The Globalization of R&D: China, India, and the Rise of International Co-invention

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Abstract: The rapid rise of China and India as innovating nations seems to contradict conventional views of the economic growth and development process. In standard models, the acquisition of innovative capacity in frontier technologies emerges as one of the final stages in a long development process. China and India are still poor, yet advanced nations are granting rapidly growing numbers of patents to inventors based in these countries. Our analysis of these patents shows that a majority of them are granted to local inventor teams working for foreign multinationals. An important fraction of these patents also incorporate direct intellectual inputs from researchers outside China or India, a trend that we characterize as "international co-invention." As such, the international patenting surge of China and India does not represent a challenge to traditional models of growth and development, so much as it represents a move toward an expanded international division of labor within global R&D networks.

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I. Introduction

For decades, international economists and development economists have worked with models that posit a kind of ladder of economic development. Countries begin the development process as largely agricultural economies. As they accumulate skill, capital, and technology, economies move into more complex manufacturing and service activities. Finally, after decades of development and steady increases in income, countries begin to create new-to-the-world technology. However, this is something that emerges at the end of the development process in the standard model (Grossman & Helpman, 1991a, 1991b; Paul Krugman, 1979; Vernon, 1966).

Despite many years of impressive growth, China, and especially India, remain quite poor in terms of their per-capita income, even when compared to other developing economies. By the usual measures, they are still in the early stages of the conventional development process. However, China and India are already innovating, as is evidenced by the rapidly rising number of patents granted by the U.S. and European patent offices to inventors resident in India and China. While the absolute number of patents remain low, the rates of growth have been exponential. Rapidly growing number of patent counts are not they only indicator of rising innovation in these emerging markets; India and China are also hosting an expanding number of R&D centers sponsored by the world's technologically elite firms (Basant & Mani, 2012; Freeman, 2006). Does this trend contradict conventional wisdom? Should we throw out our conventional economic models, or at least presume that they do not apply to these dynamic Asian giants? Respected experts in international economics have suggested as much, calling upon advocates of more traditional models to "wake up and smell the ginseng!" (Puga and Trefler, 2009).

The growing role of emerging economies in global innovation has also raised significant concerns among leaders in government, industry, and academia in the industrial West. In 2007, the U.S. National Academies referred to China and India as potential competitors, and cautioned that “the scientific and technological building blocks critical to our economic leadership are eroding at a time when many other nations are gathering strength” (National Research Council, 2007). As recently as 2010, the Royal Society also warned: “[the UK’s] scientific leadership, which has taken decades to build, can be quickly lost” (The Royal Society, 2010). Is the recent growth in emerging economies’ R&D activity undermining the traditional position of technological leadership enjoyed by the U.S. and other advanced industrial economies?

Using U.S. patent data, we examine the innovative explosions in China and India. We trace the dramatic growth of U.S. patents received by inventors resident in China and India across time, technological fields, organizational boundaries, and geographic space. We summarize findings from our field work, and examine the quality of China- and India-based patents, as evidenced by patent citations. By doing so, we are able to answer the following questions: Who is innovating what, where, and how in China and India? Why is an innovation surge occurring in China and India? What does the quality of R&D output look like and how does it change over time? Our goal is to reveal some of the facts, perceptions, and insights associated with the rising innovation phenomenon in emerging economies.

We make two contributions to the literature. First, we find that the rapid growth in U.S. patents in China and India are driven, to a great extent, by MNCs from advanced industrial economies and are highly dependent on collaborations between local inventors and other inventors in advanced economies. Therefore, China and India’s striking innovation surge may represent less of a challenge to conventional views of development economics than it appears at first glance.

What we see in China is not a fundamental change of the development process, but rather a new move towards a much greater level of globalization of R&D. The view that the increases in innovation in China and India are undermining the traditional position of technological leadership enjoyed by the U.S. and other advanced industrial economies might therefore also be exaggerated.

Second, we find evidence of an increasing trend of an international division of R&D labor -- or, phrased different, a vertical distintegration of R&D, with various intermediate stages of the R&D process now being conducted in different around the world. The general phenonmenon of a vertical disintegration of manufacturing has been well discussed in international economics literature (e.g. Yi 2003; Hummels, Ishii, and Yi 2001; P. Krugman, Cooper, and Srinivasan 1995). We find conceptually similar changes in R&D. As the innovation networks of MNCs span the globe, emerging economies like China and India that possess both a huge scientific and engineering talent pool and large markets, have become an important part of these global innovation networks. By undertaking R&D in emerging economies, MNCs can now provide innovative technologies to global markets at a lower cost, and introduce products more suitable for local and other emerging markets.

The rest of the paper is organized as follows: Section II provides the background of the rise of innovation in China and India. Section III describes our data and presents descriptive features of the rise of innovation in China and India as suggested by the data. Section IV provides insights from our field study. Section V presents the empirical models and results. Section VI concludes and discusses policy implications.

II. Background

Industrial R&D activity within the borders of mainland China has increased over the last fifteen years at a very rapid pace, and has now reached levels that are quite impressive by the standards of developing economies. The R&D intensity of China, measured by the ratio of R&D expenditure to GDP, reached 1.5% in 2008, and business expenditure on R&D has increased at an annual rate of 27% over the period 1997 – 2007 (OECD, 2010). China is now one of the few developing countries whose level of R&D intensity is above 1% (Hu & Jefferson, 2009). It is also one of the favorite destinations for multinational R&D investment. Over the 1997 – 2008 period, the total amount of U.S. multinational R&D spending increased 33-fold in China, from 35 million to 1.17 billion U.S. dollars.[1]

The growth of R&D in India has been slower. Its R&D intensity was 0.76% of GDP in 2007, essentially unchanged since 2000 (OECD, 2012). Nevertheless, the total amount of U.S. multinational R&D spending increased 17-fold in India, from 22 million to 1.17 billion U.S. dollars over the 1997 – 2007 period.[1]

Tracking patents granted by the U.S. Patent and Trademark Office (USPTO) to inventors residing in China and India provides another useful way of measuring the expansion of R&D within these countries. Anyone seeking to protect intellectual property within the borders of the U.S. must apply for patent protection from the USPTO. Given the importance of the U.S. economy to the world in general, it is reasonable to regard patents taken out in the U.S. by inventors residing in China and India as a useful indicator of innovative activity

[1] The number is for majority-owned affiliates of nonbank U.S. parent companies in China or India. A "Majority-Owned Affiliate" is a Chinese or Indian affiliate in which the combined direct and indirect ownership interest of all U.S. parents exceeds 50%. Source: U.S. Department of Commerce, Bureau of Economic Analysis, U.S. Direct Investment Abroad: Financial and Operating Data for U.S. Multinational Companies, http://www.bea.gov/iTable/iTable.cfm?ReqID=2&step=1, retrieved on August 8, 2012.

there.[2] Figure 1 presents the annual number of U.S. utility patent grants with at least one inventor residing in China from 1981 to 2010. One can clearly see that the number of U.S. patents granted to Chinese inventors exploded in recent years. Over the 1996 – 2010 period, the total number of U.S. patents granted to Chinese inventors increased 46-fold. A similar explosion can be observed using Chinese patent data (Hu & Jefferson, 2009). Over the 2000 – 2009 period, the total number of invention patents granted by the State Intellectual Property Office of P.R.C (SIPO) increased 20-fold. [3, 4]

Figure 2 shows the annual number of U.S. utility patent grants with at least one inventor residing in India. We can see that U.S. patents granted to Indian inventors also grew rapidly. Over the 1996 – 2010 period, the total number of U.S. patents granted to Indian inventors increased 25-fold.

Using U.S. patent data, one can further disaggregate patents generated in China and India into ones in which all listed inventors at the time of invention were based in those regions; ones which were created by international teams of inventors; and patents generated by inventors residing in China and India but owned by MNCs. Over 90 percent of U.S. patents granted to American inventors are generated by teams of inventors in which every inventor is residing in the U.S. at the time of application. The same is true of U.S. patents granted to Japanese inventors where over 90 percent of such patents are generated by exclusively

2 U.S. patents have been used to measure inventive output in Britain (Griffith, Harrison, & Reenen, 2006), Japan (L.G.Branstetter & Sakakibara, 2002), and Israel (Manuel Trajtenberg, 2001). At the same time, we recognize that the use of U.S. patents as an indicator of inventive output of another country poses potential problems, and we include a discussion of these later in the paper.

3 The SIPO grants three types of patents: invention, utility model, and design patents. In principle, applications for invention patents need to pass a substantive examination for novelty and non-obviousness; the utility model and design patents do not. In this sense, a Chinese invention patent is similar to a U.S. utility patent. However, the degree to which Chinese patent examiners hold domestic applicants to the same standards of novelty and non-obviousness as U.S. or European patent examiners is open to question.

4 Source: The State Intellectual Property Office of P.R.C web site, http://www.sipo.gov.cn/sipo2008/ghfzs/zltj/gnwszzlsqzknb/2009/201001/t20100122_488402.html, retrieved August 14, 2010.

