which BIC engage in technological collaborations with international actors, and by so doing enhance the innovativeness of their firms, is largely underinvestigated.

In conceptual terms, there is no consensus on the impact of international R&D collaborations on the quality of the resulting innovations (Alnuaimi et al. 2012; Furman et al., 2005; Penner-Hahan and Saver, 2005; Singh, 2008). On the one hand, there are scholars who believe that R&D collaborations result in better quality innovations because they allow the combination of diverse knowledge and competences, available at the level of different inventive teams (Levinthal and March, 1993; March, 1991). On the other hand, there are others who point to the high coordination costs and the difficulties related to integrating existing knowledge when different international inventors and/or R&D units collaborate, suggesting that innovations carried out by isolated inventive teams might be more efficient and of higher value (Furman et al., 2005; Grant, 1996; Singh, 2008). These contrasting views also characterize the literature on cross-border inventions in developing countries, as discussed below.

(a) Cross-border and Domestic Inventions in Emerging/Developing Countries

To investigate whether international collaborations generate better quality innovations than domestic cooperation, Alnuaimi et al. (2012) study intra-firm collaborative patents in the US semiconductor industry. They explore the contribution of inventors from developed countries' R&D units to innovations produced by subsidiaries of the same firm located in a developing country. They find that international collaborations have a positive impact on the quality of the patents, measured as the number of patent citations received. However, this study also confirms the difficulties encountered by the invention teams in effectively absorbing and combining external knowledge, and casts doubt on the capacity of such collaborations to promote the accumulation of technological capabilities in developing countries.

In the same vein, Branstetter et al. (2013) investigate Chinese and Indian inventors and find that cross-border inventions (i.e. those involving inventors from countries' other than India and/or China) are more valuable (in terms of received citations), than domestic patents produced by inventive teams in India or China and involving no international collaborations. However, this study also suggests that inventors from India and China are mainly involved in less important innovations (e.g. adaptations to existing technologies), while R&D units located in developed countries are responsible for the most valuable discoveries. Similarly, there are studies that indicate that international collaborations between inventors from developing and advanced countries produce higher quality innovations compared to those resulting from domestic collaborations but they also show that most of the innovative R&D units located in developing countries are subsidiaries of developed countries' MNCs (Alnuaimi et al., 2012; Montobbio and Sterzi, 2011).

This evidence is interesting in general but it leaves open the question of whether cross-border inventions are beneficial for emerging country firms. Also, in these studies the focus is on firms from advanced countries rather than on the role and benefits gained by different types of emerging market firms.

(b) Cross-border Inventions by Emerging Country Firms

While previous research focuses on advanced country MNCs operating in developing countries (Alnuaimi et al. 2012; Branstetter et al. 2013), a new generation of emerging country firms is demonstrating exceptional capacity to catch up with leading firms. For example, ZTE and Huawei Technologies, which are two of the biggest and most successful of China's high tech companies, in 2013 were respectively the second and the third top patent applicants in the world.[3] Godinho and Ferreira (2013) investigate the intellectual property rights (IPR) strategies of these two MNCs and conclude that both firms have developed dynamic capabilities in innovation by investing heavily in R&D, which investment is reflected by the dramatic growth in patent applications.

Against this background, this paper analyzes BIC firms to identify differences in the value and characteristics of cross-border vs. domestic inventions involving BIC MNCs and BIC DFs with no direct investments in other countries.[4] The rationale for distinguishing between BIC MNCs and DFs is that their capacity to take advantage of international collaborations (*vis à vis* domestic ones) may be different. Through their established networks abroad, MNC headquarters are expected to be more capable of controlling and coordinating foreign collaborators – both within and outside their own company, and thus may be able to exploit the knowledge from such external sources more effectively (Montobbio and Sterzi, 2013). Hence, BIC MNCs may be in a better state than DFs to take advantage of the diverse knowledge pools accessed through international collaborations, while keeping coordination costs to a minimum (Regnér and Zander, 2011). In contrast, the global reach of BIC DFs may be more limited, and therefore these firms may incur higher coordination costs when engaging in international collaborations which in turn, may impact negatively on their innovation outcomes (Montobbio and Sterzi, 2013).

Hence, we expect that BIC MNCs and DFs are able to benefit in different ways from international collaborations, and therefore the innovative outcomes of these collaborations –measured here as patent value and characteristics – are also likely to vary.

3. DATA AND METHODOLOGY

3.1. Data

The empirical analysis is based on applications to the European Patent Office (EPO) retrieved from the PATSTAT database. PATSTAT data are ideal for tracking BIC-EU collaborations because they include information on inventor team's country of residence, which allows us to identify both domestic and cross-border inventions. The initial sample iss constructed by searching the universe of BIC-EU cross-border inventions and BIC domestic patents in PATSTAT. Cross-border inventions are identified considering all patents, whose inventive teams are composed by BIC inventors and at least one EU inventor; domestic patents are those whose inventive team is composed *only* of inventors from the individual BIC countries (e.g. for Chinese collaborations only Chinese inventors).[5] The initial sample includes a total of 15,828 EPO patent applications, of which 3,370 are cross-border inventions and 12,458 are domestic patents.[6] Since we are interested in domestic and cross-border inventions owned by BIC firms, we identify the subset of patents with at least one BIC assignee (i.e. the entity with the rights to economically exploit the invention disclosed in the patent). PATSTAT provides patent applicants' names as they appear on the patent document that are harmonized manually by a) removing all punctuation, special characters, and firm's legal status, b) matching assignees' names using the ORBIS-Bureau van Dijk database, and c) comparing the address on the patent with the one recorded in the ORBIS-Bureau van Dijk database. We focus on applicants with more than five patents in PATSTAT.

Based on ORBIS-Bureau van Dijk information, each applicant is classified on the basis of the two following assignee types:

1. BIC MNCs: headquarter or subsidiary of a BIC MNC;
2. BIC DF: BIC firms with no direct investments in a foreign country.

The final sample includes a total of 5,215 patents: 4,210 owned by BIC MNCs and 1,005 owned by BIC DF.

From PATSTAT, we have retrieved other relevant information for all the domestic and cross-border inventions: year of patent filing, technological class indicating the technological domain of the patent, number of different countries where the patent applies. We have also gathered information related to the citations included, the citations received and the numbers of citations to previous patents, citations to previous scientific literature (i.e. the so-called non-patent literature), and citations received by subsequent patents. We have used this information to construct our control variables, described below.

