Journal of International Business Studies (2019)

www.jibs.net

Adopting knowledge from reverse innovations? Transnational patents and signaling from an emerging economy

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Abstract
Is there knowledge adoption of innovations from emerging economies? We theorize that, to help overcome information asymmetry across countries, granting patents to technology in the emerging economy of China can serve as a signal of technology potential and market opportunity to enhance technological knowledge adoption in a developed economy such as the United States. The effect may be greater in a complex technology sector with high information asymmetry than in a discrete technology sector, and in regions with less developed market intermediaries, where information asymmetry is high. Our difference-in-differences estimates using 4226 China–U.S. patent dyads and comparable U.S. patents support our hypotheses.
Journal of International Business Studies (2019).
https://doi.org/10.1057/s41267-019-00241-9

Keywords: reverse innovation; knowledge adoption; patent signaling; information asymmetry; emerging market

INTRODUCTION

Reverse innovations, which are technologies originated in and developed for an emerging economy before being adopted in an advanced country (Govindarajan & Ramamurti, 2011; Immelt, Govindarajan, & Trimble, 2009; Ramamurti, 2009), may be first developed by domestic firms in emerging economies, such as China and India or multinational enterprises (MNEs) operating in these countries. Firms in developed countries, such as the United States, may subsequently use technological knowledge from such innovations. We define this process as reverse knowledge adoption. Such adoption and development of technological knowledge from emerging countries by firms in developed countries are important because such firms are often required to expand beyond the high-end segments in their home countries and emerging markets and to preempt local firms in emerging markets from creating low-cost products to disrupt them at home (Immelt et al., 2009). For example, the Nanjing-based Quanfeng Holdings Ltd. has developed an “auxiliary handle with a laser alignment device for drills” and electrical tools for the Chinese market. In 2002, the company

Received: 19 July 2017
Revised: 4 March 2019
Accepted: 2 April 2019

applied for a patent in China, which was followed by another patent application in 2003 for the same invention in the U.S. The technological knowledge from Quanfeng's patent was subsequently adopted by Black & Decker in the U.S., as evidenced by its follow-on patented inventions citing and using Quanfeng's U.S. patent.

However, before these developed-country firms can develop suitable technological products to cater to major emerging markets or adapt these products to similarly low-priced segments at home, an accurate assessment and understanding of the unique local conditions and customer needs in emerging markets are necessary. This situation can pose difficulties, as knowledge that flows across countries, especially from developing countries, where technological conditions and market institutions are less transparent and more fluid than those in developed countries, is often subject to serious information asymmetries (Almeida, Song, & Grant, 2002; Thompson, 2006). Investigating how these firms can overcome such information asymmetry is critical in understanding reverse knowledge adoption. However, to date, we have limited understanding of how firms in a developed country can overcome such information asymmetry in their reverse knowledge adoption process.

To address this gap, we develop a conceptual framework on how firms in a developed country, such as the U.S., can overcome information asymmetries across countries by observing the granting of patents in the emerging economy of China. We postulate that patent grant in China can serve as a positive signal of technology potential and market opportunity to enhance reverse knowledge adoption by firms in the U.S. Furthermore, we theorize that patent signaling may have a greater effect in the complex technology sector, where information asymmetry is higher than that in the discrete technology sector and regions with less developed market intermediaries, where information asymmetry is higher than that in regions with better-developed market intermediaries.

To test our theory, we identify and examine reverse innovations from the emerging economy of China and analyze their subsequent reverse knowledge adoption in the U.S. Our empirical setting of transnational China–U.S. patent dyads of the same invention by the same firm across countries provides a systematic, large-scale evidence for reverse innovations that originate from and are developed for China, the world's largest emerging economy, which are subsequently patented and adopted in the U.S., the world's largest developed economy and most technologically sophisticated country. The longitudinal dataset captures fine-grained details of China–U.S. patented inventions and enables us to characterize these inventions and their knowledge adoption trajectories in the U.S., relative to comparable U.S. patented technologies in the same technology class and application year.

Our study offers the following contributions to the literature. First, we develop a conceptual framework to study how and to what extent knowledge adoption from innovations that originate in a developing country may occur in a developed country by extending signaling theory to research on innovation and knowledge transfer across national boundaries. Through this framework, this study deepens our understanding of the microfoundations of the influence of patenting strategies in an emerging economy (China) on reverse knowledge adoption in a developed country (U.S.). This study connects the body of research on strategy and economics on imperfect information and its implications for firm strategy and performance (Dushnitsky & Shaver, 2009; Heeley, Matusik, & Jain, 2007; Reuer, Tong, & Wu, 2012; Yao, 1988) with the research on the strategic and economic effects of intellectual property rights (IPR) on technological knowledge activities of organizations (Arora & Fosfuri, 2003; Gans, Hsu, & Stern, 2008; Hall & Ziedonis, 2001; Huang, 2017; Huang & Murray, 2009, 2010; Lim, 2009).

Second, we contribute to a better understanding of the signaling role played by patents that originated in an emerging market, where the technological conditions and market institutions for the protection and commercialization of innovations are substantially less transparent, weaker, and more fluid compared with the conditions in developed markets (Zhao, 2006; Berry, 2017; Huang, 2017; Huang, Geng, & Wang, 2017). In particular, information asymmetry is salient between signalers (i.e., focal firms operating in China) and signal receivers (i.e., other firms in the U.S.) (e.g., Chan, Menkveld, & Yang, 2008). Prior studies focus on the role of patent signals in developed countries in assessing the quality of new ventures (Hsu & Ziedonis, 2013; Plummer, Allison, & Connelly, 2016) and attracting external resources for firms (Zott & Huy, 2007). This study advances our understanding of the previously underexplored effect of patent grant from the emerging market of China as a signal of technology potential and market opportunity and the roles of technological complexity and market intermediary (under)development, both of which exacerbate information asymmetry, on the relationship between patent signaling and reverse knowledge adoption.

CONCEPTUAL FRAMEWORK

Reverse Innovations and Knowledge Adoption in Developed Country

Innovations that originated in and were developed for emerging markets may not include the type of technological breakthroughs that spur innovation development in advanced countries. However, these innovations frequently involve an innovative recombination of existing knowledge, technologies, and business processes that address specific local problems and market needs (Govindarajan & Ramamurti, 2011). Reverse adoption and follow-on development of technological knowledge from emerging countries by developed-country firms are important because these firms often have to expand beyond the high-end segments in emerging markets and their home countries, and are keen to preempt firms in emerging markets from creating low-cost products to disrupt them at home (Immelt et al., 2009). Indeed, many existing premium products from developed-country firms could not simply be scaled down, defeatured, or adapted to the local needs in emerging markets (Govindarajan & Ramamurti, 2011).

However, before firms in developed countries, such as the U.S., can develop suitable technological products to cater to important emerging markets, such as China, or adapt these products to similar and lower-priced segments at home, these firms must accurately assess and understand the unique local conditions and customer needs in the emerging markets. Doing so may be difficult given that knowledge flows across countries are often subject to serious information asymmetries (Almeida et al., 2002; Thompson, 2006). Therefore, firms outside these emerging markets are frequently required to look for signals from "insiders", such as domestic firms or foreign MNEs that operate locally and conduct R&D in these markets, to obtain accurate information on the suitability, fit, and potential of technological products for these markets (e.g., Kirmani & Rao, 2000), which are otherwise not readily available to "outsiders". These "insiders" have significant access to local knowledge, practices, and networks and have in-depth understanding of unique market conditions, customer needs, social norms, conventions, and customs because of their proximity to and familiarity with the domestic market. The technologies developed by these firms and patented in the domestic market may reflect the insiders' intimate understanding of local market conditions.

Signaling Through Patents from the Emerging Market of China

Other than serving as legal safeguards by providing exclusionary rights and protection against expropriation in the product market (Arora, Fosfuri, & Gambardella, 2001; Levin, Kievorick, Nelson, & Winter, 1987; Mazzoleni & Nelson, 1998), patents reduce informational asymmetries between patentees and observers through their signaling function (Haeussler, Harhoff, & Mueller, 2009; Long, 2002) in the strategic factor market, in which the necessary resources for the implementation of a strategy are acquired (Barney, 1986).

Patents conform in principle to Spence's (1973) original conceptualization of a signal—they are costly to obtain and, through a government certification process, provide a mechanism by which the innovative activities can be qualified and sorted. Importantly, patents are differentially costly to obtain for high-quality versus low-quality actors. Due to the substantial cost involved in securing a patent through the lengthy application, examination and grant process, low-quality actors (i.e., with low-quality inventions) must find it more difficult or more costly to send the signal (i.e., pass the patent examination process and obtain the patent) than do high-quality actors (i.e., with high-quality inventions), which creates a separating equilibrium for the signalers and observers (Bergh, Connelly, Ketchen, & Shannon, 2014; Connelly, Certo, Ireland, & Reutzel, 2011).[1] Furthermore, patents can be observed, hence fulfilling both of these criteria to serve as a signal.

By serving as signals, patents provide information that can alter an observer's probability distribution of unobserved variables (Spence, 1973). Previous studies have investigated how patents can act as signals to improve access and terms of trade above and beyond the product-market protection of new ventures, help assess their quality (Hsu & Ziedonis, 2013; Plummer et al., 2016), and attract external resources for firms (Zott & Huy, 2007) in developed countries. However, we are not aware of any studies that examine the effects of patent signaling from emerging markets on cross-border knowledge adoption and strategies. In particular, as knowledge flows across countries are often subject to a high level of information asymmetry (Almeida et al., 2002; Thompson, 2006), such signaling across national borders can be pertinent for firms that operate outside the focal country of interest. These firms have to understand the unique conditions in the emerging markets to adopt the appropriate technical knowledge to develop suitable technological products for these markets or adapt suitable products from these markets to similar, often low-priced, segments of their home market.

