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PATENT TRADING FLOWS OF SMALL AND LARGE FIRMS

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ABSTRACT

This article presents the results of an analysis of the patent trading flows of small and large firms and the determinants of these firm's patent sale and acquisition decisions. We also examine whether these transactions lead to an excessive concentration of patent rights. We show that small firms disproportionately sell and acquire more patents than large firms, and find no evidence that patent trading brings about a significant concentration of patent rights in the hands of large firms. We find that the match between new patented innovations and the original inventor's patent portfolio plays an important role in how successful firms are at generating value from their patents, and in the decision to sell a patent. And among the traded patents, we show that patent acquisitions respond to complementarities between the acquired patented innovation and the buyer's technological capabilities to adopt it. Our empirical analysis uses a new, comprehensive data set that matches information on patent trades and the identity of patent owners over a patent's lifetime.

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1 Introduction

What is the extent to which small firms specialize in the creation of patented innovations that are sold to large firms? Do these transactions lead to an excessive concentration of patent rights? Does the match between new innovations and the original inventor's complementary assets play a role in how successful firms are at generating value from their patents; or possibly the sale to other firms? And among traded patents, do patent acquisitions respond to complementarities between the acquired patented innovation and the buyer's technological capabilities? This paper presents the results of an analysis of the patent trading flows of small and large firms and the determinants of these firms' patent sale and acquisition decisions. We use a new, comprehensive data set that matches information on patent trades (Serrano, 2010) and the identity of patent owners over a patent's lifetime, involving patents initially owned by businesses in the United States during the period 1988-2001.

An influential literature in economics and management has contributed to the understanding of the market for innovations. This literature, which has primarily focused on the licensing of patents, shows that small firms are both more likely to license the use of their technology than large firms (see e.g., Anand and Khanna (2000) and Arora, Fosfuri, and Gambardella (2001)) and to perform a larger share of the R&D activities in a strategic alliance (Lerner and Merges, 1998). It also shows that the lack of specialized complementary assets (e.g., manufacturing or technological capabilities) increases a firm's propensity to license a patented innovation (Teece, 1986; Arora and Ceccagnoli, 2006), and that conditional on technology licensing, external knowledge acquisition and internal R&D activities are complements (Arora and Gambardella, 1994; Cassiman and Veugelers, 2006).

At the same time, the findings about the licensing of patents do not necessarily expand to the trading of patent rights. First, the acquisition of a patent does not only convey the right of use over the patented technology (as the licensing transaction does), but also the control rights to let other firms use the technology, the right to enforce the patent against infringers, as well as the option to transfer all these rights, including the patent ownership, to any other firm. Second, there is an increasing concern in academic and policy circles that firms acquire patents not to use technology, but to block competitors and stifle follow-on innovation. This can occur if patent sales lead to an excessive concentration of patent rights (Hahn, 1984), or if buyers have the incentive and the ability to hold up rivals (Lemley and Shapiro, 2005; FTC, 2012). Third, the legal requirement that all patent assignments[1] have to be filed with the USPTO in order to be legally binding

[1] Patent assignments acknowledge the transfer by a party of the rights, title, and interest in a patent or bundle of patents.

(Dykeman and Kopko, 2004)[2] can facilitate the systematic study of transactions in the market for innovation.[3] Put together, the distinctive features of patent sales indicate that their analysis can have important implications for understanding the role that the market for innovation plays as a source of incentives to invest in R&D, and how transactions in patent rights shape the nature of competition between small and large firms (Gans, Hsu, and Stern, 2002). Moreover, it is common for patents to be sold, about 13.5 percent of all granted patents are sold, and this rate is even higher for small firms or weighted by patent "value" (Serrano, 2010). Therefore it makes sense to devote some effort to the study of patent sales, especially the patent trading flows of small and large firms.

In this paper we study the patent trading flows of small and large firms, and assess the determinants of the firm's patent selling and acquisition decisions. The main focus of our analysis is to study empirically the extent to which small firms specialize in the creation of patented innovations, that are then sold to other, maybe large, firms. We also examine whether this patent trading leads to an excessive concentration of patent rights in the hands of large firms. Moreover, we analyze the role that the match between new patented innovations and the original patentee's patent portfolio (patentee fit) plays in the sale of patents, and study whether patent acquisitions respond to complementarities between a patented innovation and the buyer's technological capabilities to adopt it (technology linkages). To do so, we construct a comprehensive data set that matches information on patent trades and new data we have obtained about the identity of patent owners over a patent's lifetime, involving all patents initially applied for and granted to businesses in the United States during the period 1988-2001.

The empirical challenge is to identify the firms' size on both sides of the transactions. Patent assignment data provides detailed information on the timing of change in patent ownership, but it lacks standardized information on the identity of the patent's buyer, an issue that has limited the scope of analysis of previous studies (see e.g., Serrano, 2006, 2010). To link this assignment data with size of buyers and sellers, this paper exploits a provision in U.S. patent law that allows us to use information regarding the payment of maintenance (renewal) fees to identify whether a patent owner is either a small or large firm. Under Section 41 of the U.S. Patent Act, small entities enjoy a 50% reduction over what large entities pay for application and renewal fee amounts. Among

[2] In the context of a patent trade, only transactions of patents recorded at the USPTO act as evidence of a bona fide purchase in courts (Dykeman and Kopko, 2004).

[3] Instead, most existing studies on the licensing of patents use data from licensing and strategic alliances activities reported to the U.S. Security and Exchange Commission (SEC). These transactions are not systematic, they typically involve transactions that are significant in value, in which at least one party is a publicly traded firm (i.e., larger firms). At the same time, the transaction provide rich information about the terms of the contractual relationship between the licensor and licensee.

patents owned by businesses, small entity status is assigned to firms with less than 500 employees (including all subsidiaries); the rest are classified as large. Renewal fees are due no later than the end of the fourth, eight, and twelfth year following the patent's grant date. Moreover, the patent application and grant data contains detailed information on the name of the original patentee— the first potential seller— which allows us to construct the original patentee's patent portfolio. We have obtained the renewal fee records from the USPTO and merged them to the patent assignment, patent application and grant data. This empirical strategy means that we can only identify whether a patent was sold and the size of the original patentee and subsequent patent owners as of each renewal date, but we cannot identify the names of patent owners other than the original patentee. This paper is the first research attempt to document patent trading flows between small and large firms.

To guide our empirical analysis, we develop a dynamic model of the market for patents that focuses on how firm size and the uncertainty about the scope of utilization of new innovations affect the decision to sell and acquire patented innovations. The idea we formalize is that bigger firm size, and thus broader research activities, equip large businesses with a superior ability to reallocate innovations within the firm to their best productive use.[4] Our model shows that, under a number of general assumptions, small firms not only are more likely to sell their patents, but may also disproportionately acquire more patents than large firms. Moreover, we prove that among the traded patents, large firms are more likely to buy patents of high value. These predictions are the result of proving that, when market transaction costs are significant, scale economies in the reallocation of new innovations within the firm facilitate large firms to retain the highest value patents in their portfolio. The mechanism ultimately induces large firms to be on average more selective than small firms in their patent acquisitions.

The main empirical findings of the article are the following. First, we find that small firms disproportionately sell and acquire more patents than large firms. Moreover, we show that among the patents sold by small firms, they are not disproportionately acquired by large firms. Our findings also indicate that the patent trading of small and large firms has not led to an excessive concentration of patent rights in large firms. The traditional theory of the division of labor

[4]There is evidence supporting the importance of the flow of information across business units of large conglomerates (Miller, Fern, and Cardinal, 2007). Organizational behavior scholars have also found that knowledge transfer within firms contributes to the performance of businesses both in manufacturing and the retail sector (see e.g., Argote and Ingram (2010) and Argote, Ingram, Levine, and Moreland (2000) for a survey). Anecdotal evidence also suggests that management takes into account the importance of the flow of information across business units. For instance, the VP of Corporate Leadership Development and chief learning officer, General Electric Corporation, stated that "As to moving ideas around diverse businesses that don't have a lot in common, General Electric does this because it has to. If it doesn't, then it is just a holding company. . . ." (as quoted in Miller, Fern, and Cardinal, 2007).

guides how to interpret why small firms are more likely to sell their patents (see e.g., Arrow (1983), Teece (1986), Holmstrom (1989)). This work suggests that small firms specialize in the creation of patented innovations that are then sold to other firms, perhaps to large firms as they often have a comparative advantage in their development, commercialization, or enforcement. We find something different: small firms disproportionately acquire more patents than large firms, especially patents from other small patentees. Nonetheless, this discrepancy may reflect that ideas and/or patented innovations are distinct to traditional goods and services (Arrow, 1962; Teece, 1986; Anton and Yao, 1994; Rosenberg, 1996; Gans, Hsu, and Stern, 2008; Gans and Stern, 2010; and Moser, 2013). The remaining of our empirical analysis presents possible factors affecting the patent trading flows that account for this discrepancy.

Second, we find that patents with a lower match with the patentee's patent portfolio, which is our measure of fit between a firm's new innovation and its complementary assets, are more likely to be sold; and among patents that were not sold, the ones with the lowest fit are more likely to be discontinued.[5] We also show that small firms' patent portfolios are characterized by a lower fit between the new patented innovations and the patentee's portfolio than those of the large firms. These findings are consistent with our hypothesis that the match between a patent and the patentee plays a crucial role in the success of a firm at generating value from its patented innovations. Put together, they account for the reason why small firms disproportionately sell more patents than large firms.

Third, we show that among traded patents the likelihood of being acquired by a large firm increases with the number of patent citations received (which is our proxy for patent value).[6] This finding is consistent with the idea of economies of scale in the reallocation of innovations within the firm. Large firms take advantage of bigger size to reallocate innovations within the firm to their the best use, which in turn allows them to hold a better portfolio and are therefore more selective in their patent acquisitions. Indeed, this mechanism is also consistent with the fact that small firms disproportionately acquire more patents than large firms. This finding also suggests that at least for the most valuable patents the direction of the trading flows can be consistent with the traditional theory of the division of labor. Nonetheless, the mechanism cannot account for why among the traded patents, small firms acquire disproportionately more small firm patents than large firm patents. The next finding actually helps us account for this issue.

Finally, we present evidence showing that among traded patents the probability of being

[5] In our empirical analysis, the share of patent citations made to the patentee's patent portfolio among all patent citations made captures the match of a patent with a patentee's patent portfolio.

[6] A commonly used proxy for patent value is the number of patent citations received (Hall, Jaffe, and Tratjenberg, 2001).

acquired by a small firm increases with the match between the patent and the technology profile of existing small buyers relative to the one of large buyers. The finding is consistent with recent literature analyzing the degree of complementarity between own R&D and technology acquisition strategies (see e.g., Cohen and Levinthal (1990), Arora and Gambardella (1994), and Cassiman and Veugelers (2006)).

Regression analysis confirms the robustness of these patterns to a number of controls and econometric specifications.

Taken together, a new implication from our findings is that market transaction costs create a disproportionate "reallocation tax" on small firms. Because small firms have a relative disadvantage over large firms to match new patented innovations with complementary assets within the firm, significant market transaction costs can potentially discourage small firms' entry and growth opportunities, and ultimately distort the degree of competition between small and large firms in an industry (Gans, Hsu, and Stern, 2002). Our findings suggest that a major policy leverage to increase the incentives to innovate in R&D for early-stage businesses would be to establish clear patent rights' boundaries, and to make information on patent sales, including transaction prices, available through a public registry (Lemley and Myhrvold, 2008). This will take different forms than the typical policy levers to stimulate R&D investment.

This paper contributes to a nascent literature studying the sale of patents using patent assignment data. Seminal work by Lamoureaux and Sokoloff (1997, 1999, 2001) used a sample of sales of private-inventor patents to provide a historical account of whether organized markets for technology existed in the late 19th and early 20th centuries. More recently, Serrano (2006, 2010) documented the effects of firm size, patent technology class, patent age, and patent citations and generality on the sale of patents for all U.S. patents granted during 1983-2001. In Serrano (2012), some of these patterns were used to estimate a model of patent trading and renewal, that under some assumptions, allows the author to quantify the gains from trade in the market for patent rights. Finally, Galasso, Schankerman, and Serrano (2013) identify a new source of gains from trade in patents, which is comparative advantage in patent enforcement, and show that this mechanism accounts for the observed lower litigation risk that follows after a patent sale on average. The lack of detailed systematic information on the identity of the firms' size on both sides of the transactions has hampered the analysis of the patent trading flows of small and large firms. Moreover, previous work on patent sales has not examined whether the match between new patented innovations and a firm's complementary assets play a role in the sale and acquisition of patent rights.

