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The role of domestic-firm knowledge in international patent collaborations: evidence from Indian firms

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Abstract

In this paper, we analyse the role of international patent collaborations in the performance of domestic firms and how the relationship is augmented by the pre-existing capabilities of the domestic firms. Using data on Indian firms, we study patterns of co-invention by Indian firms and foreign partners. The results confirm the crucial role played by the absorptive capacity of domestic firms in enhancing benefits from patent collaborations. Strikingly, we find that the coefficient associated to foreign collaboration has a positive effect on performance only when complemented with previous innovative capabilities. The evidence we present in this work contributes to existing knowledge on the microeconomics behind the process of technological capability accumulation and catching up in developing countries.

Keywords Co-patenting · Foreign collaboration · Absorptive capacity · Capability accumulation · Corporate performance

JEL Classification L20 · O30 · D24 · O12

1 Introduction

The rapid pace of technological change forces globally competing firms to develop their innovative capabilities to create and commercialise knowledge in a fast and cost-efficient manner. Firms in developing countries that face significant challenges in building and strengthening their technological and innovation capabilities often rely on strategic collaborations with foreign firms that are commonly assumed to act as a stepping stone up the ladder of knowledge complexity. However, contrary to what is often assumed, the relationship between participation in such collaborations and firm performance is not

L. Napolitano: The content of this article does not reflect the official opinion of the European Union. Responsibility for the information and views expressed herein lie entirely with the authors.

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straightforward. For instance, some studies (e.g. Keil et al., 2008) found a positive effect of R&D alliances on the innovative performance of firms, while others do not find a significant effect (e.g. Hagedoorn et al., 2003). A possible explanation is that the impact of R&D collaborations or alliances on firm performance may be strongly moderated by the role of absorptive capacity. Several studies in the literature have argued for the role of absorptive capacity in various kinds of innovative firm activities such as R&D alliances (Lin et al., 2012) and in house R&D (Coad et al., 2020). However, its effect on firms' ability to extract future benefits from co-patenting with foreign partners is less studied, especially in the context of developing economies. In this work, we address this gap in the literature.

Joint patenting involves frictions due to factors such as the legal intricacy of co-patenting (Hagedoorn, 2003), incomplete contracts on the property rights in co-owned patents, and moral hazard (Kloyer & Scholderer, 2012). As Hagedoorn, (2003) argues, if companies are given a choice, they prefer to have regular patents that are fully owned. Nevertheless, firms in developing economies that want to share the costs and risks associated with research and innovation and, more importantly, wish to leverage the richer pool of knowledge available abroad, engage in research collaborations with global partners. This is evident in patent data, which show that the rapid increase in patents assigned to countries such as China and India is largely due to the presence of multinational enterprises and international collaboration activities with developed countries (Branstetter et al., 2014; Dang & Motohashi, 2015; Li et al., 2020). For example, the steep growth in Indian patenting over the last two decades has gone hand in hand with a greater propensity to engage in co-patenting with foreign partners: the share of co-patents in India increased from around 30 percent in the late eighties to around 60 percent in the mid-2010s.[1] Studies have also shown that patents arising from co-invention involving actors operating in emerging economies tend to be of higher quality than indigenous patents (Alnuaimi et al., 2012). Branstetter et al., (2014) show that joint patents developed by Indian and foreign firms receive almost 30 percent more non-self-citations than indigenous Indian patents.

Research collaborations increase the innovative potential of firms through the generation of more complex, diverse, and novel innovations (Coad et al., 2021; Phene et al., 2006; Quéré, 2003; Savino et al., 2017). In the case of international R&D collaborations, firms in developed countries tend to be closer to the technological frontier, while firms in developing countries tend to be receivers of these advanced technologies. As a result, the integration of knowledge coming from different environments by domestic firms depends on their competence in acquiring and exploiting diverse and complex external knowledge—their absorptive capacity—as put forth by Cohen and Levinthal (1990). Evidently, firms differ widely in terms of their knowledge base and their capacity to acquire and recombine new knowledge. As a consequence, not all domestic firms that have access to external knowledge through collaborations with foreign firms benefit in the same way. As documented by Keller (1996, 2010), who looked at the effects of technology purchasing, developing countries do not achieve sustained patterns of growth unless the acquisition of technology is accompanied by investment in absorptive capacity. Fu et al., (2011) pointed out that domestic innovation efforts help indigenous firms reap the benefits of foreign technology acquisition resulting from foreign direct investment (FDI) (see also Salim et al., 2009; Zanello et al., 2016). Although FDI may involve some necessary transfer of research and development, the nature of such knowledge transfer is rather different from co-patenting,

[1] Authors' calculations based on data from the PATSTAT 2021 Edition.

which is the development of new-to-the-world knowledge. In the case of FDI, knowledge is created in a firm's home country and then diffused in a developing country, mostly in the form of new products and processes. Hence, knowledge transfer mostly occurs through new product purchasing, training personnel, personnel exchange, learning through a franchise system, etc. Conversely, joint patenting is a more direct measure of knowledge spillover and transfer because it involves direct collaboration between the research and development activities of the partners involved.

In this paper, we investigate whether absorptive capacity plays a role—even for technologically advanced and complex firms—in accruing benefits from a co-patenting activity with a foreign partner. To this aim, we first test the relationship between co-patenting and firm performance in indigenous firms. We then investigate the role played by the absorptive capacity of domestic firms in moderating the relationship between co-patenting and firm performance. The paper is structured as follows. In Sect. 2, we review the literature on R&D collaborations, and in particular, the literature on the role of absorptive capacity in relation to R&D collaborations. In Sect. 3, we describe the data and present some descriptive statistics. In Sect. 4, we investigate the relationship between co-patenting and firm performance, focusing on the moderating role of the absorptive capacity of firms. In Sect. 5, we perform some robustness checks, and Sect. 6 offers some concluding remarks.

2 Background literature

2.1 Research collaborations and spillovers

R&D activities are complex and multi-disciplinary (Cassiman & Veugelers, 2006), and very few firms are able to keep pace with technological advancements solely by undertaking independent R&D activities. This is particularly true for firms in developing countries, which are commonly confronted with innovation-unfriendly environments (Kafouros & Aliyev, 2016; Khan et al., 2018). R&D collaborations represent an important vehicle for new knowledge creation and innovation, since firms engaging in collaborative R&D activities can access external resources, share R&D risks and costs, and accelerate the speed of R&D (Riccobono et al., 2015; Zhou et al., 2018). Knowledge flows that go from the collaborating partner to the focal firm are called incoming spillovers and represent a main advantage of and incentive for collaboration (Belderbos et al., 2004; Chun & Mun, 2012; Ishikawa & Shibata, 2021). Knowledge flows from the focal firm to the collaborating partner are labelled as outgoing spillovers: firms usually seek to minimise these spillovers in order to avoid favouring competitors. Indeed, the possibility of benefiting from incoming spillovers is positively associated with the probability that a firm will embark on an R&D collaboration (Cassiman & Veugelers, 2002; Capuano & Grassi, 2019).

