Neither at the cutting edge nor in a patent-friendly environment:

Appropriating the returns from innovation in a less developed economy

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Barros, H.M. (2021) **'Neither at the cutting edge nor in a patent-friendly environment: Appropriating the returns from innovation in a less developed economy'**. *Research Policy*, 50. http://dx.doi.org/10.1016/j.respol.2020.104097

Abstract

Despite increased focus on understanding how firms appropriate the returns from innovation, our knowledge regarding firms' behaviour in less developed economies (LDEs) is still scant. This paper provides a nuanced view as to how firms that are not at the technological frontier attempt to capture value when they encounter fragile patenting conditions. I analyse a unique dataset on innovative activities in Brazil. My findings reveal the effects (if any) of a number of factors on the use of a wide range of appropriability mechanisms. These factors include measures of knowledge intensity, novelty of products and processes, firm size, degree of competition, innovation cooperation, government support for innovation, and type of ownership. In addition, my empirical exercise provides evidence of the extent to which firms in an LDC adopt different appropriability mechanisms in pairs. Overall, this paper indicates that even in the absence of an effective patent system, firms do use patents. However, there are other patterns of appropriability in which firms use design (being registered or not registered accordingly), lead-time or trademarks in association with other means of appropriation.

Keywords: appropriability; less developed economy; patents; design; trademarks; first-mover.

1. Introduction

Early studies on the appropriation of returns from innovation addressed, among other issues, the factors that make firms more inclined to use the patent system (e.g., Mansfield, 1986; Scherer, 1983, 1965). Although this line of thought was informative, it could lead one "to lose sight of the forest for the trees" by exploring patents in isolation from any alternative means of appropriation. In fact, evidence indicated that patents were not standalone protective devices (Arora, 1997; Bresnahan, 1985; Hounshell and Smith, 1988). Subsequent empirical efforts incorporated other appropriability mechanisms (e.g., secrecy, lead-time advantage) in their analyses to better understand firms' behaviour as regards appropriation (Arundel, 2001; Cohen et al., 2000; Levin et al., 1987). However, extant knowledge about appropriability derives largely from evidence collected in markets where firms present relatively high innovative capabilities, obtain patents in a timely fashion, and are able to properly defend themselves against infringement (Hall et al., 2014; Lerner, 2009). We are not well acquainted with firms' appropriation behaviour in less developed economies (LDEs) (Candelin-Palmqvist et al., 2012; James et al., 2013). Hence, developing a better understanding of how firms reap the benefits of innovation under these circumstances is required.

This paper adds to this body of knowledge in at least two important ways. First, by exploring firms' appropriability behaviour in the underexplored Brazilian intellectual property rights (IPRs) environment, this paper compares the perceived effectiveness and efficiency of patents and other IPR and non-IPR appropriation methods under different institutional circumstances (unlike previous studies). This perspective adds to the research stream that has emerged since Teece's (1986) seminal paper on appropriability because it departs from the standard unit of analysis, namely, relatively highly innovative firms operating under well-functioning patent systems.

Second, by uncovering the types of appropriation mechanisms that firms in an LDE use and whether these mechanisms are (or are not) correlated, I expect to elucidate how relatively less innovative firms appropriate rents from innovation under weak patenting conditions (Mazzoleni and Póvoa, 2010). In contrast to firms in more developed markets, firms in LDEs are often far from both the technological frontier (Castellacci, 2011; Tebaldi and Elmslie, 2013) and a pro-patent environment (Chu et al., 2014). Hence, LDE firms are unlikely to rely heavily on patents to recoup their investments in innovation (Lopez, 2009; Lugones and Suárez, 2007). By putting less emphasis on the protection of technology (appropriation methods are not all 'technology based'), LDE firms may present different patterns of appropriability (Keupp et al., 2009).

My analyses are based on responses to the Brazilian Industrial Survey of Technological Innovation (Pintec), which was administered by the Brazilian Institute for Geography and Statistics (IBGE). The Pintec mirrors the European Community Innovation Survey (CIS) and aims to increase knowledge about firms' innovative activities. I explore the influence of a number of factors on the use of a wide range of appropriability mechanisms, namely, patents, utility models, registration of design, copyright, trademarks, secrecy, complex design, and lead-time advantage. I also test whether these appropriability mechanisms are correlated in pairs. Focusing on a sample that is limited to firms that perform R&D in-house and have launched a product innovation, my empirical strategy accounts for violation of the assumption of independent observations (i.e., biased standard errors). By employing a multivariate probit estimation technique, I follow existing empirical exercises that avoid inefficient estimates derived from standard econometric models (i.e., logit/probit) when alternative choices are potentially interrelated (Holm and Arendt, 2013).

This paper is organized as follows: in the next section, I put the literature on appropriability in perspective and present the empirical setting. Then, I explain my analytical approach. Subsequently, I show the findings of this investigation and discuss the empirical results. Finally, conclusions are drawn.

2. Background

2.1. The Brazilian patent system

The Brazilian patent system is grounded on the civil law framework, which is characterized by high levels of formalism (Lerner, 2009), and is recognized for its inefficiency (Buscaglia and Ulen, 1997; Desposato et al., 2015). For example, in Brazil, a widespread legal practice is to move litigations further up to the Supreme Court just to delay implementation of a lower court's ruling (Arlota and Garoupa, 2014). As a result, many cases pile up before the courts in tandem with entrenched bureaucracy (Yeung and Azevedo, 2011), with evidence of judicial bias and judicial insecurity that increase the costs of litigation in the country (Arida et al., 2005; Ferrante and Yeung, 2012). In fact, the World Bank Enterprise Survey indicates that less than 20% of the surveyed firms in Brazil believe that the court system is fair, impartial, and uncorrupted (The World Bank, 2010). Therefore, despite occasional efforts to make the Brazilian judicial system more efficient (Lichand and Soares, 2014), lack of confidence in the system is still widespread (Caleman and Monteiro, 2013).

Brazil's first patent law dates to 1830. However, foreign inventions could not be patented in Brazil at that time. This provision was formally abolished in 1883, when the country joined the Paris Convention (Mazzoleni and Póvoa, 2010). However, even if protection of inventions was already a constitutional guarantee (Kunisawa, 2009), product patents were not granted until 1996, when Brazilian patent law was revised to comply with the agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) (Ryan, 2010). As observed by Mazzoleni and Póvoa (2010), despite an initial interest in the establishment of a patent system equivalent to that observed in more developed countries, Brazil pulled back the development of its patent system. As a result, the regime of patent protection in Brazil has not significantly influenced the rate and direction of innovation in the country. According to the authors, industrial policies' incentive structures were essentially defensive and disconnected from the intellectual property rights regime. In Brazil, privately funded innovation has been driven mainly by firms' exposure to international competition (Resende et al., 2014).

The inefficiencies of the Brazilian patent system are well documented. For instance, a well-known business magazine has addressed the challenges of dealing with intellectual property in the country. The article shows that the amount of backlog per patent examiner in Brazil is about the same as in Japan, but Japan receives ten times as many patent applications as Brazil does (The Economist, 2012). In fact, practitioners see the backlog of patent applications as the greatest challenge of the Brazilian Patent and Trademark Office, also known as National Institute of Industrial Property (INPI) (Loney, 2015). INPI has made some effort in recent years to reduce its backlog and has been marginally successful in reducing the average time for a patent to be granted (from 11.5 years to around 8 years). It was only in 2019 that a new action was introduced, relying heavily on the examination carried out abroad by other patent offices (Nunes, 2019). Nevertheless, to date, Brazil's patent system ranks low in terms of strength/quality of patent systems (e.g., Park, 2008). An index that accounts for both enforcement potential and operational design shows that the Brazilian patent system fits into the 'medium low quality' category (de Saint-Georges and van Pottelsberghe de la Potterie, 2013). Another recent index to measure the strength of patent systems shows that Brazil fits with the 'very weak' group of patent systems, scoring 3.6 on a scale from 1 (worst) to 10 (best), a score better than Russia's (2.7) but worse than China's (4.4) and India's (4.8) (Papageorgiadis and Sofka, 2019).

Therefore, it is not surprising that a study commissioned by the World Intellectual Property Organization (WIPO) revealed that a limited number of inventive firms in Brazil pursue patents. In addition, according to that study, most patent applications (approximately 80%) in Brazil are from non-resident firms, and resident patent applications derive mostly from individuals (as opposed to firms). Interestingly, this study shows that utility models and design registration are mostly applied for by resident individuals, whereas trademarks are mostly requested by resident firms (Barcelos et al., 2014). To some extent, this pattern is also a result of Brazil's engagement (or not) with international agreements. While Brazil is signatory of The Patent Cooperation Treaty (PCT), the country has not joined the Hague System for the international registration of industrial designs (ibid.), and it was only in 2019 that the country became a member of the Madrid Protocol for trademarks (Nunes, 2019). Thus, limitations of the Brazilian patent system challenge the appropriation of the returns from innovation in the country.

