The Paradox of Openness:
How Product and Patenting Experience Affect R&D Sourcing in China?

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Abstract

External R&D sourcing may help firms compete in an environment characterized by rapid technological changes. Yet, prior studies have produced conflicting findings on how a firm's technological experience affects the extent to which the firm engages in external R&D sourcing. Although many highlight that firms with extensive technological experience are equipped with more technological knowledge, collaborative skills, and absorptive capacity, encouraging greater levels of external R&D, others suggest the opposite due to potential exchange hazards and partnership conflicts. Adopting an external partner's perspective, the current study reconsiders this "paradox of openness" by analyzing how a focal firm's product experience and patenting experience affect an external partner's tendency to provide external R&D services to the focal firm. Specifically, this study explore how a focal firm's knowledge protectiveness and tacitness embedded in its product and patenting experience influences the external partners' motivation for knowledge transfer. This study predicts that a firm's product experience increases the focal firm's external R&D sourcing because it provides high levels of knowledge tacitness and external openness and can encourage external partners to share and exchange knowledge with the focal firm. In contrast, a firm's patenting experience decreases the focal firm's external R&D sourcing because it denotes knowledge explicitness and protectiveness and may discourage external partners to share and exchange knowledge with the focal firm. This study further predicts that patenting experience has a negative moderating effect on the relationship between product experience and external R&D sourcing. Using a dataset of 575 high-tech firms in China, this study finds support for our predictions. Our findings contribute to the growing literature on the knowledge-based view and technology entrepreneurship in emerging markets.

Keywords: knowledge-based view, patent, R&D sourcing

Practitioner Points

- For firms in China that have significant product experience, it makes sense to outsource a portion of its non-strategic R&D to external partners.The portion of R&D that firms derive their competitive advantage from should be conducted in-house.

- However, firms that possess significant product experience and also have a long track record in patenting their technologies must be even more selective in partner selection and are more likely to experience greater difficulty finding willing external R&D partners for collaborations.

Introduction

Faced with severe pressure for expeditious product development and increasing specialization of R&D tasks, firms must select between internal and external R&D sourcing modes for their product development activities. Drawing frequently on the resource or capability based view, extant research has considered a number of factors that influence the choice between internal and external R&D sourcing (e.g., Spithoven and Teirlinck, 2015; Tsai and Wang, 2008; Van de Vrande et al., 2009; Veugelers, 1997; Veugelers and Cassiman, 1999). A key premise of these studies is that firms with more resources, capabilities, and absorptive capacity, which this study labels as technological experience, are more likely to engage in and benefit from external R&D sourcing as greater technological experience creates a stock of knowledge that enables firms to recognize, assimilate, recombine, and integrate external knowledge (Cohen and Levinthal, 1990). In contrast, other studies highlight another consequence of strong technological experience in limiting the benefits of external R&D in that technological experience makes internal development more efficient than collaborative development (Laursen and Salter, 2014; Posen and Chen, 2013).

These conflicting findings give rise to the paradox of openness— technological experience allows a focal firm to be more open to external partners, but such experience may actually make it hard for effective collaboration (Laursen and Salter, 2014). The knowledge-based view (KBV) of the firm provides an appropriate theoretical framework to explicate how firms create, organize, protect and transfer knowledge, all activities that are pertinent to the decision of how much R&D (knowledge *creation*) to externalize and thereby *organize* the firm's R&D effort, and how to *protect* its current knowledge base given issues of appropriability in the external environment (Grant, 1991).

Our study provides additional insights on the “paradox of openness” and makes several contributions. First, although prior studies shed light on transferring and sharing knowledge to the external partner (i.e., inside-out), this study focuses on the knowledge sourcing from the outside instead (outside-in). Thus, in contrast to most prior studies that have predominantly focused on the focal firm’s perspective, this study adopts the external partner’s perspective by focusing on knowledge protectiveness and tacitness that influence the external partners’ motivation for transferring knowledge and providing R&D services to the focal firm (Chen, 2004; Inkpen, 1998, 2000). Knowledge protectiveness refers to the degree of protectiveness employed by the focal firm with regard to its knowledge base and is viewed as an appropriate safeguard against opportunistic behavior (Simonin, 1999), whereas knowledge tacitness refers to the degree to which knowledge is intuitive, unarticulated, non-verbalized or non-verbalizable (Polanyi, 1958). A major problem associated with R&D sourcing from external partners relates to the fact that, in order to obtain knowledge, the focal firm has to reveal some of its own knowledge to the external partners. Therefore, from the external partner’s perspective, a focal firm’s external R&D intensity is determined by how knowledge protectiveness and tacitness influences external partners’ motivation to access the knowledge of the focal firm and to transfer knowledge and provide R&D sourcing service to the focal firm.

Second, this study decomposes a focal firm’s technological experience into two components: product experience and patenting experience. This study defines product experience as the degree to which a firm has experience managing products in its product portfolio targeted at specific product markets and patenting experience as the cumulative stock of patents the firm has in its patent portfolio (Eggers, 2012; Fernhaber and Patel, 2012). Patenting experience also constitutes a firm’s capability as it represents the cumulative codified firm-specific knowledge in selected technological domains (Kogut and Zander, 1992). We expect that product and patenting experience exert opposing influences on knowledge protectiveness and tacitness. On the one hand, a focal firm's product experience can encourage external partners to transfer knowledge to the focal firm (and seek access to the focal firm's tacit knowledge) due to its external openness and the tacitness of the knowledge associated with accumulating this experience. It thus increases the focal firm's external R&D sourcing. On the other hand, a focal firm's patenting experience signals protectiveness of its technology and represents explicit/codified knowledge. It may thus discourage external partners to provide R&D services to the focal firm because the explicit part of the knowledge is freely available and strong knowledge protectiveness scares potential external R&D providers away.

Third, this study is conducted based on an empirical setting from a weak intellectual property regime (IPR) context (China) where knowledge protectiveness and tacitness play an even more salient role for knowledge transfer and R&D sourcing compared with settings in more developed countries. One unique characteristic associated with China is the underdeveloped IPR and market for technologies (Srivastava and Wang, 2015). High-tech firms operating in China face more difficulties to protect and openly share their knowledge. As a result, knowledge protectiveness poses an even greater barrier for motivating knowledge transfer and external R&D sourcing (Buss and Peukert, 2015; Holcomb and Hitt, 2007; Spithoven and Teirlinck, 2015). However, the extensive use of tacit knowledge as opposed to explicit knowledge in weak IPR context provides greater incentives for collaboration (Becerra, Lunnan, and Heumer, 2008; Inkpen and Pien, 2006). Our focus on product and patenting experience therefore captures knowledge tacitness and knowledge protectiveness in a weak IPR context.

Theoretical Framework

Market and hierarchies as knowledge governance mechanisms

The KBV contends that the creation and deployment of valuable new knowledge may confer a competitive advantage on a technology-based firm (Grant, 1996; Nonaka, 1994). The objective of the firm is thus the creation of valuable knowledge through processes of recombination and knowledge transfer (Fleming and Sorenson, 2004; Gavetti and Levinthal, 2000; Grant, 1996; Henderson and Clark, 1990; Kogut and Zander, 1992; Levinthal, 1997; Nickerson and Zenger, 2004). A firm's key task is thus to come up with the most efficient and effective approach to structure the search and governance of the flow of knowledge (Foss, 2003). Following the literature on the theories of the firm-market boundary (Arrow, 1974; Leiblein, 2003; Nickerson and Zenger, 2004; Zenger et al., 2011), this study considers two alternative modes of organizing knowledge generation and exchange activities: market (external R&D) or hierarchy (internal R&D). These two alternative modes align with the two paradoxical views on the use of external R&D sourcing: spillover prevention and organizational openness (Arora et al. 2016). In the spillover prevention view, firms exert strong protection over its knowledge and intellectual property to reduce spillover of valuable knowledge to external partners. In contrast, in the organizational openness view, firms focus on protection and appropriability but also engage in open innovation, knowledge sharing, and collaboration.