Japanese inventor teams. However, this is not true of patents being generated in China and India. A large and growing fraction of patents with Chinese or Indian inventors result from something we call international co-invention—teams of researchers based in different countries combining their skills and knowledge to generate patented inventions. In addition, a growing fraction of the patents produced by purely Chinese or Indian inventor teams is created under the sponsorship of MNCs. In fact, as illustrated in Figure 1 and Figure 2, patents resulting from international co-invention and MNC sponsorship account for the majority of new U.S. patents granted to Chinese or Indian inventors in recent years.[5]

[Insert Figure 1 and Figure 2 here]

China and India's patent increases also differ quite substantially from the innovation explosions in Taiwan and South Korea that preceded them. The breakdowns of U.S. patent grants to Taiwanese inventors and South Korean inventors are provided in Figure 3. As can be seen, starting in the late 1980s and proceeding through the 1990s, both Taiwan and South Korea underwent a sharp transition from almost pure imitators to increasingly aggressive innovators. The speed of this transition is reminiscent of China and India's more recent invention surges, but the composition of inventor teams is not. The Taiwanese and South Korean patent explosions were generated almost entirely by purely indigenous teams of inventors. The important role of foreign firms in China and India's invention explosions may help explain why they are occurring at an even earlier stage of economic development than did the invention surges in South Korea and Taiwan.

[5] This finding was first documented in Goldberg, Branstetter, Goddard, & Kuriakose (2008).

[Insert Figure 3 here]

Patents granted by the Chinese and Indian national patent offices also bear witness to the importance of foreign firms. In China, foreigners account for more than 50% of the total number of invention patents granted by the SIPO over the 1990 – 2008 period. In 2009, the number of domestic invention patents slightly exceeded foreign invention patents, yet foreign invention patents still had a share of 49%.[6] In India, the Office of the Controller General of Patents, Designs & Trade Marks (CGPDTM) granted between 59 – 84% of patents to foreign applicants during the period from 2000 – 2001 to 2010 – 2011.[7]

Our analysis in this paper will focus primarily on U.S. patent grants as an indicator of inventive output. This is principally because prior research has established that the real economic value of most patents is extremely small (Jaffe & Trajtenberg, 2002), but the more valuable patents tend to be patented not just in the home country but in other major markets as well. Because Indi and Chinare are developing countries with still-developing patent systems, it is unclear whether a patent grant in China or India really represents an important advance over the global state of the art. However, the USPTO will apply the same standards to patent applications originating in China or India that it applies to patent applications originating in California. These U.S. patent grants are far more likely to be reflective of economically valuable new-to-the-world inventions than is "invention" for which we find Chinese or Indian patent grants but no U.S. patent grants. Furthermore, significant changes in the domestic patent systems in China and India make Chinese and Indian patent data inconsistent over time.

[6] Source: The State Intellectual Property Office of P.R.C web site, http://www.sipo.gov.cn/sipo2008/ghfzs/zltj/gnwszzlsqzknb/2009/201001/t20100122_488402.html, retrieved on August 14, 2010.

[7] Source: CGPDTM, Annual report 2010 – 11, http://ipindia.gov.in/main_text1.htm, retrieved on November 19, 2012. The authors made the calculation.

In the same way that USPTO patent data help trace the explosive growth of innovative activity in China and India, they also help put their current levels into perspective. In Figure 4, we look at patents granted to inventors based in eight different countries from 1996 – 2010, and it is clear that, in spite of the fact that China's inventive output as measured by U.S. patents places it head and shoulders above India and other so-called BRICs economies of Russia and Brazil, China's generation of patents still lags far behind that of the leading advanced industrial economies, and even behind that of the newly industrialized economies such as Taiwan and South Korea. Despite being among a population less than one-tenth that of China, Japanese inventors received 13 times as many U.S. patent grants as those based in China in 2010. Taiwan's national population is lower than that of the municipality of Chongqing in the Chinese interior, yet Taiwanese inventors received nearly three times as many patents as mainland Chinese inventors in 2010. China and India's explosive growth in U.S. patents has come from a very low base, and these two countries have a long way to go before they can claim to be a vital part of the global innovation system. However, if China's current international patenting growth rates persist, it may start to rival the patent output of Taiwan and South Korea within a few years. It will take longer for India to catch-up.

[Insert Figure 4 here]

By either assuming or predicting that innovation occurs exclusively in "the North," the Product Life Cycle theory (Vernon, 1966) and its current variants (Grossman & Helpman, 1991a, 1991b; Paul Krugman, 1979) rule out the possibility of innovation in "the South." This reflects the situation at a time when these theories have been established. R&D in developing countries at the time was sporadic, usually implemental in nature, and lacking real technological breakthroughs.

However, this stylized pattern has begun to change since the mid-1990s. First, multinationals are doing an increasing amount of R&D in emerging economies, notably in China, India, and the leading nations in Eastern Europe (L. Branstetter & Foley, 2010; Goldberg, Branstetter, Goddard, & Kuriakose, 2008; Zhao, 2006). Second, the nature of multinational R&D in emerging economies has changed from a pure adaptation of existing technologies to also including some cutting-edge R&D on a par with that undertaken in developed economies (UNCTAD, 2005) .

Some work has been done to address these changes. Grossman & Rossi-Hansberg (2006) provide a theoretical model of offshoring that also includes skill-intensive tasks. Puga & Trefler (2010) investigated innovation in emerging markets in a theoretical context in which it was treated as mostly incremental. Zhao (2006) suggested that by using closely-knit internal technological structures as an alternative mechanism to protect their intellectual property in countries with weak IP legal environments, MNCs are increasingly conducting R&D in countries such as China and India. However, systematic study on this topic is still insufficient.

MNCs' leveraging their innovation competencies across borders per se is not a new phenomenon (Cantwell, 1995; Kogut & Zander, 1993), but using co-invention as a vehicle to create novel innovations in emerging economies is. The clear importance of international co-invention in the data on U.S. patents granted to Chinese and Indian inventors may suggest something extremely interesting: the possibility that the R&D process itself can now be sliced into multiple stages, and countries may participate in different stages according to their competitive advantages. This phenomenon is often referred to as "vertical specialization" in the trade literature (Hummels, Ishii, & Yi, 2001; Krugman, Cooper, & Srinivasan, 1995; Yi, 2003). And if China and India's emergence in the global innovation system follows this economic canon, co-invention created in China and India is likely to be characterized by a division of labor in the research process. As such, Chinese and Indian researchers may undertake more repetitive, codified, and relatively routine research tasks while researchers in advanced countries may provide more sophisticated, creative, and high-level intellectual input. Combining the two, MNCs can produce a greater amount and more impactful innovative output with a given amount of R&D expenditure (Romer, 1990). As a result, an increase in R&D activity induced in China through this process might not be a direct substitute for the higher level R&D inputs from the Western advanced countries, but rather a strong complement to it.

However, this notion of complementarity could fade over time. Local Chinese and Indian inventors who initially collaborated with Western inventors through co-invention partnerships could acquire and accumulate high-level skills through this collaboration, and then engage in high-level, original inventive activity without the need for input from Western inventors. In this case, co-invention could, over time, lead to greater direct substitution between Western and local invention. But, it is also possible that after acquiring and accumulating high-level skills, these local Chinese and Indian inventors would continue to collaborate with Western inventors and thus catalyze synthetic effects (Kogut & Zander, 1992; Singh, 2008; Weitzman, 1998).

III. Data Sources and Descriptive Features

Our data comes from several sources. The first is the Selected Bibliographic Information from US Patents DVD (2009 December) released by the USPTO, which contains bibliographic information for all granted patents from

1969 – 2009.[8] The second is the Disambiguation and Co-authorship Networks of the U.S. Patent Inventor Database (Lai et al., 2011), which contains bibliographic information for granted patents and citations data for patents granted during the period of 1975 – 2010.[9] The third is the COMETS database 1.0 (Zucker & Darby, 2011), which we used to verify and supplement citation data from the Disambiguation and Co-authorship Networks of the U.S. Patent Inventor Database. The fourth is the USPTO Patent Full-Text and Image Database (online), as well as the Patent Assignment Database (online), which we used to identify and verify some important information of our dataset. We dropped withdrawn patents from our datasets, updated patent classes to Current Classifications as of the end of 2010, and standardized the assignee codes and names according to the USPTO's assignee harmonization system.[10, 11, 12]

By combining the first three datasets, we identified and characterized 3,983,050 utility patents granted from 1975 to 2010. We then used these patents to track citation relationships and counted the number of citations received (or "forward citations") for a particular patent that we were interested in.

For the purposes of our research, we separated Hong Kong and Taiwan from mainland China.[13] A total of 12,419 patents are identified as those with at

[8] The information from this data source has been included in the Disambiguation and Co-authorship Networks of the U.S. Patent Inventor Database (Lai et al., 2011). However, when we first worked on this research project, the Disambiguation and Co-authorship Networks of the U.S. Patent Inventor Database had not come out.

[9] In earlier versions of this paper, the citation data are extracted from the NBER Patent Data Project (PDP) citation file (1976 – 2006) downloaded from Professor Bronywn Hall's website and the Patent Grant Bibliographic Data/XML Version 4.2 ICE (Text Only) 2007, 2008 and 2009, downloaded from the USPTO website. These have been included in the Disambiguation and Co-authorship Networks of the U.S. Patent Inventor Database.

[10] USPTO, http://www.uspto.gov/patents/process/search/withdrawn.jsp, retrieved January 24, 2012.

[11] According to A Cassis2 DVD-ROM, Patents Class: Current Classifications of US Patents Issued 1790 to Present (2010 December).

[12] In earlier versions of this paper, the harmonized assignee codes are extracted from the Selected Bibliographic Information from US Patents DVD (2009 December). We combined them with assignee codes for patents granted in 2010 according to the files downloaded from the USPTO website. http://www.uspto.gov/web/offices/ac/ido/oeip/taf/data/misc/data_cd.doc/assignee_harmonization/, retrieved July 13, 2012.