2.2. Appropriability, innovative capabilities and LDEs

Appropriability mechanisms are means firms use to increase the returns from their innovative effort (James et al., 2013). A subset of appropriability mechanisms rests on the intellectual property rights (IPRs) framework. IPRs are legal instruments designed to combat underinvestment in socially desirable inventive activities by providing a temporary monopoly over the outcomes of creative efforts (Eckert and Langinier, 2014). The selection of IPRs (e.g., patents, utility models, registration of design, trademarks, copyright) depends on the subject matter, and all IPRs are regulated by the same principle of excludability – i.e., the right to exclude others from making, using or selling the invention (Cornish et al., 2019).

Secrecy is also a frequently used appropriability mechanism. Firms can put restrictions on who can access a piece of information and on how that information can be used. Those restrictions derive from either informal practices or formal policies within organizations (Hannah et al., 2019), and formal policies can be accompanied by legal instruments. For instance, firms use confidentiality agreements with their employees, contractors, and business partners and use non-competition covenants to prevent employees from joining a competitor for some period after departing (Graves, 2011). Despite the incorporation of trade secrets within the realm of IPRs by the TRIPS, Article 39 (Sandeen, 2011), there exist multiple regimes to account for secrecy issues, e.g., unfair competition (Denicola, 2011; Ghidini and Falce, 2011) and criminal law (Rowe and Sandeen, 2015). Therefore, it is difficult to justify trade secrets solely as an intellectual property-based mechanism (Graves, 2011).

Innovators can also use non-IPR mechanisms (e.g., technological complexity, lead-time) to impede the imitative dissipation of rents (Rumelt, 1984). Lead-time, for instance, allows pioneers to progress along the learning curve (Lieberman and Montgomery, 1988) or to establish privileged access to complementary assets (Teece, 1986) before competitors. Technological complexity creates a barrier between innovators and imitators (Pil and Cohen, 2006; Rivkin, 2001) because complexity is a result of embodying a number of elements from a variety of knowledge sources in the innovation (Simon, 1962) so that the degree to which these elements interact makes the innovation more difficult to replicate (Donoso, 2014). From an institutional perspective, non-IPR instruments do not share a legal principle and are not legally binding. In turn, non-IPR instruments are rooted in the competence and everyday management routines of firms (Neuhäusler, 2012). Not surprisingly, empirical evidence has shown that non-IPR mechanisms are of overall importance to innovative firms, whereas IPRs are often used in a selective manner (Cohen et al., 2000; Gallié and Legros, 2012; Levin et al., 1987).

To the extent that appropriability mechanisms are designed according to the nature of the creative output, firms' innovative capabilities may influence the deployment of these mechanisms (Kaplan and Tripsas, 2008; Zobel et al., 2017). For instance, while secrecy does not require *ex ante* a minimum inventive threshold above which it can be deployed, patents are granted based on the degree of novelty of the corresponding technical knowledge. In addition, firms capable of producing technologically advanced innovations can fulfil patentability criteria more easily (Hurmelinna-Laukkanen et al., 2008). Moreover, a firm may achieve pioneering advantages based on a radical innovation but obtain an enduring benefit through subsequent incremental efforts (March, 1991). That is, not all firms can stay ahead of competitors due to their limited innovative capacity (James et al., 2013); being a pioneer requires firms to have intramural capabilities (Hawk et al., 2013; Schoenecker and Cooper, 1998). Thus, the use of appropriation mechanisms is associated with firms' innovative capabilities (Arbussà and Coenders, 2007).

However, firms in LDEs often lack the innovative capabilities required to obtain appropriability instruments such as patents (Kammoun and Rahmouni, 2014). Even if LDE firms may, on occasion, present advanced technological capabilities (Figueiredo, 2003) and have entered the global competitive arena (Boehe, 2016; Cahen et al., 2016), for most of them, innovative capabilities are not at the frontier of technical progress (Castellacci, 2011; Chaminade and Fuentes, 2015; Crespi and Zuniga, 2012). Therefore, it may be more difficult for LDE firms to produce, for example, technologically complex innovations (Chung and Lee, 2015). LDE firms' limited learning capability – an ability central to the generation of complexity (Kim and Wilemon, 2007) – prevents them from developing cutting-edge technology (Frank et al., 2016). In fact, LDE firms work in a context of incremental technological evolution for which aesthetic innovation is a standard firm pursuit (Eisenman, 2013). Aesthetic innovations, also known as design innovations (Walsh, 1996) or soft innovations (Stoneman, 2010), become relevant because they have the potential to increase users' understanding of and attraction to the adjusted product offering (D'Ippolito, 2014).

Firms in LDEs also tend to operate within constrained judicial infrastructures, making it more difficult to properly defend themselves against infringements of IPRs even in the presence of enacted legislation (Léger, 2005). That is, dysfunctions in patent systems undermine their use (Grafton et al., 2000). However, to date, there are few studies on firms' appropriability behaviour in LDEs (Candelin-Palmqvist et al., 2012; James et al., 2013), where innovative capabilities are more constrained (Goedhuys and Veugelers, 2012) and property rights are not easily defended against infringement (Lerner, 2002). This understanding is needed because for those firms that are not at the cutting edge of innovative thinking (Crespi and Zuniga, 2012) and operate within patent systems that are not very effective (Papageorgiadis et al., 2016), the need to use other means of appropriation is even more pressing.

2.3. Determinants of appropriability mechanisms across firms

The use of appropriability mechanisms depends on firms' ability to engage with innovative activity (Hall and Sena, 2017; Peeters and Van Pottelsberghe De La Potterie, 2006; Scherer, 1983). However, the nature of innovation may influence the mechanisms firms pursue. For instance, process innovators are more likely than product innovators to rely on secrecy (Arundel, 2001). By the same token, product innovators are likely to be more concerned about entering earlier in the market place due to the ease with which competitors imitate their innovations (Besharat et al., 2016; Dowell and Swaminathan, 2006; Short and Payne, 2008). That is, firms' innovative capacity is central to determining the appropriation method pursued.

Firm size is also reported to influence firms' appropriability behaviour (Brouwer and Kleinknecht, 1999). Firm size, for instance, is expected to be positively correlated to firms' use of IPRs because, amongst other factors, larger firms are less constrained by the costs of applying for, prosecuting and defending IPRs (Block et al., 2015; Holgersson, 2013). Firm size may also lead to scale economies in managing innovation and IPRs (Henderson and Cockburn, 1996; Holgersson, 2013; Macher and Boerner, 2006). Not surprisingly, Arundel and Kabla (1998) have noticed that the larger a firm is, the larger the proportion of inventions that a firm patents. It is interesting perhaps that Milesi et al. (2013) have found that in Argentina, secrecy is more likely to be used by smaller firms. This finding may reflect the market power of larger firms in less competitive markets. As for non-IPR mechanisms, the literature has reported that their use also depends on firm size (Neuhäusler, 2012), but this effect is not uniform across non-IPR mechanisms (Gallié and Legros, 2012).

Firms that encounter a higher degree of competition (a common characteristic of international markets) may be more concerned with rent expropriation, especially if their home markets are small (de Faria and Sofka, 2010). Furthermore, a higher degree of competition may require incumbents to use entry deterrents, a role played by appropriability mechanisms (Levin et al., 1987). In addition, firms' engagement in innovation-oriented cooperation may also influence the use of appropriability mechanisms. Innovation cooperation allows firms to tap into resources that enhance their innovative capabilities (Tyler, 2001; Zeng et al., 2010). As a result, it is expected that firms that cooperate in innovation projects pursue appropriability mechanisms not only to defend against competitors (Belderbos et al., 2004) but also to control knowledge flows (Arora et al., 2016; Laursen and Salter, 2014). In fact, the influence of innovation cooperation on the use of appropriability mechanisms is motivated to a large extent by unintended knowledge spillovers (Cassiman and Veugelers, 2002; Spithoven and Teirlinck, 2015).

