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Patent trading flows of small and large firms

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ABSTRACT

This article provides new evidence on the patent trading flows of small and large firms. We document aggregate patterns of patent sales and acquisitions of small and large firms. We also examine the extent to which the initial innovator's and the potential buyers' prior knowledge stocks in the same technology area and in geographical proximity with a patented invention are associated with the likelihood that the patent is sold, and whether the patent sold is bought by a small or large firm. To do so, we develop a dataset that matches patent sales and information on whether transacted patents are owned by small or large firms following a patent sale.

1. Introduction

Patents are considered by many to be crucial for technological innovation and for transferring technology. A patent confers a legal right to exclude others from making, using, or selling an invention for a limited period of time. Patent rights are often exchanged through technology licenses (see e.g., Arora et al., 2001; Arora and Fosfuri, 2003) or transferred to new owners through mergers and acquisitions (see e.g., Hitt et al., 1996; Ahuja and Katila, 2001). Although less studied, the market for patents – sale and acquisition of patents – has grown over the recent years (Hagiu and Yoffie, 2013), receiving increasing attention from policy makers and government agencies (USFTC, 2011) as well as research scholars (see e.g., Serrano, 2010, 2018; Caviggioli and Ughetto, 2013; Akcigit et al., 2016).

Firms sell and acquire patents for many reasons. Patent sales can be the result of differences that emerge over time between initial innovators and other firms that are better positioned to capture value from an invention. These differences have been associated with comparative advantages between sellers and buyers in commercialization or marketing an invention (see e.g., Arora et al., 2001; Arora and Ceccagnoli, 2006) or comparative advantages in enforcing patent rights without resorting to the courts (Galasso et al., 2013). Patent sales can also arise early in the event that a new invention has a different use than the initially intended (Rosenberg, 1996). Firms that fail to find an alternative use within the firm for their own inventions may still be able to capture some value by selling them to other firms. The case of the small medical device company Uromed Corporation highlights some of the benefits and characteristics of patent sale transactions. Following a "significantly lower market acceptance" for one of their new products, Uromed sold 7 of its new patents to medical device startup Assurance Medical to free up resources and re-structure its product line. Both firms were operating in the same technology sector, located in the US state of Massachusetts, and 25 miles apart.[1]

In this paper, we investigate the sale and acquisition of patents of small and large firms, and examine factors that are associated with these transactions. We first document aggregate patterns about the proportion of newly patented inventions sold and bought early in their lifetime by small and large firms and connect these patterns with micro-level evidence on firms' decisions to sell patented inventions and whether these inventions are bought by small or large firms. In particular, we examine the extent to which the initial innovator's and potential buyers' prior knowledge stocks related with a patented invention in technology and geography are associated with the likelihood that the patent is sold (as opposed to keeping the ownership of the patent), and whether the patent sold is acquired by a small or large firm. To do so, we develop a new dataset that matches information on patent sales and

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[1] Uromed Corp. was based in Needham, MA whereas Assurance Medical was based in Hopkinton, MA.

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information on whether transacted patents are owned by small or large firms following a patent sale.

In this work we mainly contribute to the literature on markets for technology. The literature on licensing has produced a set of facts about the cross-firms technology licensing, with a frequent focus on understanding the interactions between small and large firms (see e.g., Arora and Gambardella, 1990; Arora et al., 2001). In contrast, the question of whether transferred patents are bought by small or large firms and the factors associated with these transactions have received little attention thus far. The closest paper to ours is Serrano (2010), who documents active trading in the market for patents, and higher likelihood of sales for individual inventors and small firms. Our work adds to this by documenting evidence on who buys patents – small or large firms – and factors associated with patent transactions. Patent sales, however, need not follow the same patterns as technology licensing. For instance, the sale of a patent, unlike its licensing, does not necessarily increase competition and reduce a patent owner's market share, which is a common argument used to explain why large firms are less likely to license their technology than small firms (Arora and Fosfuri, 2003).[2]

The main empirical findings of the paper are as follows. At the aggregatelevel, we find that small firms sell a higher proportion (8.5 percent) of their newly patented inventions than large firms (5.1 percent) within four years of being granted. The descriptive evidence also shows that patented inventions, especially those sold by small firms, are bought disproportionately by small firms. In particular, 16.7 percent of the new patents sold are bought by small firms; this is about 60 percent more than the share of patents issued to small firms in the our sample (10.7 percent). Among the patents sold by small firms, more than 69 percent are bought by other small firms; this is 6 times the share of patents issued to small firms in our sample. In contrast, among patents sold by large firms, only 6.1 percent were bought by small firms. Moreover, we provide evidence showing that small firms have on average lower prior knowledge stocks in the technology class and in the geographical location of their newly patented inventions than large firms.

At the micro-level, the econometric models in which we study the factors associated with patent transactions reveal some new, interesting patterns. First, we find that the likelihood that a newly patented invention is sold is negatively associated with the initial innovator's prior knowledge stock in the same technology class of the invention and that is in the geographical location of the focal invention. Moreover, the initial innovator's prior knowledge stocks in technology classes other than the technology class of the newly patented invention or the prior knowledge stocks of the same technology class of the invention but in locations other than the location of the newly patented invention have no meaningful effect on the likelihood that a new patented invention is sold. Therefore, the results reveal that the initial innovator's prior knowledge stocks that are negatively associated with the likelihood that a new patented is sold are those characterized by close proximity in technology and geography to the new patented invention. As we will later show, this finding is particularly relevant for small firms, since they have on average fewer knowledge stocks related in technology and geography to their new patented inventions than large firms. The non-random nature of the possible determinants affecting patent transactions made by sellers and buyers that we explore does not allow us to identify causal relationships. However, these results are consistent with a theoretical framework in which knowledge stocks related to the invention in technology and geography develop the ability of the initial innovator to capture more value by keeping the ownership of the patented invention than by selling it to others. In addition, the results have significant implications for managers: while creating specialized research units across the country could be beneficial for tapping local human or physical resources, spreading the research activities of a firm in a technology class across multiple geographical locations can hamper an innovator's ability to capture value from its own new patented inventions by keeping the ownership.

Second, we show that the likelihood that a patent sold is bought by a small firm is positively associated with the share of small firms' knowledge stocks (relative to all firms) in the same technology class and geographical location of the patent sold. In fact, we find that both technological and geographical proximity of the potential buyers' knowledge stocks (small or large firms) to the patents sold are critical for patent transactions: prior knowledge stocks of potential buyers that are related to the technology class of the patent sold but in other geographical locations are not associated with the likelihood that a patent sold is bought by small firms. Moreover, prior knowledge stocks of potential buyers in technology classes other than the technology class of the patent sold have no meaningful effect on patent transactions. As a result, the findings suggest that patent sale transactions are likely to take place within geographical proximity of the patent sellers and with buyers performing research activities in the same technology class of the patent sold. This effect is particularly relevant for transactions involving patents sold by small firms, since, as we show, small firms disproportionately concentrate their research activities in specific technology areas as compared to large firms. These results are also consistent with a theoretical framework in which potential buyers' knowledge stocks in a technology class and geographical location develop a firm's ability to value and integrate external technologies that share the same technology class and geographical location but not others.

This article is organized as follows. Section 2 presents a review on markets for patents and related evidence. Section 3 provides some theoretical guidance to examine and interpret the new evidence on patent transactions. In Section 4, we describe the new dataset and key variables. Section 5 presents the market-level patterns of the patent trading flows across small and large firms. In Section 6, we provide evidence on factors associated with the patent sale and acquisition decisions that account in part for the observed market-level patterns. Finally, concluding remarks close the paper.

2. The market for patents, background and related evidence

The market for technology has grown over the recent decades. One important part of that market – technology licensing – has been very well studied (Anand and Khanna, 2000; Arora et al., 2001; Arora and Fosfuri, 2003; Arora and Gambardella, 1994; Arora and Ceccagnoli, 2006; Cassiman and Veugelers, 2006; Ceccagnoli et al., 2010; Palomeras, 2007). Another channel through which technology and legal rights over it can be transferred is mergers and acquisitions (M&A), whereby in addition to patents also people and other assets are exchanged (see e.g., Makri et al., 2010; Hitt et al., 1996; Ahuja and Katila, 2001). Although the M&A literature is vast, few studies have incorporated patent sales data and directly compared M&A deals to standalone patent transactions (an exception is Caviggioli et al., 2017). In our paper, however, we will focus solely on standalone transactions in the market for patents. In the recent years the market for sales and acquisitions of patents – the market for patents – has grown considerably (Hagiu and Yoffie, 2013), receiving increasing attention from policy makers and government agencies (USFTC, 2011) as well as research scholars. The scarcity of prior empirical research on patent sales could be due to the inherent “messiness” of the USPTO Patent Assignment records (see e.g., Lamoreaux and Sokoloff, 1999). In 2015, the USPTO released the data in a format more amendable for large-scale

[2] In fact, the degree of competition could arguably remain the same following a patent sale since the sale involves the transfer of all legal rights over the patented invention, including the right over the use of the technology. More generally, patent sales not only convey the right over the use of a patented technology (as licensing does), but also the right to let other firms use the technology, to enforce the patent against potential infringers, and the option to transfer all these rights, including the patent ownership, to another firm.

study, thus opening up new opportunities for research. Marco et al. (2015) provide a useful overview of the data.