Of particular importance and interest are patent signals from emerging markets, such as China, where technological conditions, IPR, and market institutions are less transparent and less established compared with those in developed countries (Gans et al., 2008; Zhao, 2006). In this context, the signaling function of patents can be particularly pertinent. Information asymmetry is prevalent between the signalers in an emerging economy, such as China (e.g., focal firms operating and conducting R&D in China) and signal receivers in a developed economy, such as the U.S. (e.g., other firms in the U.S.) (e.g., Chan et al., 2008). In addition to the exclusivity conferred by patent rights in developed and developing countries, signaling firms in developing countries could derive significant value from their portfolio of patents by using them to convey information about their firms and technologies that may not be as credible when revealed in other contexts. If such exclusivity costs more to obtain than what they can enable assignee firms to capture in the product market rents (such as in developing countries or regions with inefficient IPR and market institutions), the signaling role of patents to convey information in a controlled and credible manner can have more important private value to firms (Long, 2002). In other words, patents can serve as an important means of credibly publicizing information in a strategic factor market with a relatively weak institutional regime (Long, 2002).

Signaling Role of China Patents on Reverse Knowledge Adoption

Following the preceding logic, firms in China could (intentionally or unintentionally) disclose information through patents applied with the State Intellectual Property Office (SIPO)[2] to raise the long-term value of their technological products, portfolio, and firms (Keupp, Friesike, & von Zedtwitz, 2012). When firms apply for patents in China, they incur substantial costs for the financial and human resources used during patent application and examination and the required amount of time to complete the process. Depending on whether reexamination and deposit of biological materials are required, direct monetary expenses (including attorney fees but excluding maintenance fees) for a typical SIPO invention patent are estimated to be CN¥ 46,000 or US$ 7300 (China Patent Trademark Office, 2010). The cost to the firms is lower when securing patents for inventions of higher quality—in terms of relative technical merits or economic value of the technology. Higher-quality inventions are generally more novel and useful than lower-quality inventions and they require less reexamination; thus, they have a greater likelihood of being awarded a patent within a shorter period. The time to secure a patent represents a particularly high opportunity cost for firms that place a premium on speed to market. Therefore, although firms can apply and receive SIPO patents for higher- and lower-quality inventions, the cost to the firms to obtain a patent for a high-quality invention is on average less than that compared to a low-quality invention. This condition is in accordance with the signaling framework (Spence, 1973), which suggests that high-quality types incur lower cost in sending a signal.

By serving as a signal, a patent that is awarded to a specific technology in the emerging market of China mitigates information asymmetry relative to other technologies from China. Such patent signaling is important for foreign firms that operate outside, and lack intimate understanding of, the local Chinese market and market conditions, although they seek to develop technologies for this important market or are adapting technologies suitable for the Chinese market to similarly low-priced segments back home. Our conversations with R&D managers of MNEs and domestic Chinese firms and their in-house patent lawyers and other patent attorneys, who are based in China and specializing in procurement, management, and enforcement of SIPO patents, indicate that firms in the U.S. increasingly commission extensive studies of the prior art of SIPO patents issued to firms operating in China (in addition to U.S. and European patents) either before filing a patent application or before developing a new product in order to plan better for their own technology development and patent portfolios.[3]

For U.S. firms that monitor and study relevant prior technologies (from China), issuance of a SIPO patent may provide: (1) assurance of technology potential for further research and commercial development, and (2) a certification of market opportunity for suitability of products in local markets or similar market segments in the developed country. In other words, SIPO-granted patents can signal the technology potential and market opportunity in China and induce reverse knowledge adoption and accumulation by firms in the U.S., which often seek to develop products for the emerging Chinese market (e.g., for different provinces) or similar markets at home.

Signal from the granting of patent in China can convey valuable information, even after the corresponding U.S. patent for the same invention has been applied (or even granted). This relationship could be a result of the high level of information asymmetry when knowledge flows across countries as previously discussed (Almeida et al., 2002; Thompson, 2006). Such information asymmetry stems from the differences between the institutional, historical, and cultural contexts of China and the U.S. and the differences in their economic conditions and market structures (Fan, Wang, & Zhu, 2011). To the extent that the technological conditions and market institutions and demands in China are substantially different and more fluid than those in the U.S., such information has additional value. The size and growth potential of the Chinese market for firms in the U.S. provides another reason why patent signals from China have important value to firms in the U.S. It follows that patent signals from firms in the emerging market of China can convey additional information beyond that of the corresponding patent in the U.S. to positively influence the reverse knowledge adoption of the technological knowledge by firms in the U.S. Thus, we hypothesize:

> **Hypothesis 1:** The granting of a patent to the invention of a focal firm in the emerging market of China will increase its subsequent reverse knowledge adoption by other firms in the developed market of the U.S.

Moderating Role of Complexity of Technology Sector

As theorized, patent grant in the emerging market of China can serve as a signal of technology potential for further research and commercial development, as well as a signal of market opportunity to enhance subsequent knowledge adoption by firms in the developed market of the U.S. To further explore these mechanisms, we investigate the moderating roles played by industry/technology sector and geographical/market location in this relationship. Specifically, we examine the role of complexity of the technology sector and (under)development of market intermediaries in different regions, both of which exacerbate information asymmetry, on the relationship between patent grant signaling and reverse knowledge adoption.

Our next hypothesis focuses on how the complexity of technology can moderate the relationship between patent grant signaling and reverse knowledge adoption. The extent to which the signal is correlated with unobservable quality could depend on the complexity of the technology sector in which the technological product resides. In a discrete technology sector, such as chemical, pharmaceutical and biotechnology, a new technological product is composed of relatively few patentable elements (Cohen, Nelson, & Walsh, 2000; Levin et al., 1987; Mansfield, 1986; Mansfield, Schwartz, & Wagner, 1981). Each technological product, such as a drug for a particular indication, provides clearer use and easier assessment of its value compared with those in a complex technology sector, such as computing and information (von Graevenitz, Wagner, & Harhoff, 2011). It follows that each technological product in the discrete technology sector can play a substantive and definitive role in further developing a product and capturing significant market value (Gans, Hsu, & Stern, 2002).

Conversely, in a complex technology sector, such as computing and information technology (Cohen et al., 2000), a new technological product is composed of numerous separately patentable elements. Each element can interact with another in a more complicated manner. This sector is characterized by a diverse set of firms that perform R&D on potentially overlapping and incremental technological products or processes. Firms in this sector also tend to develop a large portfolio of complex technologies (Cohen et al., 2000; von Graevenitz et al., 2011). This sector has experienced particularly strong growth and witnessed many innovations over the last two decades in emerging economies, such as China. The relatively fast technological development and product life cycle intensify the competition among firms in this sector as more firms are developing numerous add-ons or peripheral technologies to build on and extend their core technologies to leverage them within and outside China (Hu & Jefferson, 2009). For example, many Taiwanese computer and integrated circuit manufacturers, such as Elan Microelectronics and the Taiwan Semiconductor Manufacturing Company, are aggressively developing add-on or overlapping technologies to augment their core technologies in Taiwan and China to create strong technology and patent portfolios. Capability and ownership of such portfolios of complex technologies and products are useful as bargaining chips and for potential codevelopment of technologies when negotiating with U.S. firms, such as Agilent Technology and Avago Technology, which may enter the Chinese market down the road (Tsai, 2010).

Accordingly, the technological products and components in the complex technology sector are less definitive and more ambiguous than those in the discrete technology sector. Therefore, pinpointing the precise use and assessing the intrinsic value of these products and components in the complex technology sector are more difficult. A higher level of information asymmetry may exist in the complex technology sector than that in the discrete technology sector between "insiders", such as domestic firms or foreign MNEs that operate and conduct R&D in local markets, and "outsiders", such as firms in the U.S. that are outside the local markets. The "outsiders" have less access to accurate information on the use and value of these technological products in the local market and their potential for further research and commercial development. Given the high level of information asymmetry in the complex technology sector, the signaling effect of a patent grant in China in this sector to "outsider" firms in the U.S. may be greater than that in the discrete technology sector. In other words, granting of patents in the complex technology sector in China can serve as a more important signal of technology potential than that in the discrete technology sector to mitigate information asymmetry and enhance reverse technological knowledge adoption by other firms in the U.S. Therefore, we predict:

Hypothesis 2: The positive relationship between patent grant signaling and reverse knowledge adoption (as stated in Hypothesis 1) will be more salient when the patent is granted in a complex technology sector (such as computing and information) than in a discrete technology sector (such as chemical, pharmaceutical and biotechnology).

Moderating Role of the Development of Market Intermediaries in Regional Markets

In addition to the intrinsic complexity of technology, an important external factor that influences the relationship between patent grant signaling and reverse knowledge adoption is the development of market intermediaries in the regional markets of China. A substantial difference exists in market development and conditions across different provincial regions in a vast country like China (Fan et al., 2011; Wang, Fan, & Zhu, 2007; Jia, Huang, & Zhang, 2019). Specifically, regions with more mature markets have developed market intermediaries, such as lawyers, accountants, and industry associations, which provide more transparency and information on the regional market and market conditions (Du, Lu, & Tao, 2008; World Bank, 2008; Fan et al., 2011).

Well-developed market intermediaries in the regional market, where the signaling firm conducts R&D on the patented technology, reduces the information asymmetry between the signaling firm and receiving firms in the U.S. Even "outsider" firms located in foreign countries can obtain more credible and higher-quality information on the suitability of technological products for these regions through intermediaries such as lawyers, accountants, banks, and industry associations in these regions and when making transactions (Chan, Makino, & Isobe, 2010; Xie & Li, 2018). For firms in the U.S., these market intermediaries can convey valuable information on the suitability of products and their market opportunities for the local market, which can be adapted to similar market segments (e.g., in terms of price sensitivity and consumer preferences) in a developed country, such as the U.S. As the level of information asymmetry is lower in regions with better-developed market intermediaries, there is less reliance on the signals conveyed by patents from the signaling firms.