Another potential determinant of the use of appropriability mechanism is the support from the government. Governmental support for innovation is usually oriented towards more technologically sophisticated endeavours, which are also riskier to create (Mazzucato, 2018). Therefore, firms that receive this kind of assistance are likely to be concerned about appropriating the returns from innovation due to the supplementation of the invention-generating potential of company-financed R&D (Scherer, 1983). However, this support, on occasion, is given in exchange for a reduced license fee to be charged if other firms become interested in the innovation (Griliches, 1990), which may reduce innovators' interest in pursuing IPRs. The influence of government support is not homogeneous across appropriability mechanisms since not all of them are technology based; copyright and registration of design, for instance, may be achieved on the basis of creative endeavours not related to technology (de Laat, 2005; Dickson and Coles, 2000; Filippetti, 2011).

By the same token, the effect of firm ownership (i.e., domestic *vs.* foreign) on the use of appropriability mechanisms is unlikely to be homogeneous. In fact, this attribute has not been frequently underlined in studies on appropriation. Keupp et al. (2009) and Yang et al. (2004) observed that multinational enterprises (MNEs) have made extensive use of patents in the Chinese market, unlike Chinese firms at the time of these studies. In turn, Barros (2015) observed no differences between foreign and domestic firms in their propensity to patent in Brazil. However, the effect of firm ownership goes beyond patenting. Gallié and Legros (2012), for instance, have observed that firms that are part of a (domestic or foreign) business group in France are more inclined to use patents, trademarks and copyright than are domestic independent firms (i.e., not part of a business group). Those determinants have been well documented in the literature on firms' propensities to patent, but our knowledge as to their effects on firms' use of other instruments of appropriation is still scarce (Candelin-Palmqvist et al., 2012). Just like the influence of those determinants is not fully understood, the way firms combine appropriability mechanisms is largely unknown (Gallié and Legros, 2012).

2.4. Interactions of appropriability mechanisms

Research efforts to understand firms' behaviour in terms of appropriability began with interest in the determinants to patent (Scherer, 1983). While this research stream is useful in explaining firms' patent behaviour, it does not consider the interplay between patents and other appropriability mechanisms (Gallié and Legros, 2012). Because appropriability can be pursued by other means, firms' inclination to patent depends upon their engagement with other forms of appropriation (Arora et al., 2008; Granstrand, 2003). Therefore, firms' appropriation behaviour is likely to rest on more than one appropriability mechanism (Hurmelinna-Laukkanen, 2009). At the firm level, one can expect that IPR-based mechanisms are likely to be correlated because firms may benefit from economies of scope when managing issues related to IPRs (Granstrand, 2000, 1999; Pitkethly, 2001). In fact, the existing empirical evidence meets this expectation (Amara et al., 2008; Gallié and Legros, 2012; Thomä and Zimmermann, 2013). However, beyond the realm of IPRs, the interplay amongst those mechanisms is not well established.

As patents require an innovation to be described in certain detail, they confer property rights over the codified part of knowledge, but not all knowledge generated during the innovation process is easily codified. In fact, tacit knowledge is imperfectly mobile and difficult to imitate (Saviotti, 1998). Consequently, firms can both pursue patent protection for the knowledge that is easier to codify and keep secret the knowledge that is more difficult to codify (Hannah, 2005). However, it is interesting that one of the most comprehensive survey-based studies on appropriability to date (i.e., Gallié and Legros, 2012) did not observe a correlation between the use of patents and secrecy. This result may have to do with the sample frame of the study, which included a number of firms that are unlikely to meet the requirement for a patentable innovation[1]. Thus, the study may have misjudged the extent to which patents and appropriation methods are related. Amara et al. (2008), for example, have found that firms in knowledge-intensive business services use patents and secrecy simultaneously. It is likely that trade secrecy is also present when firms make use of other IPRs in order to avoid forfeiting their rights (Sofka et al., 2018).

In turn, patents and lead-time present contradictory features that may hinder their simultaneous use. Patents are granted through formal procedures (Cornish et al., 2019) that are not consistent with a first-mover positioning, and lead-time is achieved by avoiding procedures that slow that positioning (Haleblian et al., 2012). At the same time, innovation-oriented firms tend to obtain lead-time based on technological advancements for which patents are suitable (Bresnahan, 1985; Desyllas and Sako, 2013). As a result of these conflicting effects, the survey-based empirical findings at the firm level are not consistent for the relationship between patents and lead-time (Amara et al., 2008; Gallié and Legros, 2012). Firms may be likely to use lead-time in tandem with other, faster means to obtain IPRs, such as trademarks, copyright and registration of design; these mechanisms do not bear excessive waiting costs (as compared to patents) because the process of registration is straightforward (Cornish et al., 2019). However, the empirical findings at the firm level have shown that, at best, lead-time does not correlate with those mechanisms (Amara et al., 2008; Gallié and Legros, 2012). LDE firms achieve lead-time not by means of technology breakthroughs but, rather, by means of a series of incremental innovations (Milesi et al., 2013). In addition, the opposing timing-related aspect of patents and lead-time is even more pronounced in LDEs,

[1] I thank one of the reviewers for drawing my attention to this issue.

where the prosecution of patent filings is sluggish. Thus, LDE firms are not likely to use lead-time with patents.

Complexity is usually theorized in the literature on appropriability as a mechanism that enhances appropriation (González-Álvarez and Nieto-Antolín, 2007; Hurmelinna-Laukkanen and Puumalainen, 2007) because the degree of interdependency among the various parts of a system makes this system intractable for imitators (Rivkin, 2001, 2000). Nevertheless, complexity is persistently found to be negatively correlated with patents in the empirical literature on appropriability (Amara et al., 2008; Gallié and Legros, 2012; Thomä and Zimmermann, 2013). While there is not a clear justification for that finding, it is reasonable to expect that technological complexity is not widespread in LDEs. Technological complexity usually demands a vast commitment of resources (Yu et al., 2010) and emerges from both the breadth and the depth of knowledge involved (Wang and von Tunzelmann, 2000), attributes less likely to be found in LDE firms. In the absence of advanced technological capabilities in LDEs (Frank et al., 2016), firms in that context are more likely to pursue complexity based on stylistic attributes for which registration of design applies (Eisenman, 2013). In addition, design complexity serves to meet the demand of later-stage segmented markets (ibid.), where not only do users' needs differ but also the expression of users' identities departs from earlier market segments (Carroll and Swaminathan, 2000). In this case, design complexity is likely to be used not only with registration of design but also with trademarks. However, these expectations are only tentative since our understanding of the interplay between appropriability mechanisms is not well developed.

3. Research Method

3.1. Data and sample

My dataset derives from the Brazilian Industrial Survey of Technological Innovation (also known as Pintec). Pintec is administered by the Brazilian Institute for Geography and Statistics (IBGE) for the purpose of collecting information on firms' innovative activities in Brazil. The survey instrument mirrors the European Community Innovation Survey (CIS) questionnaire. That is, Pintec's survey instrument requests qualitative and quantitative information about various firm attributes and targets firms with more than 10 employees in both the manufacturing and the mining industries (though the latest rounds of Pintec have also encompassed specific services).

At the time I ran my analysis, there were five completed rounds of the Brazilian innovation survey. I chose the second round, which covers the period 2001-2003; this timespan was used as a reference in the wording of several questions. Thus, the dataset of each round of Pintec is a cross-section of firms as opposed to a panel. I did not use the dataset from the latest rounds because the survey instrument either did not include firms' use of appropriability mechanisms or included only a limited number of instruments (i.e., non-IPR only). In addition, as publications on this matter is rather unusual for this context, I opted to use a period that matches the period addressed in a prior publication (i.e., Barros, 2015) to cross-check the validity of the findings. My analysis is focused only on manufacturing, where firms are more likely to pursue IPRs, especially patents, utility models and registration of designs (Filitz et al., 2015a; Scherer, 1983). Data were collected by IBGE's trained personnel, who used either computer-assisted telephone interviews or personal interviews (*in loco*). However, information disclosure was voluntary.

IBGE assumes that innovation is a rare event, and hence, it adopted a disproportionate stratified sampling. One stratum comprised large firms (with 500 or more employees) or firms that had declared themselves as innovators in the previous edition of the Brazilian innovation survey; firms included in this stratum had probability set to 1. Two additional strata were created based on two groups of indicators (i.e., primary and secondary). These indicators derived from various sources of information and allowed IBGE to define one stratum in which companies had reasonable chances of being innovators and one stratum in which firms were less likely or had no chances of being innovators. This distribution was made so that 80% of the companies in the sample came from the former two strata, where innovative firms are likely to be found, and 20% from the latter stratum, where innovative firms are less likely to be found. IBGE stratified sampling also accounted for heterogeneous economic activity of each region. Therefore, different cut-off points were generated based on the importance of the economic activity (i.e., industrial transformation value) of each region. The sample in each final stratum was selected independently, with a selection probability proportional to the square root of the number of employees (IBGE, 2004). To allow robust statistical analysis, IBGE also created an adjustment (i.e., weight) for each survey respondent so that the representativeness of the sample was assured (ibid.).