Patents can be sold and bought for various reasons. In a recent survey to practitioners, Caviggioli and Ughetto (2013) investigate different reasons for which companies sell or buy patents. One such reason is the uncertainty that characterizes the process of innovation. As Rosenberg (1996) described, the value and use of an invention is not fully understood at the time of conception. This uncertainty often leads to many new patented inventions to have a different use than the intended by the initial innovators. Initial innovators that fail to find alternative uses within the firm for their new inventions can still capture some value by selling the patented inventions to other firms. For instance, the already mentioned case of medical device company Uromed that sold some of their new patents to Assurance Medical while in the process of re-structuring its product line.[3] At the extreme, firms can go out of business and have all their patents sold at liquidation (Serrano and Ziedonis, 2018). When Pebble's smartwatch startup failed in late 2016, it owned 17 issued US patents and 16 published, pending US patent applications. Fitbit, which operated in the same technology area as Pebble, acquired its intellectual property, including patents and Pebble's smartwatch OS and apps, for $23 million. Both Pebble and Fitbit operated in the same technology sector and in the same geographical area (San Francisco Bay Area).

In a related mechanism, patent sales can also be the result of differences that emerge over time between the initial innovators and other firms that may be better positioned to capture value from the invention. In particular, patent transactions have been associated with differences between sellers and buyers in their ability to develop and commercialize an invention (Lamoreaux and Sokoloff, 2001; Khan and Sokoloff, 2004; Teece, 1986; Arora et al., 2001; Gans and Stern, 2003, 2010Gans and Stern, 2010Gans and Stern, 2003, 2010; Arora and Ceccagnoli, 2006). For instance, following the decisive role that precision-guided bombs and missiles played in the Gulf War, IBM sold 59 new "target-tracking" technology patents to Lockheed Martin, a key supplier of electro-optical/infrared targeting systems for the U.S. Marine Corps.[4] Patent transactions could also be used to gain sources of competitive advantage (Grindley and Teece, 1997) or to learn some new technology or to enter into a new market (see e.g., Penrose, 1959; Hitt et al., 1996; Ahuja and Katila, 2001). As noted by Karim and Mitchell (2010), however, if firm's resources are tacit, such as when the knowledge and human capital to continue developing an invention resides in the people and organization, external unrelated technologies to the buyers may be better integrated into a firm through the acquisition of an entire company (M&A) than by acquiring the patented inventions alone. Hence, it is possible that the characteristics of sellers and buyers in standalone patent transactions and M&A deals may be different.

Patent sale transactions can also arise due to comparative advantages in patent enforcement. The market for patents can reduce litigation if it reallocates patents to entities that are more effective at resolving disputes over these rights without resorting to the courts (Galasso et al., 2013). Having the opportunities to sell patent assets to others that have better capabilities and financial resources to enforce the legal rights over new inventions can increase the initial inventors' incentives to invest in R&D ex ante, especially for small firms (Harber and Werfel, 2016). Similarly, building large patent portfolios through patent purchases can also help buyers improve their terms-of-trade in licensing agreements (Ziedonis, 2004), provide freedom to operate to new entrants that had limited opportunities to build patent portfolios organically, or help settle litigation issues (Chien, 2011). For instance, LinkedIn purchased over 900 patents between 2012 and mid-2016 while growing its organic portfolio from 36 to 1000 patents to build a patent portfolio with the intention of reducing the risk of patent litigation by a corporate competitor.[5]

Despite recent evidence that patent sale transactions are increasingly important for entrepreneurial and established firms, few studies have analyzed modern markets for patents empirically. In an early analysis of modern markets for patents, Serrano (2010) documented that 13.5 percent of all U.S. patents are sold for the period 1985–2001, with higher rates for inventions of individual inventors and small innovators. More recently, Akcigit et al. (2016) investigates markets for patents and report higher rates of patent sales in more recent years for patents of U.S. publicly held companies and especially for patents less relevant to their businesses. Arque-Castells and Spulber (2017) analyzes the relevance of the technological and geographical proximity in firm-to-firm level transactions also made by publicly held firms in North-America. Combined with other sources of data, patent ownership reassignment data has been used to quantify the gains from trade in the patent market (Serrano, 2018), to study patent assertion entities and patent enforcement (Chien, 2011; Harber and Werfel, 2016), to examine the impact of patent transactions on patent enforcement (Galasso et al., 2013), to analyze the concentration of patent ownership in the ICT equipment industry (Ozcan and Greenstein, 2013), to measure the extent of markets for technology in an industry (Mani and Nandkumar, 2016), to complement studies on patent auctions (Odasso et al., 2015), to analyze global markets for technology (DeMarco et al., 2017), to investigate differences in external technology acquisitions through standalone patent transactions and technology M&A (Caviggioli et al., 2017), and to examine the impact of patent tradability on patent-back lending by technology startups (Hochberg et al., 2018). Direct evidence on whether patents are sold and bought by small or large firms, and the extent to which these transactions are associated with initial innovator's and the potential buyers' prior knowledge stocks related with an invention remains lacking, an empirical gap that we seek to help fill.

Our paper is also related to the literature of resource relatedness and redeployment. The traditional resource-based view focuses on static economies of scope or synergies, which are the result of redeploying resources within the firm. Henderson and Cockburn (1996) associate the economies of scope of the firm's research effort (research diversity) with internal knowledge redeployment between projects that enhance each other's productivity. Miller et al. (2007) show that knowledge redeployment across business units within a firm positively affects follow-on innovation. Cockburn and Henderson (2001) show that large firms' superior performance in drug development is mainly driven by returns to economies of scope in knowledge transfer within a firm. The work of Helfat and Eisenhardt (2004) also considers the possibility that economies of scope may be derived from internal resource redeployment but over time. Building on this theory, Lieberman et al. (2017) examine the role of resource redeployment in a firm's decision to enter and exit a new business.

3. Theory development and hypotheses

This section presents some intuitive guidance on how one might interpret the empirical regularities in the patent sale transactions of small and large firms that we establish in the following sections.

3.1. Uncertainty over the use of new inventions and patent sales

The value and use of an invention is not fully understood at the time

[3] See patent assignment reel-frame 009942/0393. The business status of Uromed Corporation is discussed here: http://www.prnewswire.com/news-releases/uromed-corporation-announces-corporate-restructuring-75767502.html.

[4] See patent assignment with reel/frame 8430-312, that was executed on August 29, 1996.

[5] See "How and Why LinkedIn Learned to Love Patents," by Sara Harrington, Pierre Keeley, and Kent Richardson in IPWatchdog: http://www.ipwatchdog.com/2017/06/15/linkedin-learned-love-patents/id=82848/.

of conception (Rosenberg, 1996). Technologies are characterized by increased uncertainty in terms of their viability and commercial significance (Griliches, 1990). Patents are also subject to uncertainty over their validity and scope (Lemley and Shapiro, 2005) as well as their strategic use (Ziedonis, 2004). As a result, many new patented inventions can have a different use than the intended by the initial innovators. Firm profitability and the incentives to invest in R&D depend on how firms manage the consequences of uncertainty over the use of new inventions.

Firms have been known to employ several strategies to capture value from patented inventions that have a different use than the intended initially. One possibility is to transact in the market for patents and sell the ownership of all the legal rights over the invention to an alternative owner. Patent transactions have been associated with vertical specialization (Teece, 1986; Arora et al., 2001), comparative advantages in manufacturing and commercialization and access to complementary assets (Teece, 1986; Arora and Ceccagnoli, 2006), and patent enforcement (Galasso et al., 2013). However, significant sources of transactions costs and market failure make arm's length transactions challenging (Agrawal et al., 2015). The difficulty to value technology and patent assets can lead also to bargaining failure in transactions (Lerner and Tirole, 2004), and patent value may be tied to the original venture or the private knowledge of the team of inventors (Hoetker and Agarwal, 2007). Missed trading opportunities can also be the result of a lack of market thickness that would allow buyers and sellers to trade with a large number of transactors (Gans and Stern, 2010). Patent sales can be effective mechanisms to capture value from new inventions whenever the current patent owners lack the needs or resources that buyers have to exploit these patent rights and maximize their value.

Another strategy to appropriate value from inventions is redeploying them to an alternative use within the firm. In the event that an invention has a different use than the intended initially, firms can benefit from redeploying resources from one intended use to an alternative one (Helfat and Eisenhardt, 2004). Internal redeployment has an advantage over selling the invention in that it avoids the market transaction costs associated with arm's length transactions (Matsusaka and Nanda, 2002). Anecdotally, Steve Kerr, VP of Corporate Leadership Development and Chief Learning Officer attributed General Electric's successful development and commercialization of new inventions to the moving of ideas around business units within the firm (Miller et al., 2007). But internal redeployment may require a set of competencies to identify an alternative use for the invention and integrate it within the firm. In addition, there may be other costs such as reallocating employees, and even the building of a new unit to host the invention. If a firm can appropriate more value by folding back the invention to another use within the firm than by selling it to potential buyers, the redeployment mechanism reduces the likelihood that a new invention will be sold.

Redeploying a new invention to an alternative use within the firm is more likely to occur when the initial innovator has a deep understanding of the invention's technology. In fact, the initial innovator is unlikely to even notice the invention's potential uses or opportunities for value creation within the firm when its prior research activities do not overlap with the invention's technology (Cassiman and Ueda, 2006). We consider that a firm's prior knowledge stock that is related to the new invention's technology translates, among possibly other competencies, into higher ability to identify and integrate the invention to an alternative use within the firm. Hence, in order to understand the potential for internal redeployment of a new invention within a firm it is crucial to identify whether a firm has prior knowledge stocks related to the invention's technology.

At times, the initial innovator's prior knowledge stocks related to an invention are in multiple geographical locations. In these cases, the tacit nature of some knowledge can prevent the initial innovator from exploiting its own prior research stocks related to the invention's technology that are in geographical locations other than the location where the invention was created (Miller et al., 2007). Transferring tacit knowledge over long distances is known to be challenging since often requires personal exchange of ideas and personnel (Marshall, 1890). The potential for opportunism within the organization is also more likely to arise when geographical barriers separate groups of people with different knowledge from each other (Williamson, 1985). Therefore, the potential for redeploying a newly patented invention to an alternative use within the firm may also depend on the geographical location of the initial innovator's knowledge stock that is related the invention, and thus how the firm organizes its research activities across geographical locations.