On the other hand, in regions with underdeveloped market intermediaries, information asymmetry is high because information on technological products with good market opportunity and suitability for the local market (or for adaptation to similar market segments in a developed country) is not effectively communicated to "outsiders". If there is a lack of market intermediaries that serve the region and convey information, then the market is substantially less transparent compared with regions where market intermediaries are highly developed. As a result, firms in the U.S. need to depend more on (patent) signals from "insider" firms that operate and conduct R&D in these regions to develop suitable technological products for these local markets or adapt similar products from these markets back home, all else being equal.

Following this logic, the relationship between patent grant signaling and reverse knowledge adoption by receiving firms in the U.S. may become more salient when the patent is awarded to technologies developed by firms in regions with underdeveloped market intermediaries relative to those with more developed market intermediaries. Therefore, we make the following prediction:

Hypothesis 3: The positive relationship between patent grant signaling and reverse knowledge adoption (as stated in Hypothesis 1) will be more salient when the patent is granted to inventions developed by firms in regions with less developed market intermediaries than those in regions with more developed market intermediaries.

The conceptual framework shown in Figure 1 depicts how, under the emerging market of China, the patent awarded to the focal firm can serve as a signal of technology potential and market opportunity to increase reverse knowledge adoption by firms in the developed market in the U.S., by reducing information asymmetry. This framework also illustrates the important roles played by the complexity of the technology sector and development of market intermediaries in regional markets.

METHODOLOGY

Empirical Setting and China–U.S. Patent Dyads

To protect technologies from expropriation in domestic and international markets, firms frequently seek transnational patents as an important part of innovation and intellectual property strategy. Increasingly, the locus of R&D and innovative activities has been shifting to emerging economies such as China. Domestic start-ups, innovative firms, and MNEs develop novel technologies and product platforms in the emerging countries to take advantage of the low-cost technical personnel and proximity to market (Barrett, van Biljon, & Musso, 2011; Huang, 2010; Zhao, 2006). These firms and organizations typically apply for patents first in the emerging country to protect their inventions originated in and developed for these countries before patenting in another developed country such as the U.S.[4]

To test our theory, we collect and examine a large-scale, systematic dataset of reverse innovations in the form of transnational China–U.S. patent dyads by identifying patents which have been awarded to technological inventions originated in and developed for China, the world's largest emerging economy (International Monetary Fund, 2010), before being subsequently patented in the U.S., the world's largest and most technologically sophisticated market. Given the increasing emphasis on transnational patenting by domestic Chinese firms and foreign MNEs in China, these China–U.S. patent dyads of the same invention by the same firm (and their comparable U.S. patents) provide a suitable empirical setting to test our theory. We can exploit this large transnational patent dataset with fine-grained information over a

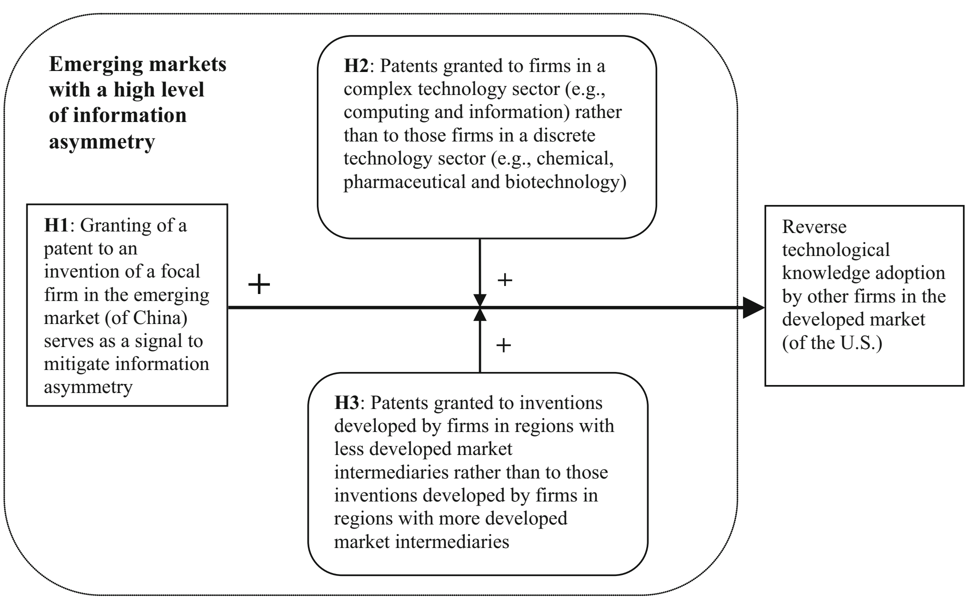

Figure 1 Conceptual framework on signaling effect of China patents on reverse knowledge adoption in the U.S.

long period of time to not only characterize these reverse innovations relative to comparable patented innovations in the U.S. but also shed light on the effects of patent grant in China on reverse knowledge adoption in the U.S.

A China–U.S. patent dyad encapsulates an invention in which the technology patent originates (and is applied for) in China, and is subsequently applied for and granted in the U.S.[5] The sample includes the entire population of the United States Patent and Trademark Office (USPTO) invention patents applied between 1985 and 2008, for which the same invention patent, known as a priority, had been first filed in China with the SIPO. This novel methodological approach involves the precise matching of the same firm name and priority right information across China and U.S. patent dyads, and the manual checking of titles, abstracts, and (sometimes) contents of the patents. The priority right (or right of priority) is essentially a time-limited right that is triggered by the first filing of an application for a patent (i.e., a technological invention's country of origin such as China). The priority right belongs to the applicant or his or her successor in title and allows the applicant to file a subsequent patent application in another country (e.g., U.S.) for the *same invention*. The priority right for patents typically lasts for 12 months.[6] Figure 2 illustrates the timeline of the relationship of a typical China–U.S. patent dyad.

Examining and final granting of a patent by the patent office in each contracting country is independent from those in other countries. The Patent Cooperation Treaty (PCT) provides a unified procedure for the possibility of filing an international application (i.e., PCT application) in each of its contracting countries. However, it does not provide for a "multinational (or international) patent" (which does not exist), because granting a patent in each country is subject to stringent patent examination procedures, which are administered by individual countries (with few exceptions). Each country has its own patent review and granting processes (similar to those undertaken by SIPO) which vary to different degrees in assessing the patentability bar of novelty, usefulness, and non-obviousness.[7] A firm may also select to patent in individual countries and forego the PCT route in securing patents in another country.

As a result of the mandatory filing, local examination, and enforcement of patents in each country, China–U.S. patent dyads provide a unique opportunity to exploit the differences in the timing of patents, which is another reason why this empirical setting is suitable for our investigation.

Empirical Strategy

To analyze the signaling effect of a China patent on its reverse knowledge adoption by other (non-focal) firms in the U.S., we rely on a number of methodological advances. First, we use forward citations (excluding firm self-citations) to the U.S. patent as a proxy for follow-on knowledge adoption by other firms in the U.S. Patent citations provide an inference on how subsequent firms adopt and build upon the technological knowledge that is captured in the focal patent. As patent citations embody legal implications in property rights, firms (especially non-focal ones) are conservative in selecting which patents to cite. Usually, only patented inventions upon which subsequent inventions are directly built are cited.

Admittedly, citations are not perfect in measuring technological knowledge adoption. For example, they are sometimes added for reasons such as avoiding litigation or clarifying claims. A few of these citations could be added by patent examiners rather than the inventors themselves. Nevertheless, scholars have shown that they correlate well with actual knowledge adoption and accumulation, especially when employing large samples (Duguet & MacGarvie, 2005; Jaffe & Trajtenberg, 2002). The potential bias created by examiner-added citations could be a source of concern (Alcacer & Gittelman, 2006; Alcacer, Gittelman, & Sampat, 2009). However, inclusion of examiner-added citations might be desirable because inventors and applicants may have strategic motives for omitting certain citations (Lampe, 2012).

A related empirical issue is the American Inventors Protection Act and the patent examination procedure. Before the enactment of the Act on November 29, 2000, information on a U.S. patent application was not published until the patent was granted. However, citing a U.S. patent application is possible because of the patent examination process and examiner-added citations in the USPTO. The procedures associated with patent examination and approval are quite systematic and well defined. After being received at a central receiving office and passing basic checks to qualify for a filing date, patent applications in the USPTO are sorted by a specialized classification branch which allocates them to one of approximately 235 "Art Units"—a group of examiners who examine closely related technology. Within the Art Unit, a "Supervisory Patent Examiner" (a senior examiner with

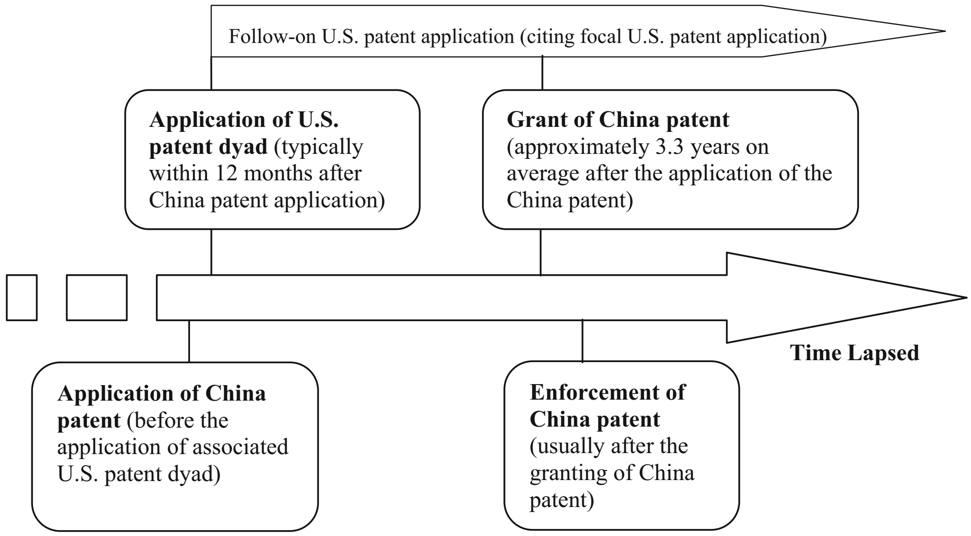

Figure 2 Timeline of relationship between a typical China–U.S. patent dyad and follow-on U.S. patent citations.

administrative responsibilities) studies the technology claimed in the application and assigns it to a specific examiner. Once the patent is allocated to a given examiner, that examiner will, in most cases, have continuing responsibility for examination of the case and interact with the applicant until it is concluded—either through rejection, allowance, or discontinuation. The examination process thus typically involves the close interaction between a single examiner and the attorneys of the inventor or patent applicant (for more details, see Cockburn, Kortum, & Stern, 2003).

