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The role of domestic-firm knowledge in foreign R&D collaborations: evidence from co-patenting in Indian firms

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Abstract

In this paper we analyze the impact of foreign R&D collaborations on 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 of Indian firms with foreign partners. The results from a causal mediation analysis confirm the crucial role played by domestic firms' absorptive capacity in enhancing the benefits from a foreign collaboration. The evidence we present in this work highlights the microeconomics behind the process of technological capability accumulation and catching up in developing countries.

JEL Codes: L20, O30, D24, O12
Keywords: Co-patenting, Foreign Collaboration, Absorptive Capacity, Capability accumulation, Corporate Performance

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1 Introduction

It is widely recognised that technological innovation is a main driver for sustained economic growth. Innovation emerges from knowledge recombination (Schumpeter, 2017; Nelson and Winter, 1982), while the fragmentation and dispersion of knowledge across different organizations make R&D collaborations an important vehicle of technological diffusion. Consequently, international R&D collaborations contribute to technological diffusion from advanced to developing countries and to the economic catch up of the latter (Montobbio and Sterzi, 2011; Giuliani et al., 2016). However technology transfer is neither an easy nor a costless process: technology adoption relies on substantial indigenous technological endeavors by enterprises (Lall, 2001, 2005) and on absorptive capacity (Cohen and Levinthal, 1990). To add, usually technologies developed in advanced economies are not easily adaptable to the socio-economic conditions of developing countries (Atkinson and Stiglitz, 1969; Acemoglu, 2002) which make it hard for technologically backward countries to catch up by simply absorbing the most advanced technologies (Romer, 1994; Grossman and Helpman, 1994). The above situation is exacerbated by the fact that, compared to advanced countries, developing countries invest fewer resources in R&D, despite the potential for high returns (Cirera and Maloney, 2017). R&D not only stimulates innovation but also develops the ability of firms to identify, assimilate, and exploit outside knowledge, which in turn helps to increase the impact of technology spillovers. As Cirera and Maloney (2017) argues within the "capabilities escalator" framework, firms first progress from basic production capabilities to competencies for technology adoption that accelerate technology transfer, which further helps them to move to more sophisticated activities like generating new technologies. This process of climbing up the "capability ladder"[1] ultimately results in the accumulation of the knowledge capital of firms. In this paper, we aim to shed light on the role that the knowledge endowment of firms based in developing countries plays in generating beneficial outcomes from foreign R&D collaboration activities.

In the past, firm collaborations for knowledge creation used to take place within the home country for a variety of reasons, e.g. the need for geographical proximity between R&D labs or concerns regarding information leakage to rivals (Miller, 1994; Cohen, 1998). In the current globalized world, factors like the rising costs and risks associated with innovation, the emergence of global value chains and, more importantly, the availability of richer sources of knowledge outside the country have increasingly pushed firms to engage in research collaborations with global partners. International collaborations contribute crucially to the rate of innovation of developing countries. The rapid increase in the number of patents assigned to developing countries such as China and India is in large part due to the presence of multinational enterprises and international collaboration activities with developed countries (Branstetter et al., 2014). These collaborations help the transfer of technologies and know-how because developed countries tend to be closer to the technological frontier and

[1]Even though conceptually similar, Coad et al. (2020) calls this as "capabilities ladder" instead of "capabilities escalator", since as they point out, there is no automatic upward tendency for capabilities over time.

developing countries tend to be receivers of these advanced technologies. As a result, patents accruing from international collaborations involving actors operating in emerging economies tend to be of higher quality than indigenous patents (Alnuaimi et al., 2012). Similar results are reported by Branstetter et al. (2014) who find that co-invented patents involving Indian firms receive almost 30 percent more non-self-citations compared to indigenous Indian patents.

Research collaborations increase the innovative potential of firms through the generation of more complex, diverse and novel innovations (Quéré, 2003; Savino et al., 2017). For instance, international collaborations have been found to increase the chances to originate breakthrough innovation (Phene et al., 2006). However, the integration of knowledge coming from different environments also poses challenges to firms, since the ability to benefit from research collaborations depends on mastering the necessary competences to acquire and exploit diverse and complex external knowledge.

Evidently, firms differ widely in terms of their knowledge base and in their capabilities to acquire and recombine new knowledge. As a consequence, not all domestic firms that have access to external knowledge through collaborations with industrialised firms would benefit from it in the same way. As documented by Keller (1996, 2010) on the effect of technology purchase, 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) points out the complementary role played by indigenous innovation efforts on achieving benefits from foreign technology acquisition through FDI. While the mediating role of absorptive capacity has been considerably explored with respect to FDI and multinational enterprises, the role of absorptive capacity with respect to research collaborations is less explored. Although FDI might involve some necessary transfer of research and development, the nature of knowledge transfer is very different from co-patenting which is development of new-to-world knowledge. Also, among the different stages within the capability escalator approach put forth by (Cirera and Maloney, 2017), FDI is categorized as an activity at a lower (specifically, the second) stage of the escalator where firms develop competencies for technology transfer, while knowledge partnerships occur at a higher (third) stage. Undoubtedly, these are activities that involve different level of sophistication and requires different competencies. Partnerships and research collaborations with foreign firms operating on the technology frontier will expose domestic firms to new, complex and diverse knowledge, and here we argue that only competitive firms with high absorptive capacity are able to gain advantage through technology transfer.

Hence, the purpose of this work is to investigate the role of absorptive capacity in explaining the effect of foreign collaborations on domestic firm performance. *Firstly*, is there an effect of foreign collaborations on firm performance? *Secondly*, if a measurable effect exists, why is there a relationship between foreign collaborations and firm performance? In other words, we ask whether and to what extent the relationship is mediated through firm's absorptive capacity. To understand this, we undertake a causal mediation analysis, which helps us to decompose the total effect of foreign collaborations on firm performance into two components: the indirect effect that is mediated via absorptive capacity and the direct effect that captures other mechanisms. The empirical analysis is based on a novel merged panel dataset obtained from two databases: PROWESS, which contains information on Indian manufacturing firms, and PATSTAT, an exhaustive database collecting information about patents filed worldwide at national and regional patent authorities. Our results indicate that absorptive capacity plays a mediating role in helping firms to benefit from foreign R&D collaborations and the effect is very high: surprisingly, the direct effect through other mechanisms is negligible, and much of the total effect is composed of indirect effect that is mediated through the ability of firms to use and assimilate external knowledge.

The paper is structured as follows. In section 2, we review the theoretical background and previous literature; in section 3, we describe the data used and present some descriptive statistics. In section 4 and 5 we investigate the relation between foreign collaborations and firm performance, focusing on the mediating role of absorptive capacity of firms. Section 6 concludes.

2 Theory and literature

2.1 Research collaborations and spillovers

Knowledge is one of the most strategically important resources in generating competitive advantage for firms (Winter, 1987; Barney, 1991). Creation of knowledge plays an important role in the success of organizations, since "even small, incremental knowledge can distinguish an organization from its competitors" (Cohen, 1998, p.23). This knowledge creation process most often builds on the recombination of existing knowledge and capabilities (Schumpeter, 2017; Nelson and Winter, 1982), while the fragmentation and dispersion of knowledge across different organizations strongly hinder the generation of innovation exclusively within firm boundaries (Tether, 2002). As Cassiman and Veugelers (2006) point out, R&D activities are complex and multi-disciplinary. Therefore very few firms are able to keep pace with technological advancements solely by undertaking independent R&D activities. For this reason, R&D collaborations represent an important vehicle of new knowledge creation and innovation for firms. Firms engage in collaborative R&D activities, which allow them to access external resources, share R&D risks and costs, and accelerate R&D speed (Riccobono et al., 2015; Zhou et al., 2018). Furthermore, collaborations promote the realization of inventions that the single firm would not be able to realize on its own. To this aim, firms are required to exchange knowledge which also leads to reciprocal learning.

The knowledge flows from the collaborating partner to the focal firm are called incoming spillovers and represent a main advantage of and incentive for the collaboration (Belderbos et al., 2004). On the opposite, knowledge flows from the focal firm to the collaborating partner are labelled outgoing spillovers: firms usually seek to minimize these spillovers in order to avoid favouring competitors. The possibility of benefiting from incoming spillovers is indeed positively associated with the probability that a firm will embark on a R&D collaboration (Cassiman and Veugelers, 2002). These incoming spillovers may be particularly relevant for organizations operating in developing countries, since interacting with partners that are often positioned closer to the technological frontier can increase innovative capacities. However, 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 the firm must overcome to appropriate the incoming knowledge flows (Cassiman and Veugelers, 2002) and to create value from the partnership (Belderbos et al., 2014). In this regard Hagedoorn (2003) argues that a collaboration in the form of co-patenting activity may represent a second best solution compared to own patenting. According to Belderbos et al. (2014, p. 850) "firms are less likely to further develop co-owned technology internally, although such consecutive developments are often crucial in appropriating economical returns for their innovation efforts". Moreover, the co-ownership of patents could generate competition between partners and strategic behavior, which in turn can lead to a reduced ability to acquire and exploit the partners' knowledge (Belderbos et al., 2014).