In addition to redeploying a new invention to an alternative use within the firm, keeping the patented invention (as opposed to selling it to others) can result from a variety of other causes, including the use of the invention in its intended use, or the utilization of the patent rights strategically in support of a business related to the patent or other businesses (see e.g., Walsh et al., 2016; Torrisi et al., 2016), all of which may be related with the initial innovator prior knowledge stocks that are in proximity to the new patented invention.

In combination, the above discussion yields a patent-firm level hypothesis on how a firm's decision to sell or keep a newly patented invention is associated with the firm's prior research stocks related to the newly patented invention.

H1. The likelihood that a newly patented invention will be sold is negatively associated with the initial inventor's prior knowledge stocks related to the new invention's technology and that are in the geographical location of the invention.

3.2. Knowledge stocks related to a new invention and patent sales by small and large firms

Large firms may be able to capture more value from their new patented inventions than small firms for various reasons. One reason is that a comparative advantage in identifying and integrating new inventions to an alternative use is more likely to exist when the initial innovator has more prior knowledge stocks and the knowledge is more technologically diverse. Having access to large prior knowledge stocks has also been associated with alternative sources from capturing value from new patented inventions such as comparative advantages in enforcing patent rights without resorting to the courts (Lanjouw and Schankerman, 2004; Galasso et al., 2013), or utilizing patent assets strategically to gain freedom to operate in new markets, or to improve the terms-of-trade in licensing negotiations (Ziedonis, 2004).

Consistent with the evidence in our sample that large firms typically have more patents per technology class and operate in a higher number of technology classes than small firms, large firms may be able to retain and significantly appropriate more value from their new inventions than small firms, whose typical next best alternative often is to sell their patented inventions to others. This discussion leads to the following hypothesis:

H2. Large firms are less likely to sell their new patented inventions than small firms.

3.3. Knowledge stocks of potential buyers and patent acquisitions

Consider now the decision of whether or not to buy an external patented invention in the market for patents. In the spirit of Cohen and Levinthal (1990), we consider that the potential buyers' prior knowledge stocks related to an external invention enhance their ability to select inventions with these characteristics and appropriate value from them. Potential buyers' prior knowledge stocks related to an external patented invention can also enhance their ability to assess the legal boundaries of the patent rights and assess their value accurately, which is known to be difficult (Merges and Nelson, 1990). In these ways, acquiring patented inventions can serve as an alternative to internal development since they can offer immediate access to new, less uncertain technologies that match the needs of buyers (Hitt et al., 1996). Patented inventions sold, thus, may be more likely to be acquired by buyers whose prior knowledge stock is related to the invention's technology.

Alternatively, acquirers of external patented inventions may seek unrelated technologies to learn something new. Acquisitions of entire firms have been seen as means of obtaining the knowledge that is necessary for a firm to establish itself into a new field or enter an industry (Penrose, 1959; Hitt et al., 1996). However, standalone patent acquisitions may be less likely to provide the same benefits. As noted by Karim and Mitchell (2010), if firm's resources are tacit, such as when the knowledge and human capital to continue developing an invention resides in the people and organization, the market for discrete resource exchange – like the market for patents – may be often less robust than the acquisition of an entire company as a mode of acquiring external technology to learn something new. Hence, we expect acquirers in transactions in the market for patents to be firms whose prior knowledge stocks are related to the acquired invention and thus buyers will likely already have the ability to select, integrate, and continue developing the external inventions.

In addition, patents transactions may also be geographically localized. As discussed above, there is a long literature that argues that most technologies contain one way or another tacit knowledge. Communication of tacit knowledge over long distances is likely to be problematic since personal communication is essential to transfer knowledge effectively, especially across firms' boundaries (Marshall, 1890). As a result, potential buyers' ability to evaluate and utilize external patented inventions may be largely dependent on the buyer's research activities and thus their prior knowledge stocks in the geographical area of the external invention. Therefore, in order to understand the potential for external redeployment of a new invention towards a potential buyer it is important to identify whether the potential buyer's prior knowledge stocks related to the external invention's technology are also geographically located near the location of the invention.

This leads to the following patent-firm level hypothesis on the decision to buy newly patented inventions.

H3. The likelihood that a newly patented invention sold is bought by a given buyer is positively associated with the prior knowledge stocks related to the patented invention's technology of that buyer and that are in the geographical location of the invention.

3.4. Knowledge stocks of potential buyers and patent acquisitions by small and large firms

We now turn to patent acquisitions by small and large firms. A buyer's ability to capture more value from its new inventions, derived in part for from a buyer's potential for the redeployment of its own future inventions to alternative uses within the firm, can also have implications on which firms – small or large – buy patented inventions. The intuition is now more subtle. Consider a firm in the event that a newly patented invention created by others, for whom it is not useful, it is of good use for a potential buyer. The potential buyer must weight the benefits of acquiring immediately the external invention versus waiting for its own new inventions. In particular, the potential buyer weights the gains from adopting *this* external invention (net of any market transaction costs) against the option value of waiting for the arrival of its own patented inventions. The higher potential for internal redeployment that we argue that may characterize large firms – firms with more diverse and superior prior knowledge stocks across technology areas – makes their option of waiting for the arrival of their own new inventions relatively more attractive than that of small firms, who typically find it harder than large firms to find an alternative use within the firm for their own future inventions. Thus, large firms' higher potential for internal redeployment can decrease the likelihood that they buy a patented invention relative to small firms. As a result, conditional on an external invention being useful for a potential buyer, we anticipate small firms to buy disproportionately more external inventions in the market for patents than large firms.

In light of Hypothesis 3, patent sale transactions in the aggregate could also depend on the way in which the prior knowledge stocks of small and large potential buyers are related to the technology of the patents sold. If inventions of small firms are concentrated in some technology areas (i.e., where the share of patents issued to small firms is disproportionately high relative to the share of patenting in small firms in the aggregate – externally redeployable towards small firms), we would expect that patents sold by small firms are bought disproportionately by other small firms too. Small firms may choose to concentrate their R&D activities in some specific technology areas for several reasons. A reason for small firms to concentrate their R&D in some specific areas is that such technology areas have a low threat of litigation. For instance, Lerner (1995) provides evidence that small biotechnology firms avoid R&D areas where the threat of litigation is high. Another reason is that they prefer to locate their R&D activities in technology areas where they may obtain technology spillovers, which may lead to clustering of small firms in certain technology classes (Bloom et al., 2013). Finally, given that large firms often have a comparative advantage in exploiting economies of scale relative to small firms (e.g., due to less financial constraints), small firms could choose to concentrate their research activities in technology areas where economies of scale in the production process are less likely to be important.

This discussion leads to the following aggregate level hypothesis.

H4. If new inventions by small firms are related in technology disproportionately to the knowledge stocks of small potential buyers, then we would expect patented inventions sold by small firms to be bought disproportionately by other small firms.

4. Data

The new facts we present in this paper are derived by merging three 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. The third dataset includes information on patent citations and patent and initial patentee characteristics from patent grant records. The merged dataset is a panel of patents applied for and granted to corporations in the U.S. with their corresponding records on renewal and patent sales for the period 1989–2001.

4.1. Sample construction

Documenting the firm size of patent owners over a patent's lifetime has been challenging. The work-horse dataset of empirical patent research, the NBER Patent Citations dataset, provides information on patent characteristics such as issue date, technology class, patent citations, and patent ownership as of the patent's issue date, but does not keep track of changes in patent ownership post- patent issuance (Hall et al., 2001). In Serrano (2010), patent assignment data has been used to identify changes in patent ownership, but neither the names nor the size of patent buyers. An issue is that both the names of sellers and buyers are not standardized by the USPTO. Most critical is that the names reported are not necessarily the real parties in the transactions, making it challenging to systematically link the names in these transactions to existing datasets on business characteristics.[6]

To overcome this issue, this paper exploits a provision in 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 are subject to a 50 percent reduction for small entities.[7] Among businesses, patents are assigned a small entity status if the patent holder is a business with less than 500 employees (including all subsidiaries); otherwise it is identified as large. Firm size is based on the definition of a small business by the US Small Business Administration. Small entity status is established by a written assertion of entitlement to such status or it is 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 the assignment of rights or an obligation to assign rights is to other parties that are small entities too. Moreover, 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. This empirical strategy means that we can only systematically identify whether buyers in patent transactions are either small or large in this article.

The first dataset we create combines information extracted from patent application and maintenance fee records to obtain the firm size for patent owners over the lifetime of patents. To identify whether patents were initially owned by small or large businesses, we use the patent application records of issued patents. We have access to these 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 from January 1, 1992, to December 31, 2001.[8] Maintenance fees are due no later than the end of the 4th, 8th and 12th year after the grant date of the patent.[9] By linking both data sources, we can identify the firm size for the patent owners by the grant date and at each of the renewal events for all patents granted in 1989 and until 1996. Consistent with our focus on newly patented inventions, the empirical analysis will exploit the firm size of the patent owner as of the patent application and the first maintenance fee event dates.