[13] One issue arises for the years after 1997, when the United Kingdom returned sovereignty over Hong Kong to China. Some inventors resident in Hong Kong continued to list Hong Kong as their inventor country; others began to list China as

least one inventor residing in China at the time of invention during the period 1981 – 2010.[14] And a total of 7,754 patents are identified as those with at least one inventor residing in India at the time of invention during the period 1975 – 2010.[15]

The USPTO has classified all patents into the seven types of assignees:

(i) Unassigned;

(ii) Assigned to U.S. non-government organizations;

(iii) Assigned to non-U.S. non-government organizations;

(iv) Assigned to U.S. individuals;

(v) Assigned to non-U.S. individuals;

(vi) Assigned to the U.S. Federal Government;

(vii) Assigned to non-U.S. Governments.

However, we want to distinguish patents granted to a firm entity from those granted to a non-firm entity. To do so, we manually screened all first assignees' information listed on patents, including original type code, name, address, etc., and consulted Dun & Bradstreet's Million Dollar Database, LexisNexis Corporate Affiliations, Hoover's Online, and assignees' websites to assign the proper assignee types for all China- and India-related assignees.

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their inventor country. (Note: politically, Hong Kong has never been a country, but USPTO designates a separate country code to it for classification purposes.) Similar mistakes can be found when a Taiwanese inventor listed Republic of China, the official name of Taiwan, as her home country. A small amount of Taiwanese patents have been mistakenly classified with an inventor country code of "CN" (which stands for China) instead of "TW" (which stands for Taiwan) by the USPTO. We corrected these mistakes by looking up an inventor's full address.

[14] The first China-based patent was granted to Dynapol, a chemical company in 1981. The patent counts are based on grant years.

[15] Similar to what happened to the China-based data, in a few cases, Indonesia and the state of Indiana were mistakenly assigned with an inventor country code of "IN" (which stands for India). We corrected all of these mistakes.

Figure 5 shows share of USPTO patents granted to Chinese inventors by assignee types. It can be seen that 78% of all 12,419 U.S. utility patents granted to Chinese inventors were assigned to a firm entity, 12% to an individual or identified as unassigned, 9% to universities and research institutes, and 1% to other entities such as governments, hospitals, etc. Figure 6 shows the similar breakdowns for India-based patents. It can be seen that 74% of all 7,754 U.S. utility patents granted to Indian inventors were assigned to a firm entity, 5% to an individual or identified as unassigned, 20% to universities and research institutes, and 2% to other entities. From Figure 5 and Figure 6, it can be concluded that firms are the main contributors of the recent increase of U.S. patents in China and India.

[Insert Figure 5 and Figure 6 here]

Who owns these patents? At the assignee nationality level, one can see in Figure 7 that Taiwanese and U.S. MNCs own the majority of Chinese patents, even more than Chinese indigenous enterprises. Of all 9,744 China-based patents assigned to a firm entity, 36% are assigned to Taiwanese MNCs or their Chinese subsidiaries, 29% are assigned to U.S. MNCs, and 23% are assigned to Chinese indigenous firms. Other important nations and areas include Hong Kong, Germany, and Japan, which account for 3%, 2%, and 2% respectively. The remainders as a whole accounts for 6%. Figure 8 shows that U.S. MNCs own the majority of India-based U.S. patents. Of all 5,716 India-based patents assigned to a firm entity, 70% are assigned to U.S. MNCs, followed by Indian indigenous firms 18%, Germany 3%, France-Italy 3% (those patents are owned by a single firm, STMicroelectronics Pvt. Ltd., the Indian subsidiary of French-Italian multinational electronics and semiconductor manufacturer STMicroelectronics), and other countries in total 5%.

[Insert Figure 7 and Figure 8 here]

At the firm level, Table 1 lists top 10 firm assignees of China-generated U.S. patents. Among them, Hon Hai, a Taiwanese manufacturing firm, also known by its English name Foxconn, leads the list. As the largest manufacturer of electronics and computer components worldwide, Hon Hai conducts intensive R&D in China and has 2,958 U.S. utility patents, or 30% of total China-based firm-owned U.S. patents. Microsoft, with 765 patents, or 8%, is a distant second. The third is Huawei, an indigenous Chinese firm that has quickly become one of the leading networking and telecommunication equipment suppliers in the world. It is worth pointing out how aggressively Huawei has been upgrading its innovative capacity—it has only taken Huawei three years to jump from No. 6 to No. 3 on the list.[16] Another way to look at such a rapid pace of growth is to compare its patent application rates with those of other telecommunication equipment manufactures that are its global rivals. In 2009, Huawei filed 551 USPTO patent applications, far more than those from Nokia Siemens Networks (58), Ericsson (151), or Alcatel-Lucent 153.[17]

Table 2 lists top 10 firm assignees of India-generated U.S. patents. Among them, eight are U.S. MNCs and one is a French-Italian MNC. The only Indian indigenous firm in the list is Ranbaxy, one of the world's top generic pharmaceutical companies.

[Insert Table 1 and Table 2 here]

[16] The rank as of the end of 2006 can be found in Branstetter & Foley (2007).

[17] Source: the USPTO Patent Application Full Text and Image Database, http://appft.uspto.gov/netahtml/PTO/search-adv.html, retrieved September 9, 2010.

To measure what kinds of invention have been done in China and India, we aggregate all China- and India-based U.S. patents that are owned by a firm entity into the widely used technology categories created by Hall, Jaffe, & Trajtenberg (2001). We will refer to their taxonomy as the HJT categories. The results presented in Figure 9 show that a large proportion of China-based patents taken out in the U.S. are in two HJT categories: Computers & Communications and Electrical & Electronic. With regard to India-based patents, Computers & Communications is the leading field. In either country, co-invention plays an important role in all categories.

[Insert Figure 9 here]

By extracting the geographic information on inventors included in patent documents, we found 27,239 inventor addresses that indicate the inventor was present in mainland China at the time of application, and 27,177 of these addresses are sufficiently complete that they can be associated with a particular province in China. Among 20,088 inventor addresses that indicate the inventor was living in India, 20,045 addresses can be associated with a particular state in India. Putting this information into maps, Figure 10 shows the geographic distribution of Chinese inventors (mainland only) at the provincial level. One can see that Chinese inventors are highly clustered in three areas: Beijing Municipality, Guangdong province, and the greater Shanghai regional economy comprising Shanghai and the bordering provinces of Jiangsu and Zhejiang. Those areas account for 86% of the frequency distribution of Chinese inventor addresses. These areas are not only the most developed areas in China, but also the places where most multinational R&D centers are located.[18] Figure 11 shows

[18] As of the end of 2009, 465 of multinational R&D centers were established as independent legal entities with approval of the Ministry of Commerce of P.R.C. These centers are mainly concentrated in Shanghai, Beijing, Guangdong,

the geographic distribution of Indian inventors at state level. Karnataka, Maharashtra, Andhra Pradesh, Uttar Pradesh, and Delhi are the top five states/territories that host most Indian inventors. Those areas together account for 76% of the frequency distribution of India inventor addresses.

[Insert Figure 10 and Figure 11 here]

All of the above features are based on the analysis of U.S. patent data, which have limitations as indicators of invention in China and India. The most obvious one is that U.S. patent data may exaggerate the roles of U.S. MNCs since companies usually patent more in their home market than somewhere else. Moreover, although the U.S. is the most important market in the world and grants more patents than any other country, patents granted by its patent office may still not be able to capture the whole picture of the rise of innovation in China and India. For these reasons, we have also analyzed European Patent Office (EPO) patent data as a robustness check. All the major patterns revealed by U.S. patent data also hold using EPO data, including the importance of co-invention and MNC sponsorship, technological concentration in IT-related fields, and geographic clustering of Chinese and Indian inventors. It is worth pointing out that U.S. MNCs play a more important role than European MNCs in India-based patenting even using EPO data. This probably reflects the fact that U.S. MNCs are following more aggressive strategies of conducting R&D in India than are MNCs from other places. Figures and tables presenting the results using the EPO patent data are available upon request.

Jiangsu and Zhejiang. Source: People's Daily online, http://english.peopledaily.com.cn/90001/90778/90861/6921243.html, retrieved August 17, 2010.

IV. Peering inside Co-invention: Lessons from Interviews of China-Based Multinational R&D Personnel

To obtain insights into the mechanisms behind the multinational R&D phenomenon in emerging economies, we took a research trip to China in December 2009 to conduct face-to-face interviews with inventors from multinational R&D centers there. These interviews were preceded by a series of telephone conversations with high-level multinational managers, most of whom were based in China and had extensive connections to the R&D activities of their firms in China.

In China, we interviewed researchers or directors from six multinational R&D subsidiaries. Among them, four are research facilities affiliated with U.S firms, one is an industrial university cooperative research center fully sponsored by a Taiwanese firm, and one is a European chemicals and pharmaceuticals firm. The U.S. multinationals include two information technology companies, a consumer products producer, and a conglomerate. We also discussed the multinational R&D phenomenon with China-based academic experts who have followed the evolution of this phenomenon closely over many years.

Our interviews focused on several aspects of multinational R&D activity: How are the international research teams formed? What do the backgrounds of Chinese participants look like? Where does the main idea for a collaborative work come from? How do team members communicate? Does a division of labor exist within international research teams, and if so, to what extent? To what degree can international co-invention work as a mechanism for Chinese researchers to acquire skills and expertise that enable them to undertake independent high-level invention without input from Western researchers?