In terms of the patent examination and review process, usually after patent applicants provide their references, patent examiners conduct their own prior art searches, such as looking for patent citations. Patent examiners are legally bound to consider an extensive amount of potential prior art including patent applications, published and issued patents. In fact, to recognize the important nature of multiple discovery (i.e., different inventors from different organizations or firms discovering and filing for similar technology and invention around the same time), patent examiners research extensively into pending and co-pending patent applications and base their decisions on these pending patent applications as much as on issued patents (Caldwell & Troyer, 2017). Consequently, patent examiners may challenge applicants' claims based on their own prior art searches, and communicate with applicants during the examination process if their own search yields different prior arts/patents search or citations from that of the applicants (Alcacer et al., 2009). Indeed, patent examiners check and add citations and prior arts, and work with applicants and their attorneys to discuss, agree upon and arrive at these citations in a process much like the revision process for academic journals (Cockburn et al., 2003). As such, both patent examiners and applicants have the opportunity to access, review and cite relevant citations of patent applications, where appropriate even before 2001, before the patent can be granted to the applicant. That is, citations to a U.S. patent can start to accrue after it has been applied.

Second, we employ the difference-in-differences identification methodology (e.g., Rysman & Simcoe, 2008; Singh & Agrawal, 2011; Huang, 2017) to examine inter-firm technological knowledge adoption. To proxy for reverse knowledge adoption, we use patent citations from non-focal firms to the set of U.S. patents that cover inventions from China (thus, each U.S. patent is matched to a China patent dyad)—known as the treatment group—as well as citations to the set of U.S. patents that cover inventions *not* originated in China (thus, *not* associated with any China patent)—known as the control group. This identification approach captures the difference between the citation rate to the U.S. patents in the treatment group and the citation rate to the U.S. patents in the control group before the granting of the China patent dyad, and compares that with the difference between the patents in the treatment group and in the control group after the granting of the China patent dyad.[8]

Third, for the treatment in the difference-in-differences approach—i.e., patent grant event in China—to be considered a largely exogenous event to the non-focal firms in the U.S., we rely on the notion that patents are "probabilistic" property rights fraught with uncertainty (Lemley & Shapiro, 2005). The three major types of uncertainty before the granting of a patent (Gans et al., 2008; Huang, 2017) are, namely, (1) patent grant uncertainty: whether the patent will be granted at all; (2) patent pendency uncertainty: how long after application will the patent be granted; and (3) patent claim and scope uncertainty: what claims and scope of patent right will eventually be allowed by the patent office after the substantive examination by the patent examiners. In other words, non-focal firms in the U.S. would not know whether or not a patent will eventually be granted (likelihood of patent grant in China is approximately 44% (SIPO, 2008)),[9] how long it will take for a patent to be granted in China after its application (approximately 3.3 years on average), number of patent claims, and scope of patent (in terms of number of patent classes (Lerner, 1994)) that will be allowed by the patent examiners should the patent be eventually granted. Indeed, the uncertainty in patent grant, pendency, claim, and scope will only be reduced after the occurrence of the patent grant event in China, which non-focal firms in the U.S. will be unable to observe prior to the event. Thus, these important conditions render the event of patent grant (to the focal firms) in China largely exogenous to the technology adoption or citation decision of non-focal firms in the U.S.

In summary, for each China–U.S. patent dyad, this identification strategy exploits the following: (1) differences in the timing of patent application and grant in China and the U.S., (2) likelihood of the China patent grant event, and (3) variation in the timing of a China patent granted to the technology of a focal firm (which is different for each China–U.S. patent dyad) as a largely exogenous event to other non-focal firms in the U.S. Compared with conventional cross-sectional data approaches, this methodology provides, as reported by Singh and Agrawal (2011), a more precise estimate of (1) the causal effect of patent grant in China after the patent (on the same invention) has been applied in the U.S. and (2) the temporal effect of patent grant by observing changes in citation rates over time.

DATA, MEASURES, AND MODELS

Overview of Data and Sources

To investigate the effects of patent grant signaling in China on reverse knowledge adoption in the U.S., we collect and analyze a novel dataset that comprises 4226 China–U.S. patent dyads assigned to 1104 unique firms and organizations. This dataset is constructed through a semi-automated process using the following procedure. As our study focuses on technologies that originated in and are developed for China and subsequently introduced to the U.S., we collected the entire population of granted USPTO invention patents with China priority until the end of 2008. A SIPO patent can be precisely linked to its corresponding USPTO patent using the priority right information identified in the USPTO patent if it is a transnational patent covering the same invention filed in China and the U.S. Having a priority in China suggests that the innovations originated in China. It also helps to ensure consistency in the country of the originating patent application, which may, for example, affect the nature of the patent filed.[10]

To provide an additional layer of comparison on the rate of knowledge adoption with comparable technologies that did not originate from China, we construct a control group of 4226 comparable U.S. patents to the treatment group of 4226 U.S. patents in the China–U.S. patent dyads. Consistent with previous studies (Jaffe et al., 1993; Singh & Agrawal, 2011), each control U.S. patent must be uniquely matched to a U.S. patent in the treatment group with the same three-digit technology classes and patent application years but must *not* be associated with a China priority patent. Most of the patented inventions in the control group (approximately 92%) originated from the U.S.

Based on the dataset of the treatment group of China–U.S. patent dyads and the control group of U.S. patents, we construct different variables to capture the characteristics of the patented technology, organization assigned to the patent, and the development of the regional market where technology R&D was conducted. We utilize the following major data sources to construct the dataset: (1) U.S. patents, citations, and other characteristics are derived from the USPTO; (2) China patents and characteristics are obtained from the SIPO; (3) comprehensive information on the development of market intermediaries at the provincial level in China is obtained from the National Economic Research Institute (NERI) 2011 Report (Fan et al., 2011); and (4) firm and organization characteristics, where available, are collected from Compustat, USPTO, and SIPO, supplemented by various industry publications, news articles, and information from official websites. These variables are manually double-checked and cross-referenced to firm annual reports and news articles online.

Variables and Measures

Dependent variable

We use *annual forward citation excluding firm self-citation* as the main dependent variable. This variable captures the yearly citation counts to a given U.S. patent excluding those made by the focal firm or organization awarded the U.S. patent. The period begins in the year that the U.S. patent was applied for (as early as 1985) and continues until 2008. This variable captures follow-on knowledge adoption and diffusion by non-focal firms and organizations in the U.S., which follows prior literature in using citations to trace knowledge flow, accumulation, and adoption (e.g., Jaffe & Trajtenberg, 2002; Singh, 2007).[11] By the end of the period, the average U.S. patent has accumulated close to six citations excluding focal organization self-citations over its lifetime as measured by the *total forward citation excluding firm self-citation* for each patent.

Independent and interaction variables

To ascertain the temporal impact of the patent grant event in China, we construct the main independent variable, *China patent in force*, following prior literature (Singh & Agrawal, 2011). For a U.S. patent with a China patent dyad (i.e., treatment group), this indicator variable is equal to 1 for all years after the granting of the China patent and 0 otherwise. For a U.S. patent without a China patent dyad (i.e., control group), this indicator variable always equals 0. As explained in the "Empirical Strategy" section, patent grant to a focal firm in China can be considered as largely exogenous to the technological knowledge adoption or citation behavior of non-focal firms in the U.S. *China grant year window* is another indicator variable that is equal to 1 when the citation is received during the year that the China patent is granted (i.e., "window") and 0 otherwise. This variable helps to account for the possibility that, in the actual grant year of the China patent, its impact may be noisy. We also construct the indicator variable, *matching China patent dyad*, which equals one if the U.S. patent is associated with a matching China patent dyad. When this indicator variable is equal to 0, the U.S. patent is not associated with any corresponding China patent and thus forms part of the control group of patents.

To assess the effects of the complex and discrete technology classes, we construct the following two pairs of variables. For the first pair, we construct *biochemical sector*, which is an indicator variable equal to 1 if the patent belongs to chemical, pharmaceutical, or biotechnology-related technology classes, and 0 otherwise. We also construct *non-biochemical sector*, which is an indicator variable equal to 1 if the patent belongs to other technology classes that are not in the chemical, pharmaceutical, or biotechnology-related classes, and 0 otherwise. For the second pair, we construct *computing and information sector*, which is an indicator variable equal to 1 if the patent belongs to the computing or information storage-related technology classes. We also construct *non-computing and information sector*, which is an indicator variable equal to 1 if the patent belongs to other technology classes that are not in the computing or information storage-related classes. We use each pair of variables in a regression model by interacting the variable individually with *China patent in force* to compare their interaction effects using a "constrained" model approach.[12]

To explore the effects of the development of market intermediaries at the provincial level regions, we obtain this information from the NERI index of marketization of China's provinces (Fan et al., 2011). Specifically, we draw upon the sub-index on development of market intermediaries in the NERI index, which is a composite index derived from survey seeking to understand the extent of service provided by the lawyers, independent accountants, and local industry associations in a particular region for firms. The sub-index is reasonably stable for each province over the available years of 1997–2009. A robustness check using the shares of lawyers and independent accountants in the local population yielded similar results. Previous studies have validated and used the data to assess various aspects of China's provincial market development (Wang & Qian, 2011; Li & Qian, 2013). Based on the data, an indicator variable, *top 25% in intermediary development*, was coded to denote if the patented technology is developed at the Chinese provincial level with more developed market intermediaries (i.e., in the top 25% on the NERI sub-index). The indicator variable, *bottom 75% in intermediary development*, denotes if the patented technology was researched and developed in one of the Chinese provincial level regions with less developed market intermediaries (i.e., in the lower 75% on the NERI sub-index).