This article is organized as follows. In Section 2 we describe a model of patent trading flows of small and large firms, and derived some key testable implications. Section 3 describes the data. In Section 4 we present the patterns of the patent trading flows of the small and the large firms. Section 5 develops some basic facts about the determinants of these patent trading flows. In Section 6, we present the baseline econometric model to empirically assess the robustness of the patent trading flows and factors that influence it. Brief concluding remarks close the paper.

2 A model of patent trading flows of small and large firms

This section presents some intuitive guidance on how one might interpret the empirical regularities that we establish in the following sections. Our analysis focuses on how firm size and the uncertainty about the usefulness of new innovations affect the decision to sell and acquire patented innovations. The key idea we consider is that bigger firm size, and thus broader research activities, equip large businesses with a superior ability to reallocate innovations within the firm to the best productive use.[7]

Consider an economy populated by a finite number of small and large firms. Small firms own one research lab while large firms own two or more. Each lab produces innovations at a fixed rate, which is independent of the owner's size, and each lab allows the firm to put one innovation to a productive use. To keep things simple, we assume that each innovation is useful (i.e., it is a good "fit") for only one lab in the economy, and that the matching process between a new innovation and a lab is completely random. While this assumption is somewhat extreme, it captures the idea that firms conduct R&D "in the shadow of uncertainty", and find it hard control *ex-ante* the exact nature, scope, and value of new innovations (Rosenberg, 1996). This gives rise to possible gains from trade *ex-post* and generates a role for the market for patents. However, there exists a transaction cost when acquiring an innovation that was generated outside the firm. This captures direct costs like capital and organizational costs to adopt a new patented innovation and the hiring of intermediaries such as patent lawyers and brokers, and market frictions arising from expropriation risk (see e.g., Arrow (1962), Anton and Yao (1994), and a recent survey by Moser (2013)).

We also consider that innovations differ in quality, and that the value of an innovation, conditionally on being a good fit for a firm, is increasing with quality. There is extensive evidence indicating that the value of patented innovation is highly heterogeneous (Pakes, 1986). The heterogeneity in innovation quality, and thus value, play an interesting role in the firm's decision to acquire external patented innovation. Since firms have a limited capacity for putting innovations

[7] A formal dynamic model of the market for patents, including the proofs of the implications presented in this section, can be found in the appendix.

to a productive use (given by the amount of labs they own), a new innovation with a good fit for them is useful only if it is better than the worst innovation they currently own. Given the transaction costs, the leap in quality to acquire an external innovation must be significant, even under the assumption that the buyer makes a take it or leave it offer, effectively capturing the whole surplus.

Finally, we assume that once created, innovations only change their quality through obsolescence, and that there is a positive discount factor between periods.

To illustrate the decision of a patentee, which will in turn determine the patent trading flows between firms in this economy, consider an innovation characterized by its value, the lab from which it originates, and the lab for which it is useful. If the innovation has a good fit with a lab owned by the same firm that originates it, the firm may keep it (if it is an improvement) or discontinue it (i.e., not renewing it). If the innovation is useful for another firm, the originator will try to sell it, and trade will occur if the gains from replacing an old invention with the new one are bigger than the transaction cost plus the option value of waiting for the arrival or acquisition of future innovations. Otherwise it will be discontinued.

Market interactions, characterized by the acquisition decisions of the different firms, generate a dynamic system where, in steady state, small and large firms hold portfolios of patented innovations of different qualities. We characterize the steady state of this model, which turns out to have the implications we find in the data.

The main predictions of the model are as follows. First, small firms are not only more likely to sell their patents, but also disproportionately acquire more patents than large firms. Second, among the traded patents, the likelihood of being acquired by either a small or large buyer depends on the degree of the fit between the focal patent and the technology profile of potential buyers. Third, among traded patents, the probability of being acquired by a large firm increases with the patent's quality. These implications are the result of demonstrating that scale economies in the reallocation of new innovations facilitate large firms to retain the highest value patents in their portfolio. Moreover, this mechanism induces large firms to be on average more selective than small firms in their patent acquisitions, which ultimately accounts for why small firms disproportionately acquire more patents than large firms.

3 Data

The facts we present are derived by merging two datasets. The first dataset contains information about the firm size of the patent owners as of the patent's application date and renewal dates.

We obtained this information using patent level application and maintenance fee records from the USPTO. The second dataset provides the transfer records decisions over the lifetime of patents (Serrano, 2010). The merged dataset is a panel of patents applied for and granted to corporations that includes the history of trade and renewal decisions, and whether the patent owner is a small or large entity at various dates during the patent's lifetime.

3.1 Sample construction

Documenting the firm size of patent owners over the lifetime of a patent has been challenging. While the NBER Patent Citations data set reports the name of a patentee as of the issue date of a patent, but it does not keep track neither of patents sales nor of subsequent patent owners (Hall, Jaffe, and Tratjenberg, 2001). Similarly, the USPTO Patent assignment data does keep track of the registration of these sales, but neither the names of the buyers nor the sellers of patents were standardized by the patent office, making it unfeasible to link these transactions to existing datasets on business characteristics in a systematic manner.[8]

To overcome this challenge, we pursue an alternative strategy, exploiting a provision in the U.S. patent law that regulates the assertion of small and large entity status and the notification of changes of entity status over the lifetime of patents. Under Section 41 of the U.S. Patent Act, the standard application and maintenance fees amounts are subject to a 50% reduction for small entities.[9] Among businesses, patents are assigned a small entity status if the patent holder is a business with less than 500 employees (including all subsidiaries); the rest are considered large. Small entity status is established by a written assertion of entitlement to small entity status or claimed with the payment of filing fees and maintenance fees over the life cycle of patents. After an assertion of small entity status has been established, a second subsequent assertion is not required when occurs an assignment of rights or an obligation to assign rights to other parties that are small entities. On the contrary, the notification of loss of entitlement to small entity status, such as upon the sale of a patent from a small entity to a large entity, is required when issue and maintenance fees are due. In short, the regulation implies that the patent's entity status reflects the actual firm size of patent owners.

The first dataset we develop combines information extracted from patent application and

[8] To the best of our knowledge, there is no systematic dataset including the buyer and seller's identify in patent transactions, the owner's firm size, or other business characteristics.

[9] Under 35 U.S.C. 41(h)(1), fees "charged under 35 U.S.C. 41(a), (b), and (d)(1) shall be reduced by 50 percent with respect to their application to any small business concern as defined under section 3 of the Small Business Act, and to any independent inventor or nonprofit organization as defined in regulations issued by the Director." This is a unique feature of the USPTO, all patentee pay the same fees at the European Patent Office and the Japanese Patent Office.

maintenance fee records to document the firm size for patent owners over the lifetime of patents. To document whether patents were initially owned by small or large businesses, we use the patent application records of issued patents. We have obtained patent application records from January 1, 1980 to December 31, 2000. To identify the firm size of patent owners over a patent's lifetime, we make use of the patent maintenance fee records held at the Finance Division of the patent office. Maintenance fees are due no later than the end of the 4th, 8th and 12th year after the grant date of the patent.[10] We obtained the patent maintenance fee records from January 1, 1992, to December 31, 2001.[11] By linking both data sources, we can identify the firm size for the patent owners at the grant date and at each of the renewal events.

The second dataset uses registrations of changes in patent ownership recorded at the USPTO in order to identify the sale of patents. The source of the data is the Patent Assignment Database. When a U.S. patent is transferred, an assignment is recorded at the patent office acknowledging the change of ownership. Under Section 261 of the U.S. Patent Act, recording the assignment protects the patent owner against previous unrecorded interests and subsequent assignments. If the patentee does not record the assignment, subsequent recorded assignments will take priority. For these reasons, patent owners have strong incentives to record assignments and patent attorneys strongly recommend this practice (Dykeman and Kopko, 2004). A typical reassignment entry indicates the patent number involved, the name of the buyer (i.e. assignee), the name of the seller (i.e. assignor), the date at which the reassignment was recorded at the patent office and the date at which the private agreement between the parties was signed. This information was collected for the period 1983-2001.[12]

A challenge in using reassignment data is to distinguish changes in patent ownership from other events recorded at the USPTO assignment data. We use an algorithm developed in Serrano (2010) that conservatively drops all the assignments that appear not to be associated with an actual patent trade. The algorithm drops assignments that refer to a "name change" of the patentee, to the patent being used as a collateral ("security interest"), to corrections ("corrections"), changes of address ("change of address"), assignments from an inventor to the employer ("first assignments"), and transactions between entities with the same name. In addition we drop assignments in which the buyer is the assignee as of the grant date of the patent, assignments recorded at the patent

[10] The failure to pay the fees by the due date will result in the patent's immediate expiration.

[11] An author obtained access from the USPTO to the maintenance fee records in exchanged for advice on their cleaning, processing, and use. A task force at the patent office used the information on the patent entity status in order to better forecast the patent office revenues from maintenance fees. While at the time that an author was involved with the patent office, the data in bulk was not publicly available. The processed data can be freely accessed nowadays at: http://www.google.com/googlebooks/uspto.html.

[12] A summary of the patent assignment data as well as an detailed discussion of its advantages and disadvantages can be found in Serrano (2006, 2010).

application date, and assignments to financial institutions.[13] The details of the procedures we used to deal with the assignment data are explained in Serrano (2010). The remaining, post-cleaning, assignment records identify the sale of a patent between distinct entities and have information about patent numbers.

Patent numbers make possible to merge both datasets with classic data on patents that others have used. In particular, we obtain data on patent citations received, patent citations made, original assignee name and number, type of assignee, patent's technology class, etc. using the NBER Patent Citations Dataset (Hall, Jaffe, and Tratjenberg, 2001). Moreover, the assignee number (a unique patentee identifier) allows us to construct patentee's patent portfolios. To the best of our knowledge, this is the first time that data on the patent entity status indicating firm size of patent holders over a patent's lifetime has been linked to data on patent trading and other patent characteristics.

In our empirical analysis we focus on corporate patents, so we use patents that were applied for and granted to businesses, which represent about 75 percent of all issued patents. In doing so, we exclude patent applied for and issued to individual inventors or individually owned, federal agencies, and universities. In addition, our analysis is restricted to patents granted in between the years 1989 and 1996. For these patents, we not only observe their entity status as of their application date, but also at the date the first maintenance fee is due (i.e., the end of the fourth year after a patent's issue date). The merged dataset has $590,873$ patents, issued to $61,239$ patentees.

Table 1 presents summary statistics of the patents in our sample. Panel A shows that 11% of these patents were owned by small firms as of their application date, and rest were owned by large firms. The same panel reports that these rates across the issue years of the patents in the sample. The proportion of small firm patents has been growing over the period of study, ranging from 9 percent in 1989-1990 to 12 percent in the years 1995-1996. In Panel B we report the proportion of patents initially owned by small and large firms across six patent technology classes (Chemical, Computer & Communications, Drugs & Medical, Electric & Electronics, Mechanical, and Other). Small firms patenting is relatively more important in the technology classes of Drugs and Medical (15.2%) and Other (20.6%). The lowest share of patenting for small firms is in the Computer and Communications (5.9%) and Chemical (6.5%) patent classes.[14]

[13] By dropping transactions to financial institution we eliminate transactions in which a patent may have been used as collateral in a loan, or that the possibility that patent was transferred to the financial institution in case the loan was not paid back.

[14] We have followed Hall, Jaffe, and Tratjenberg (2001) to classify patents into technology categories or fields.

4 Patent trading flows of small and large firms

We begin our empirical analysis describing the sale, acquisition, and expiration of patents by small and large firms. Our analysis of patent transactions will focus on patent sales made by the original patentee and that took place within four years of each patent's grant date. We do this because we have detailed information on the patent portfolio only of the original patentee. Moreover, all patents are active prior to their first renewal date.