My sample of interest consists of approximately 550 firms that have conducted R&D in-house (i.e., R&D performing firms) and that have launched a novel product to the national market. Although not all innovations depend on R&D (Moultrie et al., 2009), it is less likely that a patentable innovation that is going to be new to the (national) market will emerge without formal R&D efforts. Moreover, product innovations are more likely to be patented than process innovations (Arundel, 2001), and much of the process innovation in Brazil rests with the purchase of equipment (Prochnik and Araújo, 2007), for which IPRs cannot be applied. Thus, I focus on R&D performers and product innovators mainly to ensure that my analysis encompasses firms that are highly likely to meet the requirements for using any appropriation mechanism, and hence, the correlations among appropriability mechanisms can be properly assessed. Otherwise, my analysis would be misleading because the lack of an observed correlation could result from the absence of firms' capabilities to meet the requirements for specific appropriation methods.

3.2. Variables

I use one binary (response) variable for *each appropriability mechanism* to identify whether (or not) it is used. I then regress each response variable on a number of covariates derived from questions in the survey instrument as reported in Table 1. A word of warning is needed here. The Brazilian innovation survey asks respondents to report whether 'design complexity' was used; in this case, a reference to 'design' is likely to make respondents focus on 'aesthetic complexity' rather than on 'technical complexity'. In fact, wording was a drawback of the initial rounds of the Community Innovation Survey (CIS). Former works in more developed countries have detected that complexity and patents are used separately (Amara et al., 2008; Gallié and Legros, 2012; Thöma and Zimmermann, 2013). Thus, more recent rounds of CIS have changed the wording from 'complexity of product design' to 'complexity of goods or services', making it closer to the meaning in both the Carnegie Mellon Survey (see Levin et al., 1987) and the Policy, Appropriability and Competitiveness for European Enterprises Survey (PACE)[2] (Breschi et al., 2000), namely, 'technological complexity'. Nevertheless, although the use of complexity should be interpreted with caution in my analysis, it is not problematic. Design complexity better fits the reality of firms in LDEs than does technical complexity (Eisenman, 2013). Summary statistics and the correlation matrix of the explanatory variables can be found in Table 2.

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[2] I thank one of the reviewers for drawing attention to this change.

Insert Table 1 around here

Insert Table 2 around here

3.3. Econometric approach

Recent studies on appropriability have followed the ‘correlation approach’ (Amara et al., 2008). This approach can range from computing simple correlations, which would not control for any other characteristics, to more sophisticated analyses that control for other factors. One advantage of the correlation approach is that it does not require the specification of an objective function. Additionally, it does not restrain the number of choice variables (Gallié and Legros, 2012). Given the number of options that firms can deploy to appropriate the returns from innovation, this freedom is particularly useful in the present research.

Under the assumption of optimisation behaviour, one can examine revealed preferences because reporting the concurrent adoption of appropriability mechanisms is potentially informative about the joint returns from appropriation. Consequently, I jointly model the decision to use IPR and non-IPR appropriability mechanisms. As firms’ choice processes are not easily depicted, there may be omitted variables in these equations; hence, the estimation of separate logit/probit models would lead to inefficient estimates (i.e., biased standard errors) because the assumption of independence of observations is violated (Holm and Arendt, 2013). Thus, I followed the multivariate probit approach, which allows unobserved factors and error terms to be freely correlated (Greene, 2012). My estimation also accounts for firms’ weights provided by IBGE in order to correct for differences in the sampling fractions by strata.

This class of models has a structure like that of a seemingly unrelated regression (SUR), except that the equations have the same set of explanatory variables. Multivariate probit models have a (latent) dependent variable y_m^* in each equation that represents the mechanism '*m*' – patents, utility model, industrial design, trademarks, copyright, secrecy, complex design, or lead-time advantage – that each firm adopts, forming a system of equations (in my case, eight equations), where each equation has the following structure: $y_m^* = \beta_m x_m + \varepsilon_m$. This joint estimation controls for the existence of mutual correlations (ρ) between the disturbances ($\varepsilon_1, \ldots, \varepsilon_8$), so that ρ (i.e., $\rho_{21}, \rho_{31}, \ldots, \rho_{87}$) describes the existence (or not) of correlations between each pair (i.e., ε_2-ε_1, ..., ε_8-ε_7) of appropriability mechanisms. Consistent and asymptotically efficient parameter estimates are obtained through maximum simulated likelihood, which employs the Geweke-Hajivassiliou-Keane (GHK) simulator to evaluate the M-dimensional normal integrals in the likelihood function (Gourieroux, 2000). According to Cappellari and Jenkins (2003), the accuracy of estimations run by the method of maximum simulated likelihood (using GHK simulator) depends on the number of random draws deployed; increasing the number of replications increases accuracy (at the cost of lengthening run time). The authors show that the number of replications has to be at least as large as the square root of the sample size. I took a very conservative approach and estimated my model using 200 random draws. The reason for 200 random draws rests with my interest in using a homogeneous number of draws across estimations (and samples in robustness checks could have larger sizes).

4. Empirical Findings

4.1. Data analysis

My introductory analysis (i.e., Figure 1) of different subsamples of the Brazilian innovation survey indicates that in the subsample of innovative firms that had not necessarily launched a novel product (i.e., all manufacturing), trademarks are used more often than other mechanisms. However, the use of secrecy, patents, or lead-time is more prevalent in the subsamples encompassing firms that launched a novel product (to the national or international market). Overall, Figure 1 suggests that the use of appropriability mechanisms becomes more common as the firms' degree of innovativeness becomes higher. This suggestion reinforces my approach in limiting my sample for the purpose of testing correlations between appropriability mechanisms. That is, the sample of R&D performers in Brazilian manufacturing that have launched a product novel to the market is more likely to encompass firms that can use all appropriation methods. However, Figure 1 reveals neither the determinants of the use of appropriability mechanisms nor the correlations among these mechanisms. For example, a simple correlation matrix (Table 3) suggests that these mechanisms are positively correlated with each other. However, this approach is not particularly useful when variables are discrete (Hair et al., 2018). I have therefore estimated multivariate probit models.

Insert Figure 1 around here

Insert Table 3 around here

The results for the estimation of the multivariate probit models provide not only what makes firms more inclined to use a specific mechanism (Table 4a) but also whether appropriability mechanisms are correlated (Table 4b). The Wald test (Table 4a) rejects the hypothesis that these mechanisms are similar. Moreover, Table 4a shows that (after controlling for R&D intensity, introduction of a novel process, presence in the international market, innovation cooperation, government support, and foreign ownership) R&D performers with a product innovation are more likely to pursue patents if they are larger. Firm size (i.e., number of employees) appears as a determinant of most mechanisms, while secrecy, trademarks or utility models are used by R&D performers with a product innovation regardless of their size.

Notably, R&D intensity is a determinant of the use of patents, registration of design, secrecy, or lead-time. However, different from firm size, R&D intensity is not a determinant of the use of copyright or design complexity. Surprisingly, perhaps, are the findings on the effect of the introduction of process innovations. That is, process innovations only positively influence the use of trademarks and are not a determinant of the use of secrecy. It is also striking that broadly competing in the international arena is only relevant for the use of patents or lead-time but presents the opposite effects on the use of these mechanisms. That is, when the international market is the firm’s largest market, sample firms are more inclined to use patents and less inclined to use lead-time (Table 4a).

Insert Table 4a around here

The results in Table 4a reveal that innovation cooperation has no effect on the use of patents by R&D performers with a product innovation. Innovation cooperation influences the use of trademarks, copyright or secrecy instead. Sample firms (i.e., product innovators and R&D performers) are more likely to patent or to register trademarks when they receive formal support from the government in Brazil. Moreover, firms with government support are less likely to use design complexity. Table 4a also reveals that R&D performers with a product innovation and that are foreign controlled are more likely to use secrecy or lead-time.

Insert Table 4b around here

Table 4b, which shows the correlation among appropriability mechanisms, is a continuation of Table 4a; both tables are based on the same estimation, but Table 4b reports the correlations (ρ) of the error terms of equations reported in Table 4a. The results indicate that the correlation coefficients (ρ) are all statistically significantly different from zero (see note 'e' – Table 4b). Table 4b also shows that not all mechanisms are (statistically significantly) correlated. While patents, utility model and registration of design are positively correlated, trademarks do not relate to them. In turn, trademarks are positively correlated with copyright. Additionally, patents are not correlated with design complexity, secrecy or lead-time, and although secrecy and lead-time are correlated, they do not relate to design complexity. Design complexity, in turn, is positively related to registration of design and copyright. Somewhat surprising is the finding that secrecy only appears to be correlated to lead-time.