The second dataset uses registrations of changes in patent ownership recorded at the USPTO in order to discern the standalone sale of a patent. The source of the data is the Patent Assignment Database. When a U.S. patent is transferred, an assignment may be recorded at the patent office to acknowledge a 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 ("assignee"), the name of the seller ("assignor"), the date at which the reassignment was recorded at the patent office ("recorded date"), and the date at which the private agreement between the parties was signed ("execute date"). We have obtained this information for the period 1989–2001.[10]

A challenge in using reassignment data is to distinguish changes in patent ownership from other events recorded as assignments. We use an algorithm developed in Serrano (2010) that conservatively drops all the assignments that appear not to be associated with a change of patent ownership between distinct entities. 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"), assignments executed before the patent's issue date, and assignments between entities with the same name. We also drop assignments in which the buyer is the assignee as of the grant date of the patent, assignments recorded at the patent application date, assignments to financial institutions, duplicate assignments, etc.[11] The details of the procedures we used to deal with the assignment data are explained in Serrano (2010).[12]

A related concern in using reassignment data is that the recorded assignments may be attributable to merger and acquisition (M&A) transactions. To exclude reassignments associated with M&A, we compile supplemental data from Thomson SDC Platinum on acquisitions. Using a name-matching algorithm we are able to match target companies in SDC Platinum to patent assignees in the USPTO patent grant data. For each matched target company, we compile information about its portfolio of patents granted prior to the month and the year of the acquisition.[13] We then conservatively remove patents in reassignment records attributable to M&A transactions.[14] The remaining, post-cleaning, patent ownership reassignments represent the standalone patent sales or sales of patent portfolios unrelated to M&A transactions, and have information about patent numbers and transaction dates.

The patent numbers make possible to merge the two previous datasets with the third one: the patent grant and citation data. The source of the patent grant and citation data is an updated version of the NBER Patent Citations dataset (Hall et al., 2001). We use patent characteristics such as technology class, citations received, and citations made. We also exploit the unique identifier of each initial patentee, which allows us to construct their patent portfolio as of the patent's grant date.

Matching data on the characteristics of the initial innovator to patents is meaningful as long as the patent is owned by the original innovator at the time of the transaction. To ensure this, we focus our analysis on the first sale of a patent. As we explained above, we have no detailed information of the patent portfolios of subsequent patent owners. The majority of patent sales occur in the very first years post-

[6] Some patent buyers have been found to create shell companies to hide their real name.

[7] 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.

[8] An author obtained access from the USPTO to the maintenance fee records in exchange 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. 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.

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

[10] 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).

[11] 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.

[12] In 2015, the USPTO released the data in a format more amendable for large-scale study, thus opening up new opportunities for research. Marco et al. (2015) provide a useful overview of the data.

[13] We omit transactions labeled as bond deals, equity capital transactions, joint ventures, buy backs, exchange offers, recapitalizations, acquisitions of partial interest, and acquisition of assets.

[14] In particular, we remove any patent recorded in a USPTO assignment that is also part of the portfolio of a target company involved in a M&A transaction that that took place within a five-year window of the execute date of the patent assignment.

Table 1
Summary statistics of the patents by firm size of the initial innovator.

Panel A. Proportions of patents initially owned by small and large firms by grant year

	All patents	Patent Issue 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	0.892	0.91	0.902	0.884	0.877
	(.000)	(.001)	(.001)	(.001)	(.001)
Number of patents	590,872	135,507	144,224	151,839	159,303

Panel B. Proportions of patents initially owned by small and large firms by patent technology class

	All patents	Patent Category					
		Chemical	Computer & comm	Drugs & medical	Elec & Electro	Mechanical	Other
Small firms	0.107	0.065	0.059	0.152	0.08	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	590,872	126,865	85,924	49,857	116,232	122,642	89,352

Note: Patent's technology classes are classified into Patent Categories as defined in Hall et al. (2001). Standard errors in parentheses.

issuance and prior to the first maintenance date (four years after patent issuance).[15] Similarly, we also focus our analysis on patent sales up to the first maintenance date since patents may be let to expire thereafter. For these patents, we can observe whether the initial owner and the owner as of the first renewal date is either a small or large firm.

In our empirical analysis we focus on corporate patents, patents that were applied for and granted to businesses. Corporate patents represent about 75 percent of all issued utility patents. For these patents we have initial innovator's unique identification numbers, which allows us to construct the initial innovators' patent portfolios as of the issue date of the patents. The rest of the patents were applied for and issued to federal agencies, universities, individual inventors, and individual owners. In addition, our analysis is restricted to patents issued from 1989, the first year of comprehensive reporting of small and large entity status, through 1996. The latter is the youngest cohort for which we have sale and renewal records for five years. This allows us to observe for each patent cohort and for at least five years the sale and renewal decisions.

The final dataset has 590,872 patents, issued to 61,239 patentees. The dataset contains information on the history of patent sales and renewals, patent and original patentee characteristics, and the firm size of patent holders (both as of the application date and renewal dates).

Table 1 presents summary statistics of the patents in our sample. Panel A shows that 10.7 percent of these patents were initially owned by small firms, and the rest were owned by large firms. The same panel reports these rates across the grant year 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 percent) and Other (20.6 percent). The lowest share of patenting for small firms is in the Computer and Communications (5.9 percent) and Chemical (6.5 percent) patent classes.[16]

4.2. Main variables

4.2.1. Dependent variables

Our analysis focuses on the decision to sell a newly patented invention and whether the patented invention is bought by a small or large firm. All dependent variables are binary measures. We construct each patent sale related variable using changes in patent ownership. We describe each of these variables below.

Patent sold. The variable $Sold_i$ indicates whether patent i is sold. $Sold_i = 1$ identifies a change of ownership recorded at the USPTO during the first four years after a patent is issued. Alternatively, $Sold_i = 0$ reflects instances in which the patent was not sold during the same period.

Patent bought by a small firm. The variable $Bought\_by\_Small_i$ indicates that a newly patented invention that was sold ($Sold_i = 1$) is subsequently owned by a small entity as of the first patent's renewal event (as supposed to be owned by a large entity). Whereas the patent assignment data tells us whether the patent was sold, the patent renewal data reveals the size of the subsequent patent owner.

4.2.2. Explanatory variables

The theory development discussed in an earlier section associates patent transactions of small and large firms with the prior knowledge stock of the initial innovator and small and large potential buyers that are related to the patented invention. It is impossible to observe a firm's knowledge directly, but patents provide a convenient window into its knowledge. We operationalize the firms' knowledge stocks of initial innovators or potential buyers (small or large firms) with the number of patented inventions that were issued to the firms in the five years prior to the issue year of the focal patent. As in Jaffe (1986), we identify the patented inventions of the initial innovator and potential buyers that may (or may not be) related to the focal invention using the patent's technology classes. The technology information is provided by the allocation of all patents by the USPTO into 426 different 3-digit technology classes. Moreover, the geographical location of patents is based on the primary address of the focal inventor in a given patent.[17]

[15] In our sample, 55 percent of the patents sold are transacted within four years of being granted.

[16] We have followed Hall (2005) to classify patents into technology categories or fields.

[17] Geographical location is based on the postal address of a patent (i.e., inventor located in the same US state as the inventor of the focal patent, or inventor located in the same country of the focal patent if the focal patent is a foreign patent).

The two explanatory variables are operationalized as follows. We also describe the control variables.

Internal Relatedness. We measure the Internal Relatedness of a new patented invention with an initial innovator in terms of the number of patents related to the focal patent and that were issued to the initial innovator in the five years prior to the grant year of the focal patent.

We experiment with several measures of the Internal Relatedness of the patented invention with the initial innovator. The first measure is based on patents in the same technology class of the focal patent. The second measure expands the number of technology classes to include patents with technology classes closely related to the technology class of the focal patent.[18] In the third measure, the knowledge stocks of the initial innovator are based on patents with technology classes other than the technology class of the focal patent. Using these three measures we aim to explore the conditions under which the decision of selling a patent (as opposed to keeping the ownership)depends on the initial innovator's prior knowledge localized within the technology class of the focal patent. In the fourth measure, the initial innovator's knowledge stocks are based on patents with the technology class of the focal patent that are in the geographical location of the focal patent. The objective of this measure is to test whether the geographical proximity of the initial innovator's knowledge stocks matter in the decision to sell a patent. In the fifth and last measure, we test whether patent sales depend on the technological distance between the new invention and the patent portfolio of the initial innovator rather than on the prior knowledge stocks of the innovator that are related to the new invention. The distance metric we use is based on the average distance between the technology classes of the focal patent and the patents in the portfolio of the initial innovator issued before the focal patent.[19]

External Relatedness. We measure the External Relatedness of a patent towards small firms in terms of the share of patents issued to small firms (relative to all firms) that are related to the focal patent and that were issued in the five years prior to the patent's grant year.

We also experiment with several measures of the external relatedness of patents with small potential buyers. The first measure is based on patents in the same technology class of the focal patent. The second measure combines patents in the technology class of the focal patent and the most related technology class.[20] The third measure of external redeployment is based on the number of distinct firms (potential buyers) that were issued patents in the technology class of the focal patent. These three measures tell us whether patent transactions are associated with the potential buyers' knowledge stocks related to the patent sold's technology. The fourth measure is based on patents with the technology class of the focal patent and that are in the geographical location of the focal patent. Using this last measure we investigate whether localized knowledge stocks in the same technology of the focal patent are associated with patent sales to small or large buyers.

Main control variables. Our regression analysis controls for a number of variables that may affect the decision of selling a patent, and the patent transactions of small and large firms. The variable $Citations_i$, is the log of the cumulative number of patent citations that a patent receives as of age five, is a commonly used proxy for the economic value of an invention (Trajtenberg, 1990). The variable $Patent\,portfolio_{it}$, is the log of the number of the initial innovator's patents issued in the last five years before the issue year of the focal patent and controls for the inventiveness of the initial innovator. The variables $Tech_i$ (36 patent sub-categories as defined in Hall (2005)) and $Gyear_i$ (years 1989–1996) account for disaggregated patent technology categories and year effects, respectively.

Table A1 in the Appendix presents summary statistics of the dependent and explanatory variables and correlation matrices.