Table 2 reports information on patent sales and acquisitions. Column (1) present aggregate statistics; the rest present six different patent technology classes in our data. In Panel A, we present the proportion of patents sold by small and large firms. Column (1) shows that while small firms sell 9 percent of their patents, large firms sell only 5.5 percent. These rates are low because in our analysis trade is truncated by the fourth year since a patent's grant date. This result is consistent with Serrano (2010). The remaining of the empirical findings presented are new.[15] In panel B, we report patent acquisitions. We compute the proportion of traded patents that had been acquired by small firms and large firms and then compare it with their patenting activity. Column (1) shows that the proportion of patents acquired by small firms is about 16 percent of all the traded patents, while large firms acquire the remaining 84 percent. The striking fact from this table is that small firms disproportionately acquire more patents than large firms. To show this, we compare the proportion of traded patents acquired by small and large firms with the proportion of patents that were applied for and granted to small and large firms. Of all the patents that were applied for and granted, small firms firms applied for and were granted 10.7 percent of them, but they acquired 16 percent of the traded patents in our sample (that is, an acquisition rate about 50% higher than their patenting rate); large firms applied for and were granted the rest, 89.2 percent, but acquired 84 percent (about 6% lower than their patenting activity). Similar findings were found across patent technology classes.

In Panel C of Table 2, we study the patent trading flows between small and large firms. To do this, we focus on the subsample of traded patents by small firms and the one of patents traded by large firms. Among patents sold by small firms, 67 percent were acquired by other small firms, which is about six times times the proportion of patents granted to small firms in our sample; the rest of the patents were acquired by large firms. Among patents sold by large firms, we see that the proportion of these patents acquired by large firms is 94.2 percent, which is just 6 percent higher than the proportion of patents granted to large firms in our sample. In short, these findings indicate that small firms disproportionately acquire more small firm patents than large firms, but

[15] The lifetime rate of transfer, albeit is a somewhat different sample, is larger (see Serrano, 2010).

large firms do not especially rely on innovation from other large firms, they buy patents to what would be suggested by an uniform buying pattern. The rest of the columns in Table 2 confirm that these patterns are consistent across technology classes.

Table 3 examines the implications of the patent trading on the concentration of patent rights and the patent portfolios of firms. In Panel A, we show that patent sales have not lead to a significant increase in the concentration of patent rights in the hands of large firms. To do this, we present the proportion of patent rights held by small and large firms as of age five and immediately after the renewal decision. We find no substantial differences between the proportion of patents initially owned by large firms (10.7%) and the same proportion of patent as of age five (10%). The findings are consistent across patent technology classes.[16]

In Panel B, we examine the extent to which the market for patent rights is an important source of patented innovations for firms. To do so, we calculate the proportion of patents previously acquired relative to all the patents held by firms as of age five of these patents. We show that the proportion of patents acquired in the patent portfolio of the typical small firm (9.3%) is significantly higher than the same proportion in the patent portfolio of the larger firms (5.6%). The result indicates that small firms tend to rely more on the market for patent rights than their larger counterparts.

The theory of the firm as applied to the division of innovative labor between small and large firms guides us in how to interpret some of the previous findings. The fact that large firms are less likely than small firms to sell their patents can be explained by their comparative advantage in manufacturing and marketing. Nevertheless, the patterns concerning the acquisition of patents contradict the predictions of this theory. Not only we find that small firms disproportionately acquire more patents that large firms, but also the direction of some of the patent trading flows is the opposite to the prediction of the theory: small firm patents are not disproportionately acquired by large firms.

The next section explores why is there such a discrepancy. We plan to test three possible factors our model suggest that may affect the patent trading flows of small and large firms. Namely, the match between a patent and the downstream complementary assets of the patentee, the technology linkages between the relevant technology in the patent and the potential buyers' capacity to effectively adopt it, and a patent's value.

[16] Similar qualitative results were obtained weighting traded patents by patent citations received.

5 Determinants of patent trading flows

5.1 Hypotheses development

Patentee fit

The first focus of interest is to study the role of the match between new patented innovations and the original patentee's complementary assets. In particular, the role it plays in the success of firms at generating value from their innovations; or possibly their sale (Teece, 1986; Gans and Stern, 2003; Arora and Ceccagnoli, 2006; Cassiman and Ueda, 2006). However, the match between a patentee's new innovations and its downstream assets is hard to measure. The number of patents embedded in a product and the form in which this product interacts with the rest of the firm could provide some evidence about this, but there are no datasets providing such detailed information.

Because patented knowledge is prior art, that patent applicants and patent office examiners are required to cite, we use patent citations to construct a variable designed to reflect to what degree a patented innovation is a good match for the patentee.[17] We define $PatenteeFit$ as the number of patent citations made in a patent to the patentee's patent portfolio relative to the total number of patent citations made to the rest of patentees (i.e., self-citation rate). This measure has often been considered a proxy of the relevant degree of complementarity between new innovations and their original patentee (see e.g., Lanjouw and Schankerman, 2004).

There are two dimensions along which we can identify the importance of the match between new innovations and the original patentee's complementary assets: the decision to sell a patent and the decision to extend its life. Our first hypothesis is that patents with a lower fit with the patentee's patent portfolio will be more likely to be sold; and the second hypothesis is that among the patents that are not sold, the patentee will be more likely to let expire the ones with lower fit.

H.1 *Patents with lower fit with the patentee's patent portfolio are more likely to be traded*

H.2 *Among the untraded patents, the patents with a lower fit with the patentee's patent portfolio are more likely to be let to expire*

At the same time, recent work highlights the important role the flow of information within the firm plays in the matching of innovations with complementary assets (Nelson, 1959; Henderson

[17] Patent applicants and the lawyers representing them must include to the best of their knowledge all prior art in the application. This may include non-patentable elements (e.g., journal publications), previous patents that relate to the innovation they aim to patent and its claims, etc. These citations are then assessed by the patent examiner who ultimately either confirms or discards them during the application process.

and Cockburn, 1996; Argote et al, 2000; Miller, Fern, and Cardinal, 2007; Hellmann and Perotti, 2011).[18] We consider that bigger firm size, and thus a broader field of applications for new innovations, provides superior ability to reallocate innovations to the best productive use within the firm. This idea is closest to Nelson (1959)'s study in that we both associate broader research activities with large firms. In light of this idea, we would expect that patents originated in small firms will have a lower $PatenteeFit$ than the ones originated in large firms. An immediate corollary of this conjecture would be that small firms are more likely to sell their patents because their patents have on average poorer fit with the patentee than the patents of large firms.

Patent value

A second dimension along which the direction of the patent trading flows of small and large firms may be shaped is patent "value". If the market for patents works efficiently, we would expect that firms buy patents that represent an improvements over their current patent portfolio. Moreover, our model indicates that scale economies in the reallocation of new innovations can provide large firms with superior ability to hold high value patents, making large firms to be on average more selective than small firms in their patent acquisitions.

Because we have neither data on acquisition prices nor information on expected patent values, we can only rely on imperfect measures of patent value. A commonly used proxy for patent value is the number of patent citations received (Trajtenberg, 1990). Additional support for this measure can be found in Serrano (2010), who shows that patents with a higher number of patent citations received by a given age are more likely to be both traded and renewed. Following this line of work, we capture patent "value" using the cumulative number of patent citations received as of age five.

Our third hypothesis is that among the patents traded the ones acquired by large firms have a higher mean number of patent citations received than the patents acquired by small firms.

H.3 *Among the traded patents, the ones with higher number of patent citations received are more likely to be acquired by large firms, especially for the patents initially owned by small firms.*

Taken together, and according to our model of the patent trading flows, the three previous hypotheses can account for why small firms disproportionately sell and acquire more patents than large firms. Indeed, the hypothesis for which patents with the lowest match with the patentee's patent portfolio are the ones most likely to be traded can account for the reason why small firms disproportionately sell more patents than large firms. Similarly, the superior advantage of large

[18] Henderson and Cockburn (1996) associate the returns to the scope (or diversity) of the firm's research effort with internal spillovers of knowledge between programs that enhance each other's productivity. Henderson and Cockburn, however, are agnostic as to whether these economies of scope should increase or decrease with firm size.

firms to reallocate innovations within the firm to their the best use allows them to hold a better portfolio and are therefore more selective in their patent acquisitions. Nonetheless, the previous hypotheses cannot explain why among traded patents, small firms acquire disproportionately more small firm patents than large firm patents. To do this, we examine below whether patent acquisitions respond to the buyer's technological capabilities to adopt patented innovations.

Technology linkages

Another channel that may influence the transaction of patents is the existence of technology linkages between the relevant patented technology and the potential buyers's capacity to effectively adopt it (Cohen and Levinthal, 1990; Arora and Gambardella, 1994; Cassiman and Veugelers, 2006). Measuring this match is challenging and, to the best of our knowledge, there is no data that formally links patented innovations with their best potential buyers.

Since for each patent, and its corresponding cited patents, the patentee of the focal patent is linked to the patentees of the cited patents, we can use patent citation data to capture the degree of the match of the focal patent with potential buyers (i.e., technology linkages). Recall that our empirical strategy to identify the firms' size on both sides of the transactions implies that we can only identify whether a patent was sold and the size of the subsequent patent owner, but we cannot identify the names of patent owners other than the original patentee. We define $TechLink$ as the number of patent citations made to firms with the same size that the patentee relative to the total number of patent citations made to small and large firms (excluding self-citations).[19] Our hypothesis is that if research activities between small firms, or between small and large firms, were interconnected in some non-random fashion (such as the complementarity between own R&D and technology acquisition), we expect that part of the trading flows between small and large firms could be accounted by this effect, which would characterize the potential buyers' ability to effectively adopt external technologies.[20]

Following these ideas, the fourth hypothesis we want to assess is whether the smaller firms' research activities are more linked with each other than the ones of their larger counterparts, and whether the links in the research activities of small and large firms are associated with the direction of the observed patent trading flows.

[19] To construct $TechLink$, we use the patent citations made to corporations (i.e., assigned to a corporation as of their grant date) and that were identified as being made to a small and large entities. For a small firm patent, $TechLink$ measures the proportion of citations made to small firms among all the patent citations made to small and large firms. For a large firm patent, $TechLink$ is the proportion of citations made to large firms among all patent citations made to small and large firms.

[20] Given that all patents are subject to be cited independently of whether or not they are let to expire over their lifetime, we consider that the small and large firm patents that could potentially be cited is equal to the proportion of patents initially owned by small and large firms too.

H.4 *The direction of the patent trading flows of small and large firms depend on the degree of the match of the focal patent with the best potential buyer.*

5.2 Motivating evidence

We begin providing summary statistics of patentee fit, technology linkages, and patent value with the objective to motivate the econometric analysis to follow in the next section.

Patentee fit

Table 4A reports descriptive statistics for $PatenteeFit$ and the trade and expiration of patents. We find that the mean $PatenteeFit$ of the traded patents (0.093) is lower than the patents that were kept (0.136) by the patentee. At the same time, the $PatenteeFit$ of the renewed patents that were not previously sold (0.139) is higher than the fit of the patents that were let to expire (0.117), indicating that the patents with a lower fit with the patentee are indeed the most likely to be let to expire. All the differences are significant at p-values $< .01$. The findings suggest that higher patentee fit is associated with lower likelihood that a patentee will sell the patent; and that conditional on not selling the patent, higher patentee fit is also connected with lower likelihood of expiration. All in all, the correlations suggest that the match between a patent and the patentee's patent portfolio may be an important determinant of the trading and the expiration of patents (Hypotheses #1 and #2).

In Panel B of Table 4, we present statistics of $PatenteeFit$ for small and large firms. It shows that the mean $PatenteeFit$ for patents initially owned by large firms (0.143) is higher than for the patents issued to the small firms (0.054). The difference is also statistically significant with p-value $< .01$. This finding provides support for the conjecture that larger size equips large firms with superior ability to match new patents to the best use within the firm's boundaries.