4.2. Validity of inference

I relaxed the assumption that my sample should encompass firms that were R&D performers with a product innovation. Subsequently, I re-ran my estimation on a sample of innovative firms that did not necessarily report R&D expenses (i.e., both R&D and non-R&D performing firms) for which product innovations could be present or not. In doing so, it is possible to compare firms highly likely to be able to use all appropriability instruments (Tables 4a and 4b) to firms that are less likely to have the conditions to use all appropriation methods (Tables 5a and 5b). I also took this opportunity from enlarging the sample size to expand the categories of markets (from 'international or not' to 'international, national, state, or regional') and ownership (from 'foreign or not' to 'foreign, domestic and foreign, or domestic'). I also accounted for novel product in the estimation since in this sample, firms are not necessarily product innovators. Table 5a presents the estimation results, and Table 5b shows the correlations of error terms.

Insert Table 5a around here

As expected, Tables 5a and 5b show differences from Tables 4a and 4b. For instance, the effect of firm size is now i) significantly positive for the utility model, ii) null for copyright or design complexity, and iii) significantly negative for trademarks. Moreover, process innovators are more likely to use secrecy. Additionally, the number of statistically significant correlations (of error terms) in Table 5b is at least twice as large as the number of correlations derived from my original sample (i.e., R&D performers with a product innovation). These supplementary estimations provide a broader view of the determinants of the use of each mechanism in LDEs and allow testing for correlations that do not require a higher-order innovative capacity. However, caution must be exercised in interpreting the latter estimations because I cannot be completely sure that firms in the expanded sample are able to use multiple appropriability mechanisms. For instance, without performing R&D and launching a novel product, firms are less likely to have a patentable invention.

Insert Table 5b around here

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5. Discussion

My naive analysis in Figure 1 reveals that firms seem to become more concerned about their returns from innovation when they are more innovative. This finding is consistent with early empirical findings (Harabi, 1995; Levin et al., 1987). However, Figure 1 indicates that lead-time is not a frequently used mechanism in my data. This finding is different from previous research on appropriability in more developed markets (e.g., Gallié and Legros, 2012; Levin et al., 1987) as well as in Argentina (Milesi et al., 2013). Figure 1 also indicates a sharp contrast to evidence from more developed countries when it comes to trademarks. According to Gallié and Legros (2012), for instance, firms in French manufacturing regard patents and lead-time more highly than trademarks (apart from the consumer goods sector, where trademarks prevail). In turn, Figure 1 suggests that trademarks are instrumental among surveyed firms. The process of registering a mark is, in general, simpler and cheaper than the patent prosecution process (Cornish et al., 2019), and the granting of trademarks does not depend on firms' superior technical capabilities (Ramello and Silva, 2006). Nevertheless, the pervasiveness of trademarks in the data (as compared to other appropriation instruments) suggests that even if the Brazilian patent system has limitations (Papageorgiadis and Sofka, 2019), the IPR system may not be completely dysfunctional in this country.

Table 4a shows that the findings regarding firms' propensities to patent are in line with prior empirical evidence (e.g., Arundel, 2001; Arundel and Kabla, 1998; Brouwer and Kleinknecht, 1999; Scherer, 1983). Comparing my findings with a prior work on patenting in Brazil (Barros, 2015), the estimation result for ownership is consistent as well. This early publication on patenting in Brazil also detected that central to the use of patents is the exposure of firms to the international market, which is similar to my finding. However, the effect of innovation cooperation on the use of patents follows a different pattern from previous research (e.g., Barros, 2015; Brouwer and Kleinknecht, 1999). This difference seems to be a result of different sample attributes; when I relax my sample frame (Table 5a), the effect of innovation cooperation on the use of patents appears. By constraining my sample to R&D performers with a product innovation (Table 4a), I have focused on more innovative firms in which patents are likely to be pursued regardless of cooperation with other agents.

Patents are also more likely to be used by innovative firms that obtain government support for innovation. As expected, it seems that Brazilian innovation policies are deployed to back more technology-based projects (Mazzucato, 2018). This observation is consistent with existing literature that shows that publicly funded resources in Brazil are channelled to support higher-order innovative technological activities (Resende et al., 2014). This pattern is also supported by the evidence that aesthetic changes and improved functionalities are not within the scope of innovation policies in Brazil. At the same time, firms are likely to apply for trademarks when they have, or are very close to having, a novel offering to provide (Mendonça et al., 2004). Thus, the positive effect of government support on the use of trademarks suggests that innovation policies in Brazil help innovative firms in developing outputs that are likely to reach the marketplace.

It is intriguing that government-backed innovation does not make firms more inclined to use lead-time. Lead-time, in turn, seems to be pursued by foreign-controlled firms. In addition, innovative firms more likely to use lead-time are those oriented towards the national market (Table 4a). Hence, it seems that foreign-owned firms develop innovations abroad and introduce adapted innovations to the Brazilian market prior to their competitors. Because factor market-based entrepreneurial activities are more likely to emerge in more economically developed countries (Wan, 2005; Wan and Hoskisson, 2003), foreign-owned firms in less developed settings are expected to use resources available abroad to sustain their stream of innovations (Pérez-Nordtvedt et al., 2010). However, the orientation towards the national market by firms that use lead-time fades away when firms are not necessarily R&D performers (Table 5a). In this case, even if foreign-owned firms do not perform R&D in Brazil, they may use their affiliates in the country to reach both national and international markets to provide offerings prior to competitors (Canabal and White III, 2008; Flores and Aguilera, 2007). These findings do not mean that domestic innovative firms are not able to use lead-time. As long as they are either larger or more committed to innovation, they become likely to use lead-time.

Table 4a shows that innovation cooperation has a positive impact on the use of secrecy, and trade secrets are also more likely to be used by foreign-controlled firms. This finding corroborates that firms that can source knowledge internally or somewhere else (i.e., abroad or in cooperation with other agents) are more concerned about knowledge leakage (Hannah et al., 2019). However, my evidence that process innovations are not related to the use of secrecy is somewhat surprising as it is contrary to the usual argument in the literature (e.g., Levin et al., 1987). As my focal sample encompasses firms that have launched a novel product, the relevance of secrecy may have lost some of its importance; in the end, the trade secret (i.e., the novel product) has been revealed to a certain degree. However, when I relax my sample frame and my estimations are based on a sample of firms that do not necessarily report R&D expenses (Table 5a), the impact of introducing a new or significantly improved process on the use of secrecy is observed. Therefore, process innovators in LDEs are likely to be concerned about secrecy. To the extent that firms in LDEs become R&D performers and product innovators, secrecy is likely to be used whether or not process innovations are developed. It is also notable that secrecy is used regardless of firm size. This finding is different from evidence for Argentina, where Milesi et al. (2013) detected that secrecy is more likely to be used by smaller firms. This contrasting evidence (also supported by Table 5a) suggests that larger firms in LDEs do not always reach sufficient market power to neglect trade secrets in the appropriation of the returns from innovation.

Following the same lines of secrecy, trademarks are used irrespective of firm size (Table 4a). However, contrary to secrecy, R&D intensity makes firms more inclined to use trademarks, which confirms that trademarks are suitable indicators of innovative activity (Mendonça et al., 2004). Moreover, it is the introduction of a novel process (in addition to product innovation) or the cooperation for innovation or the support from the government that increases firms' propensity to use trademarks in Brazil. Those factors likely encourage innovative firms to provide new offerings to the marketplace, and hence, trademarks are used accordingly. When my sample is not constrained to R&D performers with a product innovation (Table 5a), it is notable that smaller innovative firms are more likely to use trademarks to reap the benefits of innovation in Brazil. That is, in the absence of either a patentable output or the financial resources to engage in patenting, smaller firms pursue appropriation by means of trademarks.

My estimation results for R&D performers with product innovations show that aesthetic-oriented appropriation methods are more likely to be used by larger firms, and this is apparently no different from the situation in more developed countries (Dan et al., 2018). In turn, R&D intensity relates differently to design complexity and to registration of design. In fact, it is remarkable that R&D intensity has no effect on the use of complex designs but is positively related to the use of design registration. Apparently, design complexity in the studied research setting is less dependent on higher-order technological capabilities. Adding to that, my findings show that innovation cooperation has no effect on the use of design complexity, registration of design or utility models by R&D performers with a product innovation (Table 4a). These results are somewhat surprising because cooperation has been documented as pivotal for design-based innovations in more developed countries (Carroll and Swaminathan, 2000; Filippetti and D'Ippolito, 2017). However, my dataset covers technology-based cooperation and not design-based cooperation, which may limit our understanding of the effects of cooperation on the use of design-based appropriability mechanisms.