The choice of governance mode should jointly consider efficiency concerns and appropriation hazards (Macher, 2006; Williamson, 1999). It is guided by knowledge tacitness and protectiveness that influences knowledge sharing by both partners (Nickerson and Zenger, 2004; Zenger et al., 2011). One distinct advantage of hierarchy is that it facilitates rapid and efficient transfer and sharing of tacit knowledge within an organization (Arrow, 1974; Kogut and Zander, 1992). Tacit knowledge sharing and transfer may require complex coordination among a diverse array of actors, knowledge sets, activities, and assets (Schulze and Hoegl, 2006). Hierarchy is superior to market transactions as a governance device in ensuring efficient coordination and economizes on the costs of tacit knowledge exchange (Conner and Prahalad, 1996; Demsetz, 1988). Moreover, hierarchy is more efficient than market at addressing knowledge-based exchange hazards when the problem-solving requires knowledge sharing as internal actors tend to be open for knowledge development (Zenger et al., 2011).

In contrast, the market enables firms to access unique resources (knowledge) not available inside the hierarchy that can be combined with internal knowledge to form a firm-specific resource that can serve as an isolating mechanism (Teece, 2006; Van de Vrande et al., 2011; Wang et al., 2009). The market is ideally suited to handle problems of low complexity when knowledge is more explicit and sharing is easy (Nickerson and Zenger, 2004). That said, collaborative R&D activities have disadvantages in that the allocation of IPR can be problematic, and partners tend to develop a strong tendency for knowledge protectiveness, which inhibits knowledge sharing.

Prior studies have elaborated and contributed to the construct of "paradox of openness" in R&D sourcing and collaboration. Arora and colleagues (2016) document the "paradox of openness" by illuminating that firms are more likely to seek external collaboration if they have greater technological experience and can protect their innovation through patents, yet the same experience and protection make the firm less efficient when collaborating with external partners and to attract partners for R&D collaboration. Likewise, Laursen and Salter (2014) find a concave relationship between a firm's openness for external collaboration and protection of its knowledge. That is, firms need to disclose some knowledge in order to engage in knowledge exchange with external parties, but they also need to protect parts of their knowledge if they are to gain value from the exchange.

Product experience and external R&D sourcing

A critical organizational factor affecting whether an external partner engages in knowledge transfer and R&D service provision is the nature of the focal firm's technological experience (Eggers, 2012; Park and Ro, 2013; Zenger et al., 2011). In general, "[e]xperience is what transpires in the organization as it performs its task. Experience can be measured in terms of the cumulative number of task performances" (Argote and Miron-Spektor, 2011, p. 1124). This article further decomposes this experience into two types: product experience and patenting experience. Greater product experience can be manifested in firms having a broad portfolio of distinct products so that the firms are well versed in solving a wide range of problems. Product experience can also manifests itself in firms' focus on very complex, systemic products with relatively long lifetimes, frequently targeted towards well-defined market niches (Argyres and Silverman, 2004; Eggers, 2012; Fernhaber and Patel, 2012; Zirger and Maidique, 1990). A history in creating knowledge through its product experience will be reflective of its search rules going forward as they are ingrained and embedded in its routines of product design, R&D, marketing, and so on (Nelson and Winter, 1982). Therefore, product experience reflects the amount of tacit technological know-how and technology-market synergy that has accumulated over time (Cohen and Levinthal, 1990). The firm-specific product expertise built over time can be viewed as a tacit body of knowledge that may motivate and attract external partners to share knowledge and collaborate on R&D with the focal firm. A focal firm's tacit knowledge is attractive within high-tech industries, as it provides external partners with the opportunity to share and recombine external knowledge with existing internal knowledge to form novel recombinations of high value (Argyres and Silverman, 2004; Fleming, 2001; Posen and Chen, 2013). This is particularly the case for small firms operating in weak IPR environments as these firms are strongly motivated to tap into external knowledge sources to develop a wide range of products due to limitations in their knowledge base and other resources. As a result, external partners will be highly motivated to form collaborative ties and share knowledge with the focal firm that possesses such tacit product knowledge and product experience, suggestive of more external R&D sourcing. Empirical evidence from the pharmaceutical industry shows that product experience in several therapeutic domains, yielding distinct products, had a negative impact on development performance and the efficiency of internal R&D because more external partners were available and motivated to collaborate with these firms that possessed broad and tacit product experience (Macher and Boerner, 2006).

At the same time, from the perspective of the focal firm, sharing tacit knowledge through product experience carries lower risk for their IP to be misappropriated by external partners (Kogut and Zander, 1992). Indeed, firms tend to be more open about knowledge sharing regarding products because "many of the key features of modern innovation do not lend themselves for formal IP protection because they related to customer experience or the 'look and feel' of a product" (Lauren and Salter, 2014, p. 869). Likewise, von Hippel (1986, 1988) shows that many innovators develop new products by working with customers and suppliers. This is particularly important for firms operating in weak IPR environments, as IP misappropriation is one of the most important concerns in collaborating with external partners. Taken together, we predict the following relationship between product experience and external R&D sourcing.

Hypothesis 1. Product experience is positively associated with external R&D sourcing.

Patenting experience and external R&D sourcing

Although a firm's product experience enhances the likelihood of engaging in external R&D, a firm's patenting experience may have the opposite effect due to the explicit character of knowledge described in patents and a high level of knowledge protectiveness. Patents are considered a representation of more explicit knowledge and are strictly and clearly documented in the filing document that is publicly available (Kogut and Zander, 1992). It is such explicitness of the knowledge that makes the collaboration and knowledge transfer unnecessary as external partners can freely and openly access the focal firm's knowledge embedded in the patent stock.

In addition to knowledge explicitness, another critical obstacle for firms to engage in external collaborations is the presence of knowledge exchange hazards (Nickerson and Zenger, 2004). For instance, potential R&D sourcing partners can strategically direct the development of knowledge creation activities and accumulate and appropriate knowledge to serve their own interests. A key factor that mitigates knowledge appropriation hazards is the degree of knowledge protectiveness the focal firm exercises in inter-firm collaborative R&D, often instrumented by the use of patents. Although patenting is an important strategic activity of firms, as it plays an increasingly important role in the protection and appropriation of R&D outcomes (Somaya, 2012; Srivastava and Wang, 2015) and helps startups gather external resources (Hsu and Ziedonis, 2013), it makes knowledge sharing and transfer more difficult (Dushnitsky and Shaver, 2009; Jensen and Webster, 2009). From a potential external R&D partner's standpoint, a focal firm's patenting experience raises the issue of exclusivity in knowledge ownership and makes the sharing and exchange problematic. A prodigious rate of patenting by a focal firm sends a strong signal of territorial behavior to potential external R&D partners that it seeks to own, control, and plausibly exploit all knowledge collaboratively created. Such exclusivity and territorial behavior hurts the motivation for exchange relationships. In the psychology literature, Brown et al. (2014) suggests that, at the individual and team level, "dependent upon the context of trust, territorial behavior may lead coworkers to negatively judge the territorial employee as less of a team contributor" (p. 463). Similarly, Cuddy et al. (2011, 2013) and DeRue et al. (2015) imply that patenting experience may be associated with cold/less warmth perceived by the outside partner ("warmth judgments affects how much we trust versus doubt others' motives"), where warmth is defined as friendliness, trustworthiness, empathy, and kindness. In particular, firms in weak IPR environments may face severe knowledge hazards for acquiring certain R&D knowledge (Ang and Cummings, 1997; Hu and Jefferson, 2009). Thus, having more patenting experience makes the focal firm holding patents a less attractive partner for knowledge exchange. Empirical evidence from the corporate venture capital literature suggests that entrepreneur-corporate investor relationships are less likely to materialize when the corporate investor perceives strong knowledge protectiveness from the entrepreneur by not disclosing his or her invention (Dushnitsky and Shaver, 2009). Lauren and Salter (2014) found evidence for the paradox of openness that overly strong emphasis on appropriability strategy such as patenting may be associated with reduced knowledge sourcing from different external actors in formal collaboration for innovation. Thus, from a motivational perspective, more patenting experience held by focal firms may reduce the willingness of external R&D partners to collaborate with the focal firm. Therefore, we posit that:

Hypothesis 2. Patenting experience is negatively associated with external R&D sourcing.

The interaction between product and patenting experience

Based on the contrasting mechanisms between product and patenting experience, this study proposes that there is an interaction effect between product and patenting experience on external R&D sourcing. Specifically, this article argues that patenting experience negatively moderates the positive relationship between product experience and the extent of external R&D. That is, we expect an increasing level of external R&D for each successive level of product experience, yet a higher level of patenting experience will attenuate such increase.