However, most of the time spillovers are asymmetric (Atallah, 2005; Ishikawa & Shibata, 2021; Petit et al., 2012), and incoming spillovers do not automatically translate into advantages in terms of innovative capabilities or profitability. On the contrary, firms need to be able to appropriate and exploit these spillovers of knowledge before they can reap any significant benefits. The advantages of benefiting from a research collaboration can therefore be overshadowed by the challenges that the firm must overcome to appropriate the incoming knowledge flows (Cassiman & Veugelers, 2002; Un & Rodríguez, 2018) and create value from the partnership (Belderbos et al., 2014). In this regard, Hagedoorn (2003) argues that collaboration in the form of co-patenting activities may represent a second-best solution compared to solo patenting. Similarly, Belderbos et al., (2014) claim that co-owned technology is less likely to be further developed compared to solely-owned patents and could increase strategic behaviours between partners that reduce the reciprocal appropriability of knowledge.

Incoming spillovers may be particularly relevant for organisations operating in developing countries since interacting with partners that are positioned closer to the technological frontier can increase innovative capacities (Un & Rodríguez, 2018). However, the challenges related to the appropriation of incoming spillovers are more intense for firms based in developing countries that collaborate with foreign organisations operating in advanced economies. This is due to the difficulties characterising collaborations between diverse partners (Kafouros et al., 2020). For instance, the average difference in technological capability between firms of advanced and developing countries reduces the likelihood of the firms from developing countries benefiting from incoming spillovers (Li, 2011). In turn, the presence of tacit knowledge and the need to share it as part of an R&D collaboration further reduces this likelihood (Montobbio & Sterzi, 2013). As a result, technology transfers tend to be more successful when the technology gap between partner organisations is small (Glass & Saggi, 1998; Vishwasrao & Bosshardt, 2001). Moreover, inventions and technologies originating from developed countries usually exploit an intensity of capital and of skilled labour that is less available in developing countries (Fu & Gong, 2011; Zanello et al., 2016). This implies that co-invention could be less appropriable and less productive for firms based in developing countries compared to those in developed countries.

In line with these arguments, Alnuaimi et al., (2012) find that international R&D collaborations within a multinational corporation network benefit advanced-country subsidiaries to a greater extent compared to developing-country subsidiaries, as these face difficulties in internalising external knowledge. Similar results are found by Giuliani et al., (2016), according to whom cross-country collaborations in the form of joint patents between BIC countries (Brazil, India, and China) and EU countries exert a positive effect in terms of innovative capabilities for firms in developing countries only if the collaboration involves inventors working for the same multinational corporation; instead, indigenous firms collaborating with European firms are not able to reap the same benefits from collaboration.

2.2 Research collaborations and absorptive capacity

We have argued that firms in developing countries face various difficulties in appropriating and creating value from incoming spillovers from a foreign R&D collaboration. The literature analysing the determinants of incoming spillovers flowing from advanced to developing countries focuses mostly on technology transfer via purchases of technology or knowledge spillovers from FDI. This literature shows that the presence of advanced-country knowledge spillovers in developing countries does not generate benefits per se. Furthermore, it suggests that in order for spillovers to generate benefits a minimum level of absorptive capacity (AC) is required on the receiving end. We pursue this line of reasoning and test the role of AC in developing-country firms gaining benefits from foreign R&D collaborations.

Absorptive capacity is the capability of a firm to identify, comprehend, and exploit external knowledge to gain a competitive advantage (Cohen & Levinthal, 1990). It is an intangible asset that results from investing in the production of new knowledge. On the one hand, AC allows a firm to recognise useful knowledge outside its boundaries. On the other hand, AC enables a firm to use this knowledge and adapt it to its overall internal needs (Amesse & Cohendet, 2001; Zahra & George, 2002). AC is not about the acquisition of codified blueprints; rather, it involves cognitive capabilities conveyed tacitly, which need a substantial learning effort to be built (Cohen & Levinthal, 1990; Narula & Marin, 2003).

A variety of studies provide evidence that the level of AC in a country impacts the ability of that country to derive benefit from incoming spillovers (Borensztein et al., 1998; Fagerberg & Verspagen, 2002; Griffith et al., 2004; Mingyong et al., 2006). For instance, Keller (1996) shows that technology acquisition in developing countries does not lead to sustained growth unless it is accompanied by investment in AC. Similarly, studies investigating geographical spillovers in developing countries receiving FDI show that higher levels of AC are associated with greater technological upgrades (Filippetti et al., 2017; Sultana & Turkina, 2020) and greater total factor productivity (Glas et al., 2016).

In the same vein, many studies find similar results through firm- or industry-level analyses (Fabrizio, 2009; Kneller, 2005; Li, 2011; Khachoo et al., 2018; Narula & Marin, 2003; Zhang et al., 2010; Zahra & Hayton, 2008), providing evidence that spillovers favour only those firms or industries that possess the capabilities required to appropriate them. According to Li (2011), technology purchases from domestic firms increase the innovation rate of the acquirer, while technology purchases from developed countries contribute to indigenous innovation only when coupled with previous investment in R&D. With reference to the spillovers deriving from FDI, Blalock and Gertler (2009) show that firms with R&D investments benefit more from the presence of FDI compared to firms that do not invest in R&D. Lu et al., (2017) find that FDI in China negatively affects domestic firms that do not spend on R&D, while this negative effect vanishes for R&D-investing firms. Similarly, Girma (2005) reports that FDI spillovers exert a positive effect only on firms with sufficiently high AC, while they produce negative effects on firms with low AC. These findings are in line with the argument made by Cohen and Levinthal (1990) that firms deliberately invest in R&D due to its ‘dual role’ in helping both generate new knowledge and as a contributor to absorptive capacity.

The evidence on spillovers from developed countries to developing countries in the form of knowledge purchase or FDI shows that AC is fundamental to making the transfer of technologies effective. Without a minimum level of AC, not only will spillovers of knowledge not be appropriated by indigenous firms but the source of these spillovers could even lead to negative consequences for the firms. For instance, while a number of works identify an overall positive influence of FDI on the performance of domestic firms (Blalock & Gertler, 2005; Cheung & Ping, 2004; Smarzynska Javorcik, 2004), a variety of studies find no effect (Sasidharan, 2006) or even a negative effect (Aitken & Harrison, 1999; Fu & Gong, 2011). Conversely, as previously mentioned, there is consensus in the literature regarding the fact that a key determinant in enabling FDI and the purchase of technology to produce positive externalities in a developing country is the ability of domestic firms to exploit the knowledge.

In this paper, we extend the investigation of these issues to the case of co-patenting between firms in developing and advanced countries. The importance of AC in (international) R&D collaborations between advanced-country firms has already been demonstrated (De Jong & Freel, 2010; Kim & Inkpen, 2005; Muscio, 2007; Seo et al., 2022). Collaborating on a research project with international partners increases the innovative performance of collaborating firms, conditional on the firms’ level of AC (Kafouros et al., 2020; Kim & Inkpen, 2005). However, understanding the impact that co-patenting has on developing-country firms and the eventual moderator effect of AC are topics that deserve to be explored.