3.2. The variables

To account for the value and characteristics of both cross-border and domestic inventions we consider four patent-level variables usually adopted in the patent literature (see Table 1 for a presentation of how these variables are operationalized). Table 2 reports the summary statistics for the variables and the correlations are presented in the Appendix.

To measure patent *value* we use the following two indicators.

NUM CITATION (i.e. forward citations): a measure of the technological importance of the patents. This indicator is used extensively in the literature and is correlated with several other measures of the patent value (Trajtenberg, 1990; Jaffe and Trajtenberg, 2002; Gambardella et al. 2008). When counting the citations we include both self-citations by the assignee, and citations by others. Both indicators signal patent importance, although self-citations might indicate that the patent is significant for internal innovations.

NUM LEGISLATION: a measures of the number of countries where the patent applies, directly associated with the market scope of the protected invention. This is a good proxy for the commercial value of the patent because the patenting company has to pay additional fees for each country in which it is registered (Bekkers et al., 2011).

Patent *characteristics* are measured in terms of patent generality and patent originality (Trajtenberg et al., 1997).

GENERALITY is measured as:

$$Generality_i = 1 - \sum_{j=0}^{n_i} s_{i,j}^2$$

where $s_{i,j}$ is the share of forward citations received by patent *i* from patents in the technological class *j* out of n_i. In particular, the more citations received by patent *i* from more technological classes, the higher is the generality index, which means that the patent contributes to knowledge in many different technological fields (e.g. general purpose technologies).

ORIGINALITY is measured by an originality index, which is calculated in the same way as the generality index, but refers to the citations made (i.e. backward citations):

$$Originality_i = 1 - \sum_{j=0}^{n_i} s_{i,j}^2$$

where $s_{i,j}$ is the share of citations made by patent *i* to patents in the technological class *j* out of n_i. If a patent cites other patents mostly belonging to a limited set of technologies, the originality index is low. A patent’s backward citations help to trace the technological domain from which an innovation emerges. The narrower this domain, the more limited the potential for new discoveries, therefore the patent is considered to be less original.[7]

Table 1 Variables and operationalization of concepts

Dependent Variables	Measure	Concept	Source
NUM CITATION	Number of received citations (Forward citations)	Patent technological value	PATSTAT
NUM LEGISLATION	Number of legislations of the equivalent patents in the INPADOC family	Patent market scope	PATSTAT
GENERALITY	1- Σs(i,j) where Σs(I,j) is the sum of all the percentages of citations made by patent i that belong to patent class j. Note that the variable is corrected for possible bias related to small number count (Hall, 2005)	Scope of the technological impact of the subsequent innovations triggered by a patent	PATSTAT
ORIGINALITY	1- Σs(i,j) where Σs(I,j) is the sum of all the percentages of citations received by patent i that belong to patent class j. Note that the variable is corrected for possible bias related to small number count (Hall, 2005)	Scope of the technologies upon which a patent is built	PATSTAT
Independent Variables	**Measure**	**Concept**	**Source**
CROSS-BORDER	Dummy equal to 1 if the patent has at least one EU inventor, and zero otherwise.	Measure of the internationalization of innovation	PATSTAT
Control Variables	**Measure**	**Concept**	**Source**
TEAM SIZE	Number of inventors in the patent	Participants to the collaborations	PATSTAT
LN NUM BACKWARD CIT	Logarithm of the number of citations in the patent (Backward citations)	Number of previous patents upon which a patent is built	PATSTAT
LN NPL	Logarithm of the number of references to Non Patent Literature (NPL)	Measure of the degree of basicness (i.e. science based) of the invention covered in the patent	PATSTAT
LN NUM CLAIMS	Logarithm of the number of claims included in the patent	Scope of the patent	PATSTAT
LN ASSIGNEE EXPERIENCE	Logarithm of the patent portfolio of the assignee	Experience gained by the assignee in patenting activities	PATSTAT
LN INVENTOR EXPERIENCE	Logarithm of the sum of the patent portfolio of all the inventors in the patent	Experience gained by the inventive team in patenting activities	PATSTAT
BIC DUMMY	Dummy variable for indicating whether the patent is originated from China or India. Brazil is the base category.	Effect of having a Chinese or an Indian inventor in the team compared to a Brazilian inventor	PATSTAT

Note: INPADOC family includes all the patent documents resulting from a patent application submitted as a first filing with a patent office and from the same patent application filed within the priority year with a patent office in any other country.

Table 2 Descriptive statistics

	Obs	Mean	SD	Min	Max
NUMCITATION	5215	0.3406	1.4259	0	33
NUMLEGISLATION	5215	5.4167	3.3234	1	39
GENERALITY	5215	0.0276	0.1009	0	0.7060
ORIGINALITY	5215	0.2273	0.2441	0	0.8609
CROSS-BORDER	5215	0.0217	0.1456	0	1
TEAM SIZE	5215	3.9870	2.2526	2	21
LN NUM CLAIMS	5215	2.0322	1.2262	0	4.7095
LN NPL	5215	1.0523	0.4536	0	4.4188
LN NUM BACKWARD CIT	5215	1.1494	0.5396	0	4.1109
LN ASSIGNEE EXPERIENCE	5215	6.6538	2.8817	0	10.0249
LN INVENTOR EXPERIENCE	5215	1.4390	0.6285	0.6931	5.6416
CHINA	5215	0.6742	0.4687	0	1
INDIA	5215	0.2583	0.4377	0	1

Source: Authors' calculations on PATSTAT

Our key independent variable is a dummy variable (*CROSS-BORDER*), which takes the value 1 if the patent is co-invented with a EU inventor, and 0 if the patent is purely domestic (i.e. involving an inventor team based only in the country of origin).

3.3. The control variables

In line with the standard literature on patent-level regression analysis (e.g. Singh, 2008; Czarnitzki, 2011; Alnuaimi et al., 2012; Lissoni and Montobbio, 2012), we include the following control variables, which might influence the patent's value and characteristics.

TEAM SIZE is the size of the inventor team, measured as the number of inventors listed on the patent. This can have a direct effect on the quality of the patent; the larger the number of inventors involved in a R&D team, the broader and more diverse the knowledge the team is able to access and exploit (Bercovitz and Feldman, 2011).