5. Patent trading flows of small and large firms

We begin the empirical analysis by describing aggregate statistics of transactions of newly patented inventions of small and large firms. We also report disaggregated statistics of patent trading across six broad patent technology categories.[21]

Table 2 reports information on patent sales and whether these patents are bought by small and large firms. Panel A reveals patent sales are more common among small firms. We find that 8.5 percent of the newly patented inventions by small firms are sold within four years of being granted, whereas large firms only transfer 5.1 percent of their patents.[22] Similar findings are reported for the six different technology classes analyzed. Of particular interest is that in the drugs and pharmaceutical sectors, as well as in chemicals, where patent rights are arguably more effective, the probability of firms to sell their newly patented inventions is higher than in other sectors.

In Panel B, we show that patents are bought disproportionately by small firms. We find that about 16.7 percent of the traded patents are sold to small firms. This is about 60 percent higher than the share of patenting by small firms in the aggregate (10.7 percent). The remaining of the patents traded, 83.3 percent, are bought by large firms. Although large firms buy more patents than small firms, they buy significantly less patents than what would be expected relative to their aggregate patenting activities. The panel also reveals that this phenomenon is consistent across the six technology sectors studied.

Panel C explores the patent trading flows of small and large firms depending on whether patents are bought by small or large firms. A striking finding is that about 69 percent of the patents sold by small firms are bought by other small firms. This is more than six times larger than the proportion of patents granted to small firms in our sample (10.7 percent). The remaining 31 percent of these patents are bought by large firms. Therefore, patent sold by small firms are bought disproportionately by other small firms because 69 percent is higher than the share of patents issued to small firms in our sample (10.7 percent). Among patents sold by large firms, however, the proportion of patents transferred to other large firms is 93.9 percent, which is just 5.3 percent higher than the share of patents issued to large firms in our sample (89.2 percent). The remaining of the patents sold by large firms, 6.1 percent, are bought by small firms. This is about half than the aggregate share of patents issued to small firms in our sample. By looking separately at the patented inventions sold by small and large firms, we show that small firms buy disproportionately patented inventions sold by small firms but not inventions sold by large firms. The results do not

[18] Patents of similar technology classes to the focal patent are chosen based on the distance measure between two technology classes developed by Akcigit et al. (2016). That is, the more often two technology classes are cited together the lower is the distance between two technology classes. In particular, the added patents from the portfolio of the patentee have a distance measure with the focal patent that is half of the mean distance measure of the portfolio. Similar qualitative findings were obtained if we add patents of the patent class that is closest to the patent class of the focal patent.

[19] We follow Akcigit et al. (2016) and construct the Technological Propinquity for each patent in our sample as of their grant year. Technological Propinquity is defined as the average distance between the technology class of the focal patent and the technology class of every patent in the patent portfolios of a firm that was issued before the focal patent. In this measure, the distance between patents with different technology classes depends on how often these two technology classes are cited together by all other patents.

[20] In particular, we add patents of small and large firms in the USPTO 3-digit technology class that has the lowest distance to the focal patent. We use the distance measure of technology classes developed by Akcigit et al. (2016).

[21] Patents are assigned to six technology categories: Chemical, Computer & Communications, Drugs & Medical, Electrical & Electronics, Mechanical, and Other (Hall et al., 2001).

[22] These rates are low because in our analysis trade is truncated by the fourth year since a patent's grant date.

Table 2
Patent sales and patent trading flows of small and large firms.

	All patents	Patent Category					
		Chemical	Computer & comm	Drugs & medical	Elec & Electro	Mechanical	Other
Panel A. Proportion of patents sold							
Small firm	0.085	0.089	0.116	0.102	0.090	0.072	0.076
	(.001)	(.003)	(.004)	(.003)	(.003)	(.002)	(.002)
Large firm	0.051	0.934	0.941	0.848	0.920	0.878	0.793
	(.000)	(.001)	(.001)	(.002)	(.001)	(.001)	(.001)
All firms	0.054	0.055	0.044	0.067	0.040	0.046	0.064
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
Panel B. Proportion of patents sold that are bought by small firms							
	0.167	0.119	0.106	0.225	0.150	0.188	0.225
	(.004)	(.004)	(.005)	(.007)	(.005)	(.005)	(.005)
Panel C. Patent trading flows of small and large firms							
Prop. of patents sold by small firms that are bought by small firms							
	0.691	0.678	0.553	0.648	0.667	0.762	0.740
	(.006)	(.017)	(.020)	(.017)	(.016)	(.013)	(.012)
Prop. of patents sold by large firms that are bought by small firms							
	0.061	0.056	0.031	0.109	0.050	0.064	0.066
	(.001)	(.003)	(.003)	(.006)	(.003)	(.003)	(.004)

Note: A patent is sold if it was transferred within four year of its grant date. Patent's technology classes are classified into Patent Categories as defined in Hall et al. (2001). Standard errors in parentheses.

depend on broad sector specific factors; Panel C also shows similar results across the six aggregate technology sectors.

In conclusion, we found that small firms are more likely to sell their patented inventions and that they buy disproportionately more of the patented inventions sold than large firms, and that most patented inventions sold by small firms were bought by other small firms. These findings are not consistent with a patent market facilitating vertical specialization, allowing small firms to specialize in discovery and in early stage development of inventions, which are then transferred to large firms who specialize in the later development, manufacturing and marketing of these inventions.

The characterization of the factors associated with the patent trading flows across small and large firms discussed in Section 3 allows us to interpret these results. In relation to the supply side of the market, small firms may be more likely to sell their patents because on average they have less diverse and lower knowledge stocks related to the technology of their new patented inventions than large firms. On the demand side, large firm's comparative advantage in capturing value from their own new inventions can make them more willing to rely on their own inventions and thus acquire less external inventions than small firms relative to what would be expected based on their share of overall patenting in our sample. Moreover, the finding that patents sold by small firms are bought disproportionately by other small firms and that patents sold by large firms are not bought disproportionately by small firms suggests that there is an important factor that makes small firms to be more prone to buy patented inventions from other small firms: patented inventions sold by small firms may belong to patent technology classes where small firms tend to concentrate their research activities, and thus patent sold by small firms are more redeployable towards other small firms. These are conjectures we plan to test in the next sections.

6. Factors associated with patent transactions

6.1. Motivating evidence

Before moving to the regression analysis, we present some summary statistics to provide some basic intuition of the factors that may be associated with the firms' decisions to sell or keep patented inventions, and whether these inventions are bought by small or large firms.

Table 3 presents descriptive statistics for initial innovator's internal relatedness and technological diversity. An initial innovator's Internal Relatedness measure is defined as the mean of the log of the number of patents issued to the initial innovator in the technology class of a focal patent in the five years before the issue year of a focal patent. Technological Diversity is the mean of the log of the number of the distinct three-digit USPTO technology classes to which an initial innovator in our sample has ever patented. Panel A shows that on average sold patents have lower internal relatedness measures and are owned by initial innovators with fewer technological diversity than the unsold patents. This is what we should expect: newly patented inventions are less likely to be sold when they are initially owned by innovators with higher prior knowledge stocks in close proximity to the technology of the patent. Consistent with our view that large firms are more technologically diverse and have higher prior knowledge stocks in close technological proximity with their newly issued patented inventions than small firms, Panel B shows that patents initially owned by large firms are characterized by higher measures of internal relatedness and technological diversity.

Table 3
Internal relatedness of the innovations and technological diversity of the initial innovators of sold and unsold patents.

	Internal Relatedness of the Patented Inventions	Technological Diversity of the Innovator
Panel A. Patents Unsold and Sold		
Patents Unsold	2.17	3.36
	(.00)	(.00)
Patents Sold	1.40	2.58
	(.01)	(.01)
All patents	2.13	3.32
	(.00)	(.00)
Panel B. Patents initially owned by small and large firms		
Small firms	0.42	0.69
	(.00)	(.00)
Large firms	2.34	3.64
	(.00)	(.00)

Note: A patent is sold if it was transferred within four year of its issue date. *Internal Relatedness* is the log of (1 + the number of patents in the technology class of the focal patent in the five years before the issue year of the focal patent). *Technological Diversity of the Innovator* is the number of distinct 3-digit USPTO patent classes in which the initial innovator ever patented. Standard errors in parentheses.

Table 4
Patent trading flows and external relatedness.

	All patents	Patent Categories					
		Chemical	Computer & Comm	Drugs & Medical	Elec & Electro	Mechanical	Other
Panel A. Proportion of patents initially owned by small and large firms							
Small firms	0.108	0.066	0.059	0.152	0.080	0.121	0.207
	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Large firms	0.892	0.934	0.941	0.848	0.920	0.879	0.793
	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Panel B. Mean External Relatedness of small and large firm patents							
Small firms	0.181	0.122	0.085	0.206	0.102	0.181	0.264
	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Large firms	0.089	0.053	0.055	0.127	0.071	0.101	0.172
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Panel C. Ratio of External Relatedness to share of patenting by small firms							
Small firms	1.68	1.86	1.43	1.36	1.28	1.49	1.28
Large firms	0.83	0.82	0.93	0.84	0.90	0.83	0.83
Panel D. Ratio of patent sales small-to-small and large-to-large firms in relation to their size of patenting							
Small firms	6.42	10.34	9.33	4.26	8.38	6.28	3.58
Large firms	1.05	1.01	1.03	1.05	1.03	1.07	1.18

Note: A patent is Sold if it was transferred within four year of its issue date. *External Relatedness* is the share of patents issued small firms in relation to the total number of patents issued to small and large firms technology class of the focal patent and in previous five years by the issue year of the focal patent. Patent Categories as defined in Hall et al. (2001). The Ratio of patent sales small-to-small in relation to their size of patenting is equal to the proportion of patents of small firms sold to small firms divided by the proportion of patents initially owned by small firms. The Ratio of patent sales large-to-large in relation to their size of patenting is equal to the proportion of patents of large firms sold to other large firms divided by the proportion of patents initially owned by large firms. Standard errors in parentheses.