In addition to the determinants of the use of appropriability mechanisms, a few patterns emerge as to how those mechanisms correlate when firms are R&D performers with a product innovation (Table 4b). One of these patterns shows that innovators familiar to patenting do not ignore formal neighbouring means of appropriation, a behaviour also found in more developed economies (Amara et al., 2008; Gallié and Legros, 2012). In this case, appropriability is pursued by a standard range of proprietary mechanisms guided by a *canonical proprietary output approach* based on technology (i.e., patents), functionality (i.e. utility models), and aesthetics (registration of design). However, it is intriguing that, unlike evidence from more developed economies, patenting neither accounts for other forms of IPRs nor goes beyond the province of IPRs. The expanded sample (Table 5b) tells a different story, but it is unlikely that patents are available to all firms in this enlarged sample frame. This finding may also apply to complexity and lead-time; thus, the lack of correlations between patents and each of these mechanisms in the expanded sample is not surprising.

The correlations in Table 4b also corroborate that different demands in terms of processing speed cause patents to be of less interest to firms interested in lead-time, for which secrecy is more suitable. Firms that pursue a head-start position want to avoid information leakage that may hamper their ability to be a first-mover (Hannah et al., 2019). Therefore, speed and privacy seem paramount for this group of firms, and the combination of these mechanisms is also documented in more developed economies (Amara et al., 2008; Gallié and Legros, 2012; Thomä and Zimmermann, 2013). However, in Brazil, this *fast-paced approach* is not attached to other forms of appropriation. At best, lead-time positively correlates with design registration. This correlation exists because, differently from patents, the registration of industrial designs does not go through a lengthy process (Filitz et al., 2015b). However, it is interesting that this *agile aesthetic-driven approach* does not encompass secrecy. Apparently, R&D performers and product innovators that pursue aesthetics as a source of differentiation attempt to compensate for the ease with which design can be copied by being ahead of the competition.

The results also indicate that there are firms that value the aesthetic nature of innovations as a source of differentiation but are not concerned about speed issues. A group of firms behave in an artistic-like manner and use design complexity in copyrighting. This *artistic aesthetic-driven approach* uses copyright as a signature of authorship. This approach is different from firms that also highly value the ornamental attributes of their innovations but emphasize industrial property. This *proprietary aesthetic-driven approach* indicates that firms attempt to capture value from their innovative endeavours by pursuing complex designs and registering them accordingly without accounting for copyright.

While there are firms that put more emphasis on aesthetic attributes, other firms pursue improved functionalities of their products, to which utility models can be applied. In this *IP-led design-driven approach,* utility models are correlated with either registration of design or copyright. In particular, the pursuit of registration of design (aesthetics) and utility models (functionality) simultaneously is likely to be pursued by firms that work with design in a comprehensive way (D'Ippolito, 2014). However, it is interesting that utility models are not correlated with complex design. To the extent that complex designs are not more likely to be used by more R&D-intensive firms (Table 4a), complex designs in Brazil seem to be based solely on creative developments of aesthetic attributes rather than encompassing functionality enhancements that also demand superior technical capabilities (Filippetti and D'Ippolito, 2017). Different from other studies on appropriability that emphasize the importance of technology-based mechanisms, these findings for Brazil highlight the role of design-based mechanisms in this context, and this is new. Design appears in its limited (i.e., aesthetic only) or extended (i.e., aesthetic and functionality) form in most patterns of correlation. As LDEs are characterized by incremental technological evolution for which aesthetic innovations are critical (Eisenman, 2013), the results of my research suggest that design is a binding element in LDE firms' appropriability behaviour.

However, design is not instrumental for all firms in Brazil. There are alternative approaches to appropriability that basically rely on either speed or communication with customers. In fact, trademarks only appear to be correlated with copyright. This pattern indicates that some firms are more concerned with making the marketplace cognizant of their offerings. Although firms are interested in managing information asymmetry to their advantage (Ramello and Silva, 2006), there are firms that put more effort into using trademarks with copyright in an *awareness-driven approach*. For this group, higher returns on innovation are more likely to be achieved by the meaning conveyed by the commercial sign. All in all, departing from standard settings (i.e., more developed economies), firms in LDEs seem to make extensive use of appropriability mechanisms that are not technology based.

6. Conclusions

It is challenging to compare my findings with those of existing studies due to sample differences. However, my results indicate that the nature of appropriability mechanisms (i.e., IPR *vs* non-IPR) is not sufficient to allow conjecture about the extent to which these mechanisms coalesce; their correlation seems to depend on firms' attributes as well. Moreover, my empirical evidence suggests that correlations among appropriability mechanisms are not institutionally invariant. As Lerner (2005) observes, the high levels of formalism seen in civil law systems (such as in Brazil) may discourage firms from relying on their legal systems. At the same time, weak patenting conditions and absence of cutting-edge technology not only limit the extent to which patents and non-IPR mechanisms interwoven but also incentivize firms to pursue alternative appropriability approaches. Therefore, my findings reinforce the notion that appropriation is multifaceted and provide a nuanced view as to how firms in a less developed economy attempt to reap the benefits of innovation.

One direct implication of theory is that in examining appropriability behaviour, firms' innovative capabilities are as important as other attributes of firms. Moreover, to the extent that patents present a probabilistic nature (Lemley and Shapiro, 2005), weak patent systems increase uncertainties. As a result, even if firms pursue patent protection, this is barely correlated with other means of appropriation. In addition, under fragile patenting and innovative conditions, lead-time, trademarks and design (registered or not) emerge as sources of competitiveness. Hence, a thoughtful analysis of appropriability in LDEs should not neglect these elements. One managerial implication of this paper is that in patent systems that are not favourable to the enforcement of IPRs, firms should put in place alternative approaches to appropriability.

This study is not free of limitations. In this paper, I have used the firm as the unit of analysis. However, the ideal method for identifying how different appropriation methods correlate would be to collect data at the innovation level to identify the appropriation mechanisms that are possible and the means of appropriation that are actually used. Additionally, my approach to complexity differs from extant studies due to differences in question wording. While this change has provided a better understanding of appropriation of design-based innovations, it departs from the most fundamental meaning of complexity, namely, technical complexity (Laursen and Salter, 2005). Moreover, my estimations do not account for potential endogeneity due to the lack of an appropriate (i.e., strong and valid) instrumental variable. In addition, my empirical effort does not examine whether there is an optimum combination of appropriability mechanisms that maximizes the appropriation of the returns from innovation, and it does not show whether that possible combination can vary throughout the innovation process. These appear to be promising areas of research. Finally, one should bear in mind that cross-country comparability is somewhat limited because different studies apply different controls and distinct sectoral scopes and have disparate legal systems (e.g., Brazil and France follow civil law, and Canada follows common law). Therefore, a promising avenue of research is to conduct more uniform cross-country comparisons to better understand the effects of institutions on the interplay among appropriability mechanisms.

Acknowledgments

I am indebted to both Paul Stoneman and Carlos Hemais (*in memorian*) for preliminary discussions that led to the development of this paper. I would like to thank FAPESP for partly funding my initial access to the dataset (Grant #07/03218-6). I am also indebted to the Ignatian Educational Foundation (FEI) as well as to CAPES for the remaining support of my stay at IBGE. I also appreciate three anonymous reviewers and Research Policy's editor, Keld Laursen, for thoughtful and invaluable comments on this manuscript. The author is also grateful to participants at the Academy of Management, British Academy of Management, and IAMOT Conferences for their constructive comments on this piece of research. Remaining errors or omissions are my own.