The challenges related to the appropriation of incoming spillovers are intensified for firms based in developing countries that collaborate with foreign organizations that operate in advanced economies. The average difference in technological capabilities between firms of advanced and of developing countries reduces the likelihood of the firms from developing countries to benefit from incoming spillovers (Li, 2011). Evidence for the above considerations is abundant in the literature on multinational corporations. Technology transfer subsidiaries based in developing countries tends to rely on not-on-the-frontier technologies, which are usually older technologies compared to the ones that are transferred to subsidiaries in developed countries. Indeed, studies have indicated that technology transfers tend to be more successful when the technology-gap between partner organizations is reduced (Glass and Saggi, 1998; Vishwasrao and Bosshardt, 2001). Moreover, inventions and technologies realized in developed countries usually exploit intensity of capital and of skilled labour that are less available in developing countries: these characteristics make the co-invention less appropriable and less productive for firms based in developing countries compared to those from developed countries (Fu and Gong, 2011).

2.2 Research collaborations and absorptive capacity

We reviewed several difficulties faced by firms in developing countries in appropriating and creating value out of incoming spillovers from organizations in advanced countries. Likely, the most important factor among them is absorptive capacity. Absorptive capacity is the capability of the firm to comprehend and exploit external knowledge to gain competitive advantage (Cohen and Levinthal, 1990; Zahra and George, 2002). Previous studies have shown that the benefits that firms are able to derive from incoming spillovers are contingent on their level of absorptive capacity (Griffith et al., 2004; Li, 2011). This point was further highlighted by Keller (1996), who showed that technology acquisition in developing countries does not lead to sustained growth unless it is accompanied by investment in absorptive capacity. Studies focusing on FDI as a way of inducing knowledge spillovers, shows that greater levels of absorptive capacity are associated with higher benefits from FDI both in the form of technological upgrade (Sultana and Turkina, 2020; Filippetti et al., 2017) and of TFP (Glas et al., 2016).

The presence of FDI is mediated by absorptive capacity also at the firm level. Blalock and Gertler (2009) showed 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) found that FDI in China negatively affects domestic firms that do not spend in R&D, while this negative effect vanishes for R&D investing firms. Girma (2005) reported that FDI spillovers exert a positive effect only on firms with sufficiently high absorptive capacity, while they produce negative effects on firms with low absorptive capacity.

While previous studies have explored the mediating role of absorptive capacity in the context of FDI, to our knowledge there is no study that addressed this aspect in the context of co-invention between firms in developing and developed countries. Needless to say, FDI and co-invention are two relevant channels of knowledge absorption, that provide conduits for the diffusion of knowledge between countries and for absorption within firms. However, they can be very different, e.g. in terms of the kind of knowledge sharing they foster. The mechanism and the kind of technology transfer that occurs through conventional channels like FDI is an important question, especially when the technology transfer mainly involves adaption to local markets. In fact, in such cases FDI might require some necessary transfer of research and development; nevertheless, it is likely that both the extent and the nature of the technology transfer would be very different from what would occur as part of a joint development of a new-to-the-world knowledge (co-patenting). Indeed, while multi-national corporations are an important source of capital investment, very little technology transfer might actually take place, since in most of the cases, the R&D labs of multi-national firms are located in advanced countries, thereby restricting knowledge flows to partners in developing countries (Cimoli et al., 2009).

In line with existing literature, we are firstly interested in understanding if Indian firms benefit from joint innovation, as proxied by shared patenting activity, with developed country firms. The benefits that firms in developing countries gain from developing joint patents with advanced country firms is not straightforward. For instance, Giuliani et al. (2016) found that cross-country collaborations in the form of joint patents between BIC countries and EU countries exert a positive effect in terms of innovative capabilities for firms in developing countries only if the collaboration takes within a multinational corporation; instead, the effect is negative for domestic firms. Secondly, we investigate the moderating role of absorptive capacity. The available evidence suggests that within a multinational corporation setting, subsidiaries based in emerging countries have difficulties in absorbing inventors knowledge (Alnuaimi et al., 2012). In the same vein, a minimum level of knowledge and capabilities may be required to be able to internalize external knowledge coming from developed country firms (Girma, 2005). We are therefore interested in exploring how the existing technological capabilities of domestic firms affect the benefits from co-patenting with foreign partners. In other words, we ask whether, in a cross-country collaboration, a higher level of absorptive capacity lead to higher performance gains for the domestic firm.

3 Data

This study employs firm-level data from the Prowess database, provided by the CMIE (Centre for Monitoring Indian Economy Pvt. Ltd.). The CMIE collects information from the annual financial reports of companies, including balance sheets and income statements. It covers both publicly listed and unlisted firms. The companies covered account for around 70 percent of industrial output, 75 percent of corporate taxes, and more than 95 percent of excise taxes collected by the Government of India. In this work, we use the data on manufacturing firms over the period 1995 to 2012.

To study the effect of foreign collaborations and the mediating role of absorptive capacity on the performance of firms, we rely on two main dependent variables, namely firm growth (in terms of sales) and relative profitability (i.e. the share of profits on sales of the firm with respect to the other firms in the sector). In particular, we define

$$
\begin{aligned}
Firm\_Gr_{i,t} &= \log Sales_{i,t} - \log Sales_{i,t-1}, && (1)\\
Profitability_{i,t} &= \left(\frac{Profits_{i,t}}{Sales_{i,t}}\right) / \left\langle \frac{Profits_{j,t}}{Sales_{j,t}} \right\rangle_{j \in S_i} && (2)
\end{aligned}
$$

where $\langle \cdot \rangle_{j \in S}$ is the average over all the firms in sector S, and S_i is main sector of activity of firm i. Our main explanatory variables refer to foreign collaborations and absorptive capacity. Foreign collaborations are identified through a dummy variable that takes the value of 1 if the firm entered into a foreign collaboration and 0 otherwise. Absorptive capacity is proxied by two interaction terms, described below, which involve R&D and patent activity. We also control for a set of explanatory variables, which, according to the literature, influence firm performance (see e.g. Bartz-Zuccala et al. 2018). These include firm size and age (Evans, 1987), cash balance and leverage (Bottazzi et al., 2014), investment activity and growth of profits to control for the growth momentum of the firm (Coad et al., 2020). Table 1 reports mean and median of our variables and the respective correlation matrix.

As mentioned above, we proxy the innovative output of firms and technological collaborations with patents. In particular, we base our analysis on PATSTAT (European Patent Office, 2020), a comprehensive database of patent data maintained by The European Patent Office, which collects data about patent applications filed at patent offices around the world and also records information about patent applicants and inventors for a vast proportion of the documents. PATSTAT covers a potentially very long time period, since it allows to trace back the history of even the oldest Patent authorities, e.g. the United States Patents and Trademarks Office, which was operating already at the end of the 19^{th} century. Of course, going very far back in time strongly reduces the amount of available information concerning each invention. This is probably in part due to the fact that Intellectual Property has become a prominent topic in relatively 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 the past decades. Fortunately, detailed patent records reporting geographical information about applicants and inventors are available for the time interval covered by the PROWESS data. Moreover, companies and inventors from the majority of countries were already heavily invested in