Table 4 reports the external relatedness measure towards small firms of newly patented inventions by the firm size of the initial innovator. External Relatedness is defined as the share of patents issued to small firms in the technology class of the focal patent. As can be seen in the table, the mean of the variable External Relatedness for newly patented inventions of small firms is 0.181. Patents of small firms are in technology classes where the mean share of patenting by small firms is 8 percentage points higher than the proportion of patents of small firms in the aggregate in our sample (0.107). In this sense, patents of small firms are potentially redeployable disproportionately towards small firms. In sharp contrast, the mean of the variable External Relatedness for patents of large firms is 0.089, which is lower than the proportion of small firm patents in the aggregate. These findings suggest that small firms concentrate their research activities in fewer technology classes as compared to large firms.

Table 4 also reveals that the technology categories where the variable that captures a patent's potential for external redeployment towards small firms is most disproportionately larger than the share of patents issued to small firms in that category are also the sectors with the highest intensity of patent transactions between small firms. As can be seen in Panel C, the sectors in which the ratio of External relatedness towards small firms to the share of patents issued to small firms (in the same category) is highest and lowest are the Chemical and Other categories, respectively. Coincidentally, Panel D shows that the sectors in which patents sold by small firms are bought most disproportionately by other small firms is Chemical and the least disproportionately is the Other category.

Taken together, these findings suggest that patent transactions are associated with the prior knowledge stocks related to the invention of the initial innovators (Internal Relatedness) and of the potential small and large buyers (External Relatedness).

6.2. Econometric results

We now turn to our regression analysis for a more detailed study of the decision to sell patented inventions, and whether patents sold are bought by small or large firms. As discussed above, the nature of our data does not allow us to identify causal relationships. Instead, we rely on correlations to provide insights into our research questions.

Our main specification is a Probit model with robust standard errors clustered at the initial innovator level. In all regressions, we include controls for patent ‘quality’ or economic value ($Citations_{it}$), the inventiveness of the initial patentee ($Patent\,portfolio_i$), and patent technology sector ($Tech_i$; 36 patent sub-categories dummy variables) and patent cohort ($Gyear_i$; years 1989–1996) effects. In unreported results, we also run additional regressions using linear probability models with a varying sets of controls and including initial innovator's fixed effects. Our results are consistent across all models and specifications. All tables report marginal effects.

6.2.1. Patent sales and internal relatedness

Table 5 presents Probit marginal effects of the likelihood that a patent is sold. The main explanatory variable, *Internal Relatedness*, is the log of the number of patents issued to the initial innovator in the last five years and that are related to the new patented invention. In the first three columns we investigate the conditions under which the decision to sell a newly patented invention depends on the initial inventor's prior knowledge related to the technology of the focal patent (*Internal Relatedness (based on technology only)*). In column 1, the knowledge stocks of the initial innovator are based on patents in the same technology class of the focal patent. In column 2, we address the potential concern that focusing on only one technology class may be too narrow to capture the knowledge stocks of the initial innovator that are related to the focal patent (Benner and Waldfogel, 2008).[23] To do this, the initial innovator's knowledge stocks are based on patent classes that are closely related to the technology class of the focal patent.[24] In column 3,

[23] In our sample, firms patent in 2.6 technology classes (std. dev = 7.3) (large firms in 4 technology classes and small firms in 1.4), on average.

[24] Patents of similar technology classes to the focal patent are chosen based on the distance measure between two technology classes developed by Akcigit et al. (2016). According to Akcigit et al. (2016), the more often two technology classes are cited together the lower is the distance between two technology classes. In particular, the added patents from the portfolio of the patentee have a distance measure with the focal patent (as developed by Akcigit et al. (2016) that is half of the mean distance measure of the portfolio. Similar qualitative findings were obtained if we add patents of the patent class that is closest to the patent class of the focal patent.

Table 5
Marginal effects of internal relatedness on the probability that a patent is sold.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Estimation method	Probit	Probit	Probit	Probit	Probit	Probit	Probit
Dependent variable	Sold	Sold	Sold	Sold	Sold	Sold	Sold
	Mar. Eff. $\times 10^2$	Mar. Eff. $\times 10^2$	Mar. Eff. $\times 10^2$	Mar. Eff. $\times 10^2$	Mar. Eff. $\times 10^2$	Mar. Eff. $\times 10^2$	Mar. Eff. $\times 10^2$
Internal Relatedness (based on technology only)	-0.70^{***}	-0.65^{***}	0.17				
	(0.11)	(0.11)	(0.20)				
Citations	0.50^{***}	0.50^{***}	0.47^{***}	0.12	0.08	0.09	0.09
	(0.08)	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)	(0.07)
Patent Portfolio	-0.42^{***}	-0.49^{***}	-0.93^{***}	-0.38^{***}	-0.37^{***}	-0.37^{***}	-0.38^{***}
	(0.09)	(0.09)	(0.18)	(0.07)	(0.07)	(0.07)	(0.08)
Internal Relatedness (based on technology and location)				-0.78^{***}	-0.78^{***}	-0.79^{***}	-0.78^{***}
				(0.09)	(0.09)	(0.09)	(0.09)
Internal Relatedness (based on technology and other location)				-0.14	-0.15	-0.15	-0.15
				(0.24)	(0.12)	(0.12)	(0.12)
Technological Propinquity (distance)							0.10
							(0.20)
	Internal Relatedness (technology only) is based on patents with the technology class of the focal patent	Internal Relatedness (technology only) is based both on patents with the technology class of the focal patent and patents with similar technology classes	Internal Relatedness (technology only) is based on patents with technology classes other than the technology class of the focal patent	Internal Relatedness (technology and location) is based on patents with the technology class and geographical location of the focal patent	Internal Relatedness (technology and other location) is based on patents with the technology class and that are in geographical locations other than that of the focal patent	Internal Relatedness (technology and other location) is based on patents with the technology class of the focal patent and that are in geographical locations other than that of the focal patent	Technological Propinquity (distance) is the average distance between the technology class of the focal patent and the technology class of every patent in the patents in the portfolio of a firm that were issued before the focal patent
Other controls							
Patent Issue Year	Y	Y	Y	Y	Y	Y	Y
Patent Subcategory	Y	Y	Y	Y	Y	Y	Y
Patent Fragmentation	N	N	N	N	Y	Y	Y
Litigation Risk	N	N	N	N	Y	Y	Y
Technological Competition	N	N	N	N	Y	Y	Y
Patent Originality	N	N	N	N	N	Y	Y
References to Non-Patent Literature	N	N	N	N	N	Y	Y
Sample	All patents	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	61,239
Observations	590,872	590,872	590,872	590,872	590,872	590,872	590,872

Note: *Sold* is equal 1 if the patent is sold, otherwise is zero. All measures of Internal Relatedness are equal to the log of the number of patents issued to the initial innovator in the five years prior to the issue year of the focal patent. In Columns 4–7 *Internal Relatedness (based on technology and location)* is the log of the number of patents issued to the initial innovator in the technology class of the focal patent and that are in the geographical locations of the focal patent. In Columns 4–7, *Internal Relatedness (based on technology and other location)* is the log of the number of patents issued to the initial innovator in the technology class of the focal patent and that are in geographical locations other than the location of the focal patent. *Technological Propinquity* is the average distance between the technology class of the focal patent and the technology class of every patent in the patents in the portfolio of a firm that were issued before the focal patent. *Patent Citations* is the log (1 + number of forward cites by age 5). *Patent Portfolio* is the log (1 + number of patents issued to the initial innovator in the five years prior to the issue year of the focal patent). *Patent Issue Year* dummies are generated using the grant year of the patent. *Patent Subcategory* dummies are generated using 36 technology subcategories as defined in Hall et al. (2001). *Patent Fragmentation* measures the extent to which the prior patent art cited by the patent is owned by multiple assignees as defined in Walsh et al. (2016). *Litigation Risk* is the sample probability that a patent in a technology class and in a given year is involved in an infringement legal suit filed in the US (only for litigation events filed within the first 10 years following the patent's grant year). *Technological Competition* is the log (1 + number of firms that patented at least once in the 3-digit USPTO technology class of the patent), as in Torrisi et al. (2016). *Patent Originality* measures the degree to which the prior cited patent art is drawn from different patent technology classes, as defined in Hall et al. (2001). *References to Non-patent Literature* is the number of citations made by a patent to scientific articles and other non-patent references. Marginal effects are evaluated at the mean of all variables. Standard errors are clustered at the firm level.

*Statistical significance: <10%.

**Statistical significance: <5%.

*** Statistical significance: <1%.

instead, we test whether an association exists between an initial innovator selling a new patent and the prior knowledge stocks of the initial innovator that are based on patents with technology classes other than the technology class of the focal patent. In the first two specifications we find that the correlation between *Internal Relatedness (based on technology only)* and Sold is negative and significant. In contrast, Column 3 shows that the marginal effect of *Internal Relatedness (based on technology only),* which is now based on initial innovator's patents in technology classes other than the technology class of the focal patent, is not significant. In combination, the findings reported in Columns 1–3 suggest that the initial innovator's prior knowledge stocks in close proximity to the technology class of the focal invention decrease the likelihood that the patent is sold.[25] To interpret the magnitude of the relationship, and using the estimates of Column 1, a one standard deviation increase in *Internal Relatedness (based on technology only)* in our sample ($std.dev. = 1.796$) from its mean is associated with a 1.14 percentage point decrease in the likelihood that a newly patented invention is sold, which accounts for 20.9 percent of the sample mean of 5.4 percent.[26]

To explore in more detail how the initial innovator's prior knowledge stocks affect the decision to sell their new patented inventions, we exploit the geographical location of the initial innovators' knowledge stocks related to the invention. If the tacit nature of some knowledge can prevent an initial innovator from exploiting its own knowledge stocks located in geographical locations other than the location of the focal patent, the effect of the variable Internal relatedness should be stronger for patents in geographical locations close to the initial innovator's prior knowledge stocks than in any other locations. In Column 4 of Table 5, we therefore distinguish between the initial innovator's prior knowledge stock in the patent class of the focal patent that is in the geographical location of the focal patent *(Internal Relatedness (based on technology and location))*and the initial innovator's prior research stock in the patent class of the focal patent *(Internal Relatedness (based on technology and other locations))*.[27] In particular, we test whether the decision to sell a new patented invention not only depends on the initial innovator's prior knowledge stocks in the same technology class of the focal patent but also on the geographical proximity of these knowledge stocks to the location of the focal patent. The findings are striking. The marginal effect of *Internal Relatedness (based on technology and location)* is negative and statistically significant at conventional levels whereas the coefficient of *Internal Relatedness (based on technology and other locations)* is much lower in magnitude and not significant. Moreover, we can reject the hypothesis that the two coefficients are equal (p-value < 0.01). To interpret, and using the estimates of Column 4, one standard deviation increase in *Internal Relatedness (based on technology and location)* in our sample ($std.dev. = 1.729$) is associated with a 1.2 percentage point decrease in the likelihood that a newly patented invention is sold. These results together show that the initial innovator's prior knowledge stocks in close technological and geographical proximity to their new patented inventions are important to appropriate value from these inventions and the legal rights over these inventions by keeping the patents' ownership (as compared to appropriating value from the inventions and legal rights by selling the patents to others).