First, in terms of knowledge protectiveness, a high level of patenting experience signals a firm’s commitment to strongly enforce its exclusive right of knowledge ownership as it did so for both of its background and core products in the past (Arora et al., 2015). Nickerson and

Zenger (2004) indicate, “embedding knowledge into saleable products provides a mechanism for extracting its value” (p. 622). Thus, high levels of patenting experience would imply that more product experience has been “packaged” into patents. Such strong linkage between products and patents would extend the protection-oriented focus and territorial behavior from products to patents and further inhibit potential R&D collaborators from working with the focal firm on joint product development efforts, as it signals mistrust of other players in its industry and lack of warmth judgment (Brown et al, 2014; Cuddy et al, 2011, 2013). Therefore, a high level of patenting experience is likely to attenuate the product experience-external R&D relationship. In a weak IPR environment, such as the case in China, the mistrust mentioned above is even more amplified in that knowledge sharing and transfer is perceived as very difficult by the focal firm for fear of knowledge leakage and outright theft in an environment where deliberate knowledge misappropriation carries little penalty (Hu and Jefferson, 2009; Jensen and Webster, 2009). Allred and Swan (2014) have shown that, when the IP appropriability is weak, the preference order of technology sourcing begins with internal development and ends with market sourcing.

Second, in terms of knowledge tacitness, although product experience tends to be tacit and can thus attract external collaboration, the strong linkage between products and patents when patenting experience increases implies that more product experience has been codified in patents. That is, external R&D partners can freely and publicly gain the explicit knowledge and insights about a firm’s products (e.g., design, features, cost, etc.) from a focal firm’s a large stock of patented technologies. Such explicit knowledge embedded in patents offers external R&D partners part of the tacit product knowledge that would have only been available through collaboration and therefore discourages external partners from actively seeking collaboration with the focal firm. As such, the positive impact of product experience is progressively attenuated when the firm patenting experience increases (stronger motivation not to collaborate). Hence, we posit that:

Hypothesis 3. Increasing levels of patenting experience will weaken (negatively moderate) the relationship between product experience and external R&D sourcing.

Methodology

Data and sample

This study uses the Survey on Science and Technology Activities conducted by the Ministry of Science and Technology of China on "National High-Tech Industrial Development Zones." The admission requirements in these zones are stringent, and most firms possess innovative and unique technologies (e.g., patents) (Srivastava and Wang, 2015). We obtain firm- and product-level data of both internal and external R&D activities of 575 high-tech firms located in one of the zones from the survey administered by the Ministry every year. We choose one zone in a mid-sized city in the coastal area of China for two reasons. First, the city hosts multiple multinational companies with internationally known brands in electronics, information technology, home appliances, biotechnology, and pharmacy sectors along with four major universities and 10 high-level research institutes in high-tech industries, providing ample opportunities for firms to mix internal and external R&D activities. Most of these industries require firms to stay actively engaged in R&D to remain competitive. Second, by limiting the sample firms from one city, we control for macro-economic, sociopolitical, and institutional factors influencing a firm's choice of R&D mode (Fang, 2011).

The survey includes five major sections: (1) basic information, (2) financial information, (3) human capital information, (4) product information, and (5) R&D activities. Sections (1), (2), (3), and (5) gather information at the firm-level, whereas section (4) focuses on product-level information. The patent information is also included in the survey. The Chief Financial Officer

(CFO) and General Manager (GM) of each firm are required to fill out the survey to provide accurate information about the firm's financials and operations. In order to conform to the "Statistics Law of the People's Republic of China" which appears on the front page of the survey, the respondents (i.e., CFO and GM) have to sign the survey to certify all their responses are accurate. Because of the certification of top executives, government oversight, and the objectivity of the surveyed data (e.g., non-subjective-based measures), the single-response bias is not likely to pose a problem. Unfortunately, we do not have information of whether the CFOs or GMs have filled out the survey. Therefore, we do not have the descriptive information about the respondents. We only have information about the CEOs whose characteristics (i.e., age, gender, education) are controlled in the analyses.

This study uses a panel data design to examine our empirical questions. Our final sample consists of 1,058 firm-year observations with 575 high-tech firms from 2006 to 2008 due to missing data and after eliminating outliers. The selection of a time frame between 2006 and 2008 is also consistent with the recent surge of patenting activities in China. The annual growth rate of patent applications has been 23% since 2000, whereas prior to 2000, it had been less than 10% (Hu and Jefferson, 2009). The focus on firm-level variables is also critical, as prior research on collaborative R&D activities has been primarily conducted at the individual project- or product-level, whereas licensing-in and licensing-out arrangements are an integral part of a collaborative innovation strategy. For instance, Aggarwal and Hsu (2009) argued, "[w]hile understanding individual deal-level outcomes is certainly important, organization-level outcomes are equally important, since managers likely make decisions taking into account the strategic implications across a portfolio of deals" (p. 839). We have conducted ANOVA on multiple firm characteristics and find that there are no significant sample selection biases. Specifically, there is no difference of patent (t value = 1.16, $p > 0.10$), product (t value = 0.96, $p > 0.10$), foreign ownership (t value = 1.67, $p > 0.05$), and export (t value = 1.74, $p > 0.05$) between sample firms in the analysis and sample firms excluded from the analysis. However, we find that the sample firms included in the analysis are older (t value = 4.71, $p < 0.01$) and larger (t value = 5.76, $p < 0.01$) than those excluded from the analysis. It is possible that younger and smaller firms tend to have less adequate R&D resources for external R&D or have more missing data in completing the survey.

Dependent variable

Intensity of external R&D vs. internal R&D. Firms can choose to allocate a discrete amount of R&D expenses to in-house or through external collaborative R&D activities (Arend, Patel, and Park, 2014; Nickerson and Zenger, 2004). Following the widely used measure of R&D intensity (R&D expenditure/total revenue) (Cohen and Levinthal, 1990; Hoskisson and Hitt, 1988), we obtain intensity of external R&D sourcing by calculating the ratio of expenditure of external R&D partners to total R&D expenditure. Hence, the value of this variable ranges from 0 to 1. Moreover, this study adopts a broad definition of external R&D activities by including various types of technology acquisition activities from the outside partners such as formal licensing, contract R&D and joint development, and R&D consulting and services (Arora and Ceccagnoli, 2006). While prior studies often use a categorical variable (make, buy, or ally) to model firm choices on R&D mode, the intensity measure based on R&D spending has certain advantages. First, the ratio variable characterizes the balance between internal and external mode, reflecting the hybrid structure in the reality. Second, because the firms in our sample are relatively young, they have less complex governance structures with external partners. Meanwhile, due to financial constraints on the R&D spending choices, these firms face more managerial challenges. Thus, the intensity measure between internal and external R&D spending can better capture the tension between the two different knowledge governance modes.

Explanatory, moderating, and control variables

Product experience. We propose that product experience can be manifested into two aspects: variety-based and accumulation-based aspects. This study defines variety-based experience as the degree to which a firm is experienced in managing multiple distinctive products in the portfolio and recombining diverse stocks of knowledge sets (Carnabuci and Operti, 2013; Eggers, 2012; Fernhaber and Patel, 2012; Fleming and Sorenson, 2000; Helfat, 1997; Henderson and Clark, 1990; Nelson and Winter, 1982). The variety-based experience helps firms develop a wide range of *distinct* solutions, as they often target related niches to maximize the applicability of relevant processes from prior experience. On the other hand, the accumulation-based product experience is gained by firms investing and developing a very specialized, narrow, and deeply familiar set of products over time (Macher, 2006; Nickerson and Zenger, 2004). Accumulation-based product experience refers to the length of experience a firm has accumulated from developing and marketing a number of products. For instance, some firms may have been focusing on one or two products over time since the inception (accumulation-based), and other firms may have expanded their core technology into various categories of products (variety-based).