3 Data

This study employs firm-level data from the Prowess database provided by the Centre for Monitoring Indian Economy Pvt. Ltd. (CMIE). The CMIE collects information from the annual financial reports of both publicly listed and unlisted firms, including balance sheets and income statements. The coverage of firms included in the database is high (Mathew, 2017); however, in this work we use only patenting firms, and more specifically manufacturing firms over the period of 1995–2015.

To study the relationship between foreign collaborations and the moderating role of absorptive capacity in the performance of firms, we rely on two main dependent variables (in line with Coad et al., 2020 and Dosi et al., 2022), namely firm growth (in terms of sales) and relative profitability (i.e. the share of profits from a firm's sales with respect to the other firms in the sector).

More specifically, we define

$$Firm\_Gr_{i,t} = \log Sales_{i,t} - \log Sales_{i,t-1}, \tag{1}$$

$$Profitability_{i,t} = \left(\frac{Profits_{i,t}}{Sales_{i,t}} \right) / \left\langle \frac{Profits_{j,t}}{Sales_{j,t}} \right\rangle_{j \in S_i}, \tag{2}$$

where $\langle \cdot \rangle_{j \in S}$ is the average over all firms in sector S and S_i is the main sector of activity of firm i defined at the three-digit level. Our main explanatory variables refer to foreign collaborations and absorptive capacity. Foreign collaborations are identified through a dummy variable that takes a value of 1 if the inventors of a patent application are located in India and in at least one foreign country and 0 if all inventors are based in India. Other works have also used co-patents as a measure of research collaboration, assuming that if firms engage formally in collaborative R&D and if the output of the R&D is measurable by patent indicators, then joint patents from both partners should be good measures of innovative output resulting from the collaboration (e.g. Kim and Song, 2007; Montobbio and Sterzi, 2013). Absorptive capacity is proxied by three different variables: (i) R&D intensity, (ii) the number of previous patent applications made by the firm and iii) the similarity of the firm's previous patent stock to the new patent co-developed with the foreign partner firm. Some of these measures have previously been used in other works (for instance, Bertrand and Mol, 2013; Cassiman and Veugelers, 2006; Griffith et al., 2003; Filippetti et al., 2017; Nooteboom et al., 2007).

We also control for a set of explanatory variables that, according to the literature, influence firm performance (see, for example, Bartz-Zuccala et al., 2018). These include firm size and age (Evans, 1987), cash balance and leverage (Bottazzi et al., 2014) and investment activity and growth of profits, to control for the growth momentum of the firm (Coad et al., 2020). Table 1 provides the definitions of the different variables we use, as well as some basic statistics.

As mentioned above, we proxy foreign R&D collaborations using information on joint patents. In particular, we base our analysis on PATSTAT (European Patent Office, 2020), a comprehensive database published by the European Patent Office, which collects data on patent applications filed at patent offices around the world and also records information about patent applicants and inventors for a large proportion of filings. PATSTAT potentially covers a very long time period since it allows tracing back the history of even the oldest patent authorities, e.g. the United States Patents and Trademarks Office, which was

Table 1 Variables, definitions and summary statistics

Variable	Definition	Mean	Median	Std. Dev.
Firm growth	Log difference in sales between t & $t-1$	0.174	0.145	0.238
Relative profitability	Profits over sales, relative to the sector mean	0.130	0.109	0.122
Foreign collaboration	Takes a value of 1 if the firm patented jointly with a foreign firm and 0 otherwise	0.056	0.000	0.229
R&D Intensity	Research and development expenses/Sales	0.034	0.007	0.090
Patent count	Number of patent applications	53.060	20.000	115.787
Relative profitability growth	Log difference in relative profitability between t & $t-1$	0.002	0.000	0.083
Sales	Total sales from industrial goods	93,347.12	5614.6	301,970.89
Age	Number of years since the year of incorporation of the firm	30.932	26.000	15.984
Investment intensity	Additions to gross fixed assets/Sales	0.127	0.065	0.159
Leverage	Borrowings/Total assets	0.309	0.305	0.164
Cash balance	Amount of cash available to the firm after payment of all expenses	314.545	2.200	955.429

already operating at the end of the 19th century. However, going back in time the amount of information available on each invention is greatly reduced. This is partly due to the fact that intellectual property has become more prominent in recent times. Moreover, the technology to effectively record and store detailed permanent records concerning the rapidly growing number of patent applications has become increasingly affordable in recent decades. Fortunately, detailed patent records reporting geographical information about applicants and inventors are available for the time interval and the industries covered by the Prowess data. This is particularly important for our purposes since we want to trace technological collaborations between Indian firms and foreign partners. To this aim, we begin by merging Indian firm-level data (Prowess) and patent data (PATSTAT) using firm names that appear in both databases. Further, using the information of countries of residence of the inventors taking part in collaborations, we are able to identify patents in which Indian inventors jointly patented with inventors resided in foreign countries.

As expected, there is significant heterogeneity in the number of patents filed by different countries. Figure 2 in the Appendix ranks the 20 countries with the highest number of patents filed in the 1985–2015 period and shows that although patenting in India has not yet reached the same intensity as in world leaders such as the United States or China, it has nevertheless reached a level that is comparable (or even superior) to several industrialised countries.

Figure 1 shows that the trend in the number of filed patents in India over recent decades has mirrored the global trend. This figure also plots a time series of the share of patents co-developed with at least one international partner. There is a noticeable cyclical pattern in the yearly data, which is probably due to some burstiness in patenting activity. Nevertheless, an increasing trend is clearly visible in the time series, showing that the growth of