These findings are consistent with the view that new patented inventions are less likely to be sold because the prior knowledge stocks of the initial innovator that are related to the patent could facilitate the redeployment of new patented inventions to another use within the firm, but there alternative interpretations too. Observing that a patent is not sold could also be associated with the new patented invention being used in its intended use, or the utilization of the patent rights strategically in support of the same or other businesses (e.g., preemptive use of patent rights, gain freedom to operate), or the patent rights just not being used due to the invention's low technological level or changes in the market or technology (Walsh et al., 2016; Torrisi et al., 2016), all of which could be related to the knowledge stocks of the initial innovator in proximity to the technology class of the new patented invention.[28] It is difficult to distinguish between these alternative interpretations because we can only observe whether a patent is either sold or unsold by the initial innovator.

To further investigate this issue, we have experimented with patent-level control variables that are associated with these alternative explanations. Column 5 of Table 5 controls for factors that have been associated with the use of patents as strategic assets in support of the patent's business or other businesses: the fragmentation of patent rights (measured by the *Fragmentation Index* in Walsh et al. (2016)), the litigation risk in the patent's technology class (measured by the sample probability that a patent in a technology class and in a given year is involved in an infringement case filed in the US (*Litigation Risk*)), and the competitive conditions in the technology class of the patent (as measured by number of firms that have patented at least once in the technology class of the patent (*Technological Competition*), as in Torrisi et al. (2016)).[29] We control for the fragmentation of patent rights, since the benefits to pool together these rights are higher when the fragmentation of patent rights is high. Whether fragmentation of patent rights leads to the keeping or the selling of the focal patent depends on the extent to which the current patentee or a potential buyer has the comparative advantage in pooling the patent rights over a technology together, possibly to facilitate their licensing to other firms (Galasso et al., 2013). We control for the litigation risk in the technology class of the patent because a patentee may be more likely to remain owner of a patent, and thus keep the possibility to exploit the patent as a strategic asset to help protect other products of the same firm or to improve the terms-of-trade in licensing agreements when the litigation risk in the technology class of the patent is more likely (Ziedonis, 2004). We also control for the competitive conditions in the technology area of the patented invention, since a higher number of competitors may increase the likelihood that the current patentee could be held up by owners of blocking patents, thus increasing the benefits to keep the patent ownership in order to exploit it as a strategic asset against hold up (see e.g., Ziedonis, 2004; Torrisi et al., 2016).[30]

In Column 6, we add proxies of technological complexity of the new patented invention to control for the uncertainty over the actual use of new patented inventions, since initial innovators with new inventions that have an actual use that matches the intended use may be more

[25] In unreported analysis we find that the variable Sold and the Internal Relatedness measure remain negatively associated after adding initial innovator fixed-effects. This finding underlines the role that prior knowledge stocks related to new inventions play patent transactions even for firms that may choose to specialize in patent sales due to comparative advantages in innovation, who could be companies that in doing so may create inventions typically characterized by low and persistent measures of Internal relatedness.

[26] In theory, the magnitude of the reported marginal effect could different when evaluated at the median of the variable instead of the means because the non-linearity of the Probit model and the high skewed distribution of some of the variables. Table A2 presents all the estimated marginal effects of Table 5 evaluated at the median of the sample.

[27] Here and henceforth geographical location is based on the postal address of a patent (i.e., inventor located in the same US state as the inventor of the focal patent, or inventor located in the same country of the focal patent if the focal patent is a foreign patent).

[28] For instance, the firm's knowledge stocks in the technology class of the patent could reduce the uncertainty over the use of new inventions (the uncertainty that the actual use of the patent is the same use as initially intended).

[29] We consider only patent litigation disputes filed in federal US courts (and not on appeal) within the first 10 years following the patent's grant year.

[30] In an unreported regression we found similar qualitative estimation results when we excluded 'failed' patents (captured by patents that are let expire in the first renewal event) of the estimated sample.

likely to keep the patent ownership. We expect patents that cite prior art drawn from a high number of technology classes (as measured by the variable *Patent Originality* in Hall et al. (2001)) to have higher rates of sale, since, all else equal, they may be more technologically complex and thus more likely to have a different use than the intended initially. We also control for the *Number of References to Non-patent Literature* because patents that cite scientific knowledge often contain more complex and fundamental knowledge, and thus it may be associated with the uncertainty over the actual use of a new invention (Cassiman et al., 2008). In both regression specifications, Columns 5 and 6, the estimates of the main variable *Internal Relatedness (based on technology and location)* are of similar magnitude and sign to those in Column 4 of Table 5.

A remaining natural question is whether the measure Internal relatedness should be based on the knowledge stocks that are related to the focal patent (as we have used above) or instead be based on the technological distance between the invention and the initial innovator's knowledge stocks. To assess this, we need a distance measure to compare the patent class of a single patent (the focal patent) with the patent classes of the entire patent portfolio of the initial innovator by the issue year of the focal patent. Established technological proximity measures like Jaffe (1986), in which the distance between firms' technological resources is assessed by calculating the distance between vectors of patent class listings, are problematic when the measures are calculated on small, unbalanced samples (Benner and Waldfogel, 2008). Instead, we follow Akcigit et al. (2016) and construct the Technological Propinquity for each patent in our sample as of their grant year. *Technological Propinquity* is defined as the average distance between the technology class of the focal patent and the technology class of every patent in the patent portfolios of a firm that was issued before the focal patent, where the distance between patents with different technology classes depends on how often these two technology classes are cited together by all other patents. Column 7 of Table 5 examines the decision of selling a newly patented invention regressed on *Technological Propinquity*, together with *Internal Relatedness (based on technology and location), Internal Relatedness (based on technology and other location)*, and a full set of controls. The marginal effect of *Internal Relatedness (based on technology and location)* remains negative and significant; in contrast, the marginal effect of *Technological Propinquity* is not significant at conventional levels.[31] The finding shows that patent sales are associated with the extent of the initial innovators' knowledge stocks that are related to the focal patent's technology but less with the average technological distance between the focal patent and the patents in the portfolio of the initial innovator.

In combination, our empirical evidence is consistent with the view that the initial innovator's prior knowledge stocks that affect the decision to sell a patent (as opposed to keeping the ownership of the patent) are in close proximity to the technology class of the focal patent as well as in geographical proximity. In particular, prior knowledge stocks of the initial innovator in the technology class and in geographical proximity to the focal patent are negatively correlated with the likelihood that a patent is sold. Therefore, these results provide support for Hypothesis 1. The results also have the following implication for the management of innovative firms: while creating specialized research units across the country could be beneficial for tapping local human or physical resources, spreading the research activities of a firm in a technology class across multiple geographical locations may hamper the innovators' ability to capture value from retaining ownership and exploiting their own new inventions relative to selling the patented inventions to other firms.

In addition, this finding is particularly relevant to account for observed high share of patents sold by small firms. Given the empirical fact that newly patented inventions of small firms have lower Internal relatedness measures on average, the finding that the variable Internal relatedness is negatively associated with patent sales is consistent with the hypothesis that small firms are more likely to sell their patents because their patents have on average lower measures of Internal relatedness than the patents of large firms (Hypothesis 2).

6.2.2. Patent acquisitions and external relatedness

Turning to the question of who buys the newly patented inventions sold in the market for patents, we examine whether patent transactions are associated with the potential buyers' prior knowledge stocks related with the patented inventions.