Cottrell and Nault (2004) use the count of different products to operationalize the firm-level scope and product experience. King and Tucci (2002) use the cumulative number of years that the firm has been operating in the market up to the year to measure cumulative industry experience. We applied the same rationale of measuring these two aspects of product experience. We first measure the variety-based product experience as the number of *different* products in the product portfolio in a given year. On the other hand, the accumulation-based experience is measured by sum of the cumulative number of years since a product was introduced until the focal year. Because this article focuses on the knowledge tacitness and openness embedded in the products that the focal firm has accumulated, the time elapsed since product launch better captures the firm's accumulation-based product experience of managing its product portfolio for two reasons. First, the launch of a product does not stop the firm from continuously redeveloping and reconfiguring the technologies to better meet customer needs. In fact, with the entry to market, our variable can better measure the tacitness of technology/knowledge in managing the product portfolio and effort in synergizing the technologies and market than the product development time. For example, Eggers (2012) and Fernhaber and Patel (2012) use the product portfolio to derive product experience depth, breadth, and complexity. Second, the openness refers to the degree of knowledge visibility and willingness to disseminate the knowledge to the outside. Obviously, the time elapsed since product launch reflects the open interactions between the focal firm and customers as well as suppliers. Indeed, firms tend to be more open about knowledge sharing regarding products because "many of the key features of modern innovation do not lend themselves for formal IP protection because they related to customer experience or the 'look and feel' of a product" (Lauren and Salter, 2014, p. 869). Therefore, the time that a product has been for sale makes the product experience more visible and demonstrates the openness to the external partners, signaling the firm's willingness to share knowledge to the outside. Prior studies have relied on the same product experience at the portfolio level to evaluate the firm's technological know-how and dynamic capabilities (Eggers, 2012). Product experiences at the portfolio level "offer more opportunities to develop radical products to meet the demand and technological and competitive uncertainty" (Fernhaber and Patel, 2012, 1518). Also, the measurement of time accumulated/spent on NPD projects could have confounding effect with the external R&D sourcing (dependent variable) as the focal firm may source R&D technologies during the NPD process.

Because product variety-based experience entails the recombinational potential as a result of *actively managing* distinctive products, this measure emphasizes the active involvement of multiple different products. The focus on a given year for the variety-based product experience also makes the measure more distinctive from the accumulation-based experience. Thus, the number of different products in the portfolio represents an important dimension of the variety of experience by our sample firms. In addition, we delete firms with more than six different products in any given year to remove outliers. The frequency table indicates that less than 2% of firms produce more than six products. Therefore, the number of different products in the portfolio in a given year ranges from 1 to 6. In the survey questionnaire, companies are required to only name major different products (i.e., products offered to different customer groups, products based on different technologies, etc.), excluding similar or incrementally improved product versions. Therefore, while those products may fall into a similar category or portfolio, such a measure of variety reflects the experience across multiple different combinations of knowledge stocks of our sample firms (Eggers, 2012; Fernhaber and Patel, 2012).

Our second measure of accumulation-based product experience aligns with the learning-by-doing and knowledge specialization argument: A firm can increase the accumulation-based experience either through developing and marketing more products within a short period of time or few products for a long period of time. Yet, both cases lead to the same theoretical justification. Having few products with long history certainly help firms develop complex routines and deep and more familiar understanding for the niche products that may help them locate the right partner and technologies from the outside. Meanwhile, having more products in a short period of time implies that those products may share some crucial and valuable platform given the youthful nature of those firms even if those products are different. Designing and marketing such platform-based product will also help to develop complex routines and deep understanding for the niche technologies, which will help to locate the right partner and technologies from the outside.

Accumulation-based experience covers all product portfolio and may have some overlap with the variety-based experience; therefore, an important remedy was applied. To take into account the heterogeneous importance of products in the firm's portfolio, this study weighted the cumulative number of years with the revenue figure from each product in a given year (measured in millions of RMB) because products generating high revenues tend to lead to more experience accumulation due to higher involvement and attention from the top management team. Moreover, greater cumulative sales also indicate that a firm has accumulated significant experience through climbing the learning curve.

Patenting experience. We count the cumulative number of domestic patent applications by the firm until the focal calendar year. The patent count has been widely used in prior studies as a measure of a firm's technological capabilities (e.g., Ahuja and Katila, 2001). By using the patent application instead of grant, we can more precisely capture the risk and protection of the intellectual property because the average grant lag can be as long as five years in China (Liegsalz and Wagner, 2013). We also performed robustness test using patent grant and obtained consistent results. Because this study focuses on firms located in the same city, we do not normalize the patent counts across regions. The ANOVA shows that there is no significant difference of patents across five industries such as electronics and IT, biotech and pharmacy, material science, optics, and machine, and energy.

Control variables. This study employs a number of control variables to rule out alternative explanations. Five *industry binary indicators* (electronics and IT, biotech and pharmacy, material science, optics and machine, and energy) are used as controls as industry characteristics are likely to affect whether a firm relies on internal vs. external R&D. In particular, by controlling the industry and region, this study controls for the availability of external partners for R&D activities. This study also controls for a number of other firm characteristics such as *firm size*, *firm age*, and human capital characteristics of CEOs (*age*, *education level*, and *gender*). This study controls for firm age and size because it captures the firm's resources and orientation dedicated towards product development. Moreover, *Year dummies* are included in statistical models to control for potential temporal effects.

Table 1 shows the descriptive statistics. It indicates that on average 11% of the total R&D spending among our sample firms is for external R&D sourcing. Firms have about two products in their portfolio at any given time. Patenting experience of all sample firms ranges from 0 to 47. The correlation between variety-based and accumulation-based experience is -0.01 and not significant, rejecting the potential multicollinearity issue of the inclusion of two aspects of product experience.

--- Insert Table 1 about here. ---

Analytical approach

Several concerns need to be addressed in the design of the analytical model. First, in our pooled time series data, one firm can be associated with multiple yearly observations that are not independent from each other. Therefore, the model should accommodate the analysis of panel data with repeated within-subject measures and address the lack of independence among the multiple observations associated with each firm (Li et al., 2012). A fixed-effect approach requires variance in both dependent and explanatory variables to ensure that these variables are distinguishable from the fixed effects. In our data, however, most explanatory and control variables do not change in the sample across years. We thus cannot estimate the model using a fixed-effect approach. In addition, when studying a relatively short period, fixed-effect models can produce biased estimates (Li et al., 2012). Although the sample frame of this study is three years, many firms are associated with fewer than three observations due to late entry or early exit from the sample. On average, our sample firms contribute to two observations in our data. Thus, random-effect models provide more robust estimates.

Second, studies modeling the relationship between firm experience and outcome have typically employed standard generalized least squares (GLS) regression. However, the firm product and patenting experience is contingent on the resources and intensity of R&D activities such as relationships with foreign firms, a phenomenon that is pertinent in the Chinese context. Therefore, we may have a potential endogeneity concern for analyzing the firms' product and patenting experience (Hamilton and Nickerson, 2003). For example, both aspects of experience might be driven by financial resources devoted to R&D activities and foreign relationships. Because both R&D sourcing mode and experience variables are continuous, the instrumental variable and two-stage least squares (2SLS) regression analysis is appropriate to alleviate the endogeneity problem. Within a 2SLS regression, this study includes three instrumental variables that are correlated with the endogenous experience variables but not correlated with the R&D sourcing mode variable: firm's export revenue (continuous variable), foreign investment (dummy variable), and total R&D expense (continuous variable). These three variables reflect the firm's R&D resources and in particular relationships with foreign partners. First, foreign investors will focus on revenue as they expect more financial return from their investment, which may reduce the scope of product portfolio but increase the cumulative time on more profitable products. However, foreign investors may not have a clear preference for strong or weak spending on R&D sourcing from the outside. Due to weak IPR, foreign investors may be more reluctant for pushing external R&D sourcing in China, yet they may seek for local partners to better penetrate the market and increase external R&D spending. Therefore, we consider foreign investment as a feasible candidate for instrument variable, as it is correlated with product experience but the correlation with external R&D spending is unclear. Empirically, the correlation between foreign investment and variety-based experience is higher (-0.14) than the correlation between foreign investment and the dependent variable (-0.08). We also include total R&D spending as instrument variable, as it has a strong influence on the design of product portfolio as more R&D spending will increase the scope of and intensify the cumulative time spent on products. However, it is not clear whether total R&D spending is associated with more or less percentage of spending towards external R&D. On the one hand, the resource abundance logic suggests that individuals tend to feel more entitled for the financial reward under the presence of more financial resource (Gino and Pierce, 2009). As such, greater total R&D spending will be associated with a higher percentage towards internal rather than external R&D sourcing. On the other hand, the complementary asset logic (Teece, 1986) would suggest that firms with more spending on R&D would be more aggressive towards acquiring new technologies and forming new partnerships with the external partners to complement the existing capabilities in order to gain from the innovation. Therefore, this study considers total R&D spending as a feasible candidate for instrument variable as it is correlated with product experience but the correlation with the percentage towards external R&D is unclear. Empirically, the correlation between total R&D spending and product experience is higher (0.21 and 0.19) than that between total R&D spending and the dependent variable (0.13). Therefore, based on these considerations, we test our hypotheses using instrumental variables and two-stage least squares for panel-data model with random effect to alleviate potential endogeneity concerns (STATA command: ‘xtivreg’). This article also uses robust standard errors to help with a collection of other concerns about the failure to meet the assumptions such as normality, heteroscedasticity, and large residuals.