LN NUM BACKWARD CIT defines the *prior art* of the invention, and therefore bounds the legal validity of the patent. Backward citations are related to both the level of cumulativeness of the invention and the crowdedness of the technological area (Lanjow and Schankermann, 2001; Harhoff et al. 2003), and, *ceteris paribus*, tends to be positively related to patent value and especially number of forward citations.

LN NUM CLAIM is the natural logarithm of the number of claims, which defines the extent of patent protection and is associated with patent breadth. The number of claims is positively related to patent value (Gambardella et al. 2008); however, broader patents are more difficult to defend in litigations, and a lower number of claims might indicate a better-crafted patent with a greater chance of surviving re-examination (Lerner, 1994).

LN NPL is the natural logarithm of the number cites to the Non-Patent Literature (NPL), or the number of (scientific) articles cited in a patent, as an indicator of science-technology linkages (Callaert et al., 2004).

LN ASSIGNEE EXPERIENCE is the natural logarithm of the number of patents applications filed by the assignee previous to the focal patent. This can positively affect the quality of the patent, and the competence for managing the bureaucratic and lengthy patent application procedure.

LN INVENTOR EXPERIENCE is the natural logarithm of the number of patents applications filed by the inventors in the team before the focal patent. We include this variable since the literature suggests that inventors' previous experience affects the quality of current performance (Lee, 2008).

3.4. The econometric methodology

Depending on the nature of the dependent variables (i.e. count variable and fractional count), we employ different econometric models. *NUM CITATION* and *NUM LEGISLATION* are count variables; therefore we can use either a Poisson or a Negative Binomial model. We choose the Poisson Quasi Maximum Likelihood (PQML) estimation because it is consistent under the weaker assumption of correct conditional mean specification, and there are no restrictions on the conditional variance (i.e. it allows for over dispersion) (Gourieroux et al., 1984; Wooldridge, 2002; Cameron and Trivedi, 2010). As a robustness check, we ran a zero-inflated model to account for the large number of zeros when the dependent variable is *NUM CITATION* (the estimates are available upon request).

The variable *NUM CITATION* is a truncated variable since recent applications have less time to be cited than older ones. We correct for this by estimating a PQML mode with exposure (Cameron and Trivedi, 1998), and include patent age (measured as the number of days between patent application date and 2012) as an offset in the conditional mean. This assumes that the likelihood of the event is not changing over time, and so we include patent filing year and technological class fixed effects.

ORIGINALITY and *GENERALITY* take values in the unit interval between zero and 1; thus a linear model is not suitable. Also, since corner solutions are possible, a log-odds transformation would require arbitrary adjustments. In order to overcome these issues we follow the approach proposed by Papke and Woodridge (1996) and estimate a Quasi-Maximum Likelihood (QML) fractional logit regression.

As Alnuaimi et al. (2012) point out, there is a risk of reverse causality in our estimations since teams involved in international collaborations may be assigned to the most promising and valuable projects. In this case the positive association between our dependent variables and *CROSS-BORDER* would be a spurious result due to projects that are potentially more innovative being pre-assigned to international rather than domestic inventor teams. We address this potential endogeneity problem using instrumental variables and two-stage regressions. This implies (a) finding reliable and strong instruments, and (b) identifying the correct econometric approach, considering that our (possibly) endogenous variable (*CROSS-BORDER*) is a binary variable, and that each of our dependent variables differs in nature (i.e. count variables, fractional counts).

To address the first point, we use two instrumental variables: (i) the propensity to collaborate internationally in the focal patent's technological class, in the year before patent filing (*INSTR1)*, and (ii) the assignee's propensity to collaborate internationally in the year before the focal patent's filing year (*INSTR2)*. Following Alnuaimi et al. (2012), we construct *INSTR1* as the frequency probability that an EPO patent involves international collaboration. For each patent in the sample in technological class *I,* applied for in year *j*, we retrieve from PATSTAT all EPO patents in the same technological class *i* that were applied for in year *j-1*. Then the instrument is measured as the percentage of these patents which involve international collaboration. The second instrument *(INSTR2)* is calculated in a similar way but at assignee rather than technological class level. The rationale for these instruments is that we expect them to be correlated to our variable of interest *(CROSS-BORDER)* but not to the quality and characteristics of the patent.[8]

To address the second problem (the econometric approach), we use a QMLE Poisson if the dependent variables are count variables (i.e. number of citations and number of legislations), and add the residuals (ρ) from the estimation where we regress our potentially endogenous variable on all the exogenous variables (i.e. instruments and controls). The significance of ρ is the endogeneity test for the potentially endogenous variable (Wooldridge, 2010, p. 743; Hilbe, 2011).[9] The potentially endogenous variable is exogenous if and only if $\rho=0$.

The other two dependent variables (i.e. originality and generality) are estimated using two-stage least squares regressions. Although these variables are not continuous, this method is commonly accepted if the potential endogenous variable is binary.[10] The endogeneity test for these cases is the difference in the two Sargan-Hansen statistics: for the equation with the smaller set of instruments where the suspect regressor(s) are treated as endogenous, and for the equation with the larger set of instruments where the suspect regressors are treated as exogenous. The null hypothesis for this test is that potentially endogenous variables can be treated as exogenous.

4. RESULTS

4.1. Descriptive statistics

Table 3 presents the distribution of cross-border vs. domestic patents in BIC showing that the frequency of cross-border inventions is still small; they account for only 2% of the patents owned by BIC assignees. Further, Chinese inventors are responsible for almost two-thirds of the patents in our sample.

Table 3 Distribution of domestic vs. cross-border inventions across BIC countries