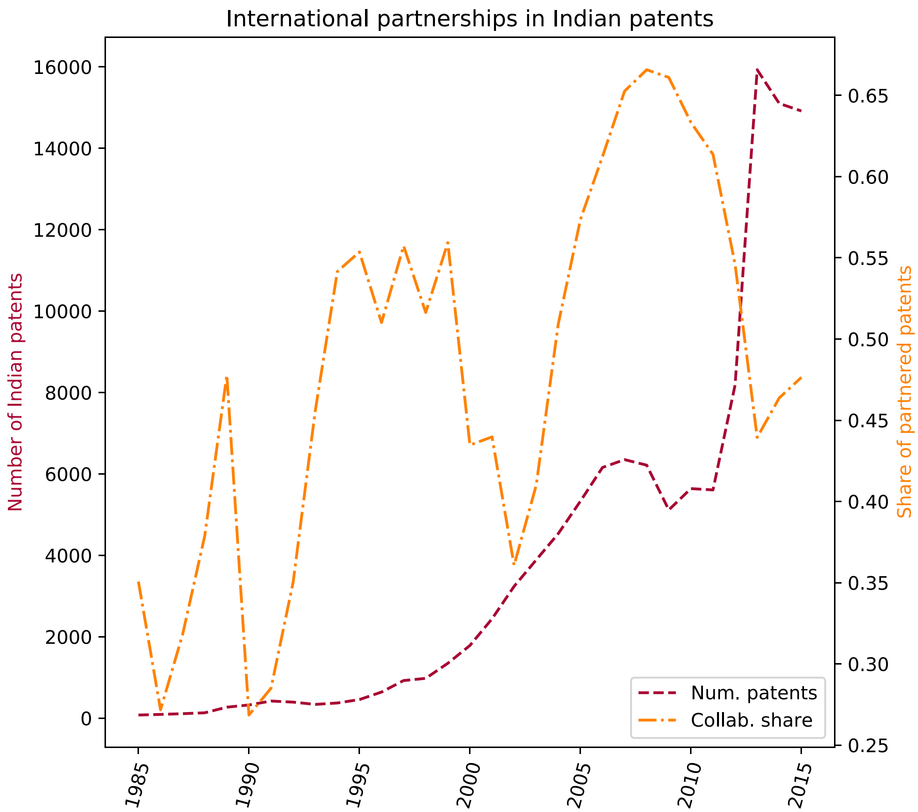

Fig. 1 Evolution of Indian technological partnerships across time

Indian patenting has gone hand in hand with a greater propensity to engage in co-patenting with foreign partners.

Concerning foreign partners, the USA ranks first in terms of the number of patents co-owned with Indian firms, as shown in Fig. 3 in the Appendix. The left panel presents patent counts on a linear scale, while the right panel does the same on a log scale. The linear graph clearly reveals a predominance of partnerships with the USA that dwarfs the contributions of all other countries. However, using a log scale shows that the landscape is more complex: co-patenting has not only involved many (mostly developed) partner countries in past decades but the number of collaborations has also grown steadily, in line with the overall increasing trend in Indian (and international) patenting activity.

Table 2 reports some comparative statistics for firms that jointly develop patents with foreign partners and firms that do not. We observe that the former category is larger and older, with slightly greater firm growth and profitability. Table 7 in the Appendix shows a correlation matrix for the variables used in the study.

Table 2 Comparison of summary statistics for firms collaborating in research with foreign partners versus others for the year 2010

Variable	No foreign R&D coll. Mean (1)	Std. Dev.	Foreign R&D coll. Mean (2)	Std. Dev.	Difference T-test (1)-(2)
Firm growth	0.099	0.162	0.158	0.044	– 0.058***
Relative profitability	0.041	0.110	0.156	0.117	– 0.115***
Profitability growth	– 0.031	0.089	0.077	0.106	– 0.109***
Sales (in INR million)	137778	520041	164789.3	124854.1	– 27011.31
Age	29.044	16.808	44.884	17.588	– 15.840***
Investment intensity	0.081	0.095	0.142	0.174	– 0.060***
Leverage	0.229	0.181	0.241	0.114	– 0.011
Cash in hand	148.400	577.773	271.682	248.908	– 123.282***
R&D Intensity	0.020	0.032	0.014	0.022	0.005
Patent count	5.22	13.141	4.00	13.14	1.224

4 Foreign R&D collaborations and firm performance

In this section, we study the relationship between the foreign R&D collaborations of firms and their performance. We estimate the following equation:

$$Y_{it} = \alpha + \beta X_{it-1} + \gamma Foreign\_Coll_{it-1} + \xi_i + \epsilon_{it}, \tag{3}$$

where Y_{it} represents either of two dimensions relating to the performance of firm i at time t, namely, sales growth and relative profitability. Our main explanatory variable of interest is the Foreign R&D Collaboration dummy, which takes a value of 1 if the firm filed a patent application together with a foreign partner and 0 if the patent is not in collaboration with a foreign partner. X_{it-1} is the vector of independent variables that we defined in Sect. 3. The controls include year and sector (two-digit industry) dummies. The firm fixed effects ξ_i absorb the time-invariant component, and ϵ_{it} represents the idiosyncratic shock term. The independent variables are lagged by one year. We estimate Eq. 3 by means of pooled and fixed effect OLS estimations. We use a fixed effects estimation since it allows us to control for time-invariant unobserved firm characteristics that could be correlated with the independent variables.

The results are reported in Table 3. Columns I and II report the results when the dependent variable is sales growth, while firm profitability results are displayed in columns III and IV. Moreover, columns I and III report the results of the pooled OLS in which we also include sector dummies. Instead, columns II and IV present the results of the fixed effects regression in which we include time dummies to account for patterns across firms as well as firm dummies to control for time-invariant firm characteristics.

Our main variable of interest, the dummy for foreign R&D collaborations, is positive and significant in all four regressions. This indicates that firms engaging in foreign R&D collaborations perform better than others, on average.

4.1 Moderating role of absorptive capacity

As discussed previously, knowledge transfer does not happen in a vacuum and there are certain factors that may play a crucial role in the process. In this section, we check whether the absorptive capacity of firms plays a moderating role in the relationship between foreign R&D collaborations and firm performance. We estimate the following three equations:

$$Y_{it} = \alpha + \beta X_{it-1} + \gamma Foreign\_Coll_{it-1} + \delta R\&D\_int + \mu R\&D \times FC + \xi_i + \epsilon_{it}, \tag{4}$$

$$Y_{it} = \alpha + \beta X_{it-1} + \gamma Foreign\_Coll_{it-1} + \delta Patents + \mu Patents \times FC + \xi_i + \epsilon_{it}, \tag{5}$$

$$Y_{it} = \alpha + \beta X_{it-1} + \gamma Foreign\_Coll_{it-1} + \delta Similarity + \mu Similarity \times FC + \xi_i + \epsilon_{it}. \tag{6}$$

We use three different measures of absorptive capacity, namely, R&D intensity, patenting, and related knowledge stock proxied by a similarity index, which are represented in Eqs. 4–6. In using these variables, the objective is to capture the existing innovative capabilities of a firm.

In Eq. 4, the variables of interest are foreign R&D collaboration, absorptive capacity proxied by R&D intensity and the interaction term between R&D intensity and foreign R&D collaboration ($R\&D * FC$). The interactive term measures the joint occurrence of innovation-related capabilities—in other words, absorptive capacity—and foreign R&D collaboration. The control variables include firm size, age, investment intensity, leverage, cash balance, profit growth, and time dummies.

In Eq. 5, we proxy absorptive capacity by previous patents filed by the firm. Here the variables of interest are foreign collaboration, absorptive capacity (proxied by the log number of patent applications) and the interactive term between patents and foreign collaboration ($Patents * FC$).