Patent value

Table 5 presents the number of patent citations received of the patents that the small and the large firms acquire relative to the average patent not sold and the average patent granted. Panel A reports a number of results. First, large firms acquire patents with higher mean of patent citations received than the small firms. Looking at this more closely, the result does depend on whether the original patentee was either a small or large firms. Among small firm patents, large firms tend to purchase the patents with higher mean number of patent citations received (5.85 (std. err. 0.181)) vs. small firms (4.12 (std. err. 0.10)), and the difference is statistically significant (p-value < 0.01).[21] Instead, among patents initially owned by large firms, there are

[21] The number of patent citations received is equal to the cumulative number of patent citations received as of

no significant differences between the patent value acquisition patterns of small and large firms (p-value = 0.44). The second result is that the mean number of patents citations received of the acquired patents is higher than those not traded, as well as higher than those initially issued to the firms. All in all, this table indicates that patentees buy improvements over their patent portfolio, and that large firms acquire higher value patents than small firms, especially among patents initially granted to small firms. Similar results were obtained using the patent's renewal decision as an alternative indicator of patent value (see Panel B of Table 5). These results provide support for Hypothesis #3 and the model of patent trading flows of Section 2.

Technology linkages

Table 6 quantifies the match between the technology profile of patentees and potential buyers. In Panels 6A and 6B, we compare the mean of *TechLink* for small and large firms with their patenting activity. We find that *TechLink* of small firm patents (16.8%) is higher than the proportion of patents initially owned by small firms (10.7%) (about 57 percent higher than the rate of a random citation pattern.)[22] In contrast, the proportion of all citations made to large firms patents from large firms (94.5%) is marginally higher than the proportion of patents initially owned by small firms (89.2%) (about 6 percent higher than random citation.) The findings indicate that there is a strong affinity in the research activities of small firms, and that large firms' research activities are broader than the one of small firms (at least in terms of their patent citation behavior and patenting).

Examining the data further we find that the results also hold across different technology fields. It is worth highlighting here that the rates of citations among small firms is highest in the Computer & Communications and the Chemical patent categories (over twice the rate of random citation); in contrast, in the mechanical and the Drug & Medical patent citations among small firms is much less common (only about 35 percent higher than the rate of random patent citation). Incidentally, the ratio of the proportion of small firm traded patents acquired by other small firms to the proportion of patents applied for and granted to small firms is also highest in the Computer & Communication and the Chemical patent classes.

Putting together the previous results suggest that the patent trading flows of small and large firms are associated with technology linkages, and thus the ability that firms have to adopt external technologies.

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year five since the grant date of the patent.

[22] The patent citations we use exclude self-citations; and the rate of random citations is the one where citations made are based on the stock of small and/or large firm patents that may be potentially cited.

6 Econometric specification and results

6.1 Identification

Taking the previous results together, we may be tempted to conclude that small firms disproportionately sell more patents than large firms because small firms' patents are more likely to have a poor fit with their patentee's patent portfolios. Similarly, we can also prematurely conclude that the stronger technology linkages between small firms cause the strong patent trading flows between small firms.

But there may be other reasonable explanations for these facts. For example, firms that aim to specialize both in the creation and the sale of patents, such as perhaps small firms, may also be businesses with patents displaying low and persistent measures of fit with their patent portfolio, i.e., patentee fit. Similarly, firms that are liquidity constrained may find it harder to be granted patents with a high fit with their complementary assets and, at the same time, are less likely to pay the maintenance fees to renew them. As for the technology linkages, some patentees, especially among small firms, may be both buying and selling more patents in technology areas where these firms' research is more interconnected, independently of whether technology linkages facilitate technology adoption. In other words, because patentee fit and technology linkages can correlate with unobservable patentee characteristics that affect the decision to trade a patent and the direction of the trade, an endogeneity problem may emerge. A cross-section analysis of observations of whether a patent was traded will not allow us to identify neither the effect of patentee fit nor the role of technology linkages on the trading and the direction of the patent trading flows, respectively.

For these reasons, we use a panel-level regression analysis with patentee fixed effects. This approach allows us to control for unobserved permanent heterogeneity that affects the trading decision of patentees and that may be correlated with the variables patentee fit and technology linkages. There are $59,839$ firms in our dataset, each firm holding on average approximately 10 patents. A patentee fixed effect should capture the impact that these unobserved characteristics may have on the decisions to trade and to whom to trade a patent that is not a consequence of patentee fit or the technology linkages. At the same time, the patentee fixed effects will undoubtedly reduce the variation in the data to precisely estimate some coefficients, especially in specifications using the subsample of traded patents.

In addition, our empirical analysis controls for the patent's technology class. Patent technology class dummies allow us to isolate the effect of unobservable determinants of the trading decision and the direction of the flows that are technology specific. For instance, the correlation between the variable patentee fit and the small firm dummy may be the result of few but large technology areas. Alternatively, the finding suggesting that large firms acquire higher value patents than small firms may also be due to large firms acquiring patents from patent classes that typically receive more patent citations on average.

Our empirical analysis also considers alternative specifications to the patentee fixed effect model (e.g., non-fixed effect linear probability model and a Probit model). In these regression specifications, we control for the size of a patentee's patent portfolio size and a dummy indicating whether the patentee is a small firm. The variable size of the patent portfolio does influence whether a patent is a good match for the patentee and at the same time may also be a determinant of the direction of the patent trading flows (see e.g., Galasso, Schankerman, and Serrano, 2013). In the absence of patentee fixed effects, the small firm dummy accounts for the potential effect of small patentee unobserved heterogeneity in the direction of the patent trading flows that cannot be explained by the rest of the covariates.

6.2 Model specification

The remaining of our empirical analysis consists of two parts. First, we study the effect of patentee fit on the patent trading and expiration decisions. Second, we examine the role of technology linkages and patent value in the direction of the patent trading flows of small and large firms. Previous literature on patent trading only looked at the effect of firm size, patent citations, etc. on whether a patent is traded or not (Serrano, 2010). Here we additionally consider the buyer's firm size and thus analyze the direction of the patent trading of small and large firms. Regarding technology licensing, the extant studies examined whether the frequency of patent licensing was lower for firms with specialized complementary assets (e.g., Arora and Ceccagnoli (2006)) only using cross-sectional data. We have access to panel-level data that facilitates the identification of the effect of the match of the patent with the patentee's patent portfolio on patent trading.

To study the importance that the match between new patented innovations and the patentee's patent portfolio play in the trading and expiration decision, we consider whether a patent was traded at least once during the first four years from the patent grant date and whether or not the patent was let to expire at the first renewal event, respectively. The estimated model is:

$$Y_i = \alpha PatenteeFit_{ij} + \beta X_{ij} + \mu_j + Tech_i + Gyear_i + u_i \quad (1)$$

where the dependent variable ($TRADE$ or $EXPIRE$) is a binary-indicator, μ_j is a patentee fixed effect, and $Tech_i$ and $Gyear_i$ denote patent technology class effects ($Tech_i$, i.e., 36 patent sub-categories) and patent grant year effects (1989 to 1996), respectively.[23]

The main variable of interest is $PatenteeFit_{ij}$ (the match between new patented innovation i and the patentee's j patent portfolio), that is measured as the percentage of citations made to the patent portfolio of the patentee. In both specifications, a negative and significant α implies that patents with higher patentee fit are associated with lower trade rates and that among the untraded patents the ones with higher patentee fit are associated with lower expiration rates, respectively.

The vector X_{ij} has potentially two components. The first one is a proxy of the value of the patent ($Citations_i$), measured as the cumulative number of patent citations received by patent i as of patent age five. The second component, the size of the patent portfolio of the patentee ($PortfolioSize_{ij}$), is included in specifications without firm fixed effects.[24]

To study the direction of the patent trading flows, we consider the sample of patents that were traded within four years after a patent's grant date and estimate the following specification:

$$\begin{aligned} TRADE_{S_i} &= \alpha_1 TechLink_{ij} * Small_{ij} + \alpha_2 TechLink_{ij} * Large_{ij} + \beta Z_{ij} \\ &\quad + \mu_j + Tech_i + Gyear_i + u_i \end{aligned} \tag{2}$$

where $TRADE_{S_i}$ is a dummy equal to 1 if a patent is traded to a small firm, and zero whenever the patent was sold to a large firm.

The variables of interest is $TechLink_{ij}$ (technology linkages between the relevant patented technology in innovation i and the potential buyers's capacity to effectively adopt it), measured as the number of patent citations made to firms with the same size that the patentee relative to the total number of patent citations made to all other firms. $Small_{ij}$ and $Large_{ij}$ are dummy variables equal to 1 if the original patentee is a small or large firm, respectively, and zero otherwise. A positive and significant coefficient of the interaction $TechLink_{ij} * Small_{ij}$ indicates that patents that would be a better fit for small firms are associated with higher rates of acquisition by small firms. Similarly, a negative and significant coefficient for $TechLink_{ij} * Large_{ij}$ implies that, among large firm patents, a better fit with large firms is associated with a lower rate of acquisition by small firms.

In equation (2), the vector Z_{ij} includes the patent specific variables patent citations received

[23] Because our interest is on the expiration decision of the intial patentees, the expiration specification uses the sample of patents still owned by the initial patentee as of the renewal decision date. Note that we would not be able to compute the subsequent owner's patent portfolio and PatenteeFit measure because while we observe the size of the patent buyer (small or large), the assignment data does not provide neither its name nor unique identifier (which is needed to compute patent portfolios in a systematic manner).

[24] Portfolio size is computed using the cumulative number of patents granted to a patentee either from 1975 (first year in our data) or the first year a firm patented.

($Citations_i$), $Tech_i$ and $Gyear_i$. Among the specifications that do not include the firm fixed effect μ_j, the vector Z_{ij} also contains the size of the patent portfolio of the patentee ($PortfolioSize_{ij}$) and a firm size dummy ($Small_{ij}$). In particular, we add the variable $Small_{ij}$ to control for unobserved firm size heterogeneity in the direction of the patent trading flows.[25]

To examine the degree to which higher value patents are more likely to be acquired by large firms, we replace the variable $Citations_i$ in equation (2) with two interactions ($Citations_i * Small_{ij}$ and $Citations_i * Large_{ij}$). A negative and significant coefficient of $Citations_i * Small_{ij}$ indicates that, among patents initially owned by small firms, the probability of these patents being acquired by a large firm increases with the number of patent citations received. Instead, a negative and significant coefficient of $Citations_i * Large_{ij}$ shows that, among patents initially owned by large firms, a higher number of citations received makes it less likely for a patent to be acquired by a small firm (and thus more likely to be acquired by a large firm).

6.3 Additional econometric issues

There is still an econometric issue that requires further discussion. In specifications (1) and (2), the patentee fit and technology linkages variables are potentially endogenous, in those cases in which a patentee had developed a patented technology in advance with the sole intention to selling it to other firms. In practice, the patentee may have arranged for the sale of a specific patent, including the potential buyer, prior to the issuing of the patent. A firm fixed effect, while useful to account for patentee specific effects in patent trading, cannot capture a strategic patent specific decision of this nature.

Unfortunately, it is challenging to find appropriate instrumental variables. Measuring the degree of complementarity between a patent and a patentee, as well as the ability to adopt a technology is hard with the available data. The previous literature, which has typically relied on cross-sectional data, has not considered this possible caveat (see e.g., Arora and Ceccagnoli, 2006). To address the extent to which our estimates are affected by this issue, we have checked whether most of the patents were traded within a year of being granted. Our conjecture is that if a large proportion of patents had been traded immediately after being granted, it would suggest that these patents were expected to be sold to an already known buyer. Interestingly, we found no evidence indicating that most patents are sold immediately. In particular, less than 15 percent of the patents that are ever traded over their lifetime are traded within a year of being issued.

[25] Another reason to add the variable $Small_{ij}$ to our econometric specification is to control for the possibility that the citations patterns of small firms towards other small firms (rather than to large firms) may be for reasons other than their proximity in the technology space.

Moreover, these patents do not have statistically significant lower measures of patentee fit than the rest of the patents. Nonetheless, below we present the estimates of panel regressions that include firm fixed effects, and patent technology class, patent calendar year effects, and provide both a causal and alternative interpretations.

There is additional evidence suggesting that our measures of patentee fit and technology flows are likely to be uncorrelated with the error terms in the regressions. Previous literature on the economics of innovation has extensively recognized the high degree of uncertainty in the process of R&D, especially for patented innovations (e.g., Pakes (1986) and Rosenberg (1996)). Moreover, patent applicants and the lawyers representing them must include in the application all existing prior art that relate to the innovation they aim to patent and its claims. These citations are then assessed by a professional patent examiner from the U.S. patent office, who ultimately either confirms, discards or includes additional citations during the application process.