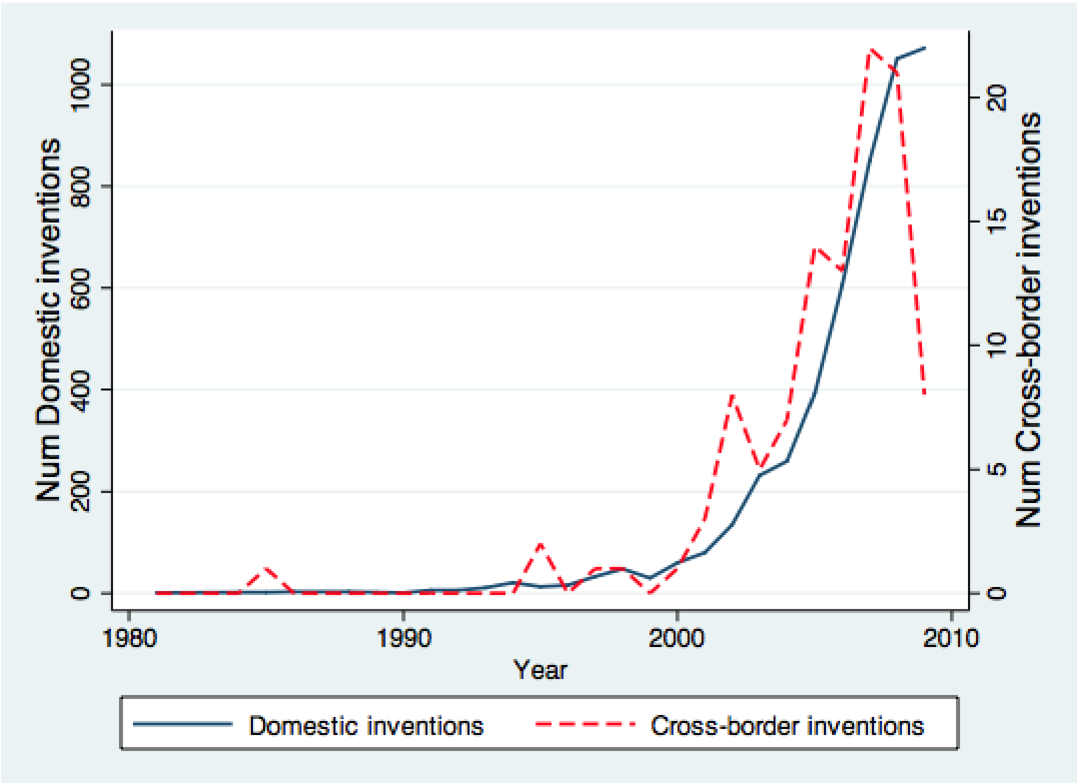
	Brazil	China	India	Total	
Domestic	322	3,474	1,306	5,102	98%
Cross-border	30	42	41	113	2%
Total	352	3,516	1,347	5,215	
	7%	67%	26%		

Source: Authors’ calculations on PATSTAT

Figure 1 displays the number of domestic and cross-border inventions (secondary axis) per application year over the period 1980-2010. The two series show a similar increasing trend although they differ in absolute size, with cross-border inventions being a tiny fraction of the domestic ones.

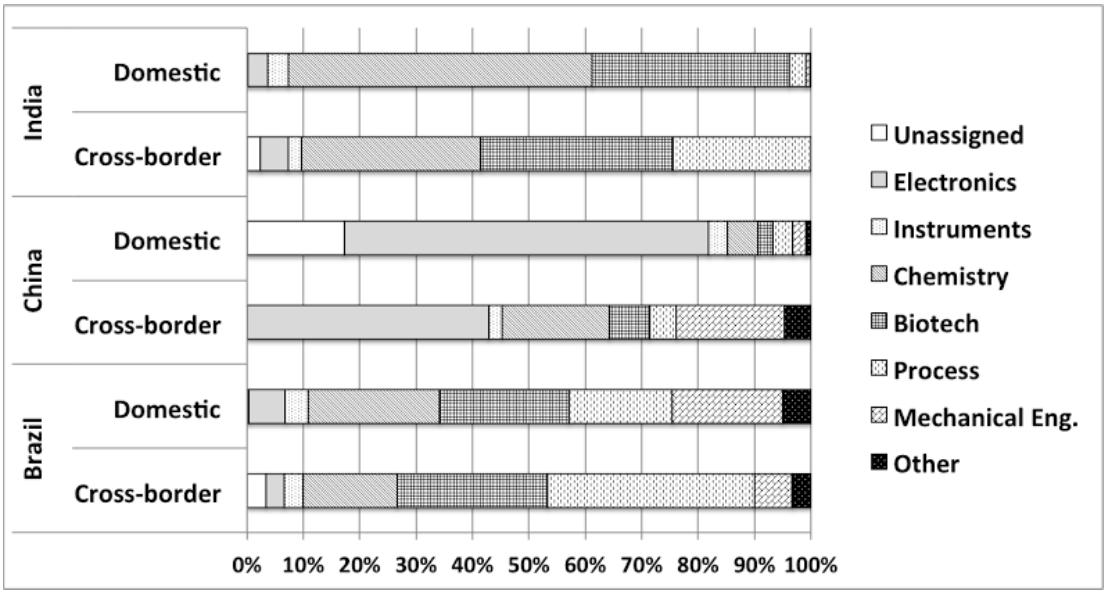
Our results for cross-border inventions differ from those in Chen et al. (2013) and Branstetter et al. (2013); those studies examine USPTO co-invented patents and find that the number of Chinese and Indian co-inventions is much larger than each country's domestic ones. These differences are due to two main facts. First, in our study the focus is on only patents *owned by* BIC firms, whereas Branstetter et al (2013) include subsidiaries of foreign MNCs operating in China and India which may be involved in numerous cross-border inventions with their U.S. headquarters.[11] Second, Chen et al. (2013) and Branstetter et al. (2013) focus on Chinese and Indian collaborations with U.S. partners, which for different reasons (e.g. high number of BIC PhD students and researchers, greater attractiveness of their high tech industries etc.), may result in more cross-border inventions compared to collaborations with EU partners.

Figure 1 Number of domestic patents per application by year



Source: Authors' calculations on PATSTAT

Figure 2 Technological domains by BIC country and cross-border vs. domestic patents



Note: Technological classification follows Schmoch (2008)

Source: Authors' calculations on PATSTAT

In terms of technological domain (Thoma, 2012; Schmoch, 2008), we find that BIC specialize in different technological areas. China is focused strongly on electronics, India on chemistry and biotech, and Brazil on chemistry and mechanical industries (Table 2). We also observe some within-country differences: Indian domestic patents are mainly in chemistry and biotech, while Indian cross-border inventions also include process engineering. Also, almost half of the Chinese domestic patents are in electronics but biotech and chemical industries are relevant among cross-border inventions. Finally, Brazilian domestic patents are distributed fairly evenly across four technological areas – chemistry, biotech, process and mechanical engineering - while cross-border inventions are generally concentrated in process engineering.

Table 4 presents the fractional count of the number of patents per inventor by country, reflecting the geographical localization of the inventive teams.[12] We find that BIC inventors collaborate mostly with the same set of countries (i.e. Germany, United Kingdom, France, Netherlands, and Italy) – although there are some differences.