Control variables

We construct the following patent-level controls. *Number of inventors* denotes the number of inventors on the U.S. patent and provides a control for the extent of collaboration on a particular invention. *Number of classes* denotes the number of national patent classes in the U.S. patent and provides a proxy for patent scope (Lerner, 1994; Scotchmer, 1991). *Number of claims* denotes the number of legal claims made by the U.S. patent and provides a proxy for legal patent strength (Harhoff & Reitzig, 2004; Lanjouw & Schankerman, 2001). *Number of patents in patent family* denotes the number of unique patents contained in the international patent family of the U.S. patent. *Number of countries in patent family* denotes the number of unique countries represented by the patents in the international patent family of the U.S. patent. Together, these two variables provide a proxy for the international scope and extent of the patent protection. Furthermore, to control for the effects of the granting of the corresponding U.S. patent, we construct an indicator variable, *U.S. patent in force*, which is equal to 1 for all years after the U.S. patent is granted and equal to 0 otherwise. We also construct an indicator variable, *U.S. grant year window*, which is equal to 1 when the citation is received during the year the U.S. patent is granted and 0 otherwise.

Finally, we construct the following indicator variables (at the patent level) to control for the type of entity to which the patent is awarded. *Firm* denotes a for-profit company or registered business entity. *University* denotes a university, college, or tertiary educational institution. *Research institute* denotes a non-profit research institute, organization, or national laboratory. *Hospital* denotes a hospital, clinic, or healthcare facility. *Government* denotes central or state government agency, bureau, ministry, army, administration, or council. Lastly, *individual* denotes individuals being awarded the patent.

Table 1 summarizes the means, standard deviations, and correlations of the key variables.

In the more stringent models, we include firm fixed effects to control for potential underlying heterogeneity across each firm and organization, and patent citation year fixed effects to control for unobserved heterogeneity in each year when the forward citation is received by the patent.

Model Specifications

To more precisely investigate the effects of patenting in China on reverse knowledge adoption in the U.S., moderating effects of complexity of technology sector, and development of market intermediaries in provincial regions, we use the difference-in-differences identification approach as described above (Furman & Stern, 2011; Rysman & Simcoe, 2008). As the dependent variable, *annual forward citation excluding firm self-citation*, is a highly right-skewed count variable that takes on non-negative integer values, we use a nonlinear regression approach to avoid heteroskedastic, non-normal residuals (Hausman, Hall, & Griliches, 1984). We use fixed-effects Poisson model based on Wooldridge (1999) because the conditional fixed-effects negative binomial model is not a true fixed-effects model since it fails to control for all of its predictors (Allison & Waterman, 2002). The fixed-effects Poisson estimator, on the other hand, produces consistent estimates of the parameters in an unobserved component multiplicative panel data model under general conditions and provides a consistent estimate of the conditional mean function even if the variances are misspecified (Wooldridge, 1999). As a robustness check, we employ the fixed-effects negative binomial regression models which yielded consistent results (more details in the "Robustness and Supplementary Analyses" section).

RESULTS

Descriptive Findings

We first show the descriptive statistics of reverse innovations from China (i.e., focal U.S. patents each matched to a patent dyad with China priority) compared with domestic U.S. innovations (i.e., control U.S. patents not associated with China patent) in Table 2. Consistent with the intuition offered by Immelt et al., (2009), we find that reverse innovations from China are characterized by technologies of substantially less value (or quality) in terms of *total forward citation excluding firm self-citation* (Jaffe & Trajtenberg, 2002; Henderson, Jaffe, & Trajtenberg, 1998) compared with domestic U.S. innovations in the same patent technology class and application year. These reverse innovations are also characterized by patents of narrower scope (i.e., smaller *number of classes*) and lower legal patent strength (i.e., smaller *number of claims*) than those of their U.S. patent counterparts. Nonetheless, granting of China patents to these

Table 1 Descriptive statistics and correlations of key variables

	Variable	Mean	SD	1	2	3	4	5	6	7	8	9
1	Annual forward citation excluding firm self-citation	0.44	1.40									
2	China grant year window	0.04	0.19	−0.03								
3	China patent in force	0.27	0.44	−0.04	−0.12							
4	Matching China patent dyad	0.50	0.50	−0.11	0.20	0.61						
5	Number of inventors	2.41	1.92	−0.01	0.00	0.00	0.03					
6	Number of classes	4.51	3.45	0.07	−0.03	−0.09	−0.12	0.09				
7	Number of claims	14.43	12.40	0.08	−0.04	−0.14	−0.18	0.06	0.09			
8	Number of patents in patent family	9.84	32.43	0.08	−0.01	−0.03	−0.04	0.10	0.09	0.14		
9	Number of countries in patent family	4.18	3.91	0.03	−0.01	0.01	0.06	0.15	0.13	0.11	0.41	
10	U.S. grant year window	0.11	0.31	−0.01	0.01	−0.04	0.01	0.00	−0.02	0.01	−0.01	−0.04
11	U.S. patent in force	0.62	0.49	0.12	−0.14	0.25	0.01	−0.03	0.02	−0.06	0.01	0.06
12	Firm	0.69	0.46	0.00	−0.01	−0.21	−0.20	0.15	0.05	0.13	0.05	0.08
13	University	0.06	0.25	−0.01	0.02	0.10	0.15	0.21	0.01	−0.01	0.01	0.03
14	Research institute	0.03	0.17	−0.01	0.03	0.12	0.13	0.23	0.06	0.02	−0.01	0.00
15	Hospital	0.00	0.05	0.01	0.00	0.01	0.01	0.02	−0.01	−0.02	0.00	0.02
16	Government	0.01	0.10	−0.02	−0.01	−0.03	−0.03	0.10	0.01	−0.01	0.00	−0.01
17	Individual	0.23	0.42	0.00	0.01	0.19	0.17	−0.28	−0.06	−0.14	−0.06	−0.09
18	Biochemical sector	0.16	0.37	−0.04	−0.02	−0.05	−0.02	0.22	0.17	0.04	0.08	0.28
19	Computing and information sector	0.02	0.13	−0.01	0.00	−0.02	−0.02	0.00	0.01	0.00	−0.01	−0.04
20	Top 25% in intermediary development	0.34	0.47	0.03	−0.04	0.00	0.09	0.21	0.12	0.05	0.14	0.15

	Variable	Mean	SD	10	11	12	13	14	15	16	17	18	19
1	Annual forward citation excluding firm self-citation	0.44	1.40										
2	China grant year window	0.04	0.19										
3	China patent in force	0.27	0.44										
4	Matching China patent dyad	0.50	0.50										
5	Number of inventors	2.41	1.92										
6	Number of classes	4.51	3.45										
7	Number of claims	14.43	12.40										
8	Number of patents in patent family	9.84	32.43										
9	Number of countries in patent family	4.18	3.91										
10	U.S. grant year window	0.11	0.31										
11	U.S. patent in force	0.62	0.49	−0.45									
12	Firm	0.69	0.46	0.04	−0.11								
13	University	0.06	0.25	−0.01	0.00	−0.25							
14	Research institute	0.03	0.17	−0.01	0.02	−0.07	0.01						
15	Hospital	0.00	0.05	0.00	0.00	−0.04	0.01	−0.01					
16	Government	0.01	0.10	0.00	0.00	−0.13	0.01	0.04	−0.01				
17	Individual	0.23	0.42	−0.04	0.11	−0.80	−0.14	−0.09	−0.02	−0.05			

Table 1 (*Continued*)

	Variable	Mean	SD	10	11	12	13	14	15	16	17	18	19
18	Biochemical sector	0.16	0.37	− 0.03	0.03	0.00	0.17	0.07	0.08	0.14	− 0.11		
19	Computing and information sector	0.02	0.13	0.01	− 0.03	0.05	− 0.02	− 0.02	− 0.01	− 0.01	− 0.05	− 0.04	
20	Top 25% in intermediary development	0.34	0.47	− 0.05	0.07	− 0.11	0.19	0.22	0.02	− 0.02	0.03	0.19	− 0.05

All correlation coefficients with a magnitude of 0.02 or greater are significant at the 0.01 level.

technologies conveys valuable information (beyond the granting of corresponding U.S. patent) to the receiving firms by enhancing knowledge adoption by firms in the U.S.

Furthermore, we analyzed the *annual forward citation excluding firm self-citation* over time, provincial level regions in China, and technology classes and draw the following observations. First, in terms of patent citations over time, the mean is 1201 citations per year (ranging from patents with no citations to 55 citations). As expected, the patent citations accrued to the U.S. patent dyads have steadily increased over the years of observation during which the citations are received. Second, in terms of patent citations across the 31 provincial level regions in China, the mean is 180 citations per region. We note that patents originated in more developed provincial level regions like Beijing (1519 citations), Guangdong (888 citations), Shanghai (766 citations), and Zhejiang (390 citations) tend to accrue more forward citations. Third, in terms of patent citations across technology classes, the mean is 79 citations per class. We note that the (3-digit) U.S. patent classes receiving the most number of forward citations are those classes where patents are particularly important to the technological sector, such as the biochemical, medical and computing, and information sectors, which have been well documented in prior literature (e.g., Mansfield, 1986; Levin et al., 1987; Cohen et al., 2000). (More details available upon request).

Main Effects of China Patent Grant

Models 3-1–3-4 in Table 3 investigate the baseline, selection, marginal, and main effects of the granting of China patent on the *annual forward citation excluding firm self-citation* of the U.S. patent dyads. We start with the ordinary least squares (OLS) regression model shown in Model 3-1, where the dependent variable is equal to the natural log of *annual forward citation excluding firm self-citation* plus 1. Although OLS provides a simple interpretation of the result, it does not account for the skewed nature of the count data.