First, we received strong confirmation from all sources that there is an emerging international division of R&D labor within multinational firms, and that a significant fraction of their China-based research manpower is being used to contribute to global research projects whose ultimate application will be in global markets, not just the Chinese market. Most interviewees emphasized their commitment to a long-run research presence in China that could engage China's large and growing endowment of engineering human resources in the service of their firm's global R&D agenda. China now has, by some measures, the world's second largest stock of human resources for science and technology. Its share of university graduates with degrees in science and engineering is 39.2%, almost twice that of the OECD average (OECD, 2008). In 2007, 43% of all 2 million university graduates with a bachelor's degree in China were in science or engineering. [19] At the graduate level, 83% of all 5,194 PhDs were in science or engineering. [20] Although the overall marginal quality of higher education in China may have suffered from a rapid expansion of enrollment rates in the past decade, the system as a whole has managed to train considerable numbers of young engineers and scientists with great potential. Since the size of the Chinese talent pool is so big, multinationals can tap the best of the best at a relatively low cost.

The firms' choice of location of their R&D operations in China—often far from the locus of manufacturing activity—was generally driven by proximity to China's elite universities, and it was really the cluster of prestigious universities in and around the capital that drew many firms to locate R&D laboratories in Beijing. Interestingly, these conversations tended to stress the scale and quality of China's human resources rather than cost, although, clearly, junior level engineers earn far less in China than do individuals of comparable raw talent in the West.

[19] Source: Ministry of Education of the People's Republic of China, Number of Students in Regular HEIs by Field of Study, http://www.moe.edu.cn/edoas/website18/level3.jsp?tablename=1249610459599815&infoid=1249434091393239&title=%C6%D5%CD%A8%B1%BE%A1%A2%D7%A8%BF%C6%B7%D6%D1%A7%BF%C6%D1%A7%C9%FA%CA%FD, retrieved May 15, 2010.

[20] Source: Ministry of Education of the People's Republic of China, Number of Postgraduate Students by Academic Field (Research Institutes), http://www.moe.edu.cn/edoas/website18/level3.jsp?tablename=1249610459599815&infoid=1249432251292226&title=%B7%D6%D1%A7%BF%C6%D1%D0%BE%BF%C9%FA%CA%FD%A3%A8%BF%C6%D1%D0%BB%FA%B9%B9%A3%A9, retrieved May 15, 2010.

Senior engineers in management positions were viewed as being roughly as expensive in China as they are in the West. Some long-term expatriates frankly admitted that the multinational R&D center might have been originally set up more as a demonstration of "commitment to the Chinese market," designed to favorably impress the Chinese government, than as a serious component in the firm's R&D network. Over time, however, international collaboration between the China center and the rest of the firm's R&D operation has grown.

This collaboration sometimes extends beyond the boundaries of the firm itself. Several interviewees noted that the Chinese government has aggressively funded efforts to promote collaboration between Chinese universities and industrial enterprises, including foreign firms. Taking advantage of this, many Western firms have been able to supplement their own research efforts by encouraging Chinese engineering and science professors to undertake R&D related to the needs of Western companies, with most of the costs underwritten by the Chinese taxpayer. One metals company had achieved notoriety within the multinational community for building up a "virtual R&D operation" that consisted almost entirely of university-based researchers performing R&D projects financed by the Chinese central government. We also visited a research institute on the grounds of one of China's most prestigious universities whose capital costs had been almost entirely underwritten by a contract manufacturing firm. The research institute was able to conduct its agenda mostly independently of its foreign corporate sponsor, but the multinational sponsor regularly reviewed research output, decided what it would like to patent, and occasionally requested a delay in publication of certain results until patent applications could be filed.

Second, we also received confirmation of the view that China's endowment of raw talent, immense and impressive though it is, still contains relatively few individuals who have become capable of directing a world-class R&D effort in key areas of technology without many years of exposure to multinational best practice. That being said, talented Chinese engineers can and do become "mature" and effective collaborators in international R&D projects, even taking on leading roles, after a few years of intense experience within a multinational R&D lab. In some organizations, it was explicitly acknowledged that the fundamental intellectual insights and the structuring of the research agenda still came from the foreign side. In others organizations, there was much more local autonomy in terms of setting the research agenda. But even in these, expatriate R&D managers and/or Chinese staff with extensive educational and work experience in the United States often maintained a key role in directing the R&D activities of younger staff whose education and experience had been obtained entirely in mainland China. Many interviewees agreed heartily with the view that highly gifted Chinese engineers were much more likely to get to do technically sophisticated work in a multinational R&D laboratory than in a laboratory run by an indigenous firm. While firms had occasionally lost personnel to indigenous rivals, they felt confident that they would be able to hold on to the most technically gifted and creative employees, in part because of the superior research environment they could offer. Likewise, while respecting the rapidly emerging talents and capabilities of their mainland Chinese competitors, most multinational managers believed that there was a still a significant gap in high-level engineering ability between the multinationals and most indigenous enterprises. Interestingly, many of these judgments were rendered by engineers who were ethnically Chinese and long-term expatriates in the PRC.

That being said, a simple story of collaboration in which U.S.-based engineers come up with the ideas and give the orders and China-based engineers carry them out was clearly far too simple to reflect the much more complex patterns of interaction we heard described in our interviews. There were certainly cases in which important ideas came in the first instance from the Chinese side, as well as cases in which the projects were conceived, developed, and implemented entirely by the Chinese side, with very little Western input.

Third, many interviewees placed far more stress on the importance of "(re)engineering products for the Chinese market" as a source of co-invention than we initially expected. In many markets for industrial intermediate goods—and even in some markets for consumer goods—the Chinese market is now substantially larger than the U.S. market or even the European market. However, China is still a poor, developing country, and the tradeoff between cost and functionality is quite different for a Chinese customer – even a Chinese corporate customer – than it is for a Western customer. Therefore, a significant fraction of Chinese engineering personnel were employed in the ongoing process of reengineering Western products for the Chinese market—in ways that were both subtle and profound. In this effort, Chinese engineers were indispensable, not just for their abundance and relatively low cost, but also for their deep understanding of the local market. In the context of this reengineering work, it is not surprising that Chinese engineers often take a leading role. However, the division between "reengineering for the Chinese market" and "contributing to the global R&D agenda" was a fuzzy one and, over time, the same Chinese engineer might be involved in both kinds of undertakings. In fact, interviewees noted that some cost-reducing innovations are often applied to products in other developing markets around the world and sometimes to even Western products and processes. For these reasons, reengineering projects could generate co-invented U.S. patents.

There were also cases in which the multinational's global center of expertise in a particular area was contained within the Chinese R&D facility. This was often because the Chinese market was an especially important domain of application. For instance, one engineering conglomerate active in power generation technology now housed its international center on coal-fired power plant technology within its China R&D laboratory. The reasons given for this by the R&D manager were simple. The Western nation in which he began his career had not built a new coal-fired power plant in about forty years. In China, a new coal-fired plant was being built every two weeks. Similarly, it is not surprising that an IT firm had placed its global center of excellence in written character recognition technology in China, a country with a character-based written language. Over time, it is reasonable to expect that the number of cases in which the global research agenda is being driven from a China-based lab will increase.

Fourth, our interviewees generally confirmed both the communications challenges posed by intercontinental research collaboration and the role of modern telecommunications technologies in meeting these challenges. Videoconferencing and software design tools that allowed a globally distributed team to work with the same virtual prototypes were important mechanisms facilitating research collaboration. R&D engineers noted that videoconferences with collaborators around the world were now a routine practice in most projects. It was also seen as important for the firms to ensure a steady flow of personnel between the various global R&D centers. Face-to-face communications helped provide a foundation of basic understanding and trust that later internet-mediated interaction could build on. Most interviewers agreed that, without modern communications tools, this kind of globally distributed R&D effort would be impossible.

Fifth, our interviewees noted that the Chinese government was clearly hoping to close the gap in engineering capabilities between multinationals and local firms. In recent years, the Chinese government has gone so far as to subsidize international patenting costs, and one of our interviewees predicted that, within a few years, we would see a rising tide of U.S. patent applications from indigenous Chinese enterprises. So far, at least, most of these patents were judged to be of limited quality.

Finally, in communications with some of our interviewees in the months since December 2009, we have noted a shift in the general attitude with which multinationals have viewed China as a business climate. In December, our interviewees complained about various features of the Chinese business climate – including China's imperfect intellectual property rights system – but the overall impression was a positive one. China was represented as a challenging business environment, but one that had grown steadily more open, transparent, and attractive to Western business. Many interviewees expressed optimism that even China's notoriously imperfect enforcement of intellectual property rights would continue to improve substantially, and not just in the major business centers where it was already seen as being reasonably good. By the summer of 2010, however, there had been a notable cooling of enthusiasm, and this was related to an increasing rhetorical emphasis on "indigenous innovation" and a widely circulated proposal to prioritize "indigenous products" in government procurement. The degree to which Chinese government policy was likely to become substantially less welcoming to international co-invention was still unclear, but, among our interviewees, concerns were rising.

V. Empirical Model and Results

A. Hypotheses

In Section II, we argued that the R&D process itself can be sliced into multiple stages, and countries participate in different stages according to their comparative advantage (Hummels et al., 2001; P. Krugman et al., 1995; Yi, 2003). Previous research found that invention being generated in developing countries is incremental in nature (Puga & Trefler, 2010; Zhao, 2006). These findings suggest that Chinese and Indian researchers under the sponsorship of MNCs, are likely to undertake low-end tasks, while Western researchers undertake high-end tasks. As such, we might expect that a comparison between Chinese or Indian invention with and without Western intellectual input would suggest that patents with Western intellectual input are of substantially higher quality than those without. The same considerations might suggest that even within the same MNC patents with Chinese input might be of lower quality than the patent output of all-Western inventor teams.