Table 4 Fractional count of the patents per inventor by country

Brazil		China		India	
FRANCE	8.077	GERMANY	13.410	FRANCE	14.379
GERMANY	5.283	NETHERLANDS	7.583	UNITED KINGDOM	11.317
NETHERLANDS	3.017	SWEDEN	4.450	CZECH REPUBLIC	5.871
ITALY	2.500	UNITED KINGDOM	3.883	GERMANY	3.200
UNITED KINGDOM	1.976	ITALY	2.950	AUSTRIA	2.125
OTHER	2.167	OTHER	2.167	OTHER	2.600
BRAZIL	47.020				
CHINA			63.293		
INDIA					100.367

Note: Fractional counting means that if a patent has three inventors from three different countries, each country will account only for 0.33 of that patent. Then in order to have a patent count at country level, the fraction of each patent is sum by country. Other refers to non-BIC and non-EU countries.

Source: Authors' calculations on PATSTAT

4.2. Comparing Domestic and Cross-border Patent Value and Characteristics

In this section we present the results of four sets of estimations (Models 1-4 in Table 5) corresponding to the following dependent variables: *NUMCITATION* (Model 1); *NUM LEGISLATION* (Model 2); *GENERALITY* (Model 3) and *ORIGINALITY* (Model 4).

In Model 1, we find that the difference for the log of the expected number of citations is 1.24 higher for cross-border inventions compared to domestic ones, and this confirms the hypothesis that cross-border inventions are more valuable than purely domestic patents. Model 2 shows that the difference between the logs of the expected number of legislations is -0.46 lower for cross-border inventions than domestic ones, which suggests that the market scope of cross-border inventions is more strongly focused in a smaller number of countries compared to domestic patents. Note that the differences in the results for Models 1 and 2 show that our patent value measure is capturing different aspects of patent value.[13]

Table 5 Impact of cross-border inventions on patent value and characteristics

	(1) NUMBER OF CITATIONS		(2) NUMBER OF LEGISLATIONS		(3) GENERALITY		(4) ORIGINALITY	
	Poisson QMLE		Poisson QMLE	Poisson IV	GLM Fractional Logit		GLM Fractional Logit	
CROSS-BORDER	1.2260***	1.2465***	-0.0609	-0.4571**	1.2057***	1.2434***	0.1418	0.1220
	(0.2404)	(0.2016)	(0.0699)	(0.2235)	(0.2699)	(0.2556)	(0.1464)	(0.1360)
TEAM SIZE		-0.1123***		-0.0127*		-0.0672*		0.0326***
		(0.0320)		(0.0066)		(0.0388)		(0.0106)
LN NUM CLAIMS		0.5795***		0.0591**		0.5079***		0.0115
		(0.0706)		(0.0232)		(0.0642)		(0.0196)
LN NPL		0.2256		0.0355*		0.2298*		0.8163***
		(0.1395)		(0.0196)		(0.1236)		(0.0475)
LN NUM BACKWARD CIT		0.5137***		-0.1052***		0.6806***		2.2185***
		(0.1374)		(0.0264)		(0.0992)		(0.0411)
LN ASSIGNEE EXPERIENCE		0.0385		0.0086		(0.0379)		0.0485***
		(0.0313)		(0.0082)		(0.0269)		(0.0095)
LN INVENTOR EXPERIENCE		0.3200**		0.0721***		0.2676*		-0.1016***
		(0.1270)		(0.0204)		(0.1585)		(0.0389)
CONSTANT					(15.8845)	-17.4731*	-13.5443***	-15.0825***
					(12.7544)	(10.0180)	(1.2184)	(1.0316)
BIC DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
YEAR DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
TECH CLASS DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
OBSERVATION	4,839	4,839	5,200	5,200	5,215	5,215	5,215	5,215
ENDOGENEITY TEST								
ρ		0.3		2.77*				
P-value		0.5864		0.0959				
Chi-sqr						1.264		0.195
P-value						0.2608		0.6591

Note: The coefficients and standard errors are in brackets. Model 1 is estimated using a QMLE Poisson with robust standard error and year-technological class fixed effect. The significance of ρ is the endogeneity test for the potentially endogenous variable (*CROSS-BORDER)* Model 2 (without controls) is estimated with a QMLE Poisson with robust standard error and year-technological class fixed effect and Model 2 (with controls) is estimated using a QMLE Poisson with residual (ρ) from the first stage. Models 3 and 4 are estimated using GLM fractional logit. The null hypothesis for the endogeneity test is that the potentially endogenous variable (*CROSS-BORDER*) can be treated as exogenous. Legend:* p<.1; ** p<.05; *** p<.01.

Source: Authors' calculations on PATSTAT

In Models 3-4 (Table 5), we find that inventors engaged in international collaborations are more likely to produce more general patents than inventors engaged only in domestic collaborations. However, international collaborations do not have any significant impact on originality (Model 4), which means that there is no difference between cross-border and domestic patents in terms of the breadth of knowledge they build on.

With regard to control variable, we find that the inventive team's experience rather than its size, is positively related to most of our dependent variables. This result contrasts with some earlier studies, which find a positive relationship between team size and innovative outcomes (Alnuaimi et al., 2012; Branstetter al., 2013).[14] All the other patent-level controls (*LN NUM CLAIMS, LN NUM BACKWARD,* and *LN NPL*) behave as expected, and in line with prior research (Alnuaimi et al. 2012; Branstetter al. 2013; Czarnitzki, 2011).

4.3. Comparing Cross-border Inventions between BIC MNCs and Domestic Firms

In this section we test whether there is a difference in the value and characteristics of cross-border and domestic inventions in relation to the different types of assignees. Table 6 shows that BIC MNCs own the majority of both domestic (81%) and cross-border (64%) inventions.

Table 6 Patent ownership by types of assignee

	Domestic		**Cross-Border**		**Total**	
	Freq	%	Freq	%	Freq	%
MNCs	4,138	81%	72	64%	4,210	81%
DFs	964	19%	41	36%	1,005	19%
Total	5,102		113		5,215	

Source: Authors' calculations on PATSTAT

Table 7 presents the top patentees for both domestic and cross-border inventions. The top assignees are almost all MNCs with the one exception of Positec Power, a Chinese company specialized in wholesale electronic and telecommunication components. Note that the top five domestic patentees are mostly different from the top cross-border inventors, except for Huawei, which is ranked high for both. Among the top assignees of domestic patents there are four Chinese MNCs (Huawei Tech, ZTE, Sinopec, and BYD) and one Indian (Dr. Reddy's), and their main industries of operation are ICT, pharmaceuticals, and extractive industries. For cross-border patents the assignees are more diverse and include Huawei and Positec Power from China, Petrobras and Natura Cosmeticos from Brazil, and three Indian MNCs - Larsen, Dishman, and Sun Pharma.