In Eq. 6, we proxy absorptive capacity by comparing the technological composition of the patent portfolio of the firm before each co-patenting event with the technological composition of the patents filed in collaboration with an international partner firm. We capture this with the similarity metric. The idea is to measure the extent to which each patent filed in collaboration with an international partner is close to the previous knowledge base of the firm. To this aim, we consider a metric that compares the vector of technologies describing patented inventions on which Indian firms collaborated with a foreign partner with the vector of International Patent Classification (IPC) technology codes (at the 8-digit level) describing the corporate patent portfolio of Indian firms prior to each co-patenting event. In particular, we employ the well-known cosine similarity metric:

$$Similarity(I, P) = \cos(\theta) = \frac{\sum_{i=1}^{n} I_i P_i}{\sqrt{\sum_{i=1}^{n} I_i}\sqrt{\sum_{i=1}^{n} P_i}}, \tag{7}$$

which, for two vectors I and P, measures the angle θ between the directions in which they are pointing. The more the vectors match entry by entry, the smaller the angle between them, and therefore, the larger the cosine similarity. In the present application, the entries of the vectors we want to compare with the similarity metric are all of the 8-digit IPC technology codes. If technology i is present in an invention (I) or in the technological portfolio of a firm (P), then I_i or P_i will be positive and reflect the weight of the technology in the

Table 3 Foreign R&D collaborations and firm performance

	Sales growth OLS	Sales growth FE	Profitability OLS	Profitability FE
Log sales	−0.0323***	−0.5388***	0.0029**	−0.0270***
	(−11.32)	(−45.91)	(2.24)	(−7.31)
Log age	−0.0511***	0.8176***	−0.0225***	−0.0610***
	(−7.31)	(25.61)	(−10.29)	(−4.84)
Investment intensity	−0.0813***	−0.1900***	−0.0221***	−0.0608***
	(−11.76)	(−20.16)	(−8.23)	(−16.87)
Log leverage	−0.0032	−0.0680***	0.0009	0.0110***
	(−0.66)	(−6.26)	(0.50)	(2.87)
Cash balance	0.0126***	−0.0025	0.0008	−0.0032***
	(6.02)	(−1.00)	(1.19)	(−3.47)
Profitability growth	0.5091***	0.1285***	0.6735***	0.2549***
	(11.68)	(3.88)	(55.72)	(16.57)
R&D Intensity	0.2618***	0.4750**	0.0206***	0.0991***
	(4.41)	(2.05)	(4.89)	(15.42)
Foreign coll.	0.1495***	0.0696***	0.0240***	0.0124***
	(9.26)	(6.40)	(5.13)	(3.01)
Time dummies	Yes	Yes	Yes	Yes
Sector dummies	Yes		Yes	
Observations	2504	2504	2504	2504
R^2	0.260	0.643	0.811	0.603
Firm clusters		120		120

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All columns include time dummies; columns I and III include sector dummies

Column I - OLS with firm growth, column II - fixed effects with firm growth, column III - OLS with profitability, column IV - fixed effects with profitability

vector. Instead, if a technology is not present, then the corresponding entry will have a value of 0. In this work, we analyze the similarity between different patent families.

It is worth noting that the similarity metric can yield different results based on how patent documents are grouped to define an invention. There are two ways of grouping: by application or by patent family. An application-based grouping treats each patent application as a separate invention. Therefore, the similarity metric will reflect the distance between the set of codes contained in an application and the set of codes contained in all other patent documents previously filed by the firm. An advantage of this grouping method is that it yields a higher number of observations. However, patent documents can also be grouped together into families when they are directly or indirectly connected by common priority applications. It is reasonable to argue that documents belonging to the same family should be considered as instances of the same invention, even though the list of applicants may change somewhat across documents and the technology codes applied to different documents within the same family can differ to an extent. Therefore, a family-based grouping of patent applications is less likely to overestimate the similarity between an invention and the previous knowledge portfolio of the firm. In the present analysis, we use patent families to define inventions.[2]

Table 4 reports the results of a fixed effects estimation with the different proxies for absorptive capacity (R&D, patents and similarity index) and the respective interaction terms, $R\&D * FC$, $Patents * FC$ and $Similarity * FC$. Each pair of columns reports results with the three different measures of absorptive capacity, columns 1–2 with R&D Intensity, columns 3–4 with Patents and columns 5–6 with the Similarity Index. Within each pair of columns, the first reports results with sales growth as an independent variable and the second with relative profitability.

As shown in the first two columns of Table 4, absorptive capacity proxied by R&D intensity is positively related to both measures of firm performance. The interaction term is positive and significant in both specifications, indicating that when combined with high levels of firm absorptive capacity, foreign R&D collaboration leads to higher performance. The most interesting result is that the foreign collaboration dummy is negative and significant after controlling for the interaction effect, suggesting that for firms with less absorptive capacity, foreign collaborations have a negative impact on performance. Taking the first column of Table 4 as reference, our results indicate that in the absence of any absorptive capacity foreign collaboration would lead to a 2.3% decrease in firm sales growth. In other words, much of the positive effect of foreign R&D collaboration is captured by absorptive capacity. This implies that the ability of firms to exploit external knowledge is not simply a factor that *either does or does not strengthen* the performance benefits, but it can also change the *direction* of the relationship. In other words, foreign R&D collaboration positively affects performance only when complemented with previous innovative capabilities. We observe similar results when the previous innovative activities of firms are proxied by previous patent applications (log of the number of patent applications) and by the similarity index, as shown in columns III–VI in Table 4. Note that for all of the different measures of absorptive capacity, foreign collaboration is negative and significant, providing confirmation for our findings.

The capabilities to benefit from foreign collaborations are likely accumulated over time, and as Hagedoorn (2003) points out, firms that engage in co-patenting activities once tend to pursue it again since the skills acquired with the first collaboration can be exploited further. Therefore, the collaboration history of firms could also matter for absorptive capacity. We perform a robustness check by replicating Table 4 but controlling for collaboration history. Foreign collaboration history is a dummy variable that takes a value of 1 if the firm previously collaborated with a foreign firm and 0 otherwise. The results are reported in Table 8 in the Appendix. We find that the results that we observed previously regarding the mediating role of absorptive capacity in the relationship between foreign collaboration and firm performance still holds even after we control for the collaboration history of firms.

As Cohen and Levinthal (1990) argue, absorptive capacity can comprise knowledge related to 'basic skills or even a shared language, but may also include knowledge of the most recent scientific or technological developments in a given field.' In other words, the results we observe confirm the insights of Cohen and Levinthal (1990) that absorptive capacity is relevant also in the context of producing sophisticated and technological knowledge. In this work, we focus on absorptive capacity in the context of the scientific and technological capabilities of firms. Our findings imply that even for advanced firms

[2] The results are robust to both definitions of invention.