However, prior literature has established that researcher collaborations may catalyze synthetic effects (Kogut & Zander, 1992; Singh, 2008; Weitzman, 1998). Though these studies mainly focus on collaborations among researchers across or within advanced economies, we suspect, at least to some extent, similar effects may also be observed among co-invention teams in emerging economies. Our field work also suggests that Chinese researchers can and do direct research projects and provide high-quality research input, and that the patterns of intellectual interaction within international teams are more complex and varied than that suggested by traditional economic theory. The extremely high quality of Chinese graduates from the leading universities and the rise of China as a strategically significant market raises the possibility of a synergy between multinational technological capability and China-based research teams. This could be producing outcomes of high quality, even relative to what multinationals produce in the industrialized world. A similar argument can be made to India-based invention.

For this reason, we will seek to measure the relative quality of China- and India-based USPTO patents in multiple ways. First, we will compare co-invention generated in China and India with patents created by purely domestic researcher teams, and compare inventions created by MNCs with those generated by indigenous enterprises. The traditional theory of "vertical specialization" would suggest our first hypothesis.

Hypothesis 1 (H1). *Co-invention and MNC sponsorship are associated with relatively higher patent quality.*

We then compare the quality of the patents MNC generated in China and India (both co-invention and purely domestic patents) with the patents the same MNCs produced in their home countries (with all inventors residing in the MNC's home country). A view based on traditional theory would suggest our second hypothesis.

Hypothesis 2.1 (H2.1). *Patents produced by MNCs in emerging economies are of lower quality than those produced by the same MNCs in their home countries, and even co-invented patents generated in emerging economies are of marginally lower quality.*

However, the possible synergy between multinational technological capability and China-based research teams would suggest an alternative to Hypothesis 2.1.

Hypothesis 2.2 (H2.2). *Co-invention generated by MNCs could be of equivalent or even higher quality than patents produced by the same MNCs in their home countries.*

Besides overall comparisons, we also want to assess the dynamics of the patent quality across different patent categories. Observations from our field study suggest it takes time for talented Chinese researchers to become "mature." This implies our next hypothesis.

Hypothesis 3 (H3). *Patents (including co-invention) produced by MNCs with little experience of doing R&D in emerging economies might be of lower quality than those produced by the same MNCs in their home countries; patents (including co-invention) produced by MNCs with more experience of doing R&D in emerging economies might be of equivalent or higher quality than those produced by the same MNCs in their home countries.*

We have pointed out the possibility that international co-invention could accelerate the advancement of indigenous innovative capability. After a period of time working under the tutelage of multinationals, talented Chinese and Indian engineers could put their skills and experience to work for indigenous firms that increasingly compete directly with the MNCs. Our field interviews suggested that this was not yet a significant problem, but it would be natural for MNC managers to discount the ability of their local rivals to catch up through strategic recruiting of former MNC employees. It will therefore be important to see what the data say, if anything, about the degree to which gaps in innovative capacity between indigenous R&D efforts and those of the multinationals are closing over time.

At this stage, however, it is difficult to capture such a dynamic process. There is no clear turning point in our dataset at which we could usefully divide the data into an "early period" with limited catch-up and a later period with more complete convergence of innovative capacity. This stems in part from the fact that some multinationals entered the Chinese and Indian market early and began building strong R&D operations ten and more years ago, whereas other multinationals have only begun to establish their research capacity much more recently. It may be that early entrants have not only incubated a strong team of local engineers within their labs, but also seeded a number of local spin-off entrants with seasoned R&D personnel. But the innovative performance of these veterans of MNC R&D activity is diluted by an inflow of newly graduated and relatively inexperienced local Chinese and Indian researchers. The ideal way to measure convergence thus would be to compare MNC-employed engineers and engineers employed in indigenous firms who are at the same stage in their inventive careers. This requires the tracking of individual inventors over time. This will be the focus of future research, but we will not attempt such a fine-grained comparison in this paper. Instead, we will arbitrarily divide the data into three periods to see if there is evidence of a declining gap in relative invention quality between indigenous enterprises and MNCs over time. Specifically, this leads us to our last hypothesis.

Hypothesis 4 (H4). *The gap in patent quality between indigenous enterprises and MNCs is declining, or unchanged over time.*

B. Empirical Model

As already noted, we regard patent citations as an indicator of patent quality. Patent citations serve an important legal function because they delimit the scope of the property rights awarded by the patent. Thus, if patent B cites patent A, it implies that patent A represents a piece of previously existing knowledge upon which patent B builds, and over which B cannot have a claim (B.H. Hall et al., 2001). Alcácer & Gittelman (2006) showed that patent citations are an imperfect measure of knowledge spillovers between inventors because examiners add a significant fraction of the citations after the initial patent application. It is obviously problematic to consider these examiner-added citations as reflecting the sources of inspiration of the inventor herself. However, we use citations as an indicator of patent quality rather than a measurement of knowledge spillover. Prior literature has shown that total citations received are highly correlated with the underlying quality of the invention (Bronwyn H Hall, Jaffe, & Trajtenberg, 2005; Harhoff, Narin, Scherer, & Vopel, 1999; A.B. Jaffe, Trajtenberg, & Fogarty, 2000; M. Trajtenberg, 1990). More valuable invention is more frequently cited by subsequently granted patents. Thus citations received can be used to proxy for the quality of each patent.

Two issues arise when using patent citations as a measure of patent quality: truncation due to time and difference due to technological fields. Prior research has demonstrated that it takes time for patent citations to occur (B.H. Hall et al., 2001). The number of citations made to a patent granted just one year ago may be only a small fraction of citations that will occur over the following fifteen years. It is easy to see that patents of different vintages are subject to different degrees of "citation truncation" (B.H. Hall et al., 2001) as one cannot simply tell that a patent from 2005 with 25 citations is better or worse than a 2008 patent with only 10 citations. Similarly, one cannot tell that an electronic device patent granted in 2000 with 25 citations is better or worse than a pesticide patent granted in the same year with only 5 citations. To address the issue of truncation, we will control for patent grant years and use count models with "exposure" (Adrian, Cameron & Trivedi, 1998) in all regressions. To address the issue of technological difference, we control for major technological fields in our empirical analysis.

Our basic model regresses the citations a patent has received on a number of control variables. These variables include a dummy variable indicating whether or not it was a product of international co-invention, a dummy variable indicating whether or not it was produced under multinational sponsorship, etc. A significantly positive coefficient on a control variable of interest indicates a higher number of citations received and suggests a higher quality of the patent.

We apply the Poisson Quasi Maximum Likelihood (PQML) estimation to our regressions for two reasons. First, patent citations are integer counts and have a minimum value of zero. This is the definition of a count variable. Second, our data are overdispersed and the PQML estimator is consistent under the weaker assumption of the correct conditional mean specification and no restriction on the conditional variance distribution (A. Colin Cameron & Trivedi, 2005; J. M. Wooldridge, 2002; J. Wooldridge, 1999). While a Negative Binomial (NB) mode can also deal with the "overdispersion" issue, it assumes that the conditional variance has a gamma distribution. The tradeoff between the NB model and the PQML model is obvious: if the gamma assumption about the conditional variance is correct, then the NB estimator will be more efficient, but if the gamma assumption does not hold, then the NB estimator will be biased. Overall, the PQML model is more likely to result in less significant results than the NB model. On one hand we are concerned with the misspecification of the NB functional assumption, and on the other hand we want to be conservative about our main results. Thus, we tend to regard the PQML model as preferable. However, we also run regressions using the NB model as a robustness check. The NB estimators are broadly consistent with the PQML estimators as presented in this paper and are available upon request. PQML estimators can be obtained by estimating an unconditional Poisson model with robust standard errors (A. Colin Cameron & Trivedi, 2005; J. Wooldridge, 1999).

Our dependent variable *Y* is the number of citations a patent has received, a quantity also referred to in literature as the count of "forward citations." We count the cumulative number of citations a patent has received as of the end of 2010, when our citation dataset ends. We drop the patents granted in 2010 in order to get at least one year of citation counts for the patents used in regression analysis.

We exclude self citations in the citation counts. Self citation happens when a patent cites a patent owned by the same assignee (firm). Two issues make the non-self citation a favorable measurement compared to inclusion of self citation. In the first place, we are concerned that an inventor working in the Chinese and Indian R&D subsidiaries of a multinational might have a higher propensity to cite her own or her colleagues' patents than an inventor working in the MNC's home country or somewhere else. This problem is exacerbated by the very rapid growth of China- and India-based U.S. patents in recent years. Second, Zhao (2006) has suggested that patents created in a developing country and resulting from multinational sponsorship are subject to more self citations than those created in advanced countries due to MNCs' internal IP protection arrangement. Based on these considerations, we regard the number of citations a patent receives, excluding self citations, as a better indicator of the "true" quality than those including self citations.

C. Cross-firm within-country Comparisons

To test H1, we run regressions over China- or India-based samples including all patents that are granted to Chinese or Indian inventors by the end of 2009 and assigned to a firm entity. Our regressions take the following form:

(1) $$E(C_i) = PatAge \cdot \exp(\alpha_0 + \alpha_1 Coinv_i + \alpha_2 MNC_i + \alpha_3 PatStock_f + \alpha_4 TeamSize_i + \alpha_5 Gdelay_i + H_i + T_i)$$

where *C* is the total number of non-self citations a Chinese- or Indian-based patent *i* receives by the end of 2010. The key coefficients of interest are those on the *Coinv* and *MNC*, which are dummy variables indicating patents that are co-invented and ones that are assigned to a multinational assignee. The key task here is to compare co-invented and MNC-owned patents generated in China and India with patents generated by indigenous firms in the same countries. In addition, we also control for other factors that may influence citations. *PatStock* denotes the assignee f's three-year patent stock before the date of application. We used *PatStock* as a proxy for a company's inventive productivity at the time of patent creation. *TeamSize* is the total number of inventors on the patent. $Gdelay$ is the year delay between the patent's application date and grant date. As mentioned earlier, forward citations are truncated in a sense that recently granted patents have less time to garner citations than earlier ones. To correct this, we estimate the PQML mode with "exposure" (Adrian Colin Cameron & Trivedi, 1998). $PatAge$ is the age of the patent, which serves as the exposure variable and is calculated as the days between the application date and the end of 2010. Thus the natural log of $PatAge$ enters as an offset in the conditional mean. "Exposure" assumes that the likelihood of events is not changing over time. However, this may not be true, so we also include grant year fixed effects *T* and HJT subcategory fixed effects.