Table 7 Top patentees characteristics by patent type

	Country	# domestic patents	%	Type of assignee	Industry
HUAWEI TECHNOLOGY	CN	1794	34%	MNC	Manufacture of electronic components
ZTE	CN	525	10%	MNC	Manufacture of communication equipment
DR REDDY S LABORATORY	IN	237	4%	MNC	Manufacture of pharmaceutical products
SINOPEC	CN	222	4%	MNC	Support activities for petroleum and natural gas extraction
BYD	CN	150	3%	MNC	Machinery, equipment, furniture, recycling
	Country	**# cross-border inventions**	**%**	**Type of assignee**	**Industry**
HUAWEI TECHNOLOGY	CN	13	12%	MNC	Manufacture of electronic components
PETROLEO BRASILERO	BR	10	9%	MNC	Extraction of crude petroleum
LARSEN TOUBRO	IN	6	5%	MNC	Manufacture of other special-purpose machinery
NATURA COSMETICOS	BR	6	5%	MNC	Wholesale of perfume and cosmetics
POSITEC POWER TOOLS SUZHOU	CN	5	4%	DF	Wholesale of electronic and telecommunications equipment and parts
DISHMAN PHARMACEUTICALS AND CHEMICAL	IN	5	4%	MNC	Manufacture of pharmaceutical preparations
SUN PHARMA	IN	5	4%	MNC	Manufacture of pharmaceutical preparations

Source: PATSTAT

Tables 8-9 show the results of the regression analysis, testing the impact of cross-border inventions on patent value and characteristics in MNCs (Models 5, 7, 9, and 11) and DFs (Models 6, 8, 10, and 12). We find that cross-border inventions owned by MNCs and DFs are more valuable (i.e. more likely to be cited) than domestic patents: the difference in the logs of expected counts of citations is 1.45 higher in the case of MNCs, and 0.67 in the case of DFs (Table 8). Also, the statistically significant difference (at the 0.001 confidence level) in the size of the coefficients for the variable *CROSS-BORDER* in Models 5 and 6 suggests that MNCs are more able to take advantage of their collaboration with European inventor(s) compared to DFs. These results are robust to different estimation models, such as negative binomial and zero-inflated negative binomial (Hilbe, 2011). If we consider patent value in terms of *NUMLEGISLATION*, we find that the variable *CROSS-BORDER* is not significant for the patents owned by MNCs but is negative and significant for patents owned by DFs (-0.36).

Table 9 shows that when MNCs engage in cross-border inventions with European inventors, their patents are both more general and more original than if patents are produced by a team of only domestic inventors (Models 9 and 11). However, these differences are not significant if we consider DF patents (Models 10 and 12) whose generality and originality is not influenced by the composition of the inventor team. The results of the control variables are largely in line with earlier research (Alnuaimi et al., 2012; Branstetter et al., 2013; Czarnitzki, 2011). We discuss the implications of these results in the next section.

Table 8 Impact of collaboration on patent value by assignee type

	NUMBER OF CITATIONS				NUMBER OF LEGISLATIONS			
	(5)		(6)		(7)		(8)	
	BIC MNC Poisson QMLE		BIC DF Poisson QMLE		BIC MNC Poisson QMLE		BIC DF Poisson QMLE	
CROSS-BORDER	1.4343***	1.4554***	0.9058***	0.6653*	0.0936	0.1043	-0.4172***	-0.3575***
	(0.2832)	(0.2851)	(0.2429)	(0.3712)	(0.0972)	(0.0955)	(0.0933)	(0.0880)
TEAM SIZE		-0.1054***		(0.1098)		(0.0032)		(0.0187)
		(0.0361)		(0.0675)		(0.0086)		(0.0123)
LN NUM CLAIMS		0.6288***		0.4996***		0.0647**		0.0325
		(0.0817)		(0.1128)		(0.0277)		(0.0205)
LN NPL		0.3996***		(0.1932)		0.0193		0.0971**
		(0.1531)		(0.3374)		(0.0251)		(0.0421)
LN NUM BACKWARD CIT		0.4636***		0.5916**		-0.0786***		-0.1946***
		(0.1483)		(0.2385)		(0.0274)		(0.0462)
LN ASSIGNEE EXPERIENCE		0.0537		0.0043		0.0162		0.0353***
		(0.0332)		(0.0762)		(0.0128)		(0.0125)
LN INVENTOR EXPERIENCE		0.2907**		0.3154		0.0133		0.0897***
		(0.1442)		(0.2103)		(0.0249)		(0.0345)
BIC DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
YEAR DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
TECH CLASS DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
OBSERVATION	3,851	3,851	740	740	4,193	4,193	981	981
			ENDOGENEITY TEST					
ρ		1.5		1.54		0.01		0.96
P-value		0.2214		0.2145		0.9186		0.3283

Note: coefficients and standard errors are in the brackets. All the models are estimated using a QMLE Poisson with robust standard error and year-technological class fixed effect. The significance of ρ is the endogeneity test for the potentially endogenous variable (*CROSS-BORDER*). Legend:* p<.1; ** p<.05; *** p<.01.