Finally, there may be a potential concern for reverse causality as prior R&D mode may affect the product experience. However, the survey is structured and collected such that our dependent variable, *Intensity of external R&D*, is observed only after prior product experience is revealed. Thus, with the unit of analysis being firm-year, it is less likely that the current R&D mode may affect prior product experience. That is, the dependent variable measured in each year is not likely to impact the product experience in the prior years. This study does not use lag variables for reverse causality issue for two reasons. First, it will reduce the number of observations by dropping observations. Second, it requires us to choose multiple arbitrary lengths of time for the lagged variables. Nevertheless, this study tested the model with the one-year lead transformation of dependent variable and the results are qualitatively consistent with our main results.

Results

First-stage model

To address our concern related to the endogeneity of product experience variables, the empirical analysis begins by first determining the predicted value of variety- and accumulation-based experience, which are then used to test our hypotheses predicting the R&D sourcing mode. The analysis in Table 2 presents the first-stage model using the export, foreign ownership, and total R&D expense as instrumental variables. To test the strength of our instruments, we find that both the foreign ownership and total R&D expense significantly ($p < 0.01$) affect the variety-based product experience, and export significantly ($p < 0.01$) affects the accumulation-based product experience. The Durbin-Wu-Hausman (DWH) test rejects the null hypothesis that both experience variables are exogenous. This study further uses the STATA command 'xtoverid' to conduct a Sargan-Hansen test for overidentification constraints. Failure to reject the null hypothesis implies that the instruments are valid. The *p*-value of the test result is 0.46, indicating that the instruments are not overidentified.

--- Insert Tables 2 about here. ---

Hypotheses test

Table 3 provides the results of the hypotheses tests. The variance inflation factors (VIF) for all the studied variables are below 2, eliminating potential multicollinearity concerns. Model 3 presents the simple GLS model with random effect and Models 4 through 8 present the 2SLS model with random effect controlling for potential endogeneity between variety- and accumulation-based product experiences by using the first-stage model results in Table 2. The comparison between Models 3 and 5 suggests that, after controlling for potential endogeneity, the predictors turn from insignificant to significant. Therefore, our hypotheses testing will be based on the 2SLS models. In Model 4, all the main effects as well as the control variables are included. Model 5 is the full model that is used to test all the hypotheses with the best goodness of fit. Because Model 5 tests interaction terms, the coefficient for the independent variables shown in Model 5 only reflects the effect of product experience when patent experience equals to zero (illustrated in Figure 1 and 2).

--- Insert Tables 3 about here. ---

H1 predicts that product experience is positively associated with external R&D sourcing (for both variety-based and accumulation-based product experience). Model 5 indicates that there is a positive and significant coefficient for variety-based product experience ($\beta = 0.11$, $p < 0.01$). Also, we find a positive and significant coefficient for accumulation-based product experience ($\beta = 0.39$, $p < 0.05$). Thus, H1 is strongly supported.

H2 predicts that patenting experience is negatively associated with external R&D sourcing. Model 5 indicates that there is a positive and significant coefficient for patenting experience (β = 0.02, $p < 0.05$). The examination of the interaction terms confirms that this effect is not supported across Model 3 to 12. It is only supported in Model 4 which suffers from omitted variable bias. Thus, H2 is not supported.

H3 predicts that patenting experience would weaken the positive relationship between product experience and external R&D sourcing. In Model 5, we find that there are negative and significant coefficients for both interactions between variety-based product experience (β = -0.01, $p < 0.05$), accumulation-based product experience (β = -0.10, $p < 0.05$) and patenting experience. Thus, H3 is also strongly supported. To better illustrate the moderating effect, this study plots the relationship between variety-based product experience, accumulation-based product experience, and external R&D intensity under different levels of patenting experience in Figure 1 and 2. To be consistent with the data range, the three levels of patenting experience are calculated based on the minimum, mean, and one standard deviation above the mean. All other variables other than product experience and patenting experience are set to the mean level with all dummy variables equal to zero. The graph suggests that an increase of patenting experience from low to high leads to a flatter slope which is consistent with the finding that the relationship between product experience and intensity of external R&D is negatively moderated by the firm's patenting experience. In addition, we notice that the pattern of interactions is not the same for low levels of the variety-based and accumulation-based product experience. For low variety-based product experience, high levels of patenting experience is associated with high external R&D. In contrast, for low levels of cumulative-based product experience, high levels of patenting experience is associated with low external R&D.

--- Insert Figures 1 and 2 about here. ---

Robustness check

Two sets of robustness tests are conducted with respect to different treatments of the dependent and explanatory variables. First, this study uses the natural log of the dependent variable, intensity of external R&D mode, to reduce the possible skewness in Model 6. The results are qualitatively consistent with those of Model 5. In Model 7, the natural log of the explanatory variables (i.e., two aspects of product experience) is used to account for the skewness. The results are also qualitatively consistent with those of Model 5. In addition, rather than deleting firms with more than five different products in their portfolio, the full sample is used by including these possible outliers and the results are shown in Model 8. It shows that the interaction between patenting experience and the variety-based product experience become insignificant, implying the possible outlier effect in the full sample. Finally, considering the dependent variable could to be truncated at zero, a logistic regression (e.g., whether the firm engages in external R&D at all) specification is used in Model 9 to tease out the possible mixed discrete-continuous nature of the dependent variable. The results show that only the interaction between the variety-based product experience and patenting experience is significant. Therefore, it suggests that the continuous variable of the dependent variable contains more variations that can be explained by both aspects of product experience. Overall, our results support the rationale of using the continuous ratio measure as dependent variable as well as the use of 2SLS for the model estimation.

Second, to ease the concerns related to patenting experience variables, a second set of robustness tests are conducted in Table 4. First, patent applications may not eventually lead to a patent grant. This study thus uses the cumulative patent grant to measure patenting experience in Model 10. The results are consistent that the two aspects of product experience are positively associated with external R&D sourcing. Moreover, the interactions between patenting experience and product experiences are significant. The only exception is that the main effect of patenting experience using patent grant measure is not significant. One possible explanation is that patent applications, regardless of whether the patent is granted, can more fully capture the knowledge spillover hazard and the protectiveness behavior towards external partners than patents granted. In addition, this study also considers patents applied to foreign patent offices (e.g., Japan, U.S., and so on.) to measure patenting experience. The results shown in Models 11 are qualitatively consistent with our main findings for H1, H2, and H3. Finally, the one-year lead is applied for the dependent variable (i.e., lag of experience and patent variable) in Model 12. The results are mostly consistent with our findings from the main model except for the accumulation-based product experience. Overall, the robustness tests using alternative operationalization of key variables provide qualitatively consistent results.