Next, we use the Poisson regression models with specifications described before, as shown in Models 3-2–3-4. Model 3-2 serves as the baseline model with controls for the number of inventors, patent classes, claims, unique patents, and countries in the patent family, U.S. grant year window, and U.S. patent in force, and whether the organization awarded the patent is a firm, university, research

Table 2 Descriptive statistics of reverse innovations from China (focal U.S. patents each matched to a patent dyad with China priority) versus domestic U.S. innovations (control U.S. patents *not* associated with China patent)

Variable	*n*	Reverse innovations (Focal U.S. patents each matched to a corresponding China patent dyad)		Domestic U.S. innovations (Control U.S. patents *not* associated with China patent)	
		Mean	SD	Mean	SD
Annual forward citation excluding firm self-citation	33,133	0.29	1.03	0.58	1.68
U.S. patent application year	4226	2001	4.68	2001	4.67
U.S. patent grant year	4226	2003	4.84	2003	5.04
Number of inventors	4226	2.41	1.99	2.41	1.81
Number of classes	4226	3.91	2.89	4.73	3.76
Number of claims	4226	12.45	8.32	17.01	14.41
Number of patents in patent family	4226	7.18	8.36	10.60	40.60
Number of countries in patent family	4226	3.91	3.10	3.63	3.99

institute, hospital, or government agency, with the reference category being individual. Model 3-2 shows that, when the China patent is granted to a firm, there is a significant ($p = 0.000$) increase in reverse knowledge adoption by 20% ($e^{0.18} - 1$), and a significant ($p = 0.000$) increase by 62% ($e^{0.48} - 1$) when the China patent is assigned to a hospital. The effects are also positive with an additional unit of patent class (4%, $p = 0.000$), patent claim (1%, $p = 0.000$) or patent in the patent family (0.1%, $p = 0.000$), and after granting of the corresponding U.S. patent (366%, $p = 0.000$). In contrast, there is a negative impact when the China patent has one less country in the patent family (− 1%, $p = 0.000$) and when it is assigned to a research institute (− 35%, $p = 0.000$) or government agency (− 39%, $p = 0.000$).

Model 3-3 shows the selection and marginal effects with the same set of controls specified in Model 3-2. In addition, this model includes *China grant year window*, *China patent in force*, and *matching China patent dyad*. Model 3-3 provides a first test of Hypothesis 1. Results show that the granting of the China patent (*China patent in force*), by serving as a signal in China, increases technological knowledge adoption by firms in the U.S. by approximately 17% ($p = 0.000$). The magnitude of the effects and significance of the control variables in this model are largely consistent with those in Model 3-2. By including *matching China patent dyad* in Model 3-3, the model allows us to estimate the difference between U.S. patents associated with a granted China patent (i.e., technologies that originated in China) and U.S. patents unassociated with a granted China patent, in terms of knowledge adoption. This selection effect suggests that U.S. patents associated with patented technologies from China (*matching China patent dyad*) are 51% less well cited cumulatively ($p = 0.000$) by other (non-focal) firms in the U.S. relative to U.S. patents not associated with China patents. This result is expected as technologies from the U.S. tend to be adopted more by other U.S. companies on average than technologies from China.

The positive effect of our main difference-in-differences variable, *China patent in force*, is further supported by the result from the more stringent (and our preferred) main Model 3-4 which also includes *China grant year window* and *matching China patent dyad* as well as patent citation year fixed effects (similar to Models 3-1 and 3-3 in Table 3) and firm fixed effects to control for potential underlying heterogeneity across each firm and organization. This result suggests that the granting of the China patent to a focal firm increases reverse knowledge adoption by other firms by approximately 60% ($p = 0.000$). Taken together, Hypothesis 1 is supported.

Figure 3 shows the coefficients using the specifications in Model 3-4 for the fixed-effects Poisson regression and the specifications in Model 5-4 for the fixed-effects negative binomial regression. The figure illustrates the estimated temporal impact of China patent grant on follow-on citations for each year preceding and following the patent grant date. There are no noticeable pre-trends before the grant of the China patent, which has a positive and significant effect on follow-on citations in both models.

As further validation, using the subsample of treatment group of U.S. patents with matching China patent dyads, Models 3-5 and 3-6 estimate

Table 3 Fixed-effects Poisson regression models to estimate the impact of China patent grant on technological knowledge adoption by firms in the U.S.

Variables	Model 3-1 OLS with selection and marginal effects	Model 3-2 Baseline with controls only	Model 3-3 Selection and marginal effects with controls and patent citation year fixed effects	Model 3-4 Main model with all fixed effects [Preferred model]	Model 3-5 Marginal effects (for subsample of focal U.S. patents with matching China patent dyads)	Model 3-6 Model with all fixed effects (for subsample of focal U.S. patents with matching China patent dyads)
China grant year window	0.028 [0.002]		0.134 [0.001]	0.209 [0.000]	0.096 [0.023]	0.281 [0.000]
China patent in force	0.004 [0.393]		0.155 [0.000]	0.471 [0.000]	0.235 [0.000]	0.722 [0.000]
Matching China patent dyad	− 0.101 [0.000]		− 0.709 [0.000]	− 0.510 [0.000]		
Number of inventors	− 0.002 [0.045]	− 0.008 [0.017]	− 0.000 [0.902]		− 0.008 [0.156]	
Number of classes	0.005 [0.000]	0.037 [0.000]	0.029 [0.000]		0.043 [0.000]	
Number of claims	0.003 [0.000]	0.010 [0.000]	0.009 [0.000]		0.021 [0.000]	
Number of patents in patent family	0.001 [0.000]	0.001 [0.000]	0.001 [0.000]		0.011 [0.000]	
Number of countries in patent family	− 0.004 [0.000]	− 0.011 [0.000]	− 0.000 [0.945]		− 0.064 [0.000]	
U.S. grant year window	0.182 [0.000]	1.182 [0.000]	1.161 [0.000]		1.274 [0.000]	
U.S. patent in force	0.235 [0.000]	1.540 [0.000]	1.486 [0.000]		1.440 [0.000]	
Firm	0.010 [0.014]	0.180 [0.000]	0.026 [0.078]		0.041 [0.079]	
University	− 0.010 [0.154]	− 0.039 [0.149]	0.069 [0.010]		0.066 [0.054]	
Research institute	− 0.039 [0.000]	− 0.427 [0.000]	− 0.204 [0.000]		− 0.253 [0.000]	
Hospital	0.086 [0.003]	0.479 [0.000]	0.489 [0.000]		0.442 [0.000]	
Government	− 0.096 [0.000]	− 0.501 [0.000]	− 0.695 [0.000]		− 0.168 [0.259]	
Constant	0.041 [0.353]	− 4.360 [0.000]	− 3.946 [0.000]		− 7.922 [0.000]	
Firm fixed effects				Yes		Yes
Patent citation year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	66,268	66,268	66,268	54,623	33,133	25,580
Log pseudolikelihood		− 61,983	− 60,892	− 42,559	− 21,589	− 14,429

Exact *p* values are reported in brackets. Models include standard errors. All tests are two-tailed.

the impact of China patent grant based only on the difference in time elapsed between the application of the U.S. patent and granting of its China patent dyad for each U.S. patent. This estimation excludes the control group of U.S. patents not associated with any China patent. Models 3-5 and 3-6 show that the granting of the China patent dyad increases subsequent technological knowledge adoption in the U.S. by 26% ($p = 0.000$) and 106% ($p = 0.000$), respectively. The magnitudes of these

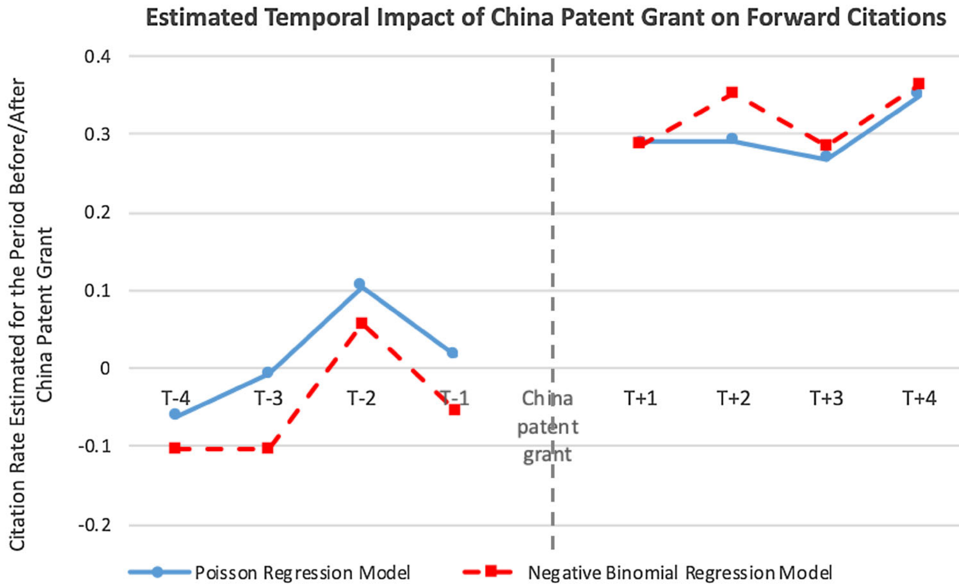

Figure 3 Estimated temporal impact of China patent grant on forward citations; Poisson vs. negative binomial regression models with firm fixed effects and patent citation year fixed effects.

coefficients are stronger than those in corresponding Models 3-3 and 3-4, respectively, and provide further support to Hypothesis 1.

Moderating Effects of Complexity of Technology Sector

In Table 4, Models 4-1 to 4-3 investigate the moderating effect of complexity of technology sector on the relationship between China patent grant as a signal and reverse knowledge adoption by other firms in the U.S. We postulate that this positive relationship will be more salient when a patent is awarded in the complex technology sector, such as *computing and information sector*, where information asymmetry is higher, than in the discrete technology sector such as *biochemical sector*. Model 4-1 compares the interaction effect between *China patent in force* and *computing and information sector* with that of *China patent in force* and *non-computing and information sector*. Having a patent awarded in the complex *computing and information sector* suggests an increase of about 60% ($p = 0.017$) in follow-on technological knowledge adoption, relative to a similar increase of about 60% ($p = 0.000$) when the patent is granted in the *non-computing and information sector*. The difference between these two coefficients is not statistically significant ($p = 0.992$).