Table 9 Impact of collaboration on patent characteristics by assignee type

	GENERALITY				ORIGINALITY			
	(9)		(10)		(11)		(12)	
	BIC MNC		BIC DF		BIC MNC		BIC DF	
	GLM Fractional Logit		GLM Fractional Logit	Linear IV 2SLS	GLM Fractional Logit		GLM Fractional Logit	Linear IV 2SLS
CROSS-BORDER	1.3276***	1.3270***	0.6843	(0.0531)	0.1827	0.3465**	0.1511	0.1429
	(0.3437)	(0.3530)	(0.4280)	(0.0515)	(0.1772)	(0.1570)	(0.2722)	(0.1029)
TEAM SIZE		(0.0582)		(0.0021)		0.0393***		0.0040*
		(0.0401)		(0.0021)		(0.0121)		(0.0024)
LN NUM CLAIMS		0.5550***		0.0066**		0.0164		0.0005
		(0.0805)		(0.0031)		(0.0218)		(0.0044)
LN NPL		0.4482***		(0.0123)		0.8534***		0.0634***
		(0.1577)		(0.0095)		(0.0485)		(0.0149)
LN NUM BACKWARD CIT		0.6858***		0.0343***		2.2567***		0.3046***
		(0.1185)		(0.0102)		(0.0451)		(0.0128)
LN ASSIGNEE EXPERIENCE		(0.0254)		0.0010		0.0625***		0.0026
		(0.0373)		(0.0022)		(0.0135)		(0.0029)
LN INVENTOR EXPERIENCE		0.2564		0.0036		-0.0975**		-0.0213**
		(0.1703)		(0.0084)		(0.0432)		(0.0084)
CONSTANT	(1.1319)	-3.9680***	-32.9102***		(0.8434)	-5.5069***	-14.4362***	
	-0.9365	-0.935	-6.9228		-0.839	-0.4699	-1.156	
BIC DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
YEAR DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
TECH CLASS DUMMY	YES	YES	YES	YES	YES	YES	YES	YES
OBSERVATION	4,210	4,210	1,005	1,005	4,210	4,210	1,005	1,005
				ENDOGENEITY TEST				
Chi-sqr		0.017		3.002*		0.127		3.119*
P-value		0.8966		0.832		0.7213		0.0774

Note: coefficients and standard errors are in the brackets. Models 9 and Models 11 are estimated using a GLM Conditional Fractional Logit with year and technological class dummies. Models 10 and Model 11 (without controls)are estimated using a GLM Conditional Fractional Logit with year and technological class dummies; Models 10 and 11 (with controls) are estimated using two-stage least squares regressions. The null hypothesis for the endogeneity test is that potentially endogenous variables can be treated as exogenous. Legend: * p<.1; ** p<.05; *** p<.01.

5. CONCLUSIONS

The exceptional growth of emerging economies such as Brazil, India and China (BIC), and their potential to become world-leading economies in the future, has attracted the attention of analysts. Emerging country firms are demonstrating outstanding capacity to internationalize their production activities and to invest abroad to acquire knowledge and other strategic assets not available in their home countries (Giuliani et al., 2014). Their rapid expansion is raising questions about the capability of these countries to catch up technologically and conduct blue-skies research and to innovate (Altenburg et al., 2008; Fu and Gong, 2011; Fu et al, 2011). Several scholars note the importance of new forms of knowledge acquisition being pursued emerging countries' firms, particularly international R&D collaboration and co-patenting which are often considered good ways to enhance the exchange of tacit knowledge, and combinations of the diverse skills possessed by emerging country firms and other international firms (Alnuaimi et al., 2012; Branstetter al., 2013; Montobbio and Sterzi, 2011, 2013). However, so far, very little empirical research has focused on the innovative outcomes of such collaborations. Analysis of this aspect is crucial for understanding the impact on emerging countries.

This paper has investigated the differences in patent value and characteristics of international collaborations compared with domestic cooperation. It analyzed the innovative output of these collaborations across different types of emerging country firms by distinguishing between BIC MNCs and BIC domestic firms with no direct investments abroad. International collaborations is considered BIC firms' collaborations with European (EU-27) companies which differentiates this study from earlier research that looks almost exclusively at U.S. patents and co-inventors.

We find that cross-border inventions between BIC and the EU are a limited but rapidly growing phenomenon. Our general results suggest that cross-border inventions are more rewarding than domestic ones as they produce both higher value patents (i.e. higher forward citations) and more general patents. This means that innovations based on international collaborations are likely to influence the development of subsequent inventions across a variety of technological fields. We also find that cross-border inventions have lower market scope compared to domestic patents (i.e. protection applies to a smaller number of countries), which suggests that international collaboration is a strategy used by BIC companies not to enter potentially new markets but rather to increase the future impact of their innovative activities.

Moreover, BIC MNCs and DFs differ in their capacities to benefit from international collaboration. BIC MNCs are more involved in international co-inventions than BIC DFs, possibly because the former can draw on their international networks to generate new and strengthen existing R&D collaborations with foreign entities (firms, research institutes, etc.). In line with our expectations, we find that the patents produced by MNCs' international collaborations are higher value (i.e. higher forward citations) and also are more general and more original than those resulting from BIC MNCs' domestic collaborations.

Results for BIC DFs are also interesting: DF cross-country collaborations generate more valuable (i.e. more cited) patents compared to domestic collaborations; however, these patents are neither more general, nor more original. In contrast, domestic collaborations foster the production of patents with higher market scope, meaning that inventions resulting from DFs' domestic inventive efforts are protected in a higher number of countries.

These novel findings contribute to a better understanding of the processes of technological catch up by developing, and especially, emerging countries. First, while most previous research focuses on more conventional means of technology transfer from advanced to developing countries, such as imports, exports, and FDI (Archibugi and Pietrobelli, 2003;

Lall, 1992; Lall and Narula, 2004), this paper focuses on international co-inventing, which is a growing phenomenon in emerging countries. Our analysis reveals that cross-border inventions provide a way for emerging country firms to tap into international knowledge pools and produce high value innovations. This suggests that these firms might play a role in fostering a process of technological catching up in their own countries by potentially generating local spillovers of valuable knowledge to other domestic firms. In the context of research on FDI and technological externalities, several studies show that the generation of spillovers by subsidiaries of foreign MNCs operating in developing countries depends largely on the innovative activities carried out at subsidiary level (Marin and Bell, 2006). In our study, we posit that BIC firms engaged in international co-patenting may also play an important role, and we consider this to be an area that deserves further investigation.

Second, our study is original in showing the meaningfulness of international co-invention activities between BIC firms and EU partners. Most extant research studies collaborations between emerging countries and the U.S. (Alnuaimi et al., 2012; Branstetter et al., 2013), and investigates co-patenting between U.S.-based firms operating in emerging economies (typically China and India) and these countries' domestic companies, and find that this type of collaboration is substantial and growing (Alnuaimi et al., 2012; Branstetter et al., 2013; Montobbio and Sterzi, 2011, 2013). Our narrower focus is on BIC firms (rather than *foreign* companies operating in *BIC* countries), and is justified by BIC companies' growing influence in the international landscape. Our results show that, especially in the case of BIC MNCs, these firms are becoming progressively more able to appropriate, and therefore to exploit the property rights of inventions that include knowledge inputs from advanced country (European) actors. Despite this being (still) a limited phenomenon, we have provided evidence of an ongoing process in the changing global division of innovative labor, which is moving towards emerging economies - China being the absolute leader in this new process (Altenburg et al., 2008; Karabag et al., 2011; Patibandla and Petersen, 2002; UNCTAD, 2006, 2005).