6.4 Results

Table 7 presents a set of regressions of the decision that a patent will be traded on patentee fit. Column (1) displays the estimates of the firm fixed effects regression model in equation (1). We control for technology, grant year effects, and patent citations received. Consistent with Serrano (2010), we find that more valuable patents and patents of firms with smaller patent portfolios are more likely to be traded. The new result refers to the fit of the patent with the patentee's patent portfolio. The regression shows that patents with higher match with the patentee's patent portfolio are less likely to be traded. The marginal effect of patentee fit (-0.0135) is negative and statistically significant (p-value < 0.01). In Columns (2) we present a Probit regression model with grant year, technology effects, and the firm's patent portfolio size, and obtain similar results. In Column (3), we present a Probit regression dropping the patent grant year and technology class effects. In this Table, as well as in the rest of the remaining Tables, Columns (4) and (5) show the same estimated coefficients using a simple linear probability model with and without the grant and technology effects, respectively. In column (6), we examine a random effects Probit specification. The results from all the regressions support Hypothesis #1, indicating that a patent that is not a good fit to the patentee is more likely to be sold.

Table 8 presents a set of regressions of the decision to let a patent expire on patentee fit. Column 1 shows the estimates of the regression model in equation (1). We control for technology, grant year effects, and patent citations received. Patents with more patent citations received are associated with lower expiration rates, confirming that patent citations received is an indicator of patent value (Serrano, 2010). The new result we want to highlight here is the association between patentee fit and the expiration decision. The marginal effect of patentee fit (-0.0191) is negative and statistically significant (p-value < 0.01). The result is confirmed in a number of econometric specifications, including a linear probability model without firm fixed effects, Probit models, and random effects Probit models. The finding indicates that among patents that were not sold there is a negative relationship of the match of the patent with the patentee's patent portfolio and the patentee's decision to let the patent expire. The result is new and confirms Hypothesis #2, which states that among the patents that were not sold, the ones with a higher fit with the patentee's portfolio are less likely to be let to expire.

Table 9 examines the relationship of technology linkages and patent value with the patent trading flows. Column (1) presents the regression model in equation (2). There are two main results we want to highlight here. First, the marginal effect of $TechLink_{ij} * Small_{ij}$ is positive (0.075) and significant (p-value < 0.01), indicating that small firm patents with higher proportion of patent citations towards small firms are more likely to be acquired by small firms too. Second, the marginal effect of $TechLink_{ij} * Large_{ij}$ is negative (-0.077) and significant (p-value < 0.01), proving that large firm patents with higher proportion of patent citations made towards large firms are more likely to be acquired by large firms. Because this specification includes firm fixed effects, the estimated coefficients are identified from variation of technology linkages at the patent level within a patentee. That is, independently of the original patentee and the technology class of the patent, the patents that are a have technological fit with small (large) firms are more likely to be acquired by small (large) firms too. The rest of the columns indicate that similar results were also obtained using a simple linear probability model, a Probit model, and a random coefficients Probit model.[26] These findings confirm Hypothesis #3, which states that the direction of the trading flows between small firms may also be associated with the patent citations flows of small and large firms.

In Table 10, we study the role of patent value in the patent acquisitions by small and large firms. To do so, we separate the total number of patent citations received (as seen in equation (2)) into two new regressors: the interactions between firm size (small and large) and patent citations received. The two interactions allow us to ascertain the potentially distinct role that patent value may have in acquired patents initially owned by small or large firms. Column (1) presents the results from the patentee fixed effects linear probability model. We find that the marginal effect of $Citations_i * Small_{ij}$ is negative (-0.0027) and significant p-value < 0.01, indicating that among

[26] For the fixed effects model, while the sign of the coefficients is also consistent with results of the random coefficients model, the estimates are not statistically different than zero. This is plausible because most firms were granted only few patents and this sample only includes traded patents, implying that the fixed effects reduce significantly the variation in the data that allows us to precisely estimate the coefficients.

patents initially owned by small firms, the probability that one of these patents is acquired by a large firm increases with the number of patent citations received. As for the patents initially owned by large firms, the marginal effect of the interaction $Citations_i * Large_{ij}$ is positive (0.001) but not highly significant (p-value = 0.101), suggesting that there are no significant differences in the patent acquisitions of large firm patents by small and large firms. Similar results were obtained in a number of econometric specifications, including a simple linear probability model, a Probit model, and a random coefficient Probit model.[27] The results confirm Hypothesis #4.

6.5 Discussion of results

The results in this section point to four important conclusions. First, we show that patents with a lower patentee fit are in fact those with the highest predicted likelihood of changing ownership, and that patents that changed ownership are more likely to be renewed. This accounts for the fact that small firms will be more likely to sell their patents, since they typically own patents with a lower fit.

Second, we show that traded patents with a higher predicted likelihood of being acquired by small firms (large firms) are those with the highest proportion of patent citations made to small firms (large firms). This suggests that the patent trading flows also depend on the buyers' ability to adopt technologies (as captured by the technology linkages). This finding also accounts for the fact that small firms acquire a higher proportion of small firm patents than of large firm patents. The result also provides new evidence consistent with studies analyzing the degree of complementarity between own R&D and technology acquisition strategies (Arora and Gambardella, 1994; and Cassiman and Veugelers, 2006), and the role that specific complementary assets play in the licensing of patents (Arora and Ceccagnoli, 2006).

Finally, we show that large firms acquire patents with a higher number of citations, especially among small firm patents. This provides evidence on the trade-off that small and large firms face in creating their own innovations versus acquiring them in the market. Large firms, which have better opportunities to find a productive use for their new innovations, find it optimal to obtain patents through the market only when the patent to be acquired is of sufficiently high value.

These facts are consistent with an economy where firms do research "in the shadow of uncertainty", as we show in our model. Bigger firms, with broader research agendas and production capacities, are more likely to find productive uses for their innovations inside the firm. Smaller firms must rely more on innovations produced outside the firm, and will also sell their patents

[27] Similarly to Table 9, for the fixed effects model, while the sign of the coefficients is consistent with results of the random coefficients model, the estimated coefficient is not statistically different than zero.

more often. Since transaction costs are non-negligible, smaller firms let some acquisition opportunities go by, and in equilibrium hold worse patents than their bigger counterparts. This implies, in turn, than larger firms are more selective in acquiring innovations, since they hold better patents. All these results are formally proved in the appendix.

7 Conclusion

In this paper we study the patent trading flows of small and large firms, and the determinants of firm's patent selling and acquisition decisions. We also examine whether this patent trading has lead to an excessive concentration of patent rights in the hands of large firms. We constructed a new, comprehensive data set that matches information on patent trades and new data about the identity of patent owners over a patent's lifetime, involving patents initially owned by businesses during the period 1988-2001. Using this data and exploiting the match between a patented innovation and a patentee's patent portfolio as well as the technology linkages between patentees and potential buyers, we provide evidence consistent with the predictions of a theory of gains from trade based on economies of scale in the reallocation of innovations within the firm.

There are four key empirical findings in the paper. First, small firms are more likely to sell their patents than large firms. We also find that small firms disproportionately acquire more patents than large firms, especially patents initially owned by other small firms. Moreover, we show that this patent trading has not lead to an excessive concentration of patent rights in the hands of large firms. Second, patents with a lower match with the patent portfolio of the patentee are more likely to be sold; and that among patents that were not sold, the ones with the lowest fit are more likely to be discontinued. At the same time, we show that large firms' patent portfolios are typically characterized by a high fit between the new patents and the patentee's patent portfolio at the time the focal patent was issued. Third, we show that while large firms disproportionately acquire fewer patents than small firms, the likelihood of a patent being acquired by a large firm increases with the patent's number citations received. Fourth, small firms disproportionately cite patents from other small firms, and the higher the proportion of patent citations made to small firms, the higher the probability that the focal patent will be acquired by a small firm. These findings are consistent with our view of the determinants of patent transactions in the market for patents.

From a theoretical point of view, we present a simple model that formalizes the role of the economies of scale in the utilization of innovations and is consistent with our empirical findings. The model captures the distinctive features of innovations, as compared to traditional goods and services. Namely, the uncertainty in the process of innovation, the complementarity of ideas and the transaction costs generated by the risk of expropriation. We show how, even in the absence of advantages of large firms in the development and commercialization of new products, these forces can explain the patterns found in the data. We argue that the uncertain nature of innovation can be seen in the third finding, highlighting that firms keep their innovations, and buy new ones, if they are related to their area of expertise. We rationalize the first, second, and third findings through the economies of scale in the utilization of innovations. Transaction costs imply that not all useful patents created outside a firm are bought. Since bigger firms are more likely to create patents that can be reallocated inside the firm, in steady state they hold better patent portfolios, therefore selling less patents than small firms and buying fewer but higher value patents. Finally, our fourth finding indicates that there is some specialization in research activities, with smaller firms directing their R&D activity towards the same fields, and that this feature can account for the fact that conditional on acquiring a patent, small firms are more likely to acquire a patent originally created by a small firm than a large firm.

Five important conclusions can be drawn. First, the fact that patents with a lower patentee fit are those with a higher predicted likelihood of changing ownership, and that patents which changed ownership are more likely to be renewed, suggests that the market for patents reallocates patent efficiently (at least in this sense). Second, this also indicates that the market for patents will likely be an important source of incentives to invest in R&D, especially for small firms being typically at a disadvantage to match their newly created innovations with a productive use or an old innovation to create synergies. At the same time, the relative disadvantage of small firms to match the new innovations to a productive use within the firm can potentially discourage their entry and growth opportunity, and also distort competition between small and large firms, especially when market transaction costs are significant. Third, the result that traded patents that are more likely to be acquired by small firms are also those with the highest proportion of patent citations made to existing small firms, provides evidence on the complementarity between own R&D and technology acquisition. Fourth, the finding that the patents with the highest value are disproportionately acquired by large firms, suggests that at least for these patents (perhaps the most valuable ones) the direction of the patent flows takes place in ways consistent with the theory of the division of innovative labor between the small and the large firms. Fifth, our empirical findings also echo theoretical results in Gans and Stern (2010) suggesting that the distinctive nature of innovations can impact the degree up to which markets for “ideas” can be developed into efficient market structures, such as those suggested by the traditional theory of the firm.

At the same time, this paper may have some limitations. Our data has no information on the business characteristics of firms acquiring patents other than whether the new owner is a small or large firm. This issue puts a limit on our ability to study the extent to which firms acquire patents to "fill gaps" within their patent portfolios. Our data also exhibited some limitations such as not reporting the sale prices or the contractual terms in patent transactions. Finally, we have no information on the licensing of patents. In this respect, while the predictions of the traditional theory of the division of innovative labor do not distinguish between the sale and the licensing of patents, we cannot assure whether our conclusions would also apply to alternative means of transactions in patent rights such as the licensing of patents. These limitations provide opportunities for further research.

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Appendix: A model of patent trading flows between small and large firms

We rationalize the empirical findings of the previous sections by building a simple model where there is no specialization in research or productive activities. Big firms are, in almost every respect, simply a scaled up version of their smaller counterparts. However, they have one advantage when compared to their smaller counterparts: they are broader in their research activities. We consider small firms that consist of only one research facility (lab), and big firms that consist of $z \geq 2$. The reason why a big firm is more than the aggregation of z small ones is that an innovation generated in a big firm can be freely reallocated inside the boundaries of that firm if it is useful to another research facility. If the trade occurs between research facilities owned by different firms, however, a transaction cost must be incurred. Therefore, big firms produce as much research as z small ones, and are z times more likely to be offered innovations that are useful for them. However, they are better off than z small firms due to the reallocation possibilities arising from their broader research agenda.

In what follows we formalize this idea and show that in a steady state, big firms own better patents due to the enhanced possibilities generated by their ability to internally reallocate innovations. This leads them to be less likely to buy, but, conditional on buying, to buy better patents. While we purposely choose a very simple formulation, with innovations that can be randomly useful to any research facility, the results are robust. As long as in a steady state big firms own a better distribution of patents, they will be less likely to buy innovations generated outside the firm and will buy better patents. The assumption that new innovations are useful to a random research facility implies that there are no technology linkages, so we do not try to explain the fact that, conditional on a patent being bought by a small firm, it is disproportionately likely that this patent was generated by another small firm.