Table 1: Correlation, mean and median

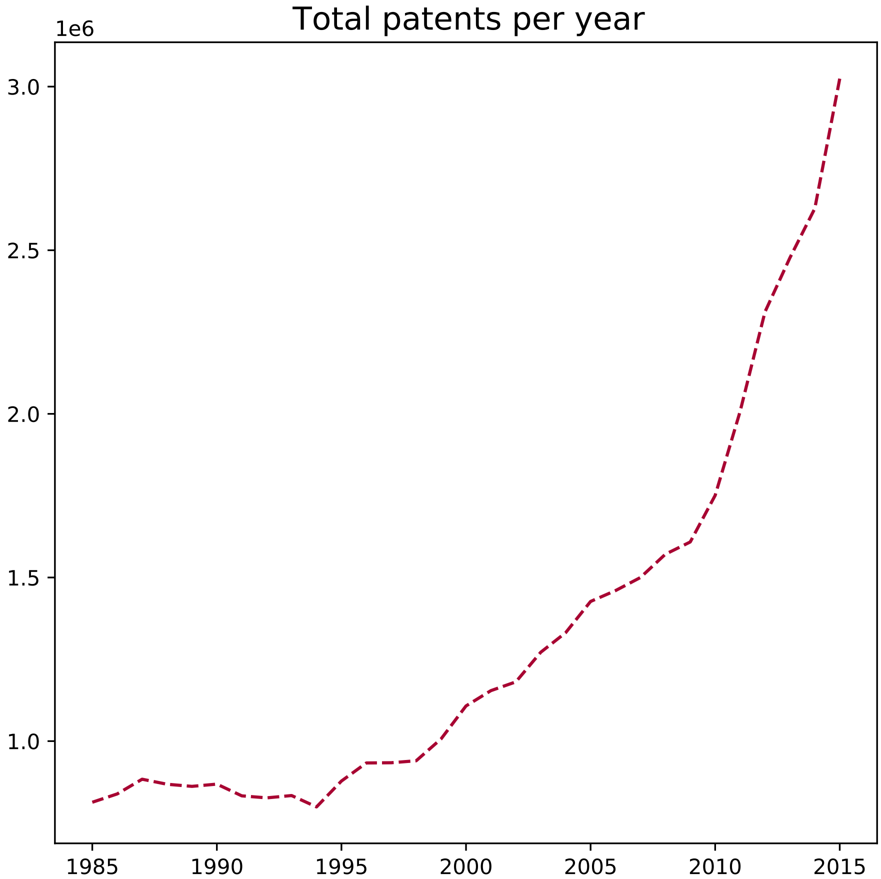
	Firm Gr.	Profita-bility	Sales	Age	Invest. Int	Leverage	Cash Bal.	R&D Exp.	Patent Count
Firm Gr.	1								
Profitability	0.207***	1							
Sales	0.092*	-0.173***	1						
Age	-0.470***	-0.192***	-0.435***	1					
Invest. Int.	0.122**	0.077	0.041	0.002	1				
Leverage	-0.136***	0.269***	-0.408***	0.075*	0.547***	1			
Cash Bal.	-0.071	0.016	0.004	0.057***	-0.067	0.021	1		
R&D Exp.	0.091*	-0.159***	0.977***	-0.398***	0.091*	-0.418***	-0.044	1	
Patent Count	-0.334***	0.184***	-0.139***	0.117***	-0.316***	-0.142***	-0.188***	-0.174***	1
Mean	0.137	0.134	8706.898	25.679	0.106	0.307	46.754	89.275	21.920
Median	0.156	0.130	1340.800	19	0.091	0.305	0.700	33.600	17

protecting their innovations through patents in many sectors over that same period. This is particularly important for our purposes, since we want to trace technological collaborations between Indian firms and foreign partners. To this aim, we need a way to match patents to the country of residence of the inventors taking part in these collaborations. The popularity of patents in many industries and the wide coverage afforded by PATSTAT over the period of interest allows us to achieve an adequate coverage concerning the above information.

For this study, we use a novel dataset obtained by merging Indian firm level data (PROWESS) and patent data (PATSTAT). The merging, at the first stage, is accomplished with the help of Bureau Van Dijk's (BvD) ORBIS database, a commercial database collecting publicly available data about firms from all over the world. The relevant feature for our purposes is that Orbis reports the unique patent application identifiers (*appln_id*) that PATSTAT assigns to patent documents, and adds these identifiers to the information about the firms identified as patent applicants. Both ORBIS and PROWESS provide the CIN (National identification number of the firm), which allows to match both these datasets. Even though the above mapping of PROWESS (CIN) with PATSTAT (*appln_id*) via ORBIS (CIN/*appln_id*) allowed us to match most of the Indian firms with information about their technological partnerships, some firms remained that we could not map using the firm and patent identifiers. We were able to fill in the sample in these cases by manually matching the firm names provided by both PROWESS and PATSTAT databases.

A testament to the ductility of patent data is its growing popularity in the empirical literature, especially in contributions and domains that focus on large datasets. At the same time, the increasing importance that patenting activity has acquired over the past decades is clearly reflected by the growth in the number of filed patents worldwide, as shown in Figure1.

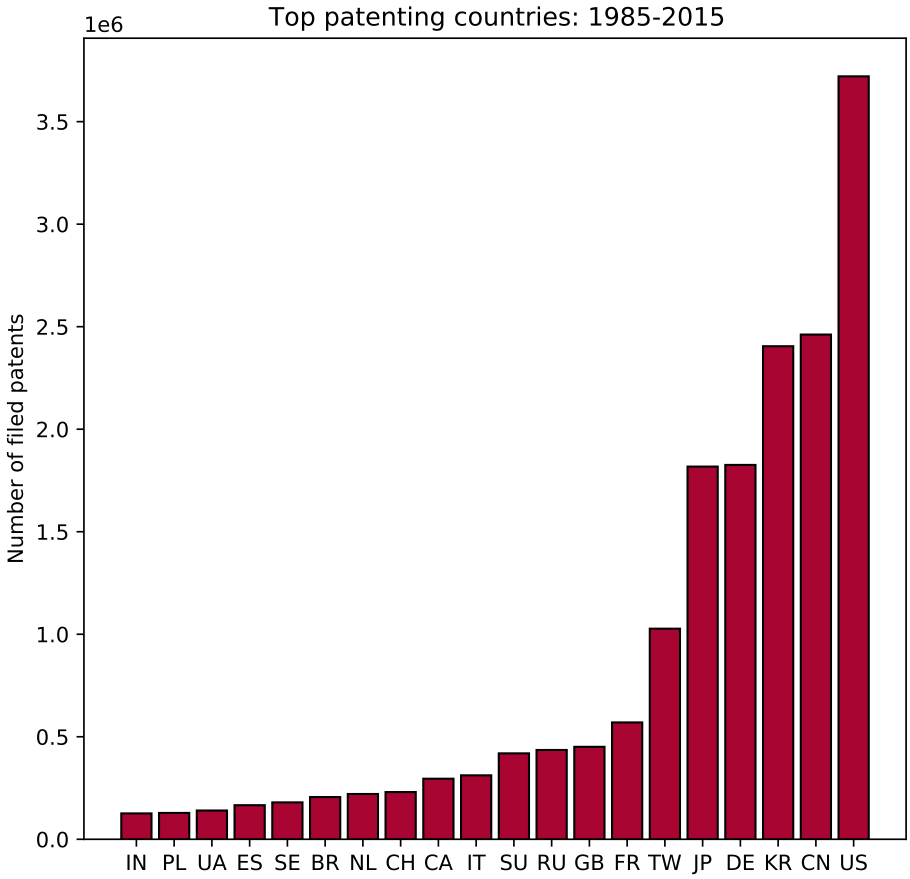
Figure 1: Time series of global patenting activity, as proxied by the number of active patent families every year. Number of patents filed yearly worldwide. The trend has been increasing at a growing rate throughout the period of analysis (source: European Patent Office (2020)).



Of course, there is wide heterogeneity in the number of patents filed by different countries. Figure 2 ranks the 20 countries with the highest number of filed patents in the period 1985–2015 and shows that, though 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 industrialized countries.

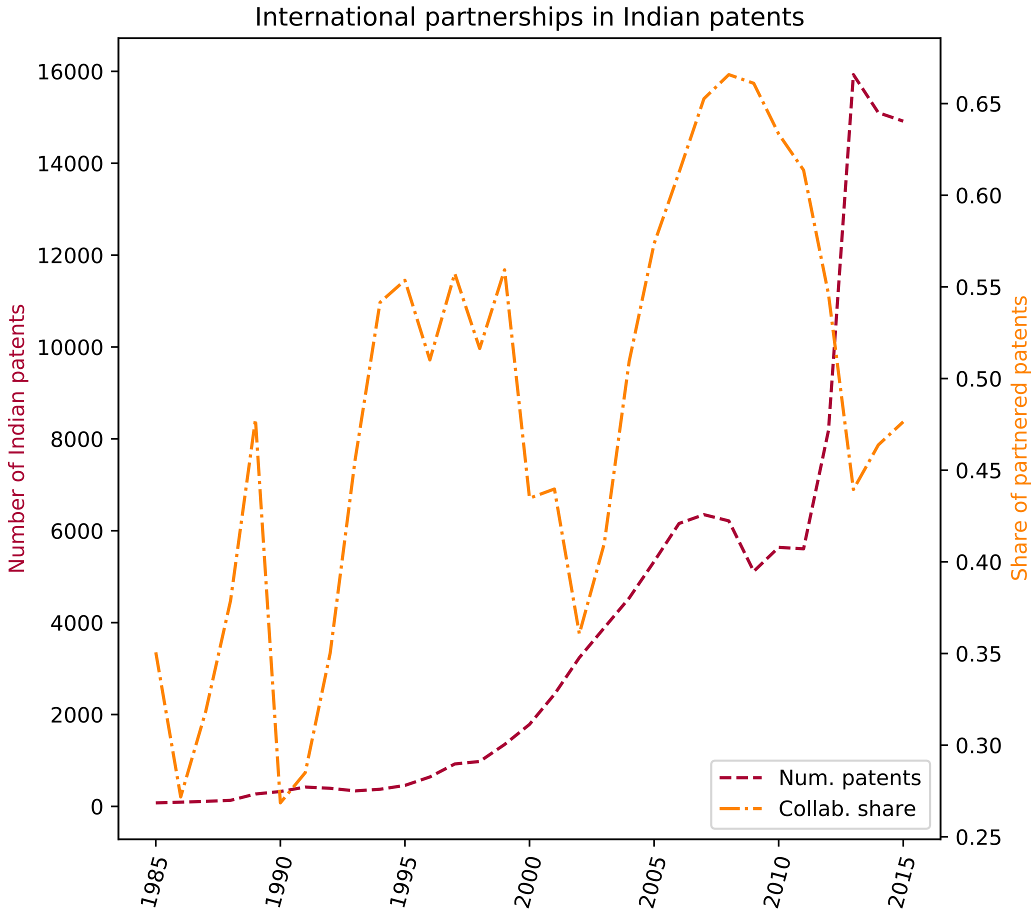
Figure 3 further shows that the trend in the number of filed patents in India over the past decades has mirrored the global trend. The figure also plots the time series of the share of patents co-developed with at least one international partner. There is noticeable cyclical pattern in the yearly data which is probably due to some burstiness in patenting activity.