Model 4-2 compares the effect of awarding a patent in the *biochemical sector* with that in the *non-biochemical sector*. When the patent is granted in the *non-biochemical sector*, there is a 69% significant increase ($p = 0.000$) in follow-on technological knowledge adoption, relative to a much smaller increase of 14% ($p = 0.051$) when the patent is granted in the less complex *biochemical sector*. Therefore, the difference between these two coefficients—55% overall stronger effect when the patent is granted in the *non-biochemical sector* compared with that in the *biochemical sector*—is statistically significant ($p = 0.000$).

Model 4-3 provides a direct test of Hypothesis 2 by comparing the interaction effect of *China patent in force* and *computing and information sector* with that of *China patent in force* and *biochemical sector*. Having a patent granted in the complex *computing and information sector* suggests an increase of 75% ($p = 0.013$) relative to a decrease of 4% ($p = 0.655$) when the patent is granted in the less complex *biochemical sector*. The 79% stronger effect when the patent is granted in the *computing and information sector* than in the *biochemical sector* is significant ($p = 0.010$). Taken together, Hypothesis 2 is supported.

Moderating Effects of Regional Market Intermediary Development

Model 4-4 investigates the effect of granting of a China patent to an invention that is researched and developed in a Chinese provincial level region of a low level of market intermediary development in the provincial level region (*bottom 75% in*

Table 4 Fixed-effects Poisson regression models on moderating effects of complexity of technology sector and regional market intermediary development

Variables	Model 4-1 Computing and information sector vs. non-computing and information sector	Model 4-2 Biochemical sector vs. non-biochemical sector	Model 4-3 Computing and information sector vs. biochemical sector	Model 4-4 Top 25 percent vs. bottom 75 percent in intermediary development
China grant year window	0.209 [0.000]	0.220 [0.000]	0.162 [0.171]	0.480 [0.000]
Matching China patent dyad	− 0.510 [0.000]	− 0.512 [0.000]	− 0.130 [0.122]	− 1.645 [0.000]
China patent in force × computing and information sector	0.469 [0.017]		0.562 [0.013]	
China patent in force × non-computing and information sector	0.471 [0.000]			
China patent in force × biochemical sector		0.130 [0.051]	− 0.039 [0.655]	
China patent in force × non-biochemical sector		0.527 [0.000]		
China patent in force × top 25% in intermediary development				0.893 [0.000]
China patent in force × bottom 75% in intermediary development				1.216 [0.000]
Firm fixed effects	Yes	Yes	Yes	Yes
Patent citation year fixed effects	Yes	Yes	Yes	Yes
Observations	54,623	54,623	9010	16,713
Log pseudolikelihood	− 42,559	− 42,541	− 5878	− 8750

Exact *p* values are reported in brackets. Models include standard errors. All tests are two-tailed.

intermediary development) compared with that of a high level of market intermediary development in the region (*top 25% in intermediary development*). Obtaining a patented technology based on R&D in a province that is in the *bottom 75% in intermediary development* shows a positive effect of 237% ($p = 0.000$) compared with the 144% increase ($p = 0.000$) from a province that is *top 25% in intermediary development*. The difference of 93% between the two coefficients is significant ($p = 0.000$). Thus, Hypothesis 3 is supported.

Robustness and Supplementary Analyses

We test the robustness of our results to alternative specifications, models, subsamples and variables. First, to test whether the results for citations to U.S. patents applied before the American Inventors Protection Act enacted on November 29, 2000 would hold, we conducted robustness check similar to Model 3-4 (our preferred model) but using the subsample of U.S. patents applied before 2001. As shown in Table 5 Model 5-1, we find that, while the magnitude of the coefficient of *China patent in force* in this subsample (0.348) is less than that (0.471) in the full sample, both coefficients are positive and significant ($p = 0.000$).

Second, to test whether the results are robust to models without the variable *China grant year window*, we perform a regression model similar to Model 3-4 but excluding this variable. As shown in Model 5-2 in Table 5, the result is robust and consistent with that of Model 3-4.

Third, to ensure the robustness of *annual forward citation excluding firm self-citation* received by the

Table 5 Robustness and supplementary analyses

Variables	Model 5-1 Model 3-4 with subsample of U.S. patents applied before 2001	Model 5-2 Model 3-4 without China grant year window	Model 5-3 Model 3-4 with subsample with citation age less than 19	Model 5-4 Model 3-4 using negative binomial regression model	Model 5-5 Model 3-4 using patent fixed effects	Model 5-6 Model 3-6 using patent fixed effects (for subsample of focal U.S. patents with matching China patent dyads)	Model 5-7 Model 3-4 with robust standard errors
China grant year window	0.206 [0.000]		0.207 [0.000]	0.201 [0.000]	0.079 [0.098]	0.209 [0.000]	0.209 [0.018]
China patent in force	0.348 [0.000]	0.409 [0.000]	0.465 [0.000]	0.422 [0.000]	0.102 [0.006]	0.565 [0.000]	0.471 [0.001]
Matching China patent dyad	− 0.384 [0.000]	− 0.468 [0.000]	− 0.509 [0.000]	− 0.484 [0.000]			− 0.510 [0.009]
Constant				− 1.902 [0.000]			
Patent fixed effects					Yes	Yes	
Firm fixed effects	Yes	Yes	Yes	Yes			Yes
Patent citation year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	34,699	54,623	53,950	54,623	43,149	19,445	54,623
Log pseudolikelihood	− 30,680	− 42,569	− 42,198	− 37,334	− 33,008	− 11,760	− 42,559

Exact *p* values are reported in brackets. Models include standard errors (except for Model 5-7 which includes robust standard errors). All tests are two-tailed.

U.S. patents over the different citation ages of the patents, we checked and found that the forward citation received is relatively stable (without significant drop-off) at least until citation age 17 or 18 years. This finding is consistent with the USPTO patent citation patterns documented by Hall, Jaffe and Tratjenberg (2002) in their figures 6 and 8. Based on this citation pattern, we performed a subsample analysis using the subsample of U.S. patents with citation age less than 19 years, as shown in Model 5-3 in Table 5, which yields a result consistent with that of Model 3-4. Using the subsample of U.S. patents with citation age less than 18 years again yields a consistent result where the coefficient of *China patent in force* is 0.460 ($p = 0.000$) (details available upon request).

Fourth, to check the robustness of our results across different model specifications, instead of using fixed-effects Poisson regression models, we employ fixed-effects negative binomial regression models as shown in Model 5-4 in Table 5. The negative binomial regression model yields consistent results with that of Model 3-4 in Table 3 (also see Figure 3). Using a fixed-effects OLS regression model (instead of a negative binomial regression model) also yielded a consistent result where the coefficient of *China patent in force* is 0.197 ($p = 0.000$) (details available upon request).

Fifth, to control for any unobserved heterogeneity across each U.S. patent, we substitute firm fixed effects—which control for any potential unobserved heterogeneity across each firm and organization—in Models 3-4 and 3-6 with patent fixed effects—which control for any potential underlying variation across each U.S. patent. In these two models, the variable *matching China patent dyad* drops out due to patent fixed effects. The results obtained as shown in Models 5-5 and 5-6 are robust and consistent with those in Models 3-4 and 3-6, respectively. Further, when we substitute firm fixed effects with patent fixed effects in the direct tests for Hypothesis 2 (Model 4-3) and Hypothesis 3 (Model 4-4), the results are consistent and robust with those in Models 4-3 and 4-4, respectively (details available upon request).

Sixth, we applied the Huber–White sandwich estimator (Allison & Waterman, 2002; Greene, 2004) in Model 3-4 to check the robustness of the results even if there were possible heteroscedasticity and lack of normality in the error terms. As shown in Model 5-7 in Table 5, the result is consistent: the coefficient of *China patent in force* is 0.471 (p = 0.001).

Lastly, to insulate the results against the possibility that the interaction effects in a non-linear model are not the same as their cross-partial derivatives (Ai & Norton, 2001), we performed additional regressions similar to Model 3-4 on split samples for Models 4-1–4-4. For example, for Model 4-1, we performed regressions using data subsamples for *computing and information sector* and *non-computing and information sector* separately. The results from these split sample analyses are consistent with the main findings (details available upon request).

Overall, our results are robust to different alternative specifications, models, samples and variables, which further support the main findings of the fixed-effects Poisson regression models as shown in Tables 3 and 4.

DISCUSSION AND CONCLUSION

Is there reverse technological knowledge adoption? In this study, we develop a conceptual framework on how patent grant to firms in the emerging economy of China can serve as a positive signal of technology potential and market opportunity to overcome information asymmetries across countries and enhance the technological knowledge adoption by firms in the U.S. Following this logic, we postulate that the effect of this signal may be greater in the complex technology sector, where information asymmetry is higher, than that in the discrete technology sector and in regions with less developed market intermediaries, where information asymmetry is higher than that in regions with more developed market intermediaries. The results from our difference-in-differences analysis of a large dataset of reverse innovation patents from China and their comparable U.S. patents provide support for our hypotheses.

This study is among one of the first that provides a large-scale and systematic analysis of reverse innovation and technological adoption from reverse innovation. This study has the potential to open up new avenues for research in this area for strategy and international business. Thus, developing a fuller understanding of reverse knowledge adoption and subsequent development of technologies originated from emerging countries by developed-country firms, particularly through the lens of signaling, is important. These firms often have to expand beyond the high-end segments in emerging markets, such as China, and in their home countries, and preempt local firms in emerging markets from creating low-cost products to disrupt them at home (Govindarajan & Ramamurti, 2011; Immelt et al., 2009). Therefore, developed-country firms outside emerging markets typically require the right signals from “insiders”, such as domestic firms and foreign MNEs that operate and conduct R&D locally in these markets, to obtain precise information about the suitability and potential of technologies for these markets that are otherwise not readily available to these “outsiders”. We theorize and empirically show that patents granted to firms in China can be a positive signal of technology potential and market opportunity by altering outside observer firms’ probability distribution of unobserved variables.