Table 3 shows the results for China-based U.S. patents, and Table 4 shows the results for India-based patents. In both tables, Column 1 includes a co-invention dummy; column 2 includes a MNC assignee dummy; Column 3 includes both dummies. For China-based data, across all three specifications, the coefficients on the co-invention dummy and the MNC assignee dummy are positive and significant. The coefficient of 0.264 in Column 1 can be interpreted to mean that co-invented patents receive more than 30% (exp(0.264)-1) non-self forward citations than purely Chinese generated patents. Similarly, Column 2 suggests that MNC-sponsored patents—with a multinational assignee—receive 50% more citations than ones under the sponsorship of Chinese indigenous enterprises, whether they are co-invented or not. When we control for both co-invention and MNC sponsorship, we can see that the cumulative impact (co-invented and MNC-sponsored) amounts to a 60% quality premium. In India, too, there is a 27% quality premium associated with co-invention and a 45% quality premium associated with MNC sponsorship. It turns out that in China there are indigenous firms engaging in co-invention, but in India almost all co-invention is found in MNC-sponsored patents. So, in India, we cannot estimate much of a separate coefficient for the MNC assignee dummy when we also control for co-invention dummy. The two dummies are almost completely collinear. It is also notable that team size has a positive and significant effect on patent quality.

We acknowledge that the biases and issues that beset patent citation data may especially complicate quality comparisons between indigenous patenting and MNC patenting, so we want to proceed with caution. But the data do suggest that co-invented and MNC-sponsored patents are more technologically sophisticated and valuable than indigenous patents, as well as more numerous.

[Insert Table 3 and Table 4 here]

D. Cross-border Comparisons within MNCs

Next, we want to know whether patents produced by MNCs in emerging economies are of equivalent, lower, or higher quality than those produced by the same MNCs in their home countries (H2). To do so, we keep only those China- and India U.S. patents that are assigned to (owned by) MNCs from 1996 – 2009. We then match them to the patents that are created by inventors in the MNCs' home countries, with the same firm assignee code, three-digit technological class and grant year. Patents without a match are dropped. We drop patents granted in years before 1996 to ensure that we have a reasonable number of Chinese and Indian domestic patents for comparison. Undertaking the same matching procedure as described above, we construct a second sample that only includes MNCs with more than 30 China- or India-based patents by the end of 2010. Our specification is as follows:

(2) $$E(C_i) = PatAge \cdot \exp(\alpha_0 + \alpha_1 Coinv_i + \alpha_2 Domestic_i + \alpha_3 PatStock_f + \alpha_4 TeamSize_i + \alpha_5 Gdelay_i + F_i + H_i + T_i$$

where *Coinv* is a dummy variable indicating whether or not an MNC-sponsored patent is co-invented. $Domestic$ is a dummy variable indicating whether or not an MNC-sponsored patent is generated exclusively by domestic inventor teams in China or India. Since we compare patents within the boundaries of the MNC, we also include F_i, which denotes assignee (firm) fixed effects. All other variables are defined as in specification (1).

We also want to investigate the dynamics of the quality difference between patents produced by MNCs in emerging economies and those produced by the same MNCs in their home countries over time (H3). Using the basic specification as in (2), we interact *Coinv* and $Domestic$ dummies with period dummies that are based on the length of a firm's experience generating USPTO patents through the work of China- or India-based inventors when the patent application was filed. We divide our data into three periods: 1 – 5 years of China or India experience, 6 –10 years of China or India experience, and more than 10 years of China or India experience.

Results for China are presented in Table 5 and Table 6. Table 5 shows that MNC's China-generated patents appear to be just as good as the patents generated at home. There is no statistically significant difference in measured patent quality. The power of the test is obviously constrained by the small number of Chinese patents, but the fact that the point estimates on our China-origin dummies are positive is quite striking.

With regard to the dynamics of the quality difference, results presented in Table 6 show that that patents generated in China by MNCs with more than a decade of experience doing R&D in China are cited significantly more than the patents generated by the same MNCs at home. And this is true for both co-invented patents and patents generated for MNCs by purely Chinese inventor teams. Column 1 in Table 6 suggests that co-invented patents generated by MNCs with more than a decade of experience doing R&D in China receive 71% more non-self forward citations than those generated at home; patents generated by MNCs with more than a decade of experience doing R&D in China by purely Chinese inventor teams receive 68% more non-self forward citations. Column 2 suggests the comparison results for MNCs having more than 30 China-based patents. One can see that there is a 93% quality premium associated with the China-based co-invented patents, and a 69% quality premium associated with the purely Chinese generated patents.

These results are consistent with the view that it takes time to build a good research team in China, but once it has been established, the quality of output is not only as same as in the MNC's home countries, but higher. The results are also consistent with the possibility of a synergy between Western experience and Chinese talent that allows firms to undertake at least some research more effectively in China than elsewhere, even at MNC's home countries. At the very least, the data are strongly suggestive of rising invention quality over time for MNC's China R&D operations. There are at least two alternative ways of interpreting these positive coefficients. First, Chinese inventions are less likely to be written up as USPTO patent applications as a matter of course than those generated in MNCs' home countries, so our results reflect a selection issue. Second, as MNCs are rushing to engineer/reengineer products for the China market, Chinese patents are in a "hot area" that the technology class match and HJT subcategory dummies may not capture.

[Insert Table 5 and Table 6 here]

As one can see in Table 7, it is a different story in India: patents generated by MNCs in India appear to get systematically fewer non-self citations than those generated at home. In most cases, the differences are statistically significant at the standard levels. When we look at the coefficients on interaction terms similar to the ones we created for MNC patents in China, the point estimates in Table 8 are all negative. Statistically significant negative quality differences fade for co-invented patents, but not for those with purely Indian inventor teams. Depending on how one looks at it, one can see limited evidence of a relative quality improvement over time in India, but the results are much weaker than for China.

[Insert Table 7 and Table 8 here]

E. The Dynamics of the Quality Gap between MNCs and Indigenous Firms

The fact that the quality of inventions generated by Chinese inventors working for MNCs seems to rise sharply over time as MNCs gain more experience doing R&D in China raises another question: are those increasingly savvy Chinese engineers working for MNCs starting to migrate over to indigenous firms, and can we find evidence that the quality difference between MNCs and indigenous firms is narrowing over time? (H4) We can examine this by dividing patents used for specification (1) into time periods according to their grant year and interacting our $Coinv$ and MNC dummies with these period dummies. We arbitrarily divide our China- and India-based patent data into three periods: grant years before 2000, grant years from 2000 – 2004, and grant years from 2005 – 2009.

We specify the regressions as follows:

(3) $$\mathrm{E(C_i) = PatAge \cdot exp\,(\varphi_0 + \varphi_1 Coinv_i * Gyear_{<2000} + \varphi_2 Coinv_i * Gyear_{2000-2004} + \varphi_3 Coinv_i * Gyear_{2005-2009} + \varphi_4 MNC_i * Gyear_{<2000} + \varphi_5 MNC_i * Gyear_{2000-2004} + \varphi_6 MNC_i * Gyear_{2005-2009} + \varphi_7 PatStock_f + \varphi_8 TeamSize_i + \varphi_9 Gdelay_i + H_i + T_i}$$

Table 9 presents results for China. It can be seen from the interaction terms that the quality premium associated with co-invention does appear to be fading over time. In the most recent period, the point estimates are positive but no longer statistically significant. However, the quality premium associated with MNC sponsorship does not appear to be fading over time. Chinese engineers are creative, but they are most productive when they work for MNCs. And interviews with Chinese engineers suggested that Chinese engineers who want to do world class R&D find better opportunities to do so in MNCs.

Table 10 presents results for India. The comparisons are complicated by smaller numbers of patents and by the more complete lack of co-invention outside of MNCs. But to the extent that we have statistically significant coefficients, the quality difference between purely domestic patents and co-invented patents, and the quality gap between MNC sponsorship and indigenous sponsorship persists.

The above results suggest that whereas there is evidence of possible spillovers from co-invention teams to purely indigenous teams within MNCs in China, spillovers from MNCs to indigenous enterprises in both China and India are very limited. This is consistent with what we learned from our field study.

[Insert Table 9 and Table 10 here]

VI. Conclusions and Implications

In this paper, a large portion of our effects has been devoted to analyzing the patterns found in China- and India-based U.S. patents. In doing so, we found that a large majority of China's U.S. patents are owned by non-Chinese MNCs, with Taiwanese and U.S. firms playing an important role. Similarly, a majority of India's U.S. patents are owned by the U.S. MNCs. We have shown that China- and India-based U.S patents are technologically concentrated in IT-related fields. We suspect that the prevalence of software-based design and engineering tools in these domains might have facilitated co-invention and long distance R&D efforts. We explored the geographic distribution of Chinese and Indian inventors and found that the majority of Chinese and Indian inventors are clustered in several of the most economically advanced regions in both countries.