Figure 2: Top patenting countries.



Nevertheless, an increasing trend is clearly visible in the time series, showing that the growth in Indian patenting has gone hand in hand with a higher propensity to engage in co-patenting with foreign partners. Among the foreign partners, USA ranks first in terms of number of patents co-owned with Indian firms as shown in figure 4. The left panel presents patent counts on a linear scale, while the right panel does the same in log scale. The linear chart clearly reveals a predominance of partnerships with the USA that dwarfes the contribution of all other countries. However, the chart with the log scale shows that the landscape is more complex; co-patenting has in fact not only involved many, mostly developed, partner countries in the past decades, but the number of collaborations has also grown steadily in line with the overall increasing trend in Indian (and international) patenting activity.

Figure 3: Evolution in time of Indian technological partnerships.



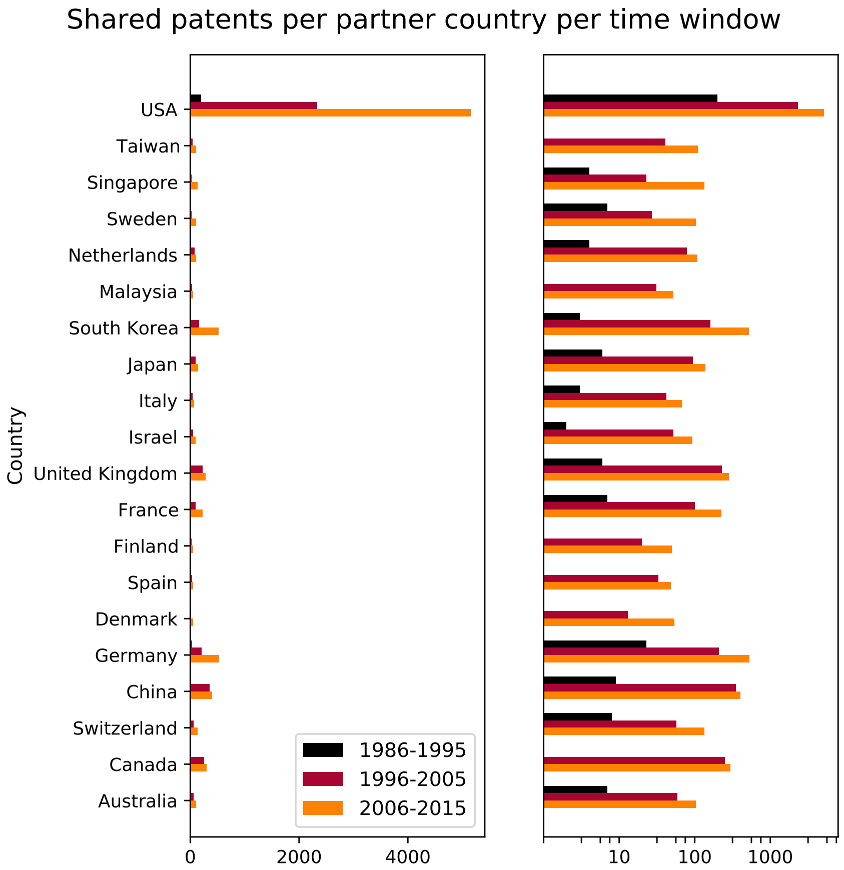
4 Foreign collaborations and firm performance

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

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

where, Y_{it} represents two dimensions of performance of firm i at time t, namely, sales growth and relative profitability; X_{it} is the vector of independent variables that we defined in section 3; $Foreign\_Coll_{it}$ is a dummy which takes value 1 if the firm i at time t filed a patent application in collaboration with a foreign firm and 0 otherwise; the firm fixed effects ξ_i absorbs the time-invariant component; and ϵ_{it} represents the idiosyncratic shock term. The

Figure 4: Co-ownership of patents: Main partner countries of India



independent variables are lagged by one year. We estimate equation 3 by means of pooled and fixed effect OLS estimations. The results are reported in Table 2. 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 effect OLS regression in which we include time dummies to account for across-firm patterns as well as firm dummies to control for time-invariant firm characteristics.

Our main variable of interest is the dummy for foreign collaborations and we find that the associated parameter γ is positive and significant in all four regressions. This indicates that firms entering a foreign technological collaboration on an average perform better than others and, as a result, gain in terms of performance.[2]

Table 2: Foreign technological collaborations and firm performance

	I	II	III	IV
Log Sales	-0.0282***	-0.5633***	-0.0050***	-0.0365***
	(-10.44)	(-55.47)	(-5.60)	(-11.52)
Log Age	-0.0361***	0.8173***	-0.0178***	-0.0500***
	(-5.47)	(28.39)	(-8.19)	(-4.45)
Investment Intensity	-0.0790***	-0.1990***	0.0090***	-0.0678***
	(-12.26)	(-23.77)	(4.38)	(-22.24)
Log Leverage	0.0046	-0.0781***	-0.0057***	0.0144***
	(1.04)	(-8.05)	(-3.99)	(4.45)
Cash Balance	0.0058***	-0.0072***	0.0008	-0.0035***
	(2.99)	(-3.27)	(1.19)	(-4.14)
Profit Growth	0.5767***	0.0932***	0.8224***	0.2401***
	(14.06)	(3.13)	(82.71)	(17.64)
R&D Intensity	0.2676***	0.4962**	0.0224***	0.1090***
	(4.75)	(2.54)	(6.06)	(19.03)
Foreign Coll.	0.1245***	0.0324***	0.0272***	0.0092***
	(10.52)	(4.56)	(7.43)	(3.37)
Time Dummies	Yes	Yes	Yes	Yes
Sector Dummies	Yes		Yes	
Observations	1870	1870	1652	1652
R^2	0.228	0.603	0.730	0.319
firm clusters	92	92	80	80

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

As we pointed out before, technology adoption is neither costless nor automatic. It is contingent on the absorptive capacity of domestic firms that enter into a foreign technological collaboration. Hence, here we check how the absorptive capacity of firms affects the relation between foreign collaborations and firm performance by adding an interaction term, which accounts for the interaction between foreign collaborations and previous innovation done by firms. Previous innovation is proxied using previous R&D and the number of patents filed by firms. Hence, we add to the basic model (equation 3) a proxy for the absorptive capacity of firms. We proxy absorptive capacity in two ways: i) Interaction between R&D spending and foreign collaboration, and ii) Interaction between number of patent applications and foreign collaboration.

[2]It is important to note that the results we observe here come from an analysis limited to patenting firms and hence one should be careful while comparing this with studies that use a bigger population of firms that include also non-patenting firms.

Table 3 and 4 report the results of an OLS and a fixed effects estimation that include the two different proxies of absorptive capacity, respectively $Patents * Foreign\_Coll$ and $R\&D * Foreign\_Coll$. Including absorptive capacity as an additional control in the model yields extremely interesting results. The coefficient of absorptive capacity is positive and significant, indicating that firms with higher absorptive capacity perform better. More interestingly, the foreign collaboration dummy is negative and significant indicating that, for firms with less absorptive capacity (or for firms with less experience) foreign collaborations have a negative impact on performance. This result is however not surprising as it is in line with previous literature on FDI that found that spillovers from FDI generate positive effect only for domestic firm with a minimum level of absorptive capacity (Girma, 2005).