We consider an economy populated by N_s small firms and N_b big firms. Small firms own one research lab while big firms own $z \geq 2$. Each lab produces innovations at a rate r, which is independent of the owner's size, and each lab allows the firm to put one innovation to a productive use. We assume that each innovation is useful (has a good "fit") for only one lab. To keep things simple, we assume that the matching process is completely random, therefore an innovation is useful for a given lab with probability $\frac{1}{N_s+zN_b}$. While this assumption is somewhat extreme, it captures the idea that firms conduct R&D "in the shadow of uncertainty", and cannot control its exact nature. This gives rise to possible gains from trade and generates a role for the market for patents. With this specification, research labs receive internal innovations at a rate

$$
\begin{aligned}
T_{s,i} &= r\frac{1}{N_s + zN_b} \\
T_{b,i} &= zr\frac{1}{N_s + zN_b}
\end{aligned}
$$

Also, the rate at which a new innovation that is useful for a lab is produced outside the boundaries of the firm is given by:

$$
\begin{aligned}
T_{s,e} &= r\frac{N_s - 1 + 2N_b}{N_s + zN_b} \\
T_{b,e} &= r\frac{N_s - z + 2N_b}{N_s + zN_b}
\end{aligned}
$$

Note that $T_{s,i}+T_{s,e} = T_{b,i}+T_{b,e}$, that is to say labs in big and small firms receive innovations at the same rate. The only difference is how many of them are from inside or outside the boundaries of the firm.

Innovations differ in their quality. Formally, we say that an innovation has quality $k \in \mathbb{N}$, and a firm that uses an innovation of quality k receives an instantaneous profit of $\pi(k)$. We assume that π is increasing (therefore higher k stands for higher quality) and that the probability that an innovation generated is of quality k is given by $p(k)$.[28] Since firms have a limited capacity for putting innovations to a productive use (small firms may use one and big firms z), a new innovation with a good fit for them is only useful if it is better than the quality of the innovation it will replace. Once created, innovations only change their quality through obsolescence, that occurs at a rate r_d and decreases quality to 0.

There exists a transaction cost c when acquiring a new innovation that was generated outside the firm. This cost captures market frictions such as expropriation risk, and the actual cost of adapting a new technology (e.g. capital costs of adoption, organizational changes, and intermediaries such as patent lawyers and brokers). Moreover, we assume that the buyer makes a take it or leave it offer, effectively capturing the whole surplus. Considering an instantaneous discount factor δ, we can then write the value function of a small firm holding a patent of quality k as:

$$\begin{aligned} \delta V_s(k) &= \pi(k) + T_{s,i} \sum_{l>k} p(l)[V_s(l) - V_s(k)] \\ &\quad + T_{s,e} \sum_{l>k} p(l) \max\{V_s(l) - V_s(k) - c, 0\} - r_d(V_s(k) - V_s(0)) \end{aligned} \tag{3}$$

Analogously, for a big firm with innovations of quality $k_1, ..., k_z$ we get that its value function is $V_b(k_1) + ... + V_b(k_z)$ where $V_b(k)$ is given by:

$$\begin{aligned} \delta V_b(k) &= \pi(k) + T_{b,i} \sum_{l>k} p(l)[V_b(l) - V_b(k)] \\ &\quad + T_{b,e} \sum_{l>k} p(l) \max\{V_b(l) - V_b(k) - c, 0\} - r_d(V_b(k) - V_b(0)) \end{aligned} \tag{4}$$

In each of these value functions, the first term in the right hand side represents the present stream of income generated by a patent of quality k. The second, the potential improvements from innovations produced inside the firm, the third the improvements from innovations produced outside the firm, and the fourth the potential losses from obsolescence. Firms obviously always take advantage of any internal innovation with a better quality than the patent they already hold in their lab. However, when it comes to innovations produced outside the firm, they buy them only if the transaction costs are offset for the marginal flow of profits generated by the new innovation. Then, given value functions $V_s(k)$ and $V_b(k)$ we can define the acceptance functions, which indicate which external innovations will be bought, as:

$$A_i(k,l) = \begin{cases} 1 & \text{if } V_i(l) - c > V_i(k) \\ 0 & \text{otherwise} \end{cases}$$

where $A_i(k,l) = 1$ indicates that a lab in a firm of size $i \in \{s, b\}$ who owns an innovation of quality $k \in \mathbb{N}$ will acquire an innovation of quality $l \in \mathbb{N}$.

These decisions, in turn, generate the instantaneous rate at which labs in small and big firms

[28] Patent quality k is independent of the size of the firm that created it, and independent of the firm that can use it. In particular, the average quality of a patent is the same for innovations created inside or outside the firm.

change states (i.e., their lowest quality patent in the firm's patent portfolio):

$$Q_s(k,l) = \begin{cases} p(l)[T_{s,i} + T_{s,e}A_s(k,l)] & \text{if } l > k \\ r_d & \text{if } l = 0 \\ 0 & \text{if } 0 < l \leq k-1 \end{cases}$$

$$Q_b(k,l) = \begin{cases} p(l)[T_{b,i} + T_{b,e}A_b(k,l)] & \text{if } l > k \\ r_d & \text{if } l = 0 \\ 0 & \text{if } 0 < l \leq k-1 \end{cases}$$

Basically, a small firm will jump from having an innovation of quality k to having one of quality l at a rate which is the sum two components. The first is the rate at which useful internal innovations of quality l are generated ($p(l)T_{s,i}$), the second is the rate at which useful external innovations of quality l are generated ($p(l)T_{s,e}$.) Of course this second term exists only if a form will decide to purchase such an external innovation (i.e., $A_s(k,l) = 1$.) The same is true for big firms.

Market interactions, characterized by the acquisition decisions of the firms, generate a dynamic system with small and big firms having patents of different qualities. An equilibrium is given by a steady state distribution of qualities for labs in small and big firms: $\{\mu_s(k)\}_{k\in\mathbb{N}}$ and $\{\mu_b(k)\}_{k\in\mathbb{N}}$. In a steady state the rate at which firms become holders of innovations of an innovation of quality k ($\sum_{l\neq k} \mu_j(l)Q_j(l,k)$ for $j \in \{s,b\}$) must be equal to the rate at which firms stop being holders of innovations of an innovation of quality k ($\sum_{l\neq k} \mu_j(k)Q_j(k,l)$ for $j \in \{s,b\}$). Moreover $\{\mu_s(k)\}_{1\leq \bar{k}}$ and $\{\mu_b(k)\}_{1\leq k\leq \bar{k}}$ must be probability measures. This is summarized in the definition below.

Definition 1. An equilibrium is given by $\{\mu_s(k)\}_{k\in\mathbb{N}}$ and $\{\mu_b(k)\}_{k\in\mathbb{N}}$ that satisfy

$$0 = \sum_{l\neq k} \mu_s(k)Q_s(k,l) - \sum_{l\neq k} \mu_s(l)Q_s(l,k) \tag{5}$$

$$0 = \sum_{l\neq k} \mu_s(k)Q_b(k,l) - \sum_{l\neq k} \mu_s(l)Q_b(l,k) \tag{6}$$

$$1 = \sum_{k\in\mathbb{N}} \mu_s(k) = \sum_{k\in\mathbb{N}} \mu_b(k) \tag{7}$$

Proposition 1. There exists and equilibrium.

Proof. See next appendix. ■

The first fact, that follows directly under reasonable assumptions, is that a patent created in a small firm is more likely to be sold than a patent created in a big firm. The basic observation is that in a big firm, the probability that a new patent has a good fit with a research lab inside the firm is bigger. Note, however, that the argument has some subtleties. When a patent from a small firm does not have a good fit with the original firm, it might go to one of $N_s - 1$ labs from another small firm or one of zN_b labs from a big firm. When this happens with a patent from a big firm, it might go to one of N_s labs from a small firm or one of $z(N_b - 1)$ labs from another big firm. In aggregate, it is more likely that it has a fit outside the originator when it comes from a small firm. However, the composition of small and big firms with which it can have a fit it is different, and the willingness to buy from a small and big forms can be different. In general, this last consideration is small, and the first order effect, big firms having a higher probability of having a good fit inside a firm, is more likely to dominate.

Lemma 1. If the probability that a patent is bought by a small firm, $\sum_{k\in\mathbb{N}} p(k) \sum_{l>k} \mu_s(l)A_s(l,z)$ is smaller than z times the probability that a patent is bought by a big firm, $\sum_{k\in\mathbb{N}} p(k) \sum_{l>k} \mu_b(l)A_b(l,z)$, then the probability that a patent created in a small firm is sold is bigger than the probability that a patent created in a big firm is sold.

Proof. See next appendix. ■

The next proposition characterizes the quality distribution of patents in big and small firms. It is not difficult to see that if small and big firms are willing to acquire the same patents conditional on their worst innovation, then big firms hold better portfolios in equilibrium, due to their ability to internally reallocate innovations. They are faced with new innovations that can be used without transaction costs more often, and therefore are always incorporated, leading to better patents in average.

Proposition 2. Suppose that $A_s(k,l) = A_b(k,l)$ for any $k,l \in \{1,...,\bar{k}\}, k < l$. Then the distribution $\mu_b(k)$ first order stochastically dominates the distribution $\mu_s(k)$. That is, the distribution of quality in labs in big firms dominates the distribution of quality in labs in small firms. This dominance is strict unless $A_s(k,l) = A_b(k,l) = 1$ for all $k < l$.

Proof. See next appendix. ■

Note that there is one case where both big and small firms hold patents of the same quality in equilibrium. This is when they are willing to buy any external innovation that implies a quality improvement. In that case, since the total rate at which small and big firms receive new innovations is the same ($T_{s,i} + T_{s,e} = T_{b,i} + T_{b,e}$), both types of labs acquire new innovations at the same rate. Moreover, since the distribution of quality of the patents being generated ($\{p(k)\}_{k\in \mathbb{N}}$) is independent of the owner's size both types of firms acquire the same quality of patents. In particular this is the case if transaction costs c are zero.

The assumption in the previous proposition states that big and small firms behave in the same way regarding the acquisition of new innovations. Basically, if a lab in a big firm has a patent with the same quality than a small firm, both firms will take the same decision when it comes to the acquisition of a new external innovation. This is not obvious, since big firms, facing a higher probability of getting innovations "from inside" in a future period, could be more patient. However, this is not a far-fetched assumption, and there are many environments where this holds. In particular, we are interested in environments where the decisions of firms are regular, in the sense that firms buy an external innovation if and only if the quality jump is big enough. This leads us to the following definition.

Definition 2. We say that an environment is $m-$regular if $A_s(k,l) = A_b(k,l) = 1$ if and only if $l > k + m$

Obviously, any $m-$regular environment satisfies the hypothesis of Proposition 2. Intuitively, big and small firms behave in the same way: they buy patents coming form outside the firm if quality jumps by more than m levels. We now give necessary and sufficient conditions, related to the transaction costs c, for the different types of $m-$regular environments to exist.

Lemma 2. Suppose that the sequence p_k is weakly decreasing. Then

-If $c < \frac{1}{\delta + r_d + T_{s,i} + T_{s,e}} \equiv \frac{1}{\delta + r_d + T_{b,i} + T_{b,e}}$ then the environment is 0-regular (both firms acquire any external innovation that is better than the innovation they have, $A_s(k,l) = A_b(k,l) = 1$ for all $l > k$).

-If $\frac{m-1}{\delta+r_d} < c < \frac{m}{\delta+r_d+T_{b,i}+T_{b,e}(p_m+...)}$ then the environment is (m-1)-regular.

Proof. See next appendix. ■

In regular environments, two results that are important for our explanation of the flow of patents are true: small firms buy disproportionately more patents and in average worse quality ones than large firms. To account for the fact that conditional on a patent being bought by a small firm, it is disproportionately likely that this patent was generated by another small firm, we would need to consider that the matching process depends on whether the patent was initially created by a small or large firm rather than being independent of firm size.

Corollary 1. Under the hypothesis of Proposition 2 the following two are true:

-In average, the number of patents bought by a big firm, $\sum\limits_{k\in\mathbb{N}} \mu_b(k) \sum\limits_{l>k} T_{b,e}p(l)A_b(k,l)$ is smaller than z times the number bought by a small firm, $\sum\limits_{k\in\mathbb{N}} \mu_s(k) \sum\limits_{l>k} T_{s,e}p(l)A_s(k,l)$.