Finally, this paper provides an original contribution by distinguishing between BIC MNCs and domestic companies. In line with the industry-specific evidence in Altenburg et al. (2008), our results suggest that the globalized company networks of BIC MNCs positively contribute to the generation of valuable and useful knowledge. In this sense, our paper builds on earlier research on the rising power of emerging market firms (Fu et al., 2011; Marin and Arza, 2009; Sinkovics et al., 2014) and finds that these actors are beginning to appropriate the property rights of valuable inventions.

Our findings have some implications for policy. If emerging countries want to build technological capabilities to catch up with the advanced countries, cross-border patenting activity represents an efficient means that could be promoted by tax reductions or other fiscal incentives for companies involved in international co-patenting. Our findings show also that cross-border innovations are more common among MNCs than DFs because the latter have fewer international contacts and are less likely to be involved in global R&D networks. Therefore, policy should focus particularly on DFs, and efforts should be directed to encourage their participation in global R&D networks by funding and facilitating technical visits abroad, conference attendance, and sponsorship for internships for foreign engineers and researchers in domestic enterprises. Korea did this successfully in the 1970s and 1980s, with Japanese technical experts (Lall and Teubal, 1998).

This paper has some limitations. First, while cross-border inventions are extensively used as a proxy for international technological cooperation, they represent only a fraction of cross-border knowledge-intensive collaborations. For instance, Bergek and Bruzelius (2010) point out that cross-border inventions are often the outcome of labor mobility or consultancy work. Hence, our general results might underestimate the extent of the phenomenon. Future research should consider other types of international collaborations. Second, our distinction between BIC MNCs and DFs is relevant but does not consider other important international dimensions of BIC firms, such as exporting level and global reach based on other forms of internationalization than FDI such as joint ventures and strategic alliances, which might also affect the quality of cross-border patents. More research is needed in this area. Finally, the geographical scope of the study is limited to Brazil, India and China, which are the leaders in cross border collaboration. An extension to this study could include other emerging countries such as Russia and Turkey.

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APPENDIX

Correlation table

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	10	11
1	*NUM CITATION*	1										
2	*NUM LEGISLATION*	0.0172	1									
3	*GENERALITY*	0.706	0.0222	1								
4	*ORIGINALITY*	0.1299	-0.0783	0.1849	1							
5	*CROSS-BORDER*	0.0337	0.0214	0.0584	-0.0009	1						
6	*TEAM SIZE*	-0.0126	0.0735	0.019	0.0322	0.0523	1					
7	*LN NUM CLAIM*	0.1127	-0.092	0.1222	0.2551	-0.0825	-0.1153	1				
8	*LN NPL*	0.0796	-0.0234	0.0993	0.5069	-0.0061	-0.0052	0.2241	1			
9	*LN BACKWARD CIT*	0.1637	-0.0619	0.1903	0.835	0.0183	0.0334	0.2275	0.4602	1		
10	*LNASSIGNEE EXPERIENCE*	-0.0683	-0.22	-0.0552	0.1633	-0.0999	-0.1552	0.4517	0.2288	0.0769	1	
11	*LN INVENTOR EXPERIENCE*	-0.03	0.0365	-0.0031	-0.0521	0.0918	0.7203	-0.0655	-0.0331	-0.0474	-0.0781	1

ENDNOTES:

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[1]However the absolute number of patents for these countries is still low (WIPO, 2008; Godinho and Ferreira, 2012): BIC countries' share of USPTO patent applications on world total is 7% in 2013 (www.uspto.gov, last accessed 25/07/2013).

[2]Available at http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS/countries?display=default

[3] Available at http://www.wipo.int/export/sites/www/ipstats/en/docs/infographics_patents_2013.pdf (last accessed on 09/08/2014).

[4] We should note that DF might have established other types of relationships with international actors (such as strategic alliances, informal contacts).

[5] Note that, as we are interested in the effect of collaboration, we do not consider patents developed by single inventors from BIC countries.

[6] The use of cross-border patents to study technological collaborations is well established in the literature, nevertheless two important caveats should be advanced. First, co-invented patents may overestimate the level of geographical dispersion of the inventive team, because they may not be able to account for labour mobility – i.e. when an inventor retains her home country residence while working abroad. Second, inventors are sometimes listed in a patent even if their contribution is not strictly related to R&D collaborations (Bergek and Bruzelius, 2010).

[7] In order to account for possible small sample bias we adjust the measures of *originality* and *generality* for the number of citations received in each technological class (see Hall, 2005 for details).

[8] The correlation between the two instruments is as low as 0.10.

[9] See Cameron and Trivedi (2010, p. 607) for an explanation of the Stata procedure.

[10] For further explanation related to the about binary dependent variables see Wooldridge (2010, p. 597) and Chiburis et al. (2012). For an explanation of the fractional count models see Wooldridge (2010).

[11] To check the robustness of our sample, we retrieved all the EPO co-invented patents (whether owned by a BIC firm or not) and found a much higher number of cross-border patents (9,216), in line with extant research on BIC-US collaborations. More specifically, we found that most of these cross-border patents are between BIC and EU inventors (3,405 patents), BIC and US inventors (3,405 patents), and BIC and other high-income countries' inventors (1,078 patents).

[12] Fractional count is used to avoid double counting of patents with inventors from more than one country. This means that if a patent has three inventors from three different countries, each country will account only for 0.33 of that patent.

[13]Note that *NUM CITATION* and NUM *LEGISLATION* are poorly correlated (Pearson coefficient is 0.0172). This low correlation is not the result of specific characteristics of the sample since correlation of the same two variables for all EPO patents is of comparable magnitude (0.0291). The calculation is based on data from the OECD Quality Database (Squicciarini et al., 2013).

[14] A possible interpretation of this result is that, since the team is composed mainly of BIC inventors, a marginal increase in its size raises coordination costs but does not result in more innovations due to the lower skills of BIC inventors compared to the U.S. ones.