Table 3: Foreign collaborations and firm performance: the role of absorptive capacity (Patents*Foreign Coll as mediator)

	I	II	III	IV
Log Sales	-0.0048**	-0.1206***	-0.0003	-0.0555***
	(-2.56)	(-16.71)	(-0.17)	(-17.54)
Log Age	-0.0478***	0.4408***	-0.0258***	-0.1511***
	(-10.20)	(11.98)	(-6.75)	(-9.13)
Investment Intensity	-0.0053	0.0668***	0.0662***	-0.0375***
	(-1.37)	(10.02)	(21.04)	(-13.25)
Log Leverage	0.0104	0.2566***	-0.1384***	-0.1054***
	(0.67)	(8.14)	(-10.69)	(-7.83)
Cash Balance	0.0032**	0.0054***	-0.0049***	-0.0153***
	(2.57)	(2.68)	(-4.83)	(-18.20)
Profitability Growth	0.2792***	0.2081***	0.6731***	0.1829***
	(7.87)	(6.36)	(23.80)	(13.39)
R&D	-0.0081	0.0026	0.0061	0.0982***
	(-1.10)	(0.22)	(0.96)	(17.00)
Foreign Coll.	-0.0355***	-0.0462***	-0.0744***	-0.0346***
	(-3.40)	(-4.61)	(-8.87)	(-8.14)
Patents*Foreign Coll.	0.2130***	0.0731***	0.2005***	0.0488***
	(15.70)	(5.10)	(18.07)	(7.97)
No. of patents	0.0015***	0.0006	0.0016***	0.0033***
	(5.39)	(1.10)	(7.56)	(13.31)
Time Dummies	Yes	Yes	Yes	Yes
Sector Dummies	Yes		Yes	
Observations	1658	1658	1517	1517
R^2	0.170	0.236	0.413	0.261
firm clusters	82	82	76	76

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Column I - OLS with firm growth, Column II - Fixed effects with firm growth, Column III - OLS with profitability, Column IV - Fixed effects with profitability

Table 4: Foreign collaborations and firm performance: the role of absorptive capacity, (R&D*Foreign Coll. as mediator)

	I	II	III	IV
Log Sales	-0.0157***	-0.4940***	0.0151***	-0.0533***
	(-3.93)	(-60.68)	(9.15)	(-16.08)
Log Age	-0.0196***	0.9813***	-0.0432***	-0.0915***
	(-2.74)	(32.95)	(-14.20)	(-6.00)
Investment Intensity	-0.1428***	-0.2641***	-0.0171***	-0.0450***
	(-17.07)	(-32.46)	(-4.93)	(-15.57)
Log Leverage	0.0153***	-0.1438***	-0.0046**	-0.0004
	(2.87)	(-18.98)	(-2.07)	(-0.14)
Cash Balance	-0.0097***	-0.0029	-0.0067***	-0.0139***
	(-4.31)	(-1.23)	(-7.21)	(-16.00)
Profit Growth	0.8125***	-0.0103	0.4518***	0.1569***
	(20.35)	(-0.35)	(23.54)	(13.44)
R&D Intensity	0.3062***	1.3058***	0.0675***	0.1517***
	(5.06)	(6.49)	(7.29)	(21.50)
Foreign Coll.	-0.1827***	-0.3214***	-0.0882***	-0.1191***
	(-5.72)	(-11.65)	(-3.70)	(-7.66)
R&D*Foreign Coll.	0.4574***	0.5433***	0.2108***	0.1778***
	(9.48)	(12.91)	(5.78)	(7.55)
Time Dummies	Yes	Yes	Yes	Yes
Sector Dummies	Yes		Yes	
Observations	1941	1941	1663	1663
R^2	0.249	0.255	0.532	0.223
firm clusters		95		80

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Column I - OLS with firm growth, Column II - Fixed effects with firm growth,
Column III - OLS with profitability, Column IV - Fixed effects with profitability

5 The mediating role of absorptive capacity: Causal Mediation analysis

In the previous section we dealt with the question of "what is the effect of foreign research collaborations on firm performance". We find that, overall, the effect is positive. However, this is not the case when we control for the effect of the pre-existing knowledge of firms. In a way, the results suggest that the overall effect is likely mostly driven by the ability of firms to use and assimilate external knowledge, in other words by their absorptive capacity. In this section, we analyze to what extent absorptive capacity plays a mediating role in the relationship between foreign research collaborations and firm performance. As Gelman and Imbens (2013) pointed out, not only the "effect of a cause" (treatment effect) is relevant, but at times the same is true for the "cause of the effect", i.e. the mechanisms through which the total effect actualizes. In the context of foreign collaborations and firm performance, understanding the mediating role of the absorptive capacity of firms is particularly interesting. Firstly, it is theoretically motivated, in line with the literature that focuses on the ability of firms to comprehend and exploit external knowledge (Cohen and Levinthal, 1990; Zahra and George, 2002). Secondly, the results we presented earlier hint to a possible intermediate role of absorptive capacity. As we observe in tables 3 and 4, the effect of foreign collaborations is not simply insignificant, but negative and significant once we control for the absorptive capacity of firms, suggesting a possible mediation effect played by the latter.

Previous studies (for instance, Czarnitzki et al., 2007) have analysed the causal impact of R&D collaboration on performance through treatment effects analysis. In this work, we go beyond estimating the average treatment effects (ATE) and explore the underlying channels through which foreign collaborations affect firm performance. To better understand this sequence of causation, we resort to a causal mediation analysis. The idea is that the causal variable (i.e, the treatment) affects the outcome through an intermediate variable, the mediator, that lies in the causal pathway between the treatment and the outcome variables (Imai et al., 2013). Hence, our goal is to decompose the ATE into an indirect effect (in our case, the effect of absorptive capacity) and a direct effect (which travels through all other channels).[3]

However, decomposing the ATE into direct and indirect effects is not trivial. Conventional regression approaches that isolate causal mechanisms often rely on strong and unrealistic identification assumptions (Green et al., 2010). In addition, there could be confounding variables that affect both the relationships: i) treatment-outcome relationship and ii) mediator-outcome relationship. An example for case i) is that firm size could affect both foreign collaboration and firm performance. In a similar way, exporting could affect both the absorptive capacity of firms and firm performance (case ii). Therefore, to get an unbiased estimate, we need the assumption that there are no confounders between both the above mentioned relationships (treatment-outcome and mediator-outcome). In addition, even though the ATE can be identified, both direct and indirect effects cannot be identified empirically. Hence, the identification of the Average Causal Mediation Effect (ACME), i.e, the indirect effect (which is of interest here) requires an additional assumption beyond the strong ignorability of the treatment, known as sequential ignorability (SI), where two ignorability assumptions are made sequentially (Imai et al., 2010b). The first assumption is that, given the observed pre-treatment confounders, the treatment is statistically independent of potential outcomes (as expressed in equation 4). The second assumption is that, given the actual treatment status and the pretreatment confounders, the observed mediator is statistically independent of the potential outcome (equation 5).

Formally, it can be written as:

$$\{Y_i(d', m), M_i(d)\} \perp D_i | X_i = x \tag{4}$$

[3]Recent studies have used mediation analysis to investigate the causal mechanisms, in particular to identify mediating effects of an independent variable on the dependent variable (for instance, Carpena and Zia (2020)).

$$Y_i(d', m) \perp M_i(d) | Di = d, X_i = x \tag{5}$$

where

$$P_r(D_i = d | M_i = m, X_i = x) > 0 \tag{6}$$

$\forall d \in \{0, 1\}$ and m, x in the support of M, X

and, D=treatment, M=mediator, Y=outcome and X=pre-treatment confounders.

Undoubtedly, the second assumption is quite a strong one. Recent contributions in the literature have tried to empirically test these identification assumptions by validating the estimates after relaxing the assumptions. Also in our work, we test these assumptions, which we discuss in the subsection 5.1 below.

On the upside, under sequential ignorability (equations 4 - 5), it is possible to identify causal mechanisms, as proved by Imai et al. (2010b). Therefore, we can obtain the nonparametric identification of the direct and the indirect effect. Hence, following Imai et al. (2013), we calculate the ACME of Absorptive Capacity (AC) on the effect that Foreign Collaboration (FC) exerts on Firm Performance (FP) by estimating the following two equations:

$$AC_{it} = \alpha_1 + \beta FC_{it} + Z_{it} + \epsilon_{i1} \tag{7}$$

$$FP_{it} = \alpha_2 + \gamma AC_{it} + \delta FC_{it} + Z_{it} + \epsilon_{i2} \tag{8}$$

The ACME is the product between the coefficient (β) of the treatment variable in equation 7 and the coefficient (γ) in the mediator model (equation 8), The Average Direct Effect (ADE) is equal to δ from equation 8. Naturally, the total effect is the sum of ACME and direct effects. Standard errors and confidence intervals for the ACME are obtained using a quasi-Bayesian Monte Carlo approximation (King et al., 2000).

Table 5 reports the results. Panel A reports the coefficients obtained by estimating Equation 8, while Panel B presents the estimates for the mediator effect (ACME) and the Direct Effects. Columns I and II correspond to the estimates with the measure of absorptive capacity based on R&D, while columns III and IV correspond to the estimates obtained with the patent-based measure. Interestingly, we find that in all the specifications, the mediator effect is the main or even the only significant component of the total effect. The direct effect is not significant in 3 out of 4 cases.[4] The mediator effect is high (0.776 and 0.155) with firm growth as dependent variable when compared to profitability. In short, the empirical results suggest that absorptive capacity is the main driver mediating the relationship between foreign collaborations and firm performance.

5.1 Sensitivity Analysis

In this section, we test the robustness of our results to the violation of the major assumptions that we make. Since we cannot test sequential ignorability directly with the data, we employ

[4] An exception is Column III, where absorptive capacity is measured using patents and firm growth as dependent variable.