--- Insert Tables 4 about here. ---

Discussion

Prior research has pointed to the existence of a paradox of openness when it comes to technological experience in that greater technological experience may facilitate external R&D, but at the same time, it can hinder external R&D (Arora et al, 2016). This study unpacks technological experience into two distinct components. Specifically, the current article explored how a firm's product experience and patenting experience directly and jointly affect its reliance on external vis-à-vis internal R&D sourcing mode. Using a sample of 575 Chinese high-tech firms from 2006 to 2008, we found that firms with greater product experience rely more on external R&D sourcing. This finding is consistent with the view that greater product experience due to its external openness and the tacitness of the knowledge associated with accumulating this experience can encourage external partners to transfer knowledge to the focal firm (and seek access to the focal firm's tacit knowledge), thus increasing the focal firm's external R&D

sourcing (Arora et al, 2016; Eggers, 2012). A second paradox concerns the role of patenting experience and its role to external R&D sourcing. In a strong IPR environment, one could expect patents to facilitate the focal firm to engage more in external R&D, but at the same time, the fact that the focal firm possesses a high stock of patenting experience might reduce external R&D (Buss and Peukert, 2015; Laursen and Salter, 2014). In an environment characterized by weak IPR, like the one in China, the outcome of the paradox is resolved in an idiosyncratic way. Indeed, we found a negative effect of a firm's patenting experience on the firm's intensity to acquire R&D knowledge from external sources. We reasoned that patenting experience, because it signals protectiveness of its technology and represents explicit/codified knowledge, may discourage external partners to provide R&D services to the focal firm because the explicit part of the knowledge is freely available and strong knowledge protectiveness may drive away potential external R&D providers, thereby decreasing its external R&D sourcing. Another reason why patenting experience negatively moderates the relationship between product experience and externalizing R&D might be explained by the fact that focal firms that engage in external R&D while patenting their technologies extensively, provide external collaborators access to both explicit and tacit knowledge. This can be problematic for rent appropriation (Giarattana and Mariani, 2014) for the focal firm in a country with IPO such as China. This finding echoes prior evidence suggesting that there is a negative relationship between inability to appropriate and openness (Cassiman and Veugelers, 2002), and is consistent with theoretical predictions from the KBV (Nickerson and Zenger, 2004).These findings highlight the role of knowledge tacitness and protectiveness serve as the two key factors influencing external R&D sourcing in an environment characterized by weak IPR.

Contributions

This study contributes to the technology management and product innovation literature in three ways. First, this study provides insights on the antecedents of firms' tendency to rely on external R&D sourcing by addressing the paradox of openness in a weak IPR environment. This study contributes to the KBV by decomposing a key antecedent of (external) knowledge creation activity—technological experience—into two components: product experience and patenting experience. These two types of experiences have distinct impacts on the focal firm's tendency to rely on external R&D that have heretofore not be considered. Our results highlight how a firm's product and patenting experience can distinctively affect its reliance on external R&D and translate into different routines and boundaries for their knowledge creation activities. Therefore, it contributes to the growing body of literature on product innovation and knowledge governance (e.g., Kapoor and Adner, 2012; Nickerson and Zenger, 2004; Park and Ro, 2013; Wolter and Veloso, 2008) by explicating how a focal firm's prior technological experience associated with different types of knowledge attributes and appropriation hazards motivates or inhibits the external partners to transfer knowledge and provide R&D sourcing serves to the focal firm.

Second, this study adds new insights into how high-tech firms make knowledge sourcing and governance decisions as predicted by the KBV. Previous studies have predominantly adopted the focal firm's perspective and examined how firm capability and resources can explain the boundary choices of knowledge production (Aggarwal and Hsu, 2009; Argyres and Zenger, 2012; Mayer and Salomon, 2006). This research complements the existing views by adopting the external partners' perspective within the KBV framework to explicate the knowledge governance choice (Park and Ro, 2013). Therefore, this study reconsiders the "paradox of openness" phenomenon by adopting the perspective of the external firm and its motivation for knowledge transfer and impact on the focal firm's mode of R&D sourcing in a weak IPR environment.

Finally, our study provides insights into the role of knowledge tacitness and protectiveness and high-tech firm R&D sourcing decisions in an environment characterized by weak IPR. The IPR regime affects knowledge protectiveness and knowledge tacitness associated with patenting and product experience in idiosyncratic ways that have not been explored in the extant literature to date. This is an important topic as firms from emerging economies with weak IPR increasingly participate in innovative activities in the global economy. Intellectual property serves as a safeguarding mechanism for contractual hazard, yet it demonstrates the impact of the protectiveness and codification of knowledge, discouraging potential partners to transfer knowledge and provide R&D sourcing service (Arrow, 1974). This dilemma, which is labeled as the second paradox of openness, is even more severe when the inventors operate in an environment with weak IPR, such as the case in China, as knowledge protectiveness is strong (Fang, 2011) and at the same time high-tech companies are increasingly filing patents and disclosing their inventions. Prior studies on this topic (e.g., Arora et al., 2016) contend that although firms are more likely to take their R&D activities externally when they possess greater technological experience as evidenced by greater patenting experience, they also face greater difficulties in attracting partnerships in such cases from an external partner's perspective. As such, managers should be aware of the more complex implications of filing for patents when they operate in countries with relatively weak IPR regimes.

Limitations and future research directions

This study has several limitations that may provide opportunities for future research. First, this study uses a single country sample of Chinese firms in multiple high-tech industries in the mid-2000s. Although this setting is important and provides a relevant backdrop for our study, by controlling for the institutional environment, our findings may not be generalizable to other settings. Future studies could employ different geographical, time periods, or industry contexts to test the robustness of our findings in different contexts. In particular, the negative moderating effect of patents on the relationship between product experience and external R&D should be validated in other emerging economies. We would expect the relationship specified in H2 to be weaker in more developed countries with stronger IPR regimes because firms are less likely to be concerned of unintended IP loss due to spillover given the stronger enforcement on patent protection. As expected, our robustness test show that the negative effect of patenting experience on external R&D is less significant for foreign patents ($p < 0.10$) as compared with domestic patents ($p < 0.05$). However, our robustness tests also show that foreign patenting experience of the sample firm produces similar findings in terms of the direction as domestic patent experience. It will thus be interesting to examine the distinctive roles of patents filed by firm located in China vis-a-vis firms located in foreign countries with relatively strong IPR regimes.

Second, our findings are based on an unbalanced panel data covering a relatively short sample period of three years. Future studies may wish to examine a longer time period to study a longer-term impact of prior product experience on subsequent R&D mode. Third, it is likely that the relationships that is found may vary depending on the importance of the R&D project. In particular, the access to knowledge and motivation to collaborate for external partners will depend on how important the particular knowledge of focal firm is to the potential partners. Unfortunately, we do not have a direct measure to gauge the importance of the project, although we have used sales figures as a proxy for the importance of products to the firm knowledge. In a similar vein, our measure of accumulation-based product experience captures the time that a product is for sale not the time that the product has been developed which highlights an important aspect of NPD experience. Unfortunately, we do not have a direct measure for the time spent on product development. Finally, while our post-estimate test offers support for the use of instrumental variables, total R&D spending still makes the interpretation unclear as it correlates with the dependent variable of external R&D sourcing intensity.

Managerial implications

The findings of this study have important managerial implications. For firms in China that have significant product experience, it makes sense to outsource a portion of its non-strategic R&D to external partners. The portion of R&D that firms derive their competitive advantage from should be conducted in-house. These firms might find competent and willing external partners from which to source R&D services from. However, firms that possess significant product experience and also have a long track record in patenting their technologies must be even more selective in partner selection and are more likely to experience greater difficulty finding willing external R&D partners for collaborations. Indeed, a firm's prodigious history of patenting may signal that it is very territorial in terms of knowledge protection and appropriation and it puts strong safeguards in place to prevent knowledge leakage, a pattern that may scare off potential external R&D collaborators. Furthermore, focal firms that provide external R&D partners access to both explicit knowledge (through patents) and tacit knowledge (by collaborating with external R&D providers) expose themselves to real dangers of IP misappropriation. Therefore, managers of these firms must develop collaborative arrangements with external R&D providers that are grounded in deep trust and governed by strong contractual provisions regarding IP. Furthermore, these managers must carefully decide what R&D projects to outsource without giving away the focal firm's crown jewels. All these considerations will invariably lead to lower levels of R&D outsourcing among these firms relative to firms that have lower levels of patenting experience.