Table 4 Foreign R&D collaboration and firm performance: the role of absorptive capacity (moderator measures in second row)

Dependent variable measure of AC	Sales growth R&D	Profitability R&D	Sales growth patents	Profitability patents	Sales growth similarity	Profitability similarity
Log sales	−0.4539***	−0.0436***	− 0.1094***	−0.0543***	−0.1530***	0.0047
	(−46.59)	(−9.87)	(−13.93)	(−15.57)	(−8.80)	(0.11)
Log age	0.9843***	−0.0871***	0.4247***	−0.1356***	0.2821***	0.2040*
	(29.78)	(−4.64)	(11.39)	(−8.03)	(5.26)	(1.92)
Investment intensity	−0.2377***	−0.0376***	0.0656***	−0.0365***	−0.1162***	−0.0599**
	(−25.72)	(−9.98)	(9.49)	(−12.32)	(−10.25)	(−2.20)
Log leverage	−0.1099***	−0.0011	0.0632***	−0.0161***	−0.0743***	0.0124
	(−11.70)	(−0.26)	(8.80)	(−5.29)	(−6.13)	(0.52)
Log cash balance	0.0059**	−0.0121***	0.0075***	−0.0151***	−0.0062	−0.0101
	(2.21)	(−11.41)	(3.57)	(−16.99)	(−1.54)	(−0.76)
Profitability growth	0.0107	0.1449***	0.2055***	0.1862***	0.4664***	0.4944***
	(0.33)	(10.33)	(6.06)	(13.04)	(13.06)	(7.40)
oreign Coll.	−0.2319***	−0.1108***	−0.0515***	−0.0328***	−0.1874***	−0.1418***
	(−7.24)	(−5.60)	(−4.93)	(−7.33)	(−10.08)	(−3.35)
R&D Intensity	1.2104***	0.1360***	0.0049	0.0966***	0.0626***	0.0160
	(5.20)	(15.89)	(0.42)	(15.98)	(10.69)	(1.11)
No. of patents			0.0004	0.0033***	0.0064***	0.0009
			(0.61)	(12.84)	(2.64)	(0.11)
R&D*For. Coll.	0.4696***	0.1574***				
	(9.87)	(5.41)				
Patents*For. Coll.			0.0827***	0.0507***		
			(5.30)	(7.49)		
Similarity*For. Coll.					0.4541***	0.1855***
					(16.07)	(4.65)
Similarity					−0.0778***	−0.0092
					(−9.67)	(−0.66)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2504	2504	2504	2504	2504	2504
R^2	0.613	0.473	0.315	0.727	0.385	0.721
Firm clusters	120	120	120	120	120	120

doing sophisticated activities such as patenting, their level of absorptive capacity in terms of previous innovative capabilities is crucial in order for them to be able to exploit external knowledge. The challenge therefore remains to identify the mechanisms by which developing-country firms are able to raise their level of absorptive capacity. For instance, the mobility of inventors (Miguélez & Moreno, 2015) or learning through interaction (Bishop et al., 2011) could represent important channels to foster the development of capabilities that increase absorptive capacity within indigenous firms.

5 Robustness checks

In this section, we perform a set of checks to test the robustness of the empirical results described above. In particular, we examine the role of the scale of foreign collaborations in firm performance and the mediating role played by absorptive capacity in this relationship. Hagedoorn (2003) shows evidence of persistent behaviour in co-patenting, that is, firms engaged in co-patenting activities in the past are more likely to adopt co-patenting in subsequent collaborative activities. This suggests that firms likely further employ the initial experience that they gained through collaborative R&D. Therefore, the intensity or the scale of foreign collaborations could play a significant role in firm performance, and we investigate whether absorptive capacity still plays a role when the scale of foreign collaborations is considered.

While the analysis in the previous section focused on whether a firm has engaged in a foreign collaboration or not, here, as a robustness check we perform a similar analysis considering the impact of the *number* of foreign collaborations (FCs) on firm performance. Table 5 replicates Tables 3 and Table 6 replicates Table 4 but with the number of foreign R&D collaborations as the independent variable. Similarly to what we observe in Table 3, the number of foreign collaborations is associated with stronger firm performance. However, when we examine the role of absorptive capacity in moderating this relationship, as reported in Table 6 not only is the coefficient for the interaction variable positive and significant but the number of foreign collaborations variable turns negative, suggesting that for firms with less absorptive capacity even a high scale of foreign collaborations (proxied by the number of FCs) can have a negative impact on performance. The results are strikingly similar to what we observed previously.

6 Concluding remarks

In this work, we investigated whether Indian firms benefit from patent collaborations and explored the role played by firms' prior knowledge in augmenting these relationships. More specifically, we assessed how absorptive capacity affects the relationship between foreign R&D collaboration and firm performance. We measure absorptive capacity through R&D intensity, patenting intensity, and a similarity index that captures the similarity between a specific patent and the previous patent stock of the applicant firm. We find that absorptive capacity is strongly significant and positive, indicating that when combined with high levels of pre-existing capabilities foreign R&D collaboration leads to stronger firm performance. More interestingly, we find that foreign collaboration is negative and significant after controlling for the interaction effect. This suggests that foreign collaborations may have a detrimental impact on the performance of firms with low absorptive capacity. The findings imply that the capability to imitate and absorb knowledge is a necessary stepping stone for the acquisition of more sophisticated competencies required to operate closer to the technology frontier. To our knowledge, this is the first work to show evidence of the effect of international co-patenting on Indian manufacturing firms.

Our main contribution to the literature addresses the fact that—as pointed out by Giuliani et al., (2016)—previous works have mostly concentrated on more conventional means of technology transfer such as imports, exports and FDI (Archibugi & Pietrobelli, 2003; Lall, 1992; Lall & Narula, 2004). In contrast, we consider technology transfer

Table 5 Foreign R&D collaborations and firm performance (robustness check with number of foreign collaborations)

	Sales growth OLS	Sales growth FE	Profitability OLS	Profitability FE
Log sales	−0.0296***	−0.5576***	0.0038***	−0.0307***
	(−7.89)	(−51.74)	(2.94)	(−8.47)
Log age	−0.0268***	0.8334***	−0.0234***	−0.0575***
	(−4.20)	(27.56)	(−10.81)	(−4.66)
Investment Intensity	−0.1206***	−0.1908***	−0.0244***	−0.0657***
	(−15.15)	(−21.91)	(−9.27)	(−18.79)
Log leverage	0.0210***	−0.0704***	0.0006	0.0114***
	(4.08)	(−7.35)	(0.36)	(3.08)
Cash balance	0.0084***	−0.0046**	0.0009	−0.0029***
	(4.01)	(−1.98)	(1.25)	(−3.12)
Profitability growth	0.5981***	0.0832***	0.6552***	0.2228***
	(14.74)	(2.67)	(54.23)	(14.94)
R&D Intensity	0.3764***	0.5950***	0.0246***	0.1021***
	(6.59)	(2.81)	(5.95)	(16.14)
No. of For. Coll.	0.0401***	0.0433***	0.0090**	0.0045
	(3.43)	(5.28)	(2.24)	(1.30)
Observations	2504	2504	2504	2504
R^2	0.407	0.666	0.804	0.603

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

through international R&D collaborations. The dynamics of knowledge transfer in a research collaboration are quite different from the processes of building the necessary organisational capabilities for the mere imitation of knowledge produced elsewhere. Furthermore, and as pointed out by Amsden (2009), the accumulation of technological and managerial capabilities usually occurs within domestic firms rather than within subsidiaries of foreign-owned firms. This is likely because while multinational corporations are an important source of capital investment, very little technological transfer takes place between subsidiaries since most of the tacit forms of knowledge reside (and most R&D activities take place) in the headquarters of firms that are generally located in developed countries (Cimoli et al., 2009). By considering co-patenting activities—a proxy for direct R&D collaborations—we are able to better capture the transfer of a type of knowledge that goes far beyond the mere development of skills for how to operate machinery produced in developed countries. The evidence presented in this work expands our knowledge of the microeconomics underlying knowledge accumulation, highlighting that technological development is gradual and that even complex and dynamic organisations close to the frontiers of technology build on their existing technological capabilities to climb the 'ladder of knowledge complexity' (Dosi et al., 2022).