Table 5: Mediating role of absorptive capacity: Causal Mediation analysis

	I	II	III	IV
Panel A. Coefficient Estimates				
R&D*Foreign Coll.	0.7777***	0.1115**		
	(4.06)	(2.37)		
R&D	-0.0501***	0.0317***		
	(-4.66)	(2.62)		
Patents*Foreign Coll.			0.2711***	0.1329***
			(12.50)	(10.44)
Number of patents			-0.0011***	0.0007***
			(-2.76)	(2.82)
Foreign Coll.	-0.5876***	0.0024	0.0264*	-0.0029
	(-3.07)	(0.08)	(1.65)	(-0.31)
Log Sales	-0.0092***	-0.0046***	-0.0136***	-0.0038**
	(-3.42)	(-2.81)	(-5.27)	(-2.42)
Log Age	-0.0319***	0.0049	-0.0456***	0.0042
	(-4.99)	(1.35)	(-7.43)	(1.19)
Investment Intensity	-0.0813***	0.0583***	-0.0818***	0.0608***
	(-15.06)	(17.39)	(-16.00)	(19.36)
Profitability Growth	1.4766***	0.7314***	1.4015***	0.7127***
	(27.52)	(21.82)	(26.42)	(21.70)
Log Leverage	-0.0208***	-0.0268***	-0.1423***	-0.1871***
	(-5.10)	(-10.69)	(-6.65)	(-13.75)
Cash Balance	-0.0102***	-0.0096***	-0.0056***	-0.0088***
	(-5.35)	(-8.60)	(-3.14)	(-8.27)
Time & Sector Dummies	Yes	Yes	Yes	Yes
Observations	1870	1543	1898	1541
R^2	0.179	0.293	0.170	0.316
Panel B: Estimates of ACME, DE and TE				
ACME	0.776***	0.072**	0.155***	0.079***
DE	-0.588	0.002	0.026**	-0.003
TE	0.188***	0.074***	0.181***	0.076***
% of Tot Eff mediated	4.12	0.968	0.855	1.039

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Column I & III - Firm growth; Column II & IV - Profitability

the sensitivity analysis proposed by Imai et al. (2010b) and Imai et al. (2010a) to explore the robustness of our results. Sensitivity analysis allows us to understand how the ACME would change for different degrees of violation of the sequential ignorability assumption.

The validity of the finding we reported above depends on the assumption of the "ignorability of the mediator", conditional on the base characteristics and observed treatment. In our case, it is likely that the mediator variable (absorptive capacity) is related to other firm capabilities that we do not observe. If such firm capabilities affect firm performance through channels other than absorptive capacity then the assumption of the "ignorability of the mediator" is violated and the ACME is confounded with the impacts of unobserved factors. The SI assumption implies that the correlation (ρ) between the error terms in equations 7 (ϵ_{i2}) and 8 (ϵ_{i3}) is zero. Thus, if ρ has non-zero value, the SI assumption is violated.

The sensitivity analysis relaxes the condition that $\rho = 0$, allowing for non-zero correlations, and estimates Equations 7 and 8 for different values of ρ. Therefore we obtain a range of estimates for the ACME, each associated to a value of ρ, which we can compare with the ACME we obtained assuming the validity of all the hypotheses underlying the estimation. Figure 5 contain a graphical representation that helps us quantify the degree of sensitivity, by looking at how large ρ should be for the mediation effect to be insignificant. The top panels shows the figures with absorptive capacity proxied by the R&D-based measure, while the bottom panels shows patent-based measure as proxy for absorptive capacity.

A small ρ implies that the results are sensitive to SI violations, while larger values ρ mean that the results are robust to unobserved confounders. However, as Imai et al. (2010a) points out, there is no absolute threshold of ρ that would allow us to confirm that the conclusions of the analysis are unequivocally valid. Nevertheless, computing ρ gives a qualitative idea of the robustness of the empirical results to relaxing the ignorability assumptions. In our case, the values of ρ for which the ACME is zero are 0.060 and 0.024 for firm growth and profitability while proxying absorptive capacity of firms using R&D. Instead, when absorptive capacity is measured using patents, the values of ρ for which the ACME is zero are 0.182 and 0.167 for firm growth and profitability respectively. Generally speaking, the results involving patents are much less sensitive than the results we obtain when considering R&D as proxy for absorptive capacity.

Further, note that the regression error ϵ_{i1} in Equation 7 captures factors that affect absorptive capacity other than the foreign collaboration, while ϵ_{i2} in Equation 8 represents other residual factors that impact performance that are contained neither in absorptive capacity nor the foreign collaboration. For instance, some unobserved factors like "in-house training of employees" may be contained in both ϵ_{i1} and ϵ_{i2}, and these two regression errors could be potentially positively correlated. In fact, we can check the magnitude of the correlation between the error terms. In Appendix A, figure 6 we show scatter plots of the sample residuals and we observe that the correlation between ϵ_{i1} and ϵ_{i2} are close to zero. This provides further support to the validity of the sequential ignorability assumption and hence, also to our results.

Our findings suggest that foreign collaborations are generally positively related to firm performance. However, this relationship is mediated by the existing capabilities of firms in using external knowledge. The higher the absorptive capacity of firms, greater the benefit from a foreign R&D collaboration. As put forth by Cohen and Levinthal (1989, 1990), external knowledge does not equally benefit all firms. On the contrary, the benefits enjoyed

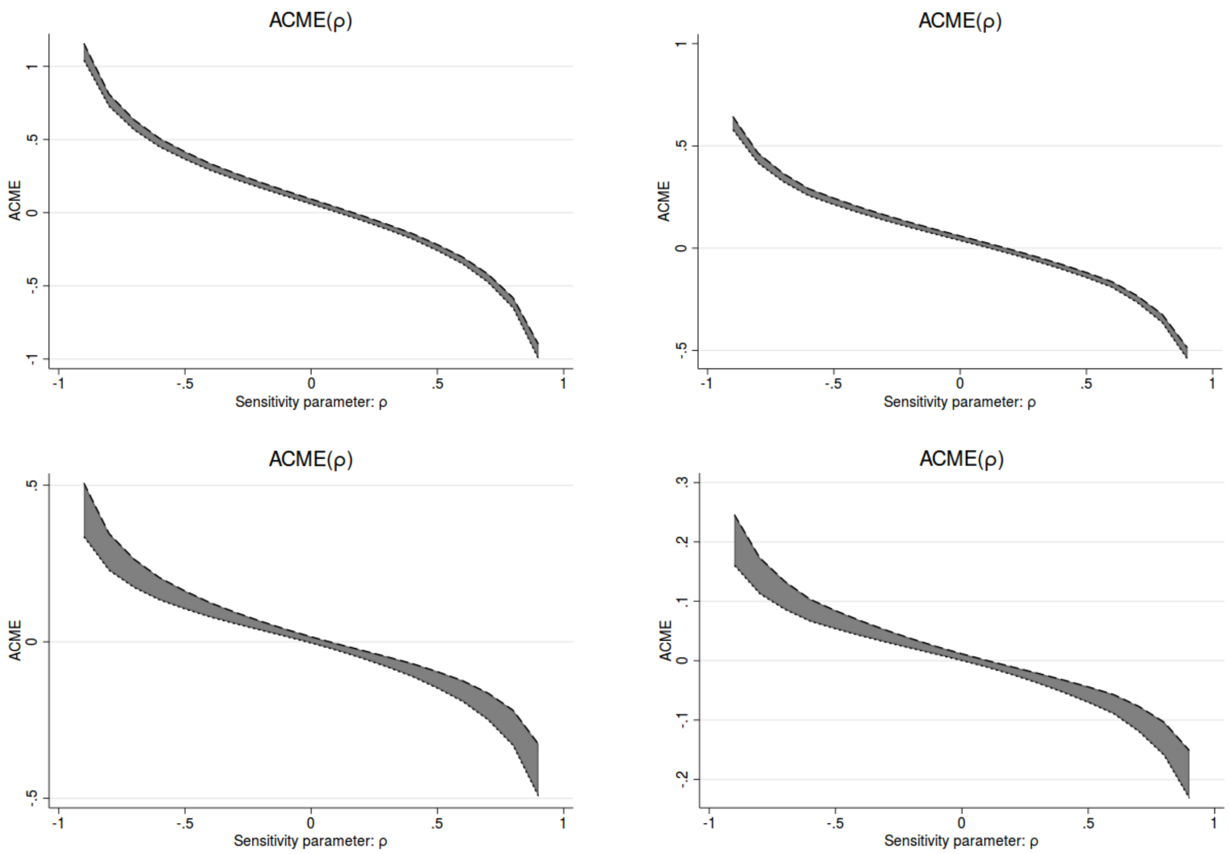


Figure 5: The panels show how the estimates of the Average Causal Mediation Effect (ACME) change with different values of ρ, the correlation between the error terms in equation 7 (ϵ_{i1}) and equation 8 (ϵ_{i2}). Sequential ignorability implies that ρ is equal to zero, so the ACME for $\rho = 0$ in the above figures corresponds to the ACME estimate in Table 5. Top: absorptive capacity as mediator with the R&D-based measure. Bottom: absorptive capacity as mediator with the patent-based measure.

by the firm are determined in part by its own actions and resources.