-The average quality of patents bought by big firms, $\sum\limits_{k\in\mathbb{N}} \mu_b(k) \sum\limits_{l>k} \frac{p(l)A_b(k,l)l}{\sum\limits_{h>k} p(h)A_b(k,h)}$ is higher than the average quality bought by small firms, $\sum\limits_{k\in\mathbb{N}} \mu_s(k) \sum\limits_{l>k} \frac{p(l)A_s(k,l)l}{\sum\limits_{h>k} p(h)A_s(k,h)}$.

Proof. See next appendix. ■

To sum up, this simple theory predicts that the determinants of the patent trading flows in the market for innovations are firm size, technology linkages between small and big firms, and innovation's fit.

Appendix: Proofs.

Proposition 1. There exists and equilibrium.

Proof. For a steady state to exist, it is enough that every state is positive recurrent. Since this Markov chain is irreducible, it is enough to prove it for one state. Let's consider state 0. It is enough to prove that $\mathbb{E}(T_0) < \infty$ where $T_0 = \inf\{t|X_t = 0|X_0 = 0\}$. This is true since the process goes to 0 at a constant rate r_d. ■

Lemma 1. If the probability that a patent is bought by a small firm, $\sum\limits_{k\in\mathbb{N}} p(k) \sum\limits_{l>k} \mu_s(l)A_s(l,z)$ is smaller than z times the probability that a patent is bought by a big firm, $\sum\limits_{k\in\mathbb{N}} p(k) \sum\limits_{l>k} \mu_b(l)A_b(l,z)$, then the probability that a patent created in a small firm is sold is bigger than the probability that a patent created in a big firm is sold.

Proof. The probability that a patent generated in a small firm is sold is given by

$$\sum_{k\in\mathbb{N}} p(k) \sum_{l>k} \mu_s(l)A_s(l,z)[\frac{N_s-1}{N_s+zN_b}] + \sum_{k\in\mathbb{N}} p(k) \sum_{l>k} \mu_b(l)A_b(l,z)[\frac{zN_b}{N_s+zN_b}]$$

while the probability that a patent generated in a big firm is sold is given by

$$\sum_{k\in\mathbb{N}} p(k) \sum_{l>k} \mu_s(l)A_s(l,z)[\frac{N_s}{N_s+zN_b}] + \sum_{k\in\mathbb{N}} p(k) \sum_{l>k} \mu_b(l)A_b(l,z)[\frac{z(N_b-1)}{N_s+zN_b}]$$

The difference is then given by

$$-\sum_{k\in\mathbb{N}} p(k)\sum_{l>k}\mu_s(l)A_s(l,z)[\frac{1}{N_s+zN_b}]+\sum_{k\in\mathbb{N}} p(k)\sum_{l>k}\mu_b(l)A_b(l,z)[\frac{z}{N_s+zN_b}]$$

which is positive because of the assumption. ■

Proposition 2. Suppose that $A_s(k,l)=A_b(k,l)$ for any $k,l\in\{1,...,\bar{k}\}, k<l$. Then the distribution $\mu_b(k)$ first order stochastically dominates the distribution $\mu_s(k)$. That is, the distribution of quality in labs in big firms dominates the distribution of quality in labs in small firms. This dominance is strict unless $A_s(k,l)=A_b(k,l)=1$ for all $k<l$.

Proof. The proof can be done considering a big and a small firm that each own a patent of quality k, and a particular history of shocks $h=(h_0,h_1,...)$ where h_i indicates either obsolescence or the generation of a new invention useful for the research lab using the patent and generated in some research lab in the economy. It is trivial to see that at any point in time the quality of the patent being used in the small firm is worse or equal than the quality of the patent being used in the big firm. The only difference is that sometimes the new innovation is generated in a lab that is owned by the same big firm, and is used by the big firm, while the small firm prefers to let it go away due to the transaction costs. ■

Lemma 2. Suppose that the sequence p_k is weakly decreasing. Then

-If $c<\frac{1}{\delta+r_d+T_{s,i}+T_{s,e}}\equiv\frac{1}{\delta+r_d+T_{b,i}+T_{b,e}}$ then the environment is 0-regular (both firms acquire any external innovation that is better than the innovation they have, $A_s(k,l)=A_b(k,l)=1$ for all $l>k$).

-If $\frac{m-1}{\delta+r_d}<c<\frac{m}{\delta+r_d+T_{b,i}+T_{b,e}(p_m+...)}$ then the environment is (m-1)-regular.

Proof. In an $m-$regular solution, the value function of a firm is given by

$$\begin{aligned}\delta V_n &= n+T_i[p_{n+1}(V_{n+1}-V_n)+p_{n+2}(V_{n+2}-V_n)+...]\\ &\quad +T_e[p_{n+m}(V_{n+m}-V_n-c)+p_{n+m+1}(V_{n+m+1}-V_n-c)+...]\\ &\quad -r_d[V_n-V_0]\end{aligned}$$

Therefore

We omit the subindices s or b for the internal and external rates, denoting them simply by T_i and T_e.

$$\begin{aligned}V_{n+m}-V_n &= \frac{m-T_i[p_{n+1}(V_{n+1}-V_n)+...+p_{n+m-1}(V_{n+m-1}-V_n)]}{\delta+r_d+T_i[p_{n+m}+...]+T_e[p_{n+m}+p_{n+2m}+p_{n+2m+1}+...]}\\ &\quad +\frac{T_ep_{n+m}c-T_e[p_{n+m+1}(V_{n+m+1}-V_n-c)+...+p_{n+2m-1}(V_{n+2m-1}-V_n-c)]}{\delta+r_d+T_i[p_{n+m}+...]+T_e[p_{n+m}+p_{n+2m}+p_{n+2m+1}+...]}\end{aligned}$$

For this to be a solution, it must be the case that $V_{n+m}-V_n\geq c$. Noting that

$$p_{n+1}(V_{n+1}-V_n)+...+p_{n+m-1}(V_{n+m-1}-V_n)\leq c[p_{n+1}+...+p_{n+m-1}]$$

and

$$\begin{aligned}
& p_{n+m+1}(V_{n+m+1} - V_n - c) + ... + p_{n+2m-1}(V_{n+2m-1} - V_n - c) \\
= \; & p_{n+m+1}(V_{n+m+1} - V_{n+m-1} + V_{n+m-1} - V_n - c) \\
& +... + \\
& + p_{n+2m-1}(V_{n+2m-1} - V_{n+m-1} + V_{n+m-1} - V_n - c) \\
\leq \; & (p_{n+m+1} + ... + p_{n+2m-2})c + p_{n+2m-1}2c
\end{aligned}$$

we get that the following condition implies $V_{n+m} - V_n \geq c$:

$$\frac{m}{\delta + r_d + T_i(p_{n+1} + ...) + T_e(p_{n+m-1} + ...) + T_e p_{n+2m-1}} \geq c$$

which must hold for every n. The most restrictive case is then:

$$\frac{m}{\delta + r_d + T_i + T_e(p_{m-1} + ...) + T_e p_{n+2m-1}} \geq c$$

If we further assume that the sequence $\{p_k\}$ is decreasing, a more restrictive condition is:

$$\frac{m}{\delta + r_d + T_i + T_e(p_{m-2} + ...)} \geq c$$

Finally, note that this inequality is more restrictive for big firms, since $T_{s,i} + T_{b,i} = T_{s,e} + T_{b,e}$ but $T_{b,e} \leq T_{s,e}$.

The other condition for c is simpler. Using the expression for V_n, we can get that

$$V_{n+m-1} - V_n \leq \frac{m - 1 + T_e p_{n+m-1} c}{\delta + r_d + T_i(p_n + m - 1 + ...) + T_e(p_{n+m-1} + p_{n+2m-1} + p_{n+2m} + ...)}$$

Therefore $V_{n+m-1} - V_n \leq c$ is implied by

$$\frac{m-1}{\delta + r_d + T_i(p_n + m - 1 + ...) + T_e(p_{n+2m-1} + p_{n+2m} + ...)} \leq c$$

and the most restrictive case is when

$$\frac{m-1}{\delta + r_d} \leq c$$

■

Corollary 1. Under the hypothesis of Proposition 2 the following two are true:

-In average, the number of patents bought by a big firm, $\sum_{k\in\mathbb{N}} \mu_b(k) \sum_{l>k} T_{b,e} p(l) A_b(k,l)$ is smaller than z times the number bought by a small firm, $\sum_{k\in\mathbb{N}} \mu_s(k) \sum_{l>k} T_{s,e} p(l) A_s(k,l)$.

-The average quality of patents bought by big firms, $\sum_{k\in\mathbb{N}} \mu_b(k) \sum_{l>k} \frac{p(l)A_b(k,l)l}{\sum_{h>k} p(h)A_b(k,h)}$ is higher than the average quality bought by small firms, $\sum_{k\in\mathbb{N}} \mu_s(k) \sum_{l>k} \frac{p(l)A_s(k,l)l}{\sum_{h>k} p(h)A_s(k,h)}$.

Proof. Note that because of Proposition 2, the distribution of the worst patent for a big firm dominates the distribution of the worst patent for a small firm. This immediately implies that small firms buy more patents. Moreover, the average quality of patents bought by a firm is an increasing function of the worse patent. The result is then direct from first order stochastic dominance. ■

Table 1: Summary Statistics

A. Proportions of Patents Initially Owned by Small and Large Firms by Grant Year

	All patents	Patent Grant Year (in groups of two years) 1989-1990	1991-1992	1993-1994	1995-1996
Small firms	0.107	0.089	0.098	0.116	0.123
	(.000)	(.001)	(.001)	(.001)	(.001)
Large firms	0.893	0.910	0.902	0.884	0.877
	(.000)	(.001)	(.001)	(.001)	(.001)
Number of Patents	590,873	135,507	144,224	151,839	159,303

B. Proportions of Patents Initially Owned by Small and Large Firms by Patent Technology Class

		Patent technology classes					
	All patents	Chemical	Computer & comm	Drugs & medical	Elec. & Electro	Mechani	Other
Small firms	0.107	0.065	0.059	0.152	0.080	0.121	0.206
	(.000)	(.001)	(.001)	(.002)	(.001)	(.001)	(.001)
Large firms	0.892	0.934	0.941	0.848	0.920	0.878	0.793
	(.000)	(.001)	(.001)	(.002)	(.001)	(.001)	(.001)
Number of Patents	590,873	126,865	85,924	49,857	116,232	122,642	89,352

Note: Standard errors in parenthesis.

Table 2: Patent Sales and Acquisitions by Small and Large Firms

		Patent Technology Classes					
	All patents (1)	Chemical (2)	Computer & comm (3)	Drugs & medical (4)	Elec. & Electro (5)	Mechanical (6)	Other (7)
A. Proportion of patents sold							
Small firm	0.090	0.091	0.130	0.112	0.096	0.074	0.078
	(.001)	(.003)	(.005)	(.004)	(.003)	(.002)	(.002)
Large firm	0.055	0.058	0.050	0.073	0.044	0.049	0.068
	(.000)	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
All firms	0.059	0.061	0.055	0.079	0.049	0.052	0.070
	(.000)	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
B. Proportion of patent acquisitions by small firms							
Prop. of patents acquired by small firms							
	0.160	0.116	0.100	0.214	0.143	0.180	0.219
	(.002)	(.004)	(.004)	(.006)	(.005)	(.005)	(.005)
C. Patent trading flows between small and large firms							
Prop. of small firm patents acquired by small firms							
	0.673	0.669	0.531	0.611	0.649	0.745	0.738
	(.006)	(.017)	(.019)	(.017)	(.016)	(.013)	(.012)
Prop. of large firm patents acquired by small firms							
	0.058	0.056	0.030	0.103	0.048	0.061	0.064
	(.001)	(.003)	(.003)	(.005)	(.003)	(.003)	(.003)

Note: A patent is traded if it was sold within four year of its grant date. Stand. errors in parenthesis

Table 3: Distribution of Patent Ownership of Small and Large Firms

		Patent Technology Classes					
	All patents (1)	Chemical (2)	Computer & comm (3)	Drugs & medical (4)	Elec. & Electro (5)	Mechanical (6)	Other (7)
A. Proportions of Patents Owned at Age 5 by Small and Large Firms							
Small firm	0.100	0.069	0.046	0.159	0.072	0.113	0.188
	(.000)	(.001)	(.001)	(.002)	(.001)	(.001)	(.001)
Large firm	0.900	0.931	0.954	0.841	0.928	0.887	0.811
	(.000)	(.001)	(.001)	(.002)	(.001)	(.001)	(.001)
B. Proportion of patents acquired in the patent portfolios of small and large firms as of age 5							
Small firms	0.093	0.107	0.110	0.114	0.093	0.081	0.081
	(.001)	(.004)	(.005)	(.004)	(.003)	(.002)	(.002)
Large firms	0.056	0.060	0.052	0.080	0.045	0.049	0.071
	(.000)	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
Number of patents	509,047	106,876	78,685	42,074	102,808	104,797	73,807

Note: Patent ownership at age 5 and the proportion of patents acquired in a patent portfolio as of age 5 are both computed after maintenance fees are due and the renewal decision.