Our findings bear fundamental policy implications. There is no doubt that the processes of knowledge accumulation and industrial development require public policies that help build technological and organisational learning. An optimal policy mix should consider the high levels of firm heterogeneity in terms of capabilities, in particular in

Table 6 Foreign R&D collaboration and firm performance: the role of absorptive capacity (robustness checks with number of foreign collaborations)

	Sales growth R&D	Profitability R&D	Sales growth patents	Profitability patents	Sales growth similarity	Profitability similarity
Log sales	−0.4202***	−0.0483***	−0.1129***	−0.0510***	−0.1151***	0.0472***
	(−48.31)	(−12.50)	(−13.48)	(−13.22)	(−7.02)	(4.83)
Log age	0.8798***	−0.1635***	0.4005***	−0.1452***	0.1446***	−0.2545***
	(27.87)	(−8.96)	(10.23)	(−7.98)	(2.68)	(−7.97)
Investment intensity	−0.2450***	−0.0443***	0.0646***	−0.0364***	0.0257**	−0.0047
	(−28.37)	(−11.15)	(8.61)	(−11.13)	(2.04)	(−0.63)
Log leverage	−0.4285***	−0.0907***	0.2303***	−0.0907***	0.1625***	0.0501
	(−10.35)	(−5.39)	(6.68)	(−5.85)	(3.00)	(1.56)
Cash balance	0.0067***	−0.0089***	0.0050**	−0.0138***	0.0096***	−0.0013
	(2.68)	(−8.78)	(2.27)	(−14.63)	(3.02)	(−0.69)
Profitability growth	0.4870***	0.1458***	0.0902**	0.1491***	−0.3399***	0.0699**
	(11.99)	(8.42)	(2.48)	(9.53)	(−6.98)	(2.42)
No. of For. Coll.	−0.0320**	−0.0134**	−0.0164*	−0.0306***	−0.1158***	0.0026
	(−2.39)	(−2.47)	(−1.71)	(−7.35)	(−3.81)	(0.14)
R&D Intensity	1.5639***	−0.6946***	0.0089	0.0936***	0.3864	0.2027
	(7.18)	(−6.22)	(0.72)	(14.46)	(1.01)	(0.90)
No. of patents			0.0005	0.0031***	0.0012*	0.0024***
			(0.82)	(11.36)	(1.87)	(6.40)
R&D*For. Coll.	2.9921***	0.5879***				
	(7.40)	(3.18)				
Patents*For. Coll.			0.1058***	0.0594***		
			(6.13)	(7.68)		
Similarity*For. Coll.					0.1145***	−0.0313
					(3.51)	(−1.62)
Similarity					0.0167*	0.0258***
					(1.78)	(4.52)
Observations	2504	2504	2504	2504	2504	2504
R^2	0.635	0.558	0.242	0.625	0.428	0.118
Pseudo R^2						

the case of emerging economies. As Cirera and Maloney (2017) point out, for firms that are in a lower stage of development, policy should ensure ease of access to foreign technology, initiate programmes to stimulate knowledge transfer and nurture the organisational capabilities that allow them to absorb technology from advanced countries. However, as sectors move towards the technological frontier, firms tend to be more complex and sophisticated. As this process unfolds, policy should involve building instruments that help firms in supporting large R&D projects, where they can learn to seize technological and organisational opportunities.

Although our work focuses on a sample of Indian manufacturing firms, we believe that the evidence presented could also hold true for firms in other developing countries. Future research should investigate this possibility by focusing on data from other countries in various stages of economic development.

Appendix

See Figs. 2, 3 and Tables 7, 8.