6 Concluding Remarks

In this work, we employed a novel database to investigate whether Indian firms benefit from international R&D collaborations and to explore the role played by firms' prior knowledge in augmenting these relationships. By applying a causal mediation analysis that allows us to quantify the mediation effect, we are able to disentangle the mediating role played by the absorptive capacity of firms from other effects of foreign collaborations on firm performance. The evidence suggests that the capabilities to imitate and absorb knowledge are necessary stepping stones for the acquisition of more sophisticated competencies required to operate closer to the technology frontier. The notion that previous knowledge is necessary to absorb new knowledge is not new, but what one might not realize is the validity of this even for complex and dynamic patenting firms. To our knowledge, this is the first work to show evidence of the effect of international R&D collaborations 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 like imports, exports, and FDI (Archibugi and Pietrobelli, 2003; Lall, 1992; Lall and Narula, 2004). In contrast, we consider technology transfer through international R&D collaborations. While the conventional avenues of technology transfer involve firms in the "maturing" stage of the capability ladder (table 7.1 in Cirera and Maloney (2017)), by focusing on international research partnerships we address the mechanism at play in more complex and dynamic corporate organizations that have reached a "mature" stage. It is important to note that the dynamics on the technological frontier are quite different from the processes of building the necessary organizational capabilities for imitation and absorption of knowledge. Further, as pointed out by Amsden (2009), usually the accumulation of technological and managerial capabilities occurs within domestic firms rather than within subsidiaries of foreign owned firms. Likely this is because while multi-national 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 the firm which are mostly located in developed countries (Cimoli et al., 2009). By considering 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 on how to operate machinery produced in developed countries.

The evidence presented in this work highlights the microeconomics underlying knowledge accumulation, that technological development is gradual, and even complex and dynamic organizations close to technological frontier build on their existing technological capabilities to climb the "ladder of knowledge complexity"(Dosi et al., 2019). Indeed, the results we observe are in line with the theory of capability accumulation. As pointed out by (Dosi et al., 1988, p. 1130) , "what a firm can hope to do in the future is narrowly constrained by what it has been capable of doing in the past". Our findings add to the existing evidence on the role played by existing knowledge within firms ("absorptive capacity" in our case) in enhancing the benefits of inter-organizational technology transfer.

All this bears fundamental policy implications. No doubt, processes of knowledge accumulation and industrial development require public policies that help build technological and organizational learning. Firms differ greatly with respect to their stages of capability development. This is particularly true in developing countries, where an optimal policy mix should consider such heterogeneity. As Cirera and Maloney (2017) points out, for firms that are in a lower stage of development, policy should ensure ease of access to foreign technology, programs to stimulate knowledge transfer and nurture the organizational capabilities allowing to absorb technology from advanced countries. However, as sectors move toward 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 big R&D

projects, where they can learn to seize technological and organizational opportunities.

Even though our work focuses on a sample of Indian manufacturing firms, there are reasons to believe that this might hold true also for firms in other developing countries. Future research could investigate this possibility by focusing on data from other countries going through various stages of economic development.

Appendix A: Robustness checks

As an additional robustness check, we investigate the correlation between the error terms as shown in figure 6. The scatter plots show the correlation between ϵ_{i1} on y-axis and ϵ_{i2} on x-axis. In these figures, the red line represents the fitted line from the bivariate linear regression of ϵ_{i1} on ϵ_{i2}, thus indicating the correlation between the two. Importantly, all scatterplots show that the correlations between the sample regression residuals are all close to zero. These patterns support the validity of the sequential ignorability assumption, providing additional evidence for the robustness of our results.

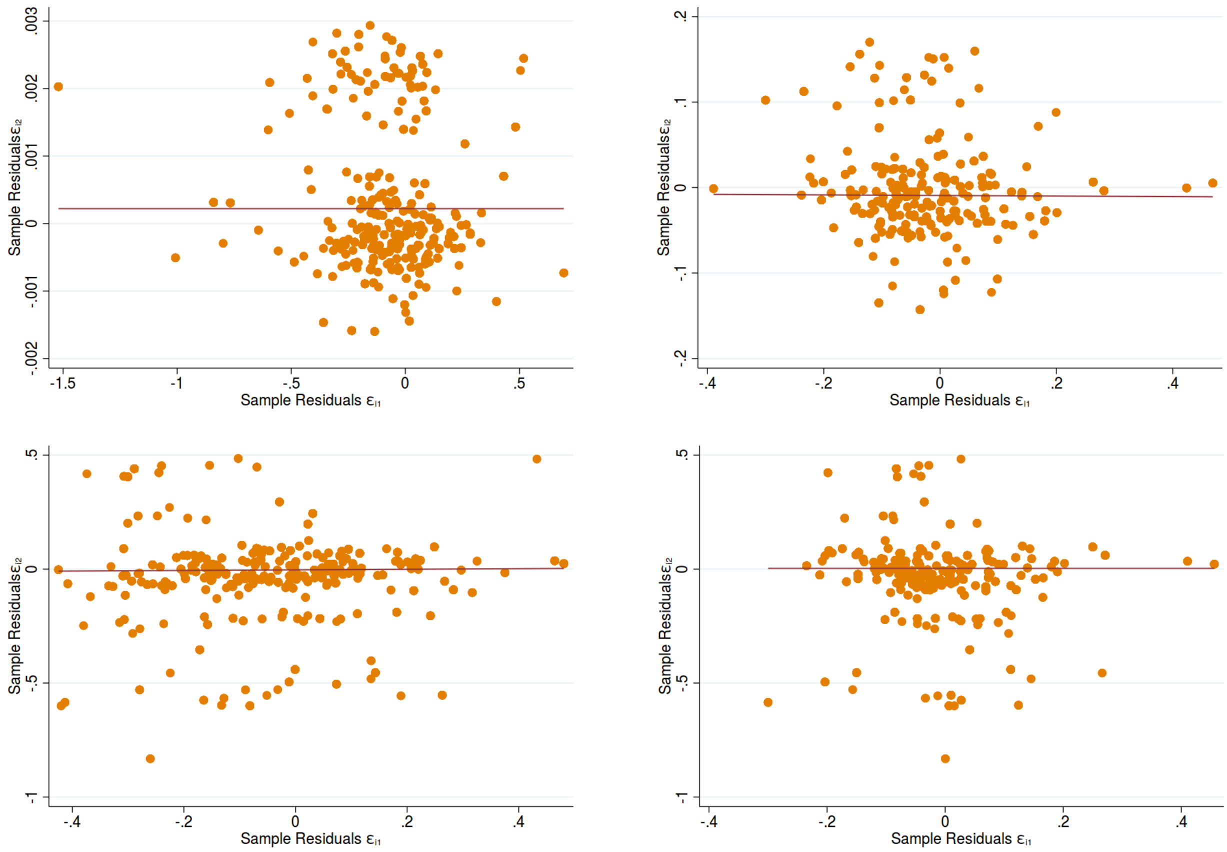


Figure 6: The panels show the scatterplots of the error terms in equation 7 (ϵ_{i1}) and 8 (ϵ_{i2}). Top: absorptive capacity as mediator with the R&D-based measure. Bottom: absorptive capacity as mediator with the patent-based measure. Left: Profitability as dependent variable. Right: Firm growth as dependent variable.

References

ACEMOGLU, D. (2002): "Directed technical change," *The Review of Economic Studies*, 69, 781–809.

ALNUAIMI, T., J. SINGH, AND G. GEORGE (2012): "Not with my own: Long-term effects of cross-country collaboration on subsidiary innovation in emerging economies versus advanced economies," *Journal of Economic Geography*, 12, 943–968.

AMSDEN, A. H. (2009): "Nationality of firm ownership in developing countries: who should 'crowd out'whom in imperfect markets," in *Industrial policy and development: the political economy of capabilities accumulation.*, ed. by M. Cimoli, G. Dosi, and J. Stiglitz, Oxford University Press, 470–506.

ARCHIBUGI, D. AND C. PIETROBELLI (2003): "The globalisation of technology and its implications for developing countries: Windows of opportunity or further burden?" *Technological forecasting and social change*, 70, 861–883.

ATKINSON, A. B. AND J. E. STIGLITZ (1969): "A New View of Technological Change," *Economic Journal*, 79, 573–78.

BARNEY, J. (1991): "Firm resources and sustained competitive advantage," *Journal of management*, 17, 99–120.

BARTZ-ZUCCALA, W., P. MOHNEN, AND H. SCHWEIGER (2018): "The role of innovation and management practices in determining firm productivity," *Comparative Economic Studies*, 60, 502–530.

BELDERBOS, R., M. CARREE, B. DIEDEREN, B. LOKSHIN, AND R. VEUGELERS (2004): "Heterogeneity in R&D cooperation strategies," *International journal of industrial organization*, 22, 1237–1263.

BELDERBOS, R., B. CASSIMAN, D. FAEMS, B. LETEN, AND B. VAN LOOY (2014): "Co-ownership of intellectual property: Exploring the value-appropriation and value-creation implications of co-patenting with different partners," *Research policy*, 43, 841–852.