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Table 1
Questions in the survey instrument that originated the variables of the estimation models

Variable [a]	Survey instrument question [a,b,c]	References
Response variables		
Use of appropriability mechanism	Questions 163-170: Between 2001 and 2003, did your firm use any of the following methods to protect your product/ process innovations? *Written methods of protection* ( ) Patents ( ) Utility models ( ) Registration of industrial design ( ) Trademarks ( ) Copyright [d] *Strategic methods of protection* ( ) Complexity of design ( ) Secrecy ( ) Lead-time over competitors	(Gallié and Legros, 2012; Thomä and Zimmermann, 2013)
Explanatory variables		
Number of employees {re: firm size - in logarithmic form}	Question 8: What was the number of employees in your enterprise in 31 December 2003? [*answer*]	(Andries and Faems, 2013; Licht and Zoz, 1998)
R&D intensity {re: *ex ante* innovative capacity - in logarithmic form}	Question 31: Please report your enterprise's intramural R&D expenditure in 2003. [*answer*] Question 9: What was your enterprise's net sales revenue (reported in the balance sheet) in 2003? [*answer*] {Figures from question 31 were divided by figures from question 9}	(Arora et al., 2008; Cincera, 1997)
Novel Product {re: *ex post* innovative capacity}	Question 11: Between 2001 and 2003, did your enterprise introduce any new or significantly improved products, which were new to the Brazilian market? (*Yes/No*)	(Cohen et al., 2000; Sattler, 2003)
Novel Process {re: *ex post* innovative capacity}	Question 17: Between 2001 and 2003, did your enterprise introduce any new or significantly improved processes for producing or supplying products, which were new to the Brazilian market? (*Yes/No*)	(Filson, 2002; Milesi et al., 2013)
International Market {re: degree of competition}	Question 5: What was your enterprise's largest market between 2001 and 2003? ( ) Federal-State ( ) Regional ( ) National ( ) International {For the main regression we used only 'International *vs*. others'}	(Aghion et al., 2005; Levin et al., 1985)
Innovation cooperation	Question 134: Between 2001 and 2003, was your enterprise involved with cooperative arrangements with other(s) organization(s) to develop innovative activities? (*Yes/No*) {Cooperation is defined in the questionnaire as active participation in joint innovation projects}	(Robin and Schubert, 2013; Tether, 2002)
Government support	Questions 156-162: Between 2001 and 2003, did your enterprise use any of the following government programs to support your innovative activities? {Government supporting programs were listed but for operational purposes this question was transformed in a 'yes/no' variable if a firm had responded 'yes' to any of the options provided}	(Guo et al., 2016; Shu et al., 2015)
Foreign (ownership)	Question 1: Please report your enterprise's origin of capital: ( ) National ( ) Foreign ( ) National and Foreign {For the main regression we used only 'Foreign *vs*. others'}	(López, 2009; Zhao, 2006)
Industry	{This was not a direct question obtained from the survey instrument. Firms reported their national registration number - also known as CNPJ in Brazil - and the Brazilian Office for National Statistics, IBGE, matched this registration to a firm's major economic activity in a specific database. For the purposes of this research we convened respondents in 17 industry dummies [e]}	(Enkel and Gassmann, 2010; Malerba and Orsenigo, 1996)

[a] Braces denote our own observations.
[b] Parentheses refer to categorical variables.
[c] Brackets are numerical variables.
[d] The Brazilian judicial system follows Continental Europe's legal tradition in which copyright is called author's right - the latter attaches moral rights to the author as opposed to the owner (Varian, 2005).
[e] Food, beverages and tobacco; Textiles and clothing; Wood and furniture; Paper and cellulose; Chemicals (incl. drugs); Rubber and plastic products; Non-metallic; Steel, non-ferrous, and casting; Basic metals; Machinery, except office; Office and computing equipments; Electrical equipment; Communication equipments; Precision instruments; Motor vehicles; Auto parts; and Other manufacturing.

Table 2
Correlation matrix and descriptive statistics of explanatory variables [a]

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Number of employees (Ln)	1.000						
(2) R&D intensity (Ln)	-0.528***	1.000					
(3) Novel Process	0.385***	-0.098***	1.000				
(4) International Market	0.136***	-0.087***	0.087***	1.000			
(5) Innovation cooperation	0.396***	-0.112***	0.332***	0.063***	1.000		
(6) Government support	0.127***	0.029	0.152***	0.009	0.194***	1.000	
(7) Foreign	0.290***	-0.147***	0.203***	0.106***	-0.228***	-0.051**	1.000
Mean	5.572	-4.936	0.184	0.075	0.267	0.311	0.206
Standard deviation	1.624	1.801	0.387	0.263	0.442	0.463	0.405
Median	5.691	-4.914	0.000	0.000	0.000	1.000	0.000

[a] ** Significant at 5%; *** Significant at 1%.

Table 3
Correlation matrix of appropriability mechanisms [a]

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Patent	1.000							
(2) Utility model	0.390***	1.000						
(3) Design registration	0.263***	0.421***	1.000					
(4) Trademarks	0.171***	0.155***	0.203***	1.000				
(5) Copyright	0.184***	0.204***	0.199***	0.204***	1.000			
(6) Design complexity	0.146***	0.098***	0.192***	0.145***	0.222***	1.000		
(7) Secrecy	0.190***	0.093***	0.168***	0.235***	0.198***	0.282***	1.000	
(8) Lead-time	0.193***	0.108***	0.146***	0.204***	0.136***	0.246***	0.431***	1.000

[a] ***significant at 1%.

Table 4a
Results of the multivariate probit estimation using sampling weights (sample of R&D performers with a product innovation) [a,b]

Covariates	Patent (1)	Utility model (2)	Registration of design (3)	Trademarks (4)	Copyright (5)	Design Complexity (6)	Secrecy (7)	Lead-time advantage (8)
Number of employees	0.3327***	0.07116	0.3469***	0.0135	0.1775**	0.2621***	-0.0465	0.2022***
	(0.0626)	(0.0846)	(0.0683)	(0.0779)	(0.0867)	(0.0565)	(0.0695)	(0.0587)
R&D intensity	0.2243***	0.0859	0.1641**	0.0497	0.0456	0.0980	0.1278**	0.1457**
	(0.0588)	(0.0733)	(0.0759)	(0.0648)	(0.0623)	(0.0512)	(0.0618)	(0.0641)
Novel process	-0.2426	0.5211	0.2180	0.4571**	0.1120	0.0068	0.1943	0.1835
	(0.1475)	(0.2894)	(0.2398)	(0.2023)	(0.1775)	(0.1689)	(0.2333)	(0.2093)
International market [c]	0.8307***	-0.4276	0.0673	-0.2210	-0.1929	-0.0800	0.4783	-0.7009***
	(0.2814)	(0.3117)	(0.2887)	(0.2924)	(0.3072)	(0.3100)	(0.2942)	(0.2318)
Innovation cooperation	0.1397	0.0239	-0.0554	0.5917***	0.6643**	0.2512	0.9492***	0.1356
	(0.2301)	(0.1897)	(0.1750)	(0.2060)	(0.2969)	(0.1546)	(0.2252)	(0.2254)
Government support	0.4257**	0.3996	0.1650	0.4448**	-0.1761	-0.4216**	0.1603	-0.0008
	(0.1683)	(0.2459)	(0.1960)	(0.2227)	(0.1860)	(0.1718)	(0.2198)	(0.1662)
Foreign [d]	0.2338	0.0462	-0.0912	0.1002	0.1893	0.1854	0.4310**	0.3932***
	(0.2039)	(0.2287)	(0.1769)	(0.1607)	(0.1850)	(0.1762)	(0.1734)	(0.1516)
Constant	-2.2839***	-1.9306***	-2.8669***	-0.1530	-3.3914***	-2.8604***	0.3532	-1.4759
	(0.3826)	(0.4573)	(0.5001)	(0.3905)	(0.5560)	(0.3938)	(0.4044)	(0.3484)

Industry dummies	Yes	Log-pseudolikelihood	-3940.24	AIC	8144.48
Sample size (n)	547	Wald chi-square	575.02***	BIC	8712.66

[a] Robust standard errors in parentheses.
[b] **significant at 5%; ***significant at 1%.
[c] The basis of comparison is the national market (herein a composite variable encompassing local, regional and national commercial areas).
[d] The reference is the domestic ownership.

Table 4b

Correlation among error terms of the multivariate probit model estimated in Table 4a [e,f,g]

	Patent	**Utility model**	**Registration of design**	**Trademarks**	**Copyright**	**Design Complexity**	**Secrecy**	**Lead-time advantage**
Patent	1.0000							
Utility model	0.4769***	1.0000						
Reg. of design	0.3027***	0.5548***	1.0000					
Trademarks	0.1501	0.0634	-0.1341	1.0000				
Copyright	0.2088	0.2023**	0.1630	0.5241***	1.0000			
Design Complexity	0.1422	0.1372	0.4346***	0.1278	0.4596***	1.0000		
Secrecy	-0.0088	0.1598	0.1298	-0.1176	0.0936	0.2487	1.0000	
Lead-time	-0.0375	0.0357	0.2483***	-0.0832	-0.0639	0.1862	0.5483***	1.0000

[e] Likelihood ratio test of $\rho_{21}=\rho_{31}=\rho_{41}=\rho_{51}=\rho_{61}=\rho_{71}=\rho_{81}=\rho_{32}=\rho_{42}=\rho_{52}=\rho_{62}=\rho_{72}=\rho_{82}=\rho_{43}=\rho_{53}=\rho_{63}=\rho_{73}=\rho_{83}=\rho_{54}=\rho_{64}=\rho_{74}=\rho_{84}=\rho_{65}=\rho_{75}=\rho_{85}=\rho_{76}=\rho_{86}=\rho_{87}=0$:
chi2(28) =4499.8 Prob > chi2 = 0.0000.