Our study offers the following contributions. First, we develop a conceptual framework to study how and to what extent knowledge adoption from reverse innovation originating from an emerging economy may occur in a developed country, by extending signaling theory to research on innovation and knowledge transfer across national boundaries. Through this framework, this study deepens our understanding of the micro-foundations of how reverse knowledge adoption in the U.S. can be influenced by patenting strategies in China. This study connects the body of research on strategy and economics on imperfect information and its implications for firm strategy and performance (Dushnitsky & Shaver, 2009; Heeley et al., 2007; Reuer et al., 2012; Yao, 1988) with the research on the strategic and economic effects of IPR on technological knowledge activities of organizations (Arora & Fosfuri, 2003; Gans et al., 2008; Hall & Ziedonis, 2001; Huang, 2017; Huang & Murray, 2009, 2010; Lim, 2009).

Second, we contribute to an improved understanding of the role played by patents granted to innovations originated in an emerging market, where the technological and market institutions for the protection and commercialization of innovations are weaker and more fluid compared to those of developed markets (Zhao, 2006; Huang et al., 2017) and where information asymmetry abounds. Prior studies have focused on the role of patent signals in developed countries by assessing the quality of new ventures (Hsu & Ziedonis, 2013; Plummer et al., 2016) to attract external resources for firms (Zott & Huy, 2007). In the context of emerging economies, where the information gap between developing and developed countries is high, patents granted to reverse innovations that originate in the developing country serves another critical function: they provide a means for outsider firms to bridge this information gap by conveying valuable information on technology potential and market opportunities in the emerging economy. They do so despite the fact that these reverse innovations from China typically have less value and a narrower scope (Immelt et al., 2009). Furthermore, this study advances our understanding of the roles of complexity of technology and underdevelopment of market intermediaries, both of which exacerbate information asymmetry, on the patent–signaling relationship.

Managerial Implications

These findings have strategic and managerial implications for innovating and entrepreneurial firms that produce, integrate, and assimilate technological knowledge across international and geographic boundaries. Cumulative knowledge is an important strategic asset that enables long-term exploration and expansion into new and uncertain external markets (Kogut & Zander, 1992). Managers and decision-makers should consider transnational patenting as a crucial component of their overall IPR strategies. Patenting a technology in an emerging market can influence the reverse adoption of the technology by other firms in developed countries. It does so by bridging the information gap across these countries by enabling the developed-country firms to possess an accurate assessment and understanding of the unique local conditions and customer needs in emerging markets. Thus, these developed-country firms can develop suitable technological products to cater to major emerging markets or adapt these products to similarly low-priced segments at home. The differences in technology complexity and development of regional market intermediaries can influence the subsequent use and accumulation of knowledge from the reverse innovations of another market. Innovating firms should evaluate these important strategic choices, given their expanding global reach into different market segments, intensifying global competition, and the increasing complexity of R&D operations in emerging markets.

Limitations and Future Research Directions

This study has a number of limitations that provide potentially fruitful avenues for future research. Toward the end of this section, we also highlight promising future research directions beyond those related to the limitations. First, this study only focuses on technological knowledge encoded in patents and does not examine non-codified knowledge. To the extent that inventions kept as industrial secrets contribute little to the stock of codified knowledge that can be more readily transferred and built upon by other firms and organizations, patent citations represent a useful indicator of future technological knowledge adoption and use. Nevertheless, studying the effects of patenting in one market on the accumulation of non-codified knowledge in another market is a potentially important area for future research.

Second, this study only examines the effects of patenting in China on the reverse knowledge adoption of the technology in the U.S. using citations to USPTO patents. As citations to SIPO patents are not mandatory and therefore incomplete, understanding the flow and accumulation of technological knowledge within China is hindered by such methodological constraints. However, as the focus of this study is on reverse knowledge adoption by firms in the U.S., citations to USPTO patents serve as an appropriate proxy. Future research can investigate the substantive differences between USPTO and (any available) SIPO patent citations, such as the completeness and motivation behind SIPO citations and their usefulness in tracing knowledge flow in China.

Third, this study focuses on just two countries, namely, the U.S. and China. Although they are the world's two largest economies with contrasting market characteristics and institutional developments, and represent considerable managerial and policy interests for different key stakeholders, future research could extend our methodological approach to identify, link, and analyze patented innovations from other emerging and developed countries to expand our understanding of the dynamics and effects of patenting on firms' knowledge and innovative activities in those countries. Doing so might open up new areas for investigation, and could represent a promising agenda for future research, given that we still have much to learn about innovations from emerging markets.

Apart from the potential future studies arising from the limitations, it may be promising for future research to look into the antecedents of reverse innovation. While the present study focuses on the consequences of reverse innovation, it would be meaningful to investigate the factors and conditions influencing the likelihood of firms taking their innovations from emerging economies to more advanced economies and when they are likely to do so. More broadly, a comprehensive understanding of the antecedents and consequences of reverse innovation will shed light on the issues of knowledge creation, the influence of formal and informal institutions, internationalization, and the innovation strategies of firms operating in the emerging economies.

ACKNOWLEDGEMENTS

We are grateful to Editor Gabriel Benito and anonymous reviewers for their insightful feedback during the review process. Earlier versions of this paper benefited from the helpful comments of Xuesong Geng, Ivan Png, Jasjit Singh, Heli Wang and the participants at the Academy of Management annual meeting, Academy of International Business annual meeting, CEIBS strategy and entrepreneurship academic symposium, DRUID conference, INSEAD entrepreneurship research workshop, NUS RISE seminar, SHUFE research forum, SMU research seminar, U.C. Berkeley-Peking university patent conference, and research seminars at Fordham University, Nankai University, Peking University, Renmin University, Shandong University, Tsinghua University, University of Sydney, University of Western Australia, and Xiamen University. We thank Wenxin Guo for her excellent research assistance. We gratefully acknowledge funding support from the Ministry of Education AcRF Tier 1 Grant R-266-000-118-133, and from the Research Grants Council of Hong Kong (HKUST #16505817). The usual disclaimers apply.

NOTES

[1]The government examination process is designed to provide a certification function through the rejection of inventions that fail to meet the standards required for patentability (an invention must be novel, useful, and non-obvious to receive a patent). The direct monetary expenses for a typical SIPO invention patent are estimated to be CN¥ 46,000 or US$ 7300, excluding maintenance fees (China Patent Trademark Office, 2010), which can be quite high for some firms. So a high-quality invention will have a higher probability of receiving a patent in a shorter amount of time, and incur less financial cost and cost in terms of waiting time, compared with a low-quality invention, which will cost more in financial resources and time and may not be granted.

[2]Following a restructuring, the State Intellectual Property Office (SIPO) of China was renamed to China National Intellectual Property Administration (CNIPA) in August 2018.

[3]Several face-to-face semi-structured and telephone interviews with managers of U.S. and other foreign-based MNEs that conduct R&D in China and domestic Chinese firms, their in-house patent lawyers and attorneys, who specialize in intellectual property law firms, service providers, and SIPO officials were conducted between March 2008 and April 2012 in the U.S., Beijing, Shanghai, and Singapore. Information was updated through e-mails and telephone calls in the following months on confidentiality conditions.

[4]For example, from 1995 to 2004, the number of U.S. patents awarded to U.S. firms based on technologies first developed (outside the U.S.) in non-OECD countries more than doubled (OECD, 2005). This corresponds to the steady increase in SIPO patents awarded to U.S. firms that conduct R&D in China (SIPO, 2008).

[5]The sample includes only patents eventually granted in the U.S. to control for the "quality" of the invention and mitigate underlying heterogeneity. This approach is consistent with previous literature (Jaffe, Trajtenberg, & Henderson, 1993; Murray & Stern, 2007).

[6]Details on the identification and matching procedure of China–U.S. patent dyads are available upon request.

[7]For example, the USPTO patent approval rate dropped from approximately 72% in 2000 to 44% in 2008 (Wild, 2008), and the SIPO has a similar average approval rate of approximately 44% for invention patents from 1985 to 2007 (SIPO, 2008).

[8]In theory, only the first level of comparison is required for the difference-in-differences estimate (Singh & Agrawal, 2011; Huang & Murray, 2009) as it already provides the "control group", that is, forward citations in the patent-years before the China patent grant (of the U.S. patents in the treatment group associated with a China patent dyad). This approach is arguably a superior control to the sample of comparable U.S. patents that are never associated with a China patent dyad. Including the control group of U.S. patents in the same technology classes and application year serves as an additional level of comparison with "matching" inventions not originated in China.

[9]The relatively low likelihood of patent grant is consistent across all technological sectors (Liegsalz & Wagner, 2013).

[10]Consistent with previous studies (e.g., Hu & Mathews, 2008; Huang, 2010; Chua, Huang, & Jin, 2019), the present study excludes patents from Hong Kong, Macau, and Taiwan as these regions are not considered part of domestic China because of the intrinsic differences in their historical and technological developments, patent filing, and reporting systems.

[11]To investigate the effects on citations by both focal and non-focal firms and citations by other non-focal inventors, we replaced the dependent variable, *annual forward citation excluding firm self-citation*, with two alternative dependent variables, namely, *annual forward citation* and *annual forward citation excluding inventor self-citation*, respectively. The results are consistent with those in the original models, which suggest that reverse knowledge adoptions by both focal and non-focal firms and by non-focal inventors are equally salient.

[12]A "constrained" model is a standard approach in econometrics, which compares two sets of constrained interactions (e.g., Murray & Stern, 2007; Huang & Murray, 2009), i.e., *China patent in force* $\times$ *biochemical sector* versus *China patent in force* $\times$ *non-biochemical sector*. As is standard for such constrained models, we are not able to further add the main effect term, *China patent in force*, in the regression model because it is fully partialed out and included in the two separate interaction variables.

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Accepted by Gabriel Benito, Consulting Editor, 2 April 2019. This article has been with the authors for three revisions.