BLALOCK, G. AND P. J. GERTLER (2009): "How firm capabilities affect who benefits from foreign technology," *Journal of Development Economics*, 90, 192–199.

BOTTAZZI, G., A. SECCHI, AND F. TAMAGNI (2014): "Financial constraints and firm dynamics," *Small Business Economics*, 42, 99–116.

BRANSTETTER, L., G. LI, AND F. VELOSO (2014): "The rise of international coinvention," in *The changing frontier: Rethinking science and innovation policy*, University of Chicago Press, 135–168.

Carpena, F. and B. Zia (2020): "The causal mechanism of financial education: Evidence from mediation analysis," *Journal of Economic Behavior & Organization*, 177, 143–184.

Cassiman, B. and R. Veugelers (2002): "R&D cooperation and spillovers: some empirical evidence from Belgium," *American Economic Review*, 92, 1169–1184.

——— (2006): "In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition," *Management science*, 52, 68–82.

Cimoli, M., G. Dosi, and J. E. Stiglitz (2009): *Industrial policy and development: The political economy of capabilities accumulation*, Oxford Oxford University Press.

Cirera, X. and W. F. Maloney (2017): *The innovation paradox: Developing-country capabilities and the unrealized promise of technological catch-up*, The World Bank.

Coad, A., N. Mathew, and E. Pugliese (2020): "What's good for the goose ain't good for the gander: heterogeneous innovation capabilities and the performance effects of R&D," *Industrial and Corporate Change*, 29, 621–644.

Cohen, D. (1998): "Toward a knowledge context: Report on the first annual UC Berkeley forum on knowledge and the firm," *California management review*, 40, 22–39.

Cohen, W. M. and D. A. Levinthal (1989): "Innovation and learning: the two faces of R & D," *The economic journal*, 99, 569–596.

——— (1990): "Absorptive capacity: A new perspective on learning and innovation," *Administrative science quarterly*, 128–152.

Czarnitzki, D., B. Ebersberger, and A. Fier (2007): "The relationship between R&D collaboration, subsidies and R&D performance: empirical evidence from Finland and Germany," *Journal of applied econometrics*, 22, 1347–1366.

Dosi, G., C. Freeman, R. Nelson, G. Silverberg, and L. Soete, eds. (1988): *Technical Change and Economic Theory*, London, Pinter.

Dosi, G., N. Mathew, and E. Pugliese (2019): "What a firm produces matters: diversification, coherence and performance of Indian manufacturing firms," Tech. rep., LEM Working Paper Series.

European Patent Office (2020): "EPO PATSTAT Database," Spring edition.

Evans, D. S. (1987): "The Relationship between Firm Growth, Size, and Age: Estimates for 100 Manufacturing Industries," *Journal of Industrial Economics*, 35, 567–81.

Filippetti, A., M. Frenz, and G. Ietto-Gillies (2017): "The impact of internationalization on innovation at countries' level: the role of absorptive capacity," *Cambridge Journal of Economics*, 41, 413–439.

Fu, X. and Y. Gong (2011): "Indigenous and foreign innovation efforts and drivers of technological upgrading: evidence from China," *World development*, 39, 1213–1225.

Fu, X., C. Pietrobelli, and L. Soete (2011): "The role of foreign technology and indigenous innovation in the emerging economies: technological change and catching-up," *World development*, 39, 1204–1212.

Gelman, A. and G. Imbens (2013): "Why ask why? Forward causal inference and reverse causal questions," Tech. rep., National Bureau of Economic Research.

Girma, S. (2005): "Absorptive capacity and productivity spillovers from FDI: a threshold regression analysis," *Oxford bulletin of Economics and Statistics*, 67, 281–306.

Giuliani, E., A. Martinelli, and R. Rabellotti (2016): "Is co-invention expediting technological catch up? A study of collaboration between emerging country firms and EU inventors," *World Development*, 77, 192–205.

Glas, A., M. Hübler, and P. Nunnenkamp (2016): "Catching up of emerging economies: the role of capital goods imports, FDI inflows, domestic investment and absorptive capacity," *Applied Economics Letters*, 23, 117–120.

Glass, A. J. and K. Saggi (1998): "International technology transfer and the technology gap," *Journal of Development Economics*, 55, 369–398.

Green, D. P., S. E. Ha, and J. G. Bullock (2010): "Enough already about "black box" experiments: Studying mediation is more difficult than most scholars suppose," *The Annals of the American Academy of Political and Social Science*, 628, 200–208.

Griffith, R., S. Redding, and J. V. Reenen (2004): "Mapping the two faces of R&D: Productivity growth in a panel of OECD industries," *Review of economics and statistics*, 86, 883–895.

Grossman, G. M. and E. Helpman (1994): "Endogenous innovation in the theory of growth," *Journal of Economic Perspectives*, 8, 23–44.

Hagedoorn, J. (2003): "Sharing intellectual property rights—an exploratory study of joint patenting amongst companies," *Industrial and Corporate Change*, 12, 1035–1050.

Imai, K., L. Keele, and D. Tingley (2010a): "A general approach to causal mediation analysis." *Psychological methods*, 15, 309.

Imai, K., L. Keele, and T. Yamamoto (2010b): "Identification, inference and sensitivity analysis for causal mediation effects," *Statistical science*, 51–71.

Imai, K., D. Tingley, and T. Yamamoto (2013): "Experimental designs for identifying causal mechanisms," *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 176, 5–51.

Keller, W. (1996): "Absorptive capacity: On the creation and acquisition of technology in development," *Journal of development economics*, 49, 199–227.

——— (2010): "International trade, foreign direct investment, and technology spillovers," in *Handbook of the Economics of Innovation*, Elsevier, vol. 2, 793–829.

King, G., M. Tomz, and J. Wittenberg (2000): "Making the most of statistical analyses: Improving interpretation and presentation," *American journal of political science*, 347–361.

Lall, S. (1992): "Technological capabilities and industrialization," *World development*, 20, 165–186.

——— (2001): *Competitiveness, technology and skills*, Cheltenham: Edward Elgar Publishing.

——— (2005): "Rethinking industrial strategy: the role of the State in the face of globalization," *Putting Development First: The Importance of Policy Space in the WTO and IFIs.*

Lall, S. and R. Narula (2004): "Foreign direct investment and its role in economic development: do we need a new agenda?" *The European Journal of Development Research*, 16, 447–464.

Li, X. (2011): "Sources of external technology, absorptive capacity, and innovation capability in Chinese state-owned high-tech enterprises," *World Development*, 39, 1240–1248.

Lu, Y., Z. Tao, and L. Zhu (2017): "Identifying FDI spillovers," *Journal of International Economics*, 107, 75–90.

Miller, R. (1994): "Global R & D networks and large-scale innovations: The case of the automobile industry," *Research policy*, 23, 27–46.

Montobbio, F. and V. Sterzi (2011): "Inventing together: exploring the nature of international knowledge spillovers in Latin America," in *Catching up, spillovers and Innovation Networks in a Schumpeterian Perspective*, Springer, 81–117.

Nelson, R. R. and S. Winter (1982): *An evolutionary theory of economic change*, harvard university press.

Phene, A., K. Fladmoe-Lindquist, and L. Marsh (2006): "Breakthrough innovations in the US biotechnology industry: the effects of technological space and geographic origin," *Strategic management journal*, 27, 369–388.

Quéré, M. (2003): "Knowledge dynamics: biotechnology's incursion into the pharmaceutical industry," *Industry and Innovation*, 10, 255–273.

Riccobono, F., M. Bruccoleri, and G. Perrone (2015): "External knowledge sourcing for R&D activities: antecedents and implications of governance mode choice," *Technology Analysis & Strategic Management*, 27, 142–160.

Romer, P. M. (1994): "The origins of endogenous growth," *Journal of Economic perspectives*, 8, 3–22.

Savino, T., A. Messeni Petruzzelli, and V. Albino (2017): "Search and recombination process to innovate: a review of the empirical evidence and a research agenda," *International Journal of Management Reviews*, 19, 54–75.

Schumpeter, J. A. (2017): *Theory of economic development*, Routledge.

Sultana, N. and E. Turkina (2020): "Foreign direct investment, technological advancement, and absorptive capacity: A network analysis," *International Business Review*, 29, 101668.

Tether, B. S. (2002): "Who co-operates for innovation, and why: an empirical analysis," *Research policy*, 31, 947–967.

Vishwasrao, S. and W. Bosshardt (2001): "Foreign ownership and technology adoption: evidence from Indian firms," *Journal of development economics*, 65, 367–387.

Winter, S. G. (1987): "Knowledge and Competences as Strategic Assets," in *The Competitive Challenge: Strategy and Organization for Industrial Innovation and Renewal*, ed. by D. J. Teece, Ballinger: Cambridge, MA.

Zahra, S. A. and G. George (2002): "Absorptive capacity: A review, reconceptualization, and extension," *Academy of management review*, 27, 185–203.

Zhou, X., M. Shan, and J. Li (2018): "R&D strategy and innovation performance: the role of standardization," *Technology Analysis & Strategic Management*, 30, 778–792.

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