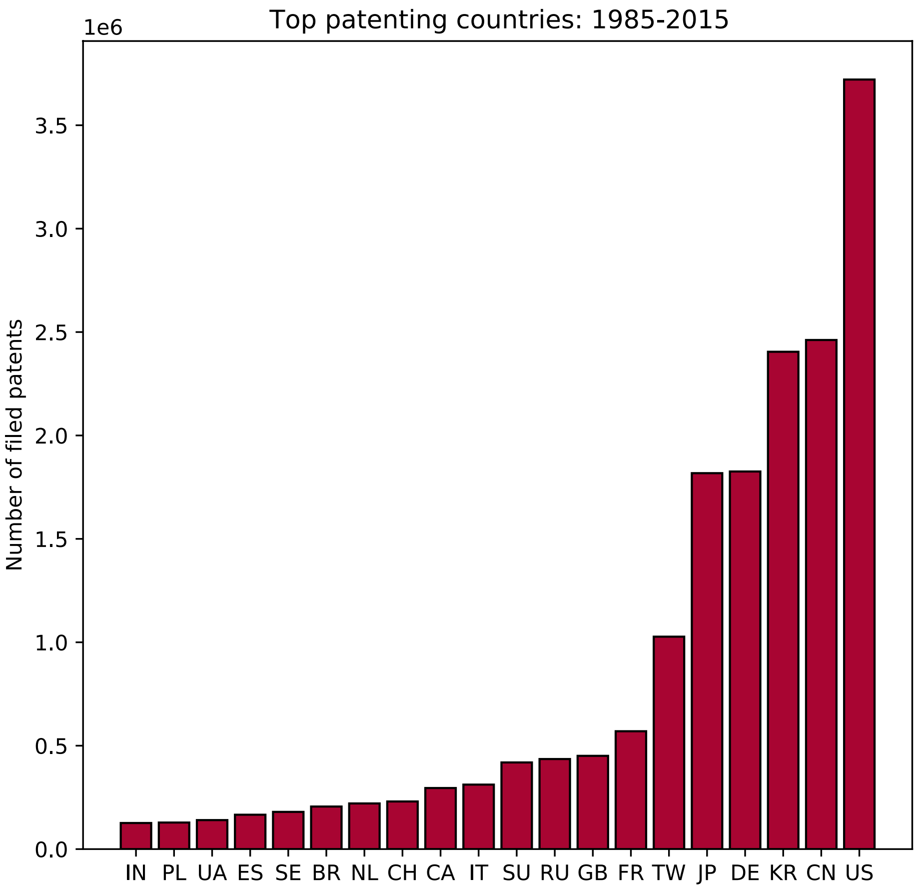

Fig. 2 Top patenting countries

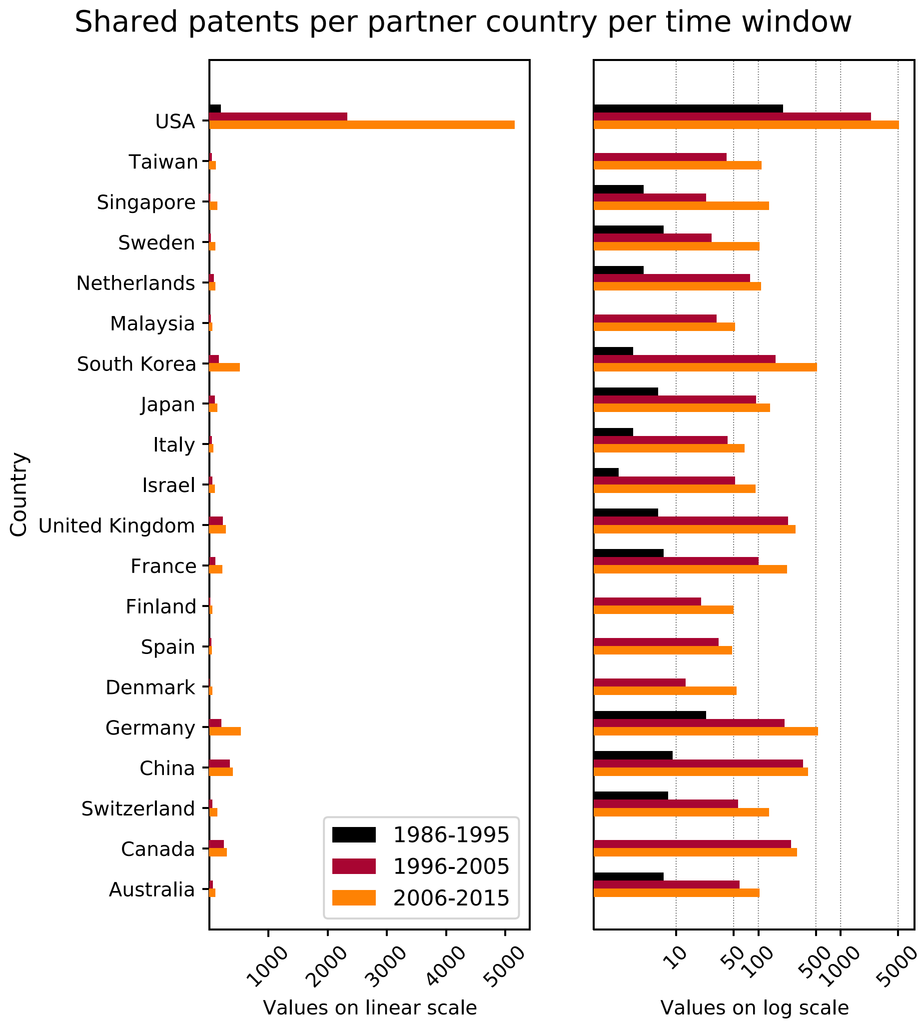

Fig. 3 Co-ownership of patents: India's main partner countries

Table 7 Correlation matrix

	Firm Gr.	Profit.y	Sales	Age	Invest. Int.	Leverage	Cash balance	R&D Intensity	Patent count	Sim.y	R&D* FC	Pat* FC	Sim.y* FC
Firm Gr.	1												
Profit.y	0.156	1											
Sales	0.024	−0.453	1										
Age	−0.194	−0.153	0.302	1									
Inv. Int.	0.205	0.265	−0.106	−0.220	1								
Leverage	0.009	−0.177	0.016	−0.085	0.026	1							
Cash Bal.	0.0138	−0.446	0.743	0.320	−0.126	−0.028	1						
R&D	0.063	0.034	−0.084	−0.185	0.820	−0.064	−0.096	1					
Patents	0.072	0.114	−0.078	−0.177	−0.003	−0.018	−0.092	−0.006	1				
Sim.y	−0.007	0.079	0.113	0.086	−0.053	−0.064	0.126	−0.080	−0.270	1			
R&D*FC	0.155	0.008	−0.017	−0.013	0.001	−0.012	−0.071	−0.057	−0.069	0.031	1		
Pat*FC	0.022	−0.076	0.095	0.201	0.001	0.041	0.095	0.014	−0.548	0.252	0.088	1	
Sim.y*FC	0.015	0.099	−0.010	0.494	0.072	−0.012	−0.012	−0.027	−0.074	0.250	0.560	0.097	1

Table 8 Foreign R&D collaboration and firm performance: the role of absorptive capacity (robustness checks after controlling for collaboration history)

	Sales growth R&D	Profitability R&D	Sales growth patents	Profitability patents	Sales growth Similarity	Profitability Similarity
Log sales	−0.4717***	−0.0529***	– 0.1153***	−0.0502***	−0.2168***	0.0689
	(−52.97)	(−14.33)	(– 14.13)	(−13.40)	(−14.82)	(1.30)
Log age	0.9741***	−0.1204***	0.3990***	−0.1423***	0.3480***	−0.0727
	(30.78)	(−7.08)	(10.22)	(−7.91)	(7.30)	(−0.46)
Investment Intensity	−0.2539***	−0.0473***	0.0571***	−0.0379***	−0.1976***	−0.0100
	(−28.98)	(−14.49)	(7.82)	(−11.85)	(−18.92)	(−0.29)
Log leverage	−0.5507***	−0.0643***	0.1978***	−0.1053***	−0.0035	−0.0615*
	(−13.42)	(−4.02)	(5.75)	(−6.85)	(−0.30)	(−1.96)
Cash balance	0.0050*	−0.0132***	0.0045**	−0.0140***	0.0434***	0.0019
	(1.95)	(−13.96)	(2.04)	(−14.93)	(14.51)	(0.20)
Profit growth	−0.0411	0.1332***	0.0371	0.1465***	0.3937***	0.5392***
	(−1.30)	(10.27)	(1.34)	(11.75)	(10.56)	(6.87)
Foreign Coll. Dummy	−0.1965***	−0.1097***	0.0280**	−0.0200***	0.0190	−0.1259***
	(−6.04)	(−6.22)	(2.24)	(−3.76)	(0.76)	(−3.65)
R&D Intensity	1.6781***	0.1398***	0.0018	0.0934***	−7.0808***	0.5621
	(7.68)	(18.36)	(0.14)	(14.52)	(−19.45)	(0.67)
R&D*For. Coll.	0.4818***	0.1536***				
	(10.64)	(6.00)				
Patents*For. Coll.			0.1364***	0.0566***		
			(7.40)	(6.85)		
No. of Patents			0.0003	0.0030***	0.0263***	−0.0092
			(0.47)	(11.10)	(6.98)	(−0.81)
Distance*For. Coll.					0.1212***	0.1575***
					(3.83)	(3.08)
Distance					0.0003	−0.0070
					(0.03)	(−0.56)
Foreign Coll. History	−0.1002***	0.0073	– 0.0758***	−0.0101	−0.0206	−0.0155
	(−6.02)	(1.18)	(– 5.06)	(−1.57)	(−1.10)	(−0.78)
Observations	2504	2504	2504	2504	2504	2504
R^2	0.632	0.609	0.243	0.630	0.608	0.572
Firm clusters	120	120	120	120	120	120

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