[f] **significant at 5%; ***significant at 1%.

[g] #200 random draws.

Table 5a
Results of the multivariate probit estimation using sampling weights (sample of innovative firms in Brazilian manufacturing) [a,b]

Covariates	Patent (1)	Utility model (2)	Registration of design (3)	Trademarks (4)	Copyright (5)	Design Complexity (6)	Secrecy (7)	Lead-time advantage (8)
Number of employees	0.1330***	0.1073***	0.1719***	-0.0572**	0.0500	0.0220	-0.0440	0.1859***
	(0.0387)	(0.0331)	(0.0351)	(0.0261)	(0.0431)	(0.0460)	(0.0310)	(0.0369)
% High Edu	3.6943***	2.9119***	1.6942	2.2937**	3.2835***	1.6475	1.8707*	2.1395**
	(0.9945)	(1.0001)	(1.2285)	(0.9790)	(1.1350)	(1.3288)	(1.0752)	(1.0463)
Novel product	0.8820***	0.4348***	0.2278**	0.2195**	0.0788	0.6973***	0.6469***	1.2051***
	(0.1345)	(0.1290)	(0.1105)	(0.1109)	(0.1264)	(0.1555)	(0.1262)	(0.1598)
Novel process	0.3313**	0.4478***	0.4121**	0.5951***	0.2180	0.6553***	0.5905***	0.3592**
	(0.1609)	(0.1710)	(0.1803)	(0.1493)	(0.1386)	(0.2077)	(0.1690)	(0.1737)
State market [c]	-0.1247	-0.2273*	-0.2089*	-0.0299	-0.1822	-0.1931	-0.0863	-0.1349
	(0.1236)	(0.1296)	(0.1247)	(0.0857)	(0.2038)	(0.1562)	(0.1044)	(0.1519)
Regional market [c]	-0.4620***	-0.2776**	-0.2747*	0.0154	-0.5695**	-0.1048	-0.1789	0.1583
	(0.1285)	(0.1398)	(0.1650)	(0.1096)	(0.2583)	(0.1787)	(0.1503)	(0.2051)
International market [c]	0.1459	-0.3049	-0.5270***	-0.2421	-0.1668	-0.3545*	0.4103**	-0.2655*
	(0.2131)	(0.2138)	(0.1378)	(0.1920)	(0.1737)	(0.1942)	(0.1733)	(0.1423)
Innovation cooperation	0.2721**	0.0658	0.0817	0.4726***	0.3234*	0.2787**	0.9940***	0.3938***
	(0.1269)	(0.1327)	(0.1081)	(0.1366)	(0.1705)	(0.1199)	(0.1560)	(0.1111)
Government support	-0.1822*	0.1559	0.1920*	0.2047**	-0.0477	0.1091	0.0749	-0.0201
	(0.1029)	(0.1137)	(0.1152)	(0.0913)	(0.1696)	(0.1640)	(0.1075)	(0.1260)
Foreign [d]	0.1465	-0.2470**	-0.1347	-0.1183	0.2142	0.3006**	0.2370**	0.4767***
	(0.1231)	(0.1177)	(0.1094)	(0.0936)	(0.1541)	(0.1217)	(0.1082)	(0.1523)
Domestic & foreign [d]	-0.2348	-0.3055	0.0850	0.2428	-0.0514	0.1174	0.2185	0.2106
	(0.2131)	(0.3691)	(0.2196)	(0.3227)	(0.2544)	(0.2802)	(0.2161)	(0.2019)
Constant	-2.038***	-1.5809***	-1.6559***	-0.4012	-1.9679***	-2.2602***	-1.026***	-2.5826***
	(0.2329)	(0.2598)	(0. 3137)	(0.2444)	(0.2988)	(0.3585)	(0.2919)	(0.4400)

Industry dummies	Yes	Log-pseudolikelihood	-35106.97	AIC	70701.93
Sample size (n)	4731	Wald chi-square	2681.57***	BIC	72278.63

[a] Robust standard errors in parentheses.
[b] **significant at 5%; ***significant at 1%.
[c] The basis of comparison is the national market.
[d] The reference is the domestic ownership.

Table 5b

Correlation among error terms of the multivariate probit model estimated in Table 5a [e,f,g]

	Patent	**Utility model**	**Registration of design**	**Trademarks**	**Copyright**	**Design Complexity**	**Secrecy**	**Lead-time advantage**
Patent	1							
Utility model	0.713***	1						
Reg. of design	0.536***	0.708***	1					
Trademarks	0.368***	0.432***	0.388***	1				
Copyright	0.543***	0.609***	0.321***	0.695***	1			
Design Complexity	0.133	0.183***	0.464***	0.437***	0.452***	1		
Secrecy	0.198***	0.181***	0.262***	0.308***	0.321***	0.536***	1	
Lead-time	0.058	0.008	0.183**	0.102	-0.028	0.282***	0.548***	1

[e] Likelihood ratio test of $\rho_{21}=\rho_{31}=\rho_{41}=\rho_{51}=\rho_{61}=\rho_{71}=\rho_{81}=\rho_{32}=\rho_{42}=\rho_{52}=\rho_{62}=\rho_{72}=\rho_{82}=\rho_{43}=\rho_{53}=\rho_{63}=\rho_{73}=\rho_{83}=\rho_{54}=\rho_{64}=\rho_{74}=\rho_{84}=\rho_{65}=\rho_{75}=\rho_{85}=\rho_{76}=\rho_{86}=\rho_{87}=0$:
chi2(28) = 58038.1 Prob > chi2 = 0.0000.

[f] **significant at 5%; ***significant at 1%.

[g] #200 random draws.

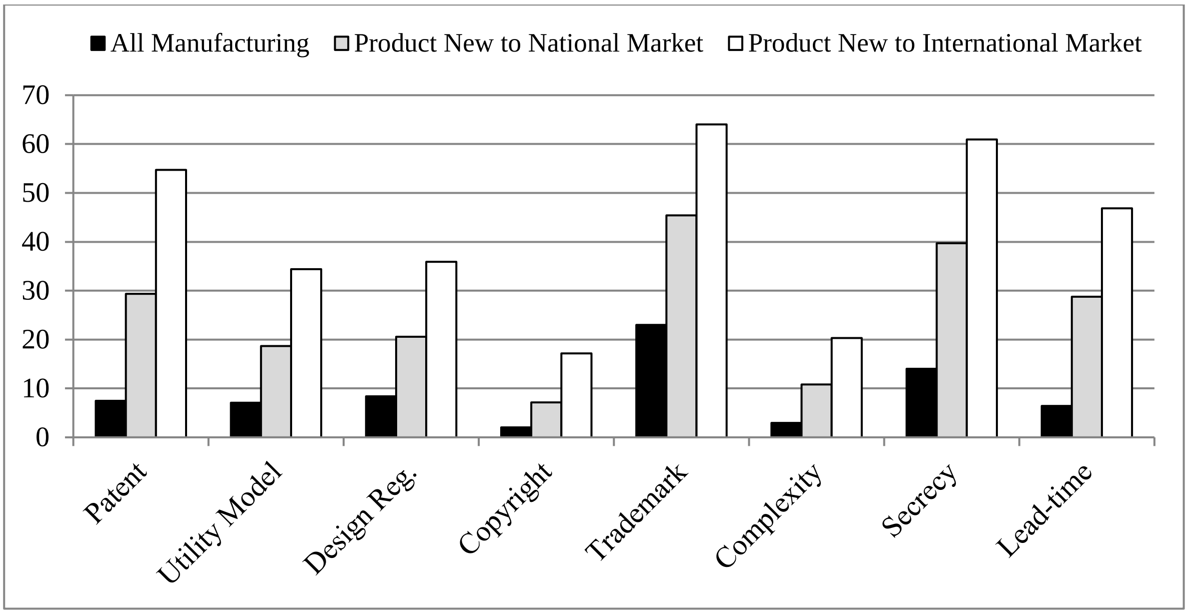

Fig. 1. Use (%) of appropriability mechanisms across subsamples of the Brazilian innovation survey