We complemented statistical analyses of the patent data with in-person interviews with researchers in multinational R&D subsidiaries in China. These interviews confirmed that China-based R&D personnel are increasingly seen as an integral part of MNCs' global R&D operations, and they are increasingly contributing to innovations whose ultimate market targets are outside of China. However, the patterns of international collaboration within MNCs are more complex than those that arise directly out of traditional views of comparative advantage. Our interviews supported the view that modern advances in telecommunications technologies have been instrumental in facilitating international R&D collaborations. Our interviews also supported the view that, despite impressive progress by indigenous Chinese firms, a gap remains in innovative capability, vis-à-vis the MNCs, and that is not expected to close in the immediate future. This view was further verified by our empirical analysis.

We have used non-self patent forward citations to compare the quality of patents in multiple ways. Our within-border, across-firm comparisons suggest the following main conclusions:

- Co-invented patents are of higher quality than purely indigenous patents;
- Patents under the sponsorship of MNCs are of higher quality than those under the sponsorship of indigenous enterprises;
- A patent quality gap between MNCs and indigenous firms persists in China and India.

Our within-MNC, across-border comparisons result in the following main conclusions:

- Aggregating over time, co-invented and purely Chinese invented patents are equivalent in quality to patents generated by the same MNC in the home countries;
- Aggregating over time, co-invented and purely Indian invented patents are of lower quality than patents generated by the same MNC in the home countries;
- China-based patents have risen sharply in relative quality over time compared with patents generated by the same MNC in the home countries;
- The quality improvement of India-based patents is more limited than that in China.

The results for China indicate the possibility of a synergy between high quality (and still relatively low cost) Chinese engineering labor and multinational research experience. This synergy allows MNCs to do at least some R&D more effectively in China than they could at home, even in quickly evolving technological domains. However, we did not find similar evidence in the case of Indian engineering so far.

Our study suggests that the increase in U.S. patents in China and India are to a great extent driven by MNCs from advanced economies and are highly dependent on collaborations with inventors in those advanced economies. As such, China and India's striking rise in innovation may represent less of a challenge to conventional views of development economics. The view that the rise of innovation in China and India is undermining the traditional position of technological leadership enjoyed by the U.S. and other advanced industrial economies has been exaggerated.

Nevertheless, the world of R&D is indeed undergoing a major change. MNCs' innovation networks are spanning the globe. The increase in R&D activity in emerging economies such as China and India represents an emerging trend of international division of R&D labor in industrial R&D process. Evidence from our study indicates that as globalization continues, emerging economies like China and India that possess a huge scientific and engineering talent pool and large markets have become an increasingly important part of MNCs' global innovation networks. By undertaking R&D in emerging economies, MNCs can now provide innovative technologies to global markets at a lower cost and introduce products more suitable for emerging markets.

All of this leads us to the possibility of a win-win outcome for a more integrated global innovation system that can benefit both emerging and advanced economies. By participating in MNCs' R&D networks, emerging economies not only bring in more investment and create more employment, they can also participate in the generation of new technology at an earlier stage in the economic development process, even before they have internally developed all of the necessary categories of capabilities required for the complete R&D process. Their participation can also shift the direction of global R&D in a way that creates more goods and services suited to the income levels and conditions of emerging markets. Jones (2009) suggests diminishing productivity in R&D as the "burden of knowledge" rises, but this can by offset by adding enough new scientists into a globalized innovation process, generating gains at the global level. By letting their companies do R&D in countries like China and India, advanced economies will also benefit from a faster pace of innovation and more rapidly expanding stock of knowledge.

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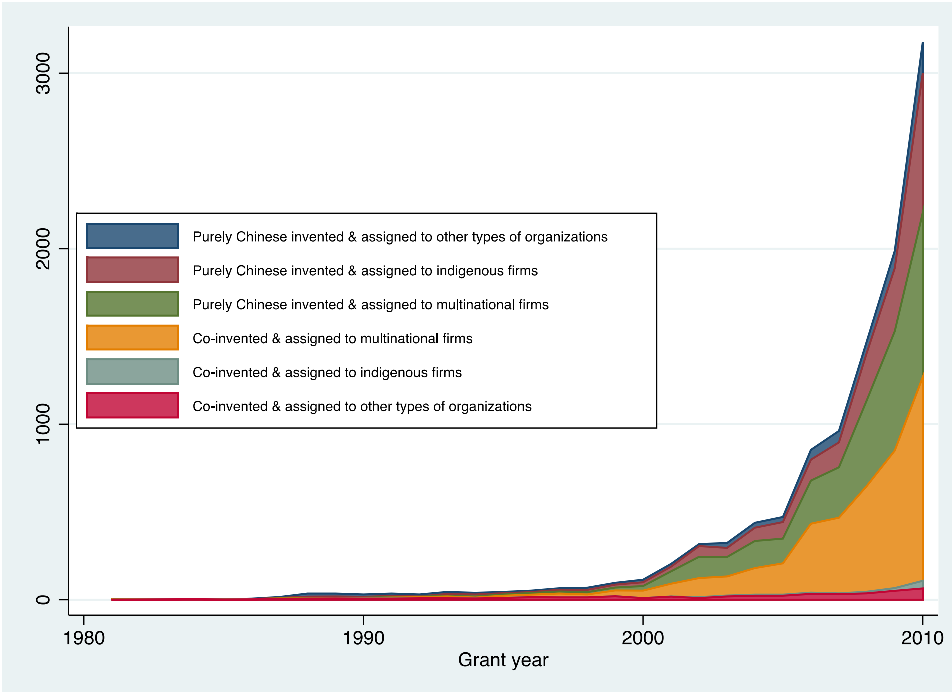