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Table 1
Variable Definitions and Descriptive Statistics

Part A: Variable definition and coding

Variable	Definition	Coding
1. Intensity of external R&D	Degree of a firm's tendency to acquire technologies from external sources	Expenditure of external R&D / total R&D expenditure
2. Variety-based product experience	Variety of experience of a firm in managing different products	Number of different products in the portfolio in a given year
3. Accumulation-based product experience	Length of experience a firm has accumulated from managing different products, weighted by the sales	Σ(current year – product launch year)*sales, sales is measured in millions of RMB
4. Patenting experience (exp.)	The cumulative number of patents a firms has applied	Directly taken from the survey
5. Electronics and IT	Industry dummy variable	1 = yes, no = otherwise
6. Biotech	Industry dummy variable	1 = yes, no = otherwise
7. Material science	Industry dummy variable	1 = yes, no = otherwise
8. Machinery	Industry dummy variable	1 = yes, no = otherwise
9. Energy	Industry dummy variable	1 = yes, no = otherwise
10. Firm size	Number of employees a firms has in a given year	Natural log (number of employees)
11. Male CEO	CEO's gender	1 = male, 0 = female
12. CEO age	CEO's age	Directly taken from the survey
13. CEO education	CEO's level of education	1 = bachelor or higher, 0 = otherwise
14. Firm age	Number of years since inception	Current year – firm inception year
15. Year of 2006	Year dummy variable	1 = yes, no = otherwise
16. Year of 2007	Year dummy variable	1 = yes, no = otherwise
17. Year of 2008	Year dummy variable	1 = yes, no = otherwise
Instrument variables:		
18. Export	Amount of export revenue in a given year	In thousands of RMB (/1,000), 1 US dollar = 6.2 RMB
19. Foreign ownership	Whether the firm has ownership held by foreign companies	1 = yes, no = otherwise
20. Total R&D expense	Total spending in R&D activities	Natural log (R&D expenses)

Part B: Frequency table of the number of products

Number of Products	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	606	56.58	606	56.58
2	161	15.03	767	71.62
3	119	11.11	886	82.73
4	70	6.54	956	89.26
5	88	8.22	1044	97.48
6	**14**	**1.31**	**1058**	**98.79**
From 7 to 16	13	1.21	1071	100.00

Part C: Means, standard deviations, and correlation matrix (N = 1058)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1.Intensity of external R&D	1																			
2.Variety-based experience	0.08	1																		
3.Accumulation-based experience	-0.03	-0.01	1																	
4.Patenting exp.	0.00	0.21	0.04	1																
5.Electronics and IT	-0.02	0.01	0.03	-0.05	1															
6.Biotech	0.03	-0.01	-0.03	0.02	-0.16	1														
7.Material science	-0.06	-0.06	0.09	0.03	-0.21	-0.20	1													
8.Machinery	0.04	0.09	-0.04	0.04	-0.24	-0.22	-0.29	1												
9.Energy	0.01	-0.03	-0.04	-0.05	-0.26	-0.24	-0.31	-0.35	1											
10.Firm size	0.06	0.15	0.27	0.23	-0.12	0.00	0.05	0.03	0.02	1										
11.Male CEO	0.00	-0.01	-0.15	0.00	-0.06	0.00	0.06	-0.04	0.03	0.07	1									
12.CEO age	0.01	0.02	0.12	0.02	-0.09	0.04	0.07	-0.09	0.06	0.14	0.00	1								
13.CEO education	0.05	0.17	-0.06	0.08	0.15	-0.02	-0.03	-0.03	-0.05	-0.01	0.04	-0.14	1							
14.Firm age	0.02	0.10	0.05	-0.02	-0.03	-0.03	0.02	-0.03	0.05	0.21	0.05	0.23	-0.07	1						
15.Year of 2006	0.14	-0.03	0.01	-0.03	-0.03	0.01	0.05	-0.02	0.00	0.10	0.06	0.01	-0.08	-0.01	1					
16.Year of 2007	-0.08	-0.07	-0.02	-0.03	0.00	0.01	0.01	-0.01	-0.01	-0.04	-0.01	-0.04	-0.06	-0.04	-0.46	1				
17.Year of 2008	-0.04	0.09	0.01	0.06	0.03	-0.02	-0.05	0.03	0.01	-0.05	-0.05	0.03	0.13	0.05	-0.41	-0.63	1			
18.Export	0.09	-0.02	0.35	0.03	0.02	-0.03	0.01	-0.03	0.03	0.22	-0.02	0.09	0.01	0.02	-0.01	0.03	-0.02	1		
19.Foreign ownership	-0.08	-0.14	0.04	-0.05	0.04	-0.03	0.05	-0.14	0.08	0.14	0.09	0.16	0.04	0.04	-0.01	0.00	0.00	0.10	1	
20.Total R&D expense	0.13	0.21	0.19	0.21	-0.02	0.00	0.02	-0.05	0.04	0.62	0.05	0.10	0.07	0.10	0.03	-0.03	0.01	0.15	0.02	1
Mean	0.11	1.97	0.06	1.03	0.15	0.13	0.20	0.25	0.27	4.89	0.92	47.10	0.71	8.46	0.23	0.41	0.36	8.88	0.24	7.52
Standard deviation	0.20	1.38	0.53	3.55	0.35	0.34	0.40	0.43	0.45	1.26	0.27	8.40	0.45	4.25	0.42	0.49	0.48	80.34	0.43	1.68
Minimum	0	1	0	0	0	0	0	0	0	1.39	0	23	0	0	0	0	0	0	0	2.77
Maximum	1	6	12.25	47	1	1	1	1	1	10.65	1	76	1	20	1	1	1	2377	1	12.96

Note: Any correlation with the absolute value above 0.06 is significant at 5%.

Table 2

First-Stage Model: Factors Affecting Two Aspects of Product Experience

	Variety-based product experience (1)	Accumulation-based product experience (2)
	Coeff.(sd)	Coeff.(sd)
Patenting exp.	0.05(0.01)**	0.00(0.00)
Electronics and IT	0.12(0.14)	0.11(0.05)*
Biotech	-0.01(0.14)	0.01(0.05)
Material science	-0.13(0.13)	0.14(0.05)**
Machinery	0.24(0.12)+	0.00(0.04)
Energy	Excluded	Excluded
Firm size	0.01(0.04)	0.09(0.02)**
Male CEO	0.00(0.15)	-0.29(0.05)**
CEO age	0.01(0.01)	0.00(0.00)*
CEO education	0.40(0.09)**	-0.07(0.03)*
Firm age	0.03(0.01)**	0.00(0.00)
Year of 2006	-0.16(0.09)+	-0.02(0.03)
Year of 2007	-0.18(0.07)*	-0.03(0.03)
Year of 2008	Excluded	Excluded
Instrument variables:		
Export	0.00(0.00)	0.00(0.00)**
Foreign ownership	-0.43(0.10)**	-0.03(0.04)
Total R&D expense	0.13(0.03)**	0.01(0.01)
Constant	0.31(0.34)	-0.37(0.13)**
Number of observations	1058	1058
Number of groups	575	575
Chi-square(d.f.)	145(15)**	234(15)**

Note: (1) **: p<0.01, *: p<0.05, +: p<0.10.

Table 3

Second-Stage Model: Influence of Product Experience on R&D Sourcing Mode

	DV: Intensity of external R&D (Model 4 and 5 for hypothesis test)			DV: Natural log (Intensity of external R&D)	IV: Natural log (experience)	Full sample including possible outliers	DV: Dummy variable of whether the firm engages in external R&D
	GLS (3)	2SLS (4)	2SLS (5)	2SLS (6)	2SLS (7)	2SLS (8)	Logistic Regression (9)
	Coeff.(sd)	Coeff.(sd)	Coeff.(sd)	Coeff.(sd)	Coeff.(sd)	Coeff.(sd)	Coeff.(sd)
Variety-based experience (H1)	0.01(0.00)*	0.10(0.03)**	0.11(0.03)**	0.09(0.03)**	0.25(0.07)**	0.09(0.03)**	0.22(0.09)*
Accumulation-based experience (H1)	-0.01(0.03)	0.14(0.06)*	0.39(0.17)*	0.28(0.13)*	0.58(0.23)*	0.35(0.14)*	-0.45(0.61)
Patenting exp. (H2)	0.00(0.00)	-0.01(0.00)*	0.02(0.01)*	0.01(0.01)**	0.01(0.01)*	0.01(0.01)	0.16(0.08)$^{+}$
Variety-based experience*Patenting exp. (H3)	0.00(0.00)		-0.01(0.00)*	-0.01(0.00)*	-0.01(0.01)*	0.00(0.00)	-0.05(0.02)*
Accumulation-based experience*Patenting exp. (H3)	0.00(0.01)		-0.10(0.04)*	-0.07(0.03)*	-0.09(0.03)*	-0.08(0.03)*	0.25(0.22)
Electronics and IT	-0.01(0.02)	-0.04(0.03)	-0.06(0.03)$^{+}$	-0.04(0.03)	-0.05(0.03)$^{+}$	-0.05(0.03)	-0.33(0.42)
Biotech	0.02(0.02)	0.02(0.03)	0.02(0.03)	0.02(0.02)	0.02(0.03)	0.02(0.03)	0.89(0.43)**
Material science	-0.02(0.02)	-0.03(0.03)	-0.02(0.03)	-0.01(0.02)	-0.03(0.03)	-0.02(0.03)	0.26(0.37)
Machinery	0.01(0.02)	-0.02(0.02)	-0.02(0.03)	-0.02(0.02)	-0.03(0.03)	-0.02(0.03)	-0.20(0.37)
Energy	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded
Firm size	0.01(0.01)	-0.02(0.01)$^{+}$	-0.02(0.01)$^{+}$	-0.01(0.01)	-0.02(0.01)$^{+}$	-0.02(0.01)*	0.57(0.12)**
Male CEO	-0.02(0.02)	0.03(0.03)	0.00(0.03)	0.00(0.03)	0.00(0.03)	0.02(0.03)	0.13(0.45)
CEO age	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.01)
CEO education	0.02(0.01)	-0.01(0.02)	-0.02(0.02)	-0.02(0.02)	-0.03(0.02)	-0.01(0.02)	0.19(0.27)
Firm age	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.03)
Year of 2006	0.06(0.02)**	0.07(0.02)**	0.07(0.02)**	0.05(0.01)**	0.07(0.02)**	0.09(0.02)**	0.40(0.25)
Year of 2007	0.00(0.01)	0.02(0.02)	0.02(0.02)	0.02(0.01)	0.02(0.02)	0.03(0.02)$^{+}$	0.34(0.21)
Year of 2008	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded
Constant	0.03(0.05)	0.03(0.07)	0.05(0.08)	0.03(0.06)	0.14(0.08)$^{+}$	0.02(0.08)	-4.08(1.03)**
Number of observations	1058	1058	1058	1058	1058	1071	1058
Number of firms	575	575	575	575	575	581	575
Chi-square(d.f.)	34.17(16)**	32.36(14)**	29.95(16)**	29.76(16)**	32.49(16)**	32.55(16)**	42.06(16)**