Table 6 presents Probit marginal effects of the likelihood that a patent sold is bought by a small firm. The main explanatory variable, *External Relatedness*, is the share of patents related to the focal patent that were issued to small firms (relative to all firms) in the five years prior the issue year of the focal patent. In the first three columns, we investigate whether patent transactions are associated with the share of small firms' prior knowledge stocks (relative to large firms) in related technology classes of the focal patent, *External Relatedness (based on technology only)*. In Column 1, the External relatedness is based on patents in the same technology class as the focal patent. In Column 2, External relatedness is based on patents in the technology class of the focal patent and in the other most related technology class.[32] In Column 3, External relatedness is based on the share of the number of distinct small firms that were issued at least one patent (relative to the number of all firms that were issued patents) in the technology class of the focal patent. The estimates of *External Relatedness (based on technology only)* in Columns 1–3 are positive and significant at conventional levels, indicating that conditional on a patent sale patents with higher measures of External relatedness towards small buyers are more likely to be bought by small firms. These estimates are consistent with the interpretation that potential buyers' knowledge stocks develop the ability to value external technology related to these knowledge stocks and integrate this technology in the firm. To interpret the magnitudes, and using the marginal effects in Column 1, conditional on a patented invention sold, a one standard deviation ($std.dev. = 0.123$) increase in *External Relatedness (based on technology only)* from its mean is associated with a 3.4 percentage points increase in the likelihood that a patent is bought by a small firm, or 20 percent of the average probability that a patent sold is bought by a small firm (16.7 percent).[33]

To investigate whether geographically localized knowledge stocks of potential buyers are a determinant in patent transactions, Column 4 adds the variable *External Relatedness (based on technology and location),* which is defined as the share of patents issued to small firms (relative to all firms) in the technology class and the geographical location of the focal patent. The marginal effect of the variable *External Relatedness (based on technology and location)* is estimated positive and significant at conventional levels whereas the marginal effect of *External Relatedness (based on technology only)* is close to zero and not significant, suggesting that whether patents sold are bought by either small or large firms depends primarily on the prior knowledge stocks related to the invention's technology and that are next to the geographical location of the

[31] The marginal effect of *Technological Propinquity* is also not significant if the regression has *Internal Relatedness (based on technology only)* instead of *Internal Relatedness (based on technology and location)* and*Internal Relatedness (based on technology and other location)* together, or only *Internal Relatedness (based on technology and location)*.

[32] In particular, we add patents of small and large firms in the USPTO 3-digit technology class that has the lowest distance to the focal patent. We use the distance measure of technology classes developed by Akcigit et al. (2016).

[33] As noted before, in theory, the magnitude of the reported marginal effects could be different when evaluated at the median of the variable instead of the means because the non-linearity of the Probit model and the high skewed distribution of some of the variables. Table A3 presents all the estimated marginal effects of Table 6 evaluated at the median of the sample.

Table 6
Marginal effects of external relatedness on the probability that a patent sold is bought by a small firm.

	(1)	(2)	(3)	(4)
Estimation method	Probit	Probit	Probit	Probit
Dependent variable	Bought by Small	Bought by Small	Bought by Small	Bought by Small
	Mar. Eff.	Mar. Eff.	Mar. Eff.	Mar. Eff.
External Relatedness (based on technology only)	0.30***	0.30***	0.30***	0.03
	(0.03)	(0.04)	(0.05)	(0.03)
Citations	0.00	0.00	0	−0.00
	(0.08)	(0.00)	(0.00)	(0.00)
Patent Portfolio	−0.05***	−0.05***	−0.05***	−0.04***
	(0.00)	(0.00)	(0.00)	(0.00)
External Relatedness (based on technology and location)				0.28***
				(0.02)
	External Relatedness (technology only) is based on the share of patents issued to small firms in the technology class of the focal patent	External Relatedness (technology only) is based on the share of patents issued to small firms in the technology class of the focal patent and the most related technology class	External Relatedness (technology only) is based on the share of distinct small firms (related to all firms) operating in the technology class of the focal patent	External Relatedness (technology and location) is based on the share of patents issued to small firms in the technology class and geographical location of the focal patent
Other controls				
Patent Issue Year	Y	Y	Y	Y
Patent Subcategory	Y	Y	Y	Y
Sample	Patents Sold	Patents Sold	Patents Sold	Patents Sold
Firms	8907	8907	8907	8907
Observations	32,129	32,129	32,129	32,129

Note: *Bought by Small* is equal to 1 if the patent sold is bought by a small firm. In columns 1, 2, and 4, *External Relatedness (based on technology only)* is the share of patents issued to small firms in the technology class and in the five years by the issue year of the focal patent. In Column 3, *External Relatedness (based on technology only)* is based on the share of distinct small firms (related to all firms) operating in the technology class of the focal patent. In Column 4, *External Relatedness (based on technology and location)* is the share of patents issued to small firms in the technology class and geographical location of the focal patent. *Patent citations* is equal to the log (1 + number of forward cites by age 5). *Patent Portfolio* is equal to the log (1 + number of patents issued to the patentee in the five years prior to the issue year of the focal patent). *Patent Issue Year* dummies are generated using the grant year of the patent. *Patent Subcategory* dummies are generated using 36 technology subcategories defined as in Hall et al. (2001). Marginal effects are evaluated at the mean of all variables. Standard errors are clustered at the firm level.

*Statistical significance: <10%.

**Statistical significance: <5%.

*** Statistical significance: <1%.

invention. In other words, prior's knowledge stocks in the technology class of the patent but in geographical locations other than the location of the focal patent have no meaningful effect on patent transactions. To illustrate the magnitude of the estimated effect, a one standard deviation increase ($std.dev. = 0.226$) in *External Redeployment (based on technology and location)* is associated with a 8 percent point increase in the likelihood that a patent bought by a small firm, or 48 percent of the average probability that a patent sold is bought by a small firm (16.7 percent).

In combination the estimates are consistent with the view that patent acquisitions by small and large firms are positively associated with the buyers' knowledge stock related to the patents sold, and particularly the knowledge stock that buyers developed in the geographical location of the firm that sells the patent, which supports Hypothesis 3. These results suggest that patent market transactions are likely to take place within close geographic proximity of the patent sellers and with buyers that operate in the same technology class of the transacted patent. Moreover, this effect is particularly relevant for transactions involving patents sold by small firms, since small firms disproportionately concentrate their research activities in specific technology areas as compared to large firms.

In light of these results, and given the empirical fact that small firms' prior knowledge stocks are related disproportionately to patented inventions sold by small firms, we can account for the pattern that small firms buy disproportionately patents sold by other small firms in the aggregate (Hypothesis 4).

7. Conclusion

In this article we have provided novel evidence on the sale and acquisition of patents by small and large firms. We have also examined the extent to which the initial innovator and potential buyers' prior knowledge stock related with the inventions is associated with patent transactions. To do so, we developed a comprehensive dataset that matched patent sales with new information on patents' buyers.

The main results of the paper are as follows. At the aggregate level, we predicted and documented that small firms sell a higher proportion (8.5 percent) of their newly patented inventions than large firms (5.1 percent) within four years of being granted (Hypothesis 2). We also found that patented inventions sold, especially those sold by small firms, are bought disproportionately by other small firms (Hypothesis 4). In particular, 16.7 percent of the new patents sold are bought by small firms; and among the patent sold by small firms, more than 69 percent were bought by other small firms. This is about 60 percent and 6 times more than the share of patents issued to small firms in our sample, respectively. In contrast, among patents sold by large firms, only 6.1 percent were bought by small firms, which is 40 percent less than the share of patents issued to small firms in our sample.

At the micro-level, we showed that the likelihood that a newly patented invention is sold is negatively associated with the initial innovators' prior research stock in the technology class of the invention and in the geographical location of the invention (internal relatedness) (Hypothesis 1). This finding suggests that the aggregate level pattern that patented inventions of small firms are more likely to be sold than those of large firms is related, in part, to the empirical fact that small firms have on average fewer knowledge stocks related in technology and geography to their new patented inventions than large firms. These results are consistent with a theoretical framework in which knowledge stocks related to the invention in technology and geography develop the ability of the initial innovator to capture value by keeping the ownership of the patented inventions and exploiting its own new inventions than by selling them to others in the patent market.

Importantly, we also showed that the likelihood that a patented invention sold is bought by a small firm relative to a large firm is positively associated with the patented invention's external relatedness towards small firms (as proxy by the share of patents issued to small firms in the technology class of the invention and that are in the geographical location of the invention) (Hypothesis 3). The empirical support for Hypothesis 3, given the evidence that inventions of small firms are disproportionately related with the prior research of other small firms, explains in part the very salient aggregate level pattern that patents sold by small firms are bought disproportionately by other small firms. These results are consistent with a theoretical framework in which potential buyers' knowledge stocks in the technology class of the patent that be may purchased and that are in the same geographical location of this patent develop a firm's ability to identify external technologies and integrate them into the firm.

Theoretically and taken together, these results reveal that the initial innovator's prior knowledge stocks that allow innovators to capture value from their own inventions within the firm (as opposed to transferring their ownership to others) are highly localized in the technology class and geographical proximity to the invention. This finding has significant implications for managers: while creating specialized research units across the country could be beneficial for tapping local human or physical resources, spreading the research activities of a firm in a technology class across multiple geographical locations will hamper the opportunities from capturing value from new inventions within the firm. In addition, the findings on whether patents sold are bought by small or large firms reveal that potential buyers' prior knowledge stocks develop an ability to select and value external technologies but that ability appears to be highly localized within technology and geography. The finding suggests that patent transactions are likely to involve buyers that operate in the same technology class of the patent sold and take place within geographical proximity of the patent seller. In other words, managers eager to tap into other firms' external technologies through the market for patents must choose the location of research facilities close to those firms that may be the potential sources of patent rights and inventions. Finally, we found no evidence that the market for patents facilitates vertical specialization between small firms specializing in the discovery and early stage development of inventions and large firms specializing in the later development and commercialization of these inventions. Instead, we found that most patents sold by small firms are acquired by other small firms.

At the same time, the analysis has some limitations, which could be addressed in future research. An important limitation of our study is that among patents that are not sold we cannot distinguish whether the initial innovator uses them in the use intended initially or instead are redeployed to alternative uses within the firm, or the patent is exploited strategically as preemptive motive (e.g., blocking patents, pure defense), or to improve the terms-of-trade in licensing deals. Another limitation is that our empirical analysis does not directly analyze alternative modes of acquiring external technology and patents such as technology M&A deals. Moreover, although we observe whether a subsequent patent owner following a patent transaction is a small or large firm, we have no information on the buyers' patent portfolios. This issue, for instance, restricts our ability to test in more detail that the patents that firms buy in the patent market help them fill gaps within their patent portfolios. These limitations provide opportunities for further research.

Conflict of interest

None declared.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.respol.2019.03.002.

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