Table 4: Firm's Patentee Fit for Kept, Traded, and Expired Patents

	PatenteeFit	At least one self-citations
A. Patents Kept, Traded, and Expired		
Kept patents	0.136	0.370
	(.000)	(.001)
Kept and renewed	0.139	0.381
	(.000)	(.001)
Kept and expired	0.117	0.305
	(.001)	(.002)
Traded patents	0.093	0.304
	(.001)	(.002)
All patents	0.134	0.366
	(.000)	(.001)
B. Patents initially owned by small and large firms		
Small firms	0.054	0.194
	(.001)	(.002)
Large firms	0.143	0.387
	(.000)	(.001)

Note: Standard errors in parenthesis.

Table 5: Patent Quality of Acquired Patents

A. Mean number of patent citations received

Initially owned	All patents	Acquired by			Not Traded
		Small firms	Large firms	All firms	
Small firms	3.44	4.12	5.85	4.68	3.31
	(.021)	(.100)	(.181)	(.090)	(.021)
Large firms	3.48	3.59	3.70	3.69	3.47
	(.007)	(.129)	(.033)	(.032)	(.007)

B. Patent expiration rates at age five

Initially owned	All patents	Acquired by			Not Traded
		Small firms	Large firms	All firms	
Small firms	0.192	0.186	0.017	0.131	0.198
	(.002)	(.006)	(.003)	(.004)	(.002)
Large firms	0.132	0.057	0.119	0.115	0.133
	(.000)	(.006)	(.002)	(.002)	(.000)

Note: standard errors in parenthesis

Table 6: Patent Trading Flows and Technology Linkages

	All patents (1)	Patent technology classes: Chemical (2)	Computer & comm (3)	Drugs & medical (4)	Elec. & Electro (5)	Mechani (6)	Other (7)
A. Proportion of patents initially owned by small and large firms							
Small firms	0.107	0.065	0.059	0.152	0.080	0.121	0.206
	(.000)	(.001)	(.001)	(.002)	(.001)	(.001)	(.001)
Large firms	0.892	0.934	0.941	0.848	0.920	0.879	0.793
	(.000)	(.001)	(.001)	(.002)	(.001)	(.001)	(.001)
B. Average proportion of citations made to firms of same size (excluding self-cites)							
Small firms	0.168	0.134	0.122	0.195	0.119	0.172	0.213
	(.001)	(.003)	(.003)	(.004)	(.003)	(.003)	(.003)
Large firms	0.945	0.966	0.951	0.915	0.952	0.944	0.908
	(.000)	(.000)	(.000)	(.001)	(.000)	(.001)	(.001)

Note: standard errors in parenthesis.

Table 7: Marginal Effects of Patentee Fit on the Probability that a Patent is Traded

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	OLS Fixed Effects	OLS	OLS	Probit	Probit	Probit Random Effects
Dependent variable	Traded	Traded	Traded	Traded	Traded	Traded
	Coef.$\times 10^2$	Coef.$\times 10^2$	Coef.$\times 10^2$	Mar.Eff.$\times 10^2$	Mar.Eff.$\times 10^2$	Coef.$\times 10^2$
Patentee fit	-1.35***	-3.13***	-3.13***	-3.56***	-3.61***	-22.15***
	(0.12)	(0.37)	(0.41)	(0.50)	(0.56)	(1.80)
Citations	0.03***	0.09***	0.10***	0.07***	0.09***	0.65***
	(0.006)	(0.02)	(0.02)	(0.01)	(0.02)	(0.07)
Patent Portfolio		-0.0002***	-0.0003***	-0.0003**	-0.0003**	0.002***
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.001)
Controls						
Grant Year	Yes	Yes	No	Yes	No	Yes
Technology	Yes	Yes	No	Yes	No	Yes
Firm fixed effects	Yes	No	No	No	No	No
Sample	All patents	All patents	All patents	All patents	All patents	All patents
Firms	61,239	61,239	61,239	61,239	61,239	61,239
Observations	590,873	590,873	590,873	590,873	590,873	590,873

Note: Standard errors are clustered at the firm in columns 1-5. Statistical significance: *** 1 percent, ** 5 percent, and * 10 percent. Traded=1 if the patent is sold. Patent citations: number of forward cites by age 5 Technology Dummies are generated using the 36 technology subcategories defined in Hall et al. (2001). Patent Portfolio Size: total number of patents granted to the patentee from 1975 or the year the patentee first patented.

Table 8: Marginal Effects of Patentee Fit on the Probability that a Patent is Let to Expire

	(1)	(2)	(3)	(4)	(5)	(6)#
Estimation method	OLS Fixed Effects	OLS	OLS	Probit	Probit	Probit Random Effects
Dependent variable	Expired	Expired	Expired	Expired	Expired	Expired
	Coef.$\times 10^2$	Coef.$\times 10^2$	Coef.$\times 10^2$	Mar.Eff.$\times 10^2$	Mar.Eff.$\times 10^2$	Coef.$\times 10^2$
Patentee fit	-1.91***	-4.65***	-3.25***	-4.67***	-3.39***	-
	(0.20)	(0.72)	(0.88)	(0.77)	(0.72)	
Citations	-0.36***	-0.56***	-0.71***	-0.95***	-1.14***	-
	(0.01)	(0.03)	(0.05)	(0.01)	(0.03)	
Patent Portfolio		-0.0001	-0.0003*	-0.0001	-0.0003	-
		(0.0001)	(0.0002)	(0.0000)	(0.0000)	
Controls						
Grant Year	Yes	Yes	No	Yes	No	Yes
Technology	Yes	Yes	No	Yes	No	Yes
Firm fixed effects	Yes	No	No	No	No	No
Sample	Untraded Patents	Untraded Patents	Untraded Patents	Untraded Patents	Untraded Patents	Untraded Patents
Firms	57,009	57,009	57,009	57,009	57,009	57,009
Observations	556,273	556,273	556,273	556,273	556,273	556,273

Note: Standard errors are clustered at the firm level. Statistical significance: *** 1 percent, ** 5 percent, and * 10 percent. Expired=1 if the patent expired at the first renewal date. Patent citations: number of forward cites by age 5. Technology Dummies are generated using the 36 technology subcategories defined in Hall et al. (2001). Patent Portfolio Size: number of patents granted to the patentee since 1975 or the year the patentee first patented. Grant year is the calendar year a patent was issued. Model convergence: # indicates that the model did not converge due to a problem of initial values.

Table 9: Marginal Effects of Technology Linkages on the Probability that a Traded Patent is Sold to Small Firms

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	OLS Fixed Effects	OLS	OLS	Probit	Probit	Probit Random Effects
Dependent variable	Traded to Small	Traded to Small	Traded to Small	Traded to Small	Traded to Small	Traded to Small
	Coef.$\times 10^2$	Coef.$\times 10^2$	Coef.$\times 10^2$	Mar.Eff.$\times 10^2$	Mar.Eff.$\times 10^2$	Coef.$\times 10^2$
TechLink*Small	7.47***	6.09**	6.10**	2.64**	2.83**	24.29**
	(1.90)	(2.73)	(2.75)	(1.29)	(1.39)	(12.24)
TechLink*Large	-7.71***	-6.73***	-7.16***	-7.49***	-8.13***	-51.92***
	(0.66)	(1.19)	(1.18)	(1.11)	(1.14)	(9.68)
Citations	0.02	-0.09**	-0.18***	-0.07*	-0.16***	-0.62**
	(0.02)	(0.04)	(0.04)	(0.04)	(0.05)	(0.32)
Patent Portfolio		-0.0004***	-0.0004***	-0.001***	-0.001***	-0.01***
		(0.0000)	(0.0000)	(0.000)	(0.000)	(0.003)
Small		51.55***	51.47***	39.99***	39.43***	227.5***
		(1.58)	(1.59)	(2.93)	(2.93)	(9.06)
Controls						
Grant year	Yes	Yes	No	Yes	No	Yes
Technology	Yes	Yes	No	Yes	No	Yes
Firm fixed effects	Yes	No	No	No	No	No
Sample	Traded Patents	Traded Patents	Traded Patents	Traded Patents	Traded Patents	Traded Patents
Firms	9,179	9,179	9,179	9,179	9,179	9,179
Observations	34,599	34,599	34,599	34,599	34,599	34,599

Note: Standard errors are clustered at the firm level. Statistical significance: *** 1 percent, ** 5 percent, and* 10 percent. Traded to Small=1 if a traded patent was sold to a small firm. Small=1 if patent was initially owned by a small patentee; it is zero othewise. Large=1 if patent owned by a large patentee; it is zero othewise.Patent citations: number of forward cites by age 5. Technology Dummies are generated using 36 technology subcategories as defined in Hall et al. (2001). Patent Portfolio Size: number of patents granted to the patentee since 1975 or the year the patentee first patented. Grant year is the calendar year a patent was issued.

Table 10: Marginal Effects of Patent Citations on the Probability that a Traded Patent is Acquired by Small Firms

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	OLS Fixed Effects	OLS	OLS	Probit	Probit	Probit Random Effects
Dependent variable	Traded to Small	Traded to Small	Traded to Small	Traded to Small	Traded to Small	Traded to Small
	Coef.$\times 10^2$	Coef.$\times 10^2$	Coef.$\times 10^2$	Mar.Eff.$\times 10^2$	Mar.Eff.$\times 10^2$	Coef.$\times 10^2$
TechLink*Small	6.57***	6.09**	6.10**	2.70**	2.87**	25.14**
	(1.92)	(2.71)	(2.73)	(1.30)	(1.33)	(12.25)
TechLink*Large	-7.12***	-6.61***	-7.02***	-7.46***	-8.07***	-51.66***
	(0.68)	(1.19)	(1.18)	(1.12)	(1.15)	(9.69)
Citations*Small	-0.27***	-0.67***	-0.74***	-0.23***	-0.33***	-2.01***
	(0.07)	(0.13)	(0.14)	(0.06)	(0.07)	(0.45)
Citations*Large	0.01	0.09**	-0.002	0.08*	-0.01	0.58
	(0.03)	(0.04)	(0.04)	(0.05)	(0.06)	(0.40)
Patent Portfolio		-0.0004***	-0.0005***	-0.001***	-0.001***	-0.01***
		(0.0000)	(0.0000)	(0.000)	(0.000)	(0.003)
Small		55.28***	55.14***	43.31***	42.64***	239.1***
		(1.67)	(1.67)	(2.97)	(3.01)	(11.13)
Controls						
Grant year	Yes	Yes	No	Yes	No	Yes
Technology	Yes	Yes	No	Yes	No	Yes
Sample	Traded Patents	Traded Patents	Traded Patents	Traded Patents	Traded Patents	Traded Patents
Firms	9,179	9,179	9,179	9,179	9,179	9,179
Observations	34,599	34,599	34,599	34,599	34,599	34,599

Note: Standard errors are clustered at the firm level. Statistical significance: *** 1 percent, ** 5 percent, and * 10 percent. Traded to Small=1 if a traded patent was sold to a small firm. Small=1 if patent was initially owned by a small patentee; it is zero othewise. Large=1 if patent was initially owned by a large patentee; it is zero othewise. Patent citations: number of forward cites by age 5. Technology Dummies are generated using 36 technology subcategories as defined in Hall et al. (2001). Patent Portfolio Size: number of patents granted to the patentee since 1975 or the year the patentee first patented. Grant year is the calendar year a patent was issued.