Note: (1) **: $p<0.01$, *: $p<0.05$, +: $p<0.10$; (2) Model 3-7 uses the filtered sample where Model 8 uses the full sample including possible outliers; (3) Except for Model 3, Model 4-8 uses the instrumental variables and two-stage least squares for panel-data model with random effect (STATA command: xtivreg).

Table 4
Robustness Tests with Alternative Patenting experience Measures

	Patenting exp.: Patent grant (10)	Patenting exp.: Foreign patenting exp. (11)	DV: One-year lead (12)
	Coeff.(sd)	Coeff.(sd)	Coeff.(sd)
Variety-based experience (H1)	0.06(0.03)*	0.07(0.04)+	0.12(0.05)*
Accumulation-based experience (H1)	0.17(0.07)*	0.25(0.09)**	0.03(0.08)
Patenting exp. (H2)	0.01(0.01)**	0.02(0.02)	0.02(0.01)
Variety-based experience*Patenting exp.(H3)	-0.00(0.00)*	-0.01(0.01)+	-0.01(0.00)+
Accumulation-based experience*Patenting exp. (H3)	-0.05(0.02)*	-0.03(0.07)**	-0.01(0.03)
Firm size	-0.01(0.01)	-0.01(0.01)	-0.01(0.01)
Male CEO	0.05(0.03)+	0.06(0.03)+	0.00(0.04)
CEO age	0.00(0.00)	0.00(0.00)	0.00(0.00)
CEO education	-0.02(0.02)	-0.01(0.02)	-0.01(0.02)
Firm age	0.00(0.00)	0.00(0.00)	0.00(0.00)
Industry dummies	Included	Included	Included
Year dummies	Included	Included	Included
Constant	0.00(0.07)	-0.03(0.07)	-0.03(0.09)
Number of observations	1416	1348	518
Number of firms	656	633	387
Chi-square(d.f.)	179.09(17)**	165.15(17)**	20.75(15)

Note: **: p<0.01, *: p<0.05, +: p<0.10.

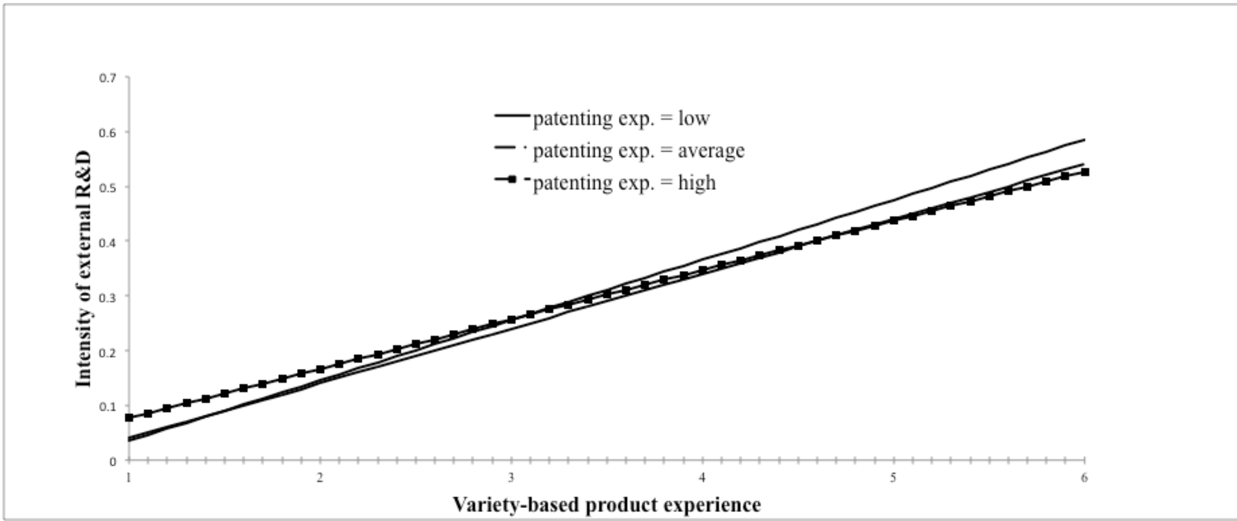

Figure 1
The Moderating Effect of Patenting Experience on the Variety-based Product Experience

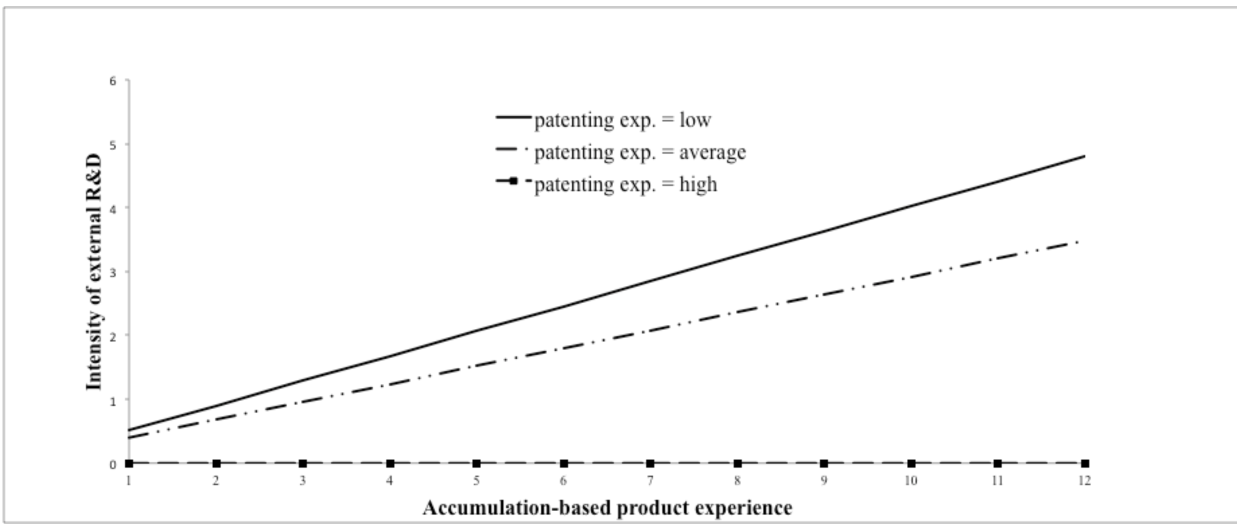

Figure 2
The Moderating Effect of Patenting Experience on the Accumulation-based Product Experience