FIGURE 1: THE RISE OF CO-INVENTED AND MNC-SPONSORED USPTO PATENTS IN CHINA

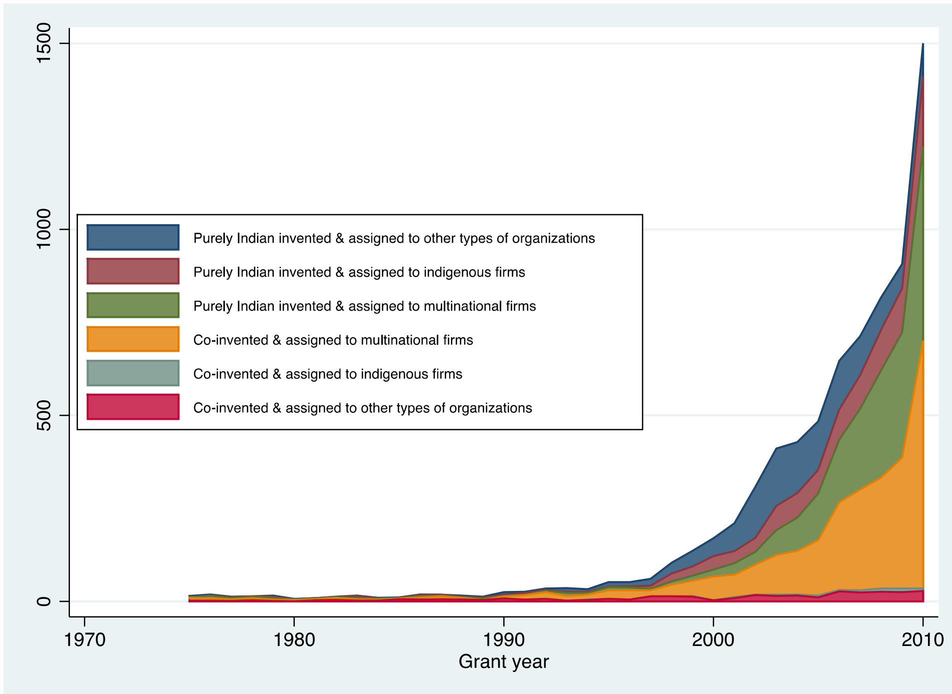

FIGURE 2: THE RISE OF CO-INVENTED AND MNC-SPONSORED USPTO PATENTS IN INDIA

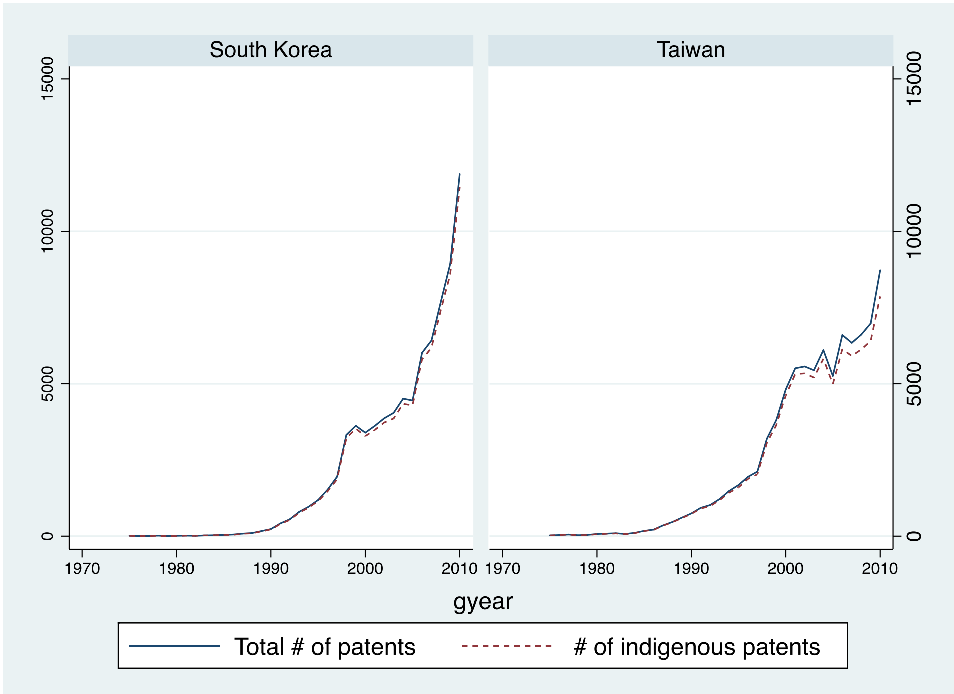

FIGURE 3: PATTERNS OF USPTO PATENTING FROM SOUTH KOREA AND TAIWAN

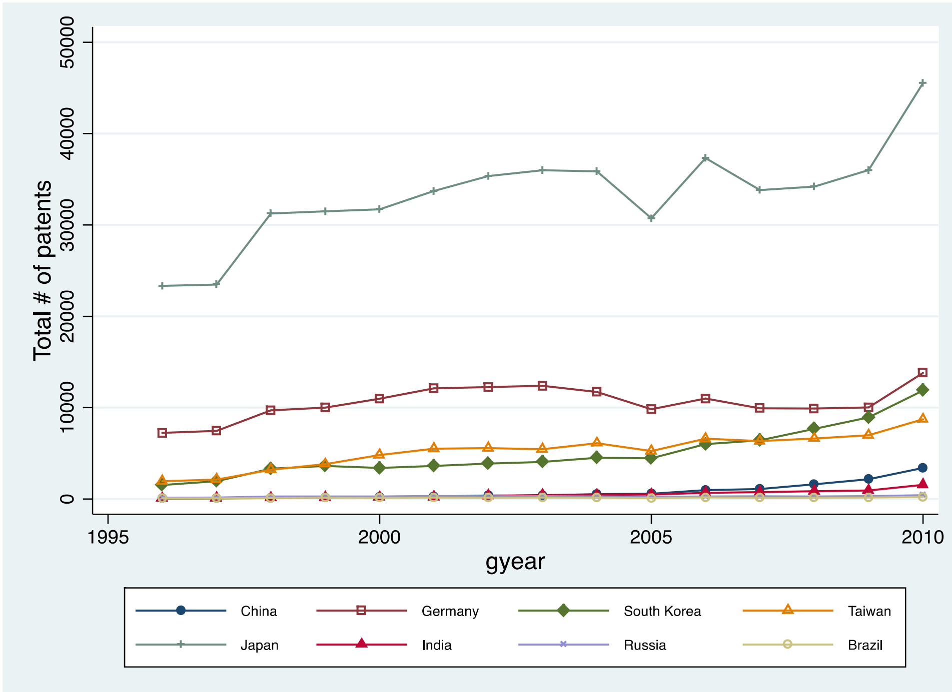

FIGURE 4: CHINA- AND INDIA-BASED USPTO PATENTING IN COMPARATIVE PERSPECTIVE

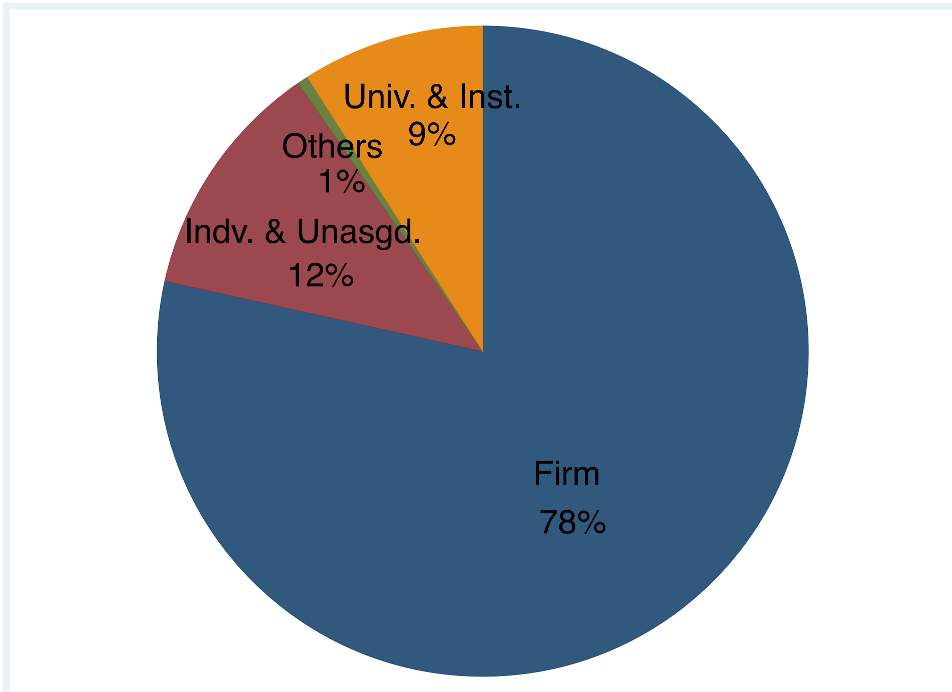

FIGURE 5: SHARE OF CHINA-BASED USPTO PATENTS BY ASSIGNEE TYPE

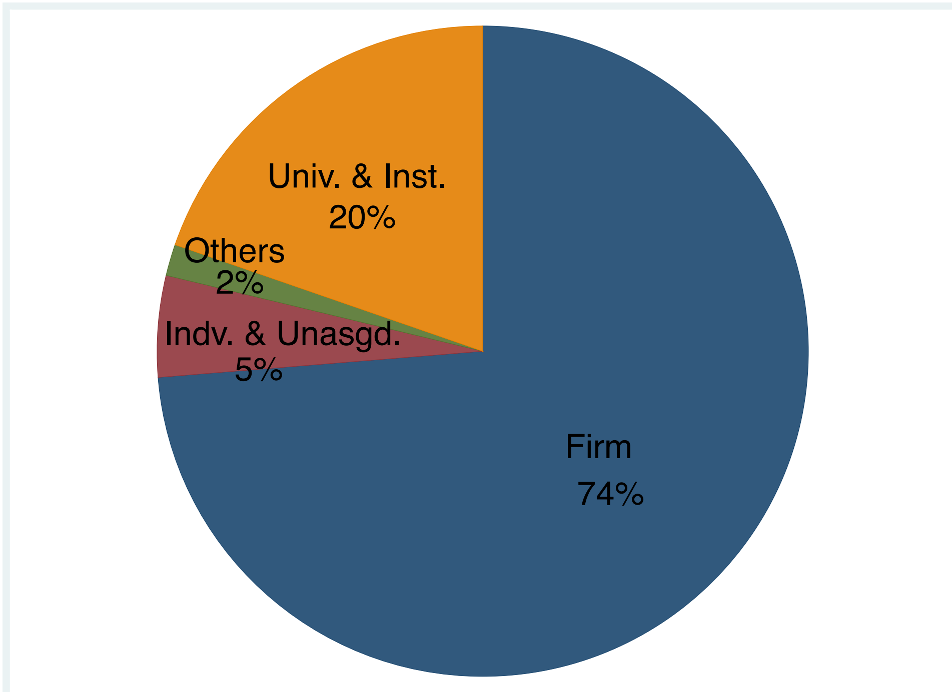

FIGURE 6: SHARE OF INDIA-BASED USPTO PATENTS BY ASSIGNEE TYPE

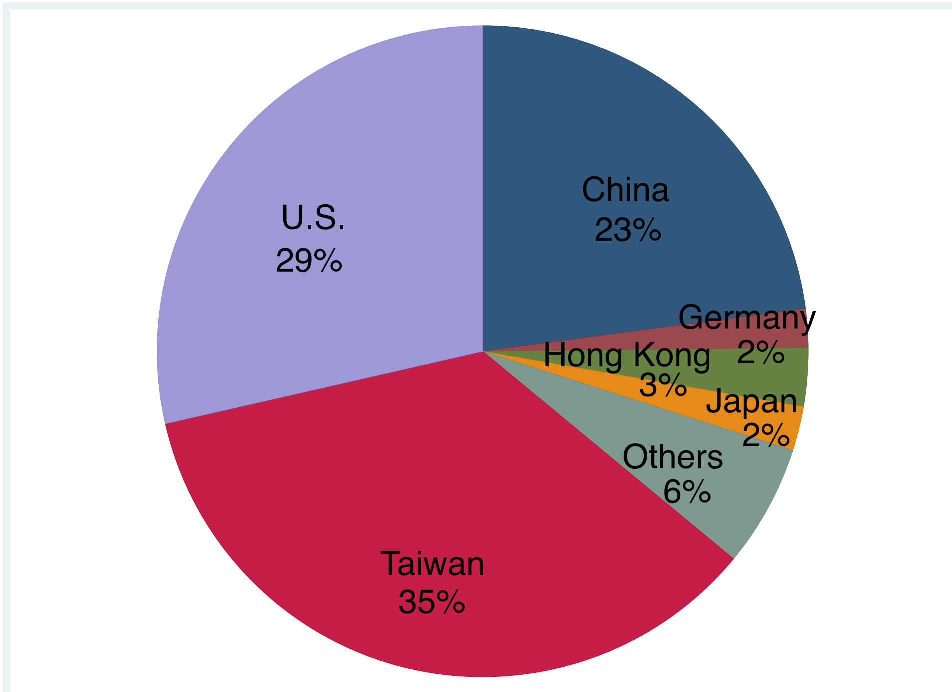

FIGURE 7: SHARE OF FIRM-OWNED CHINA-BASED USPTO PATENTS BY ASSIGNEE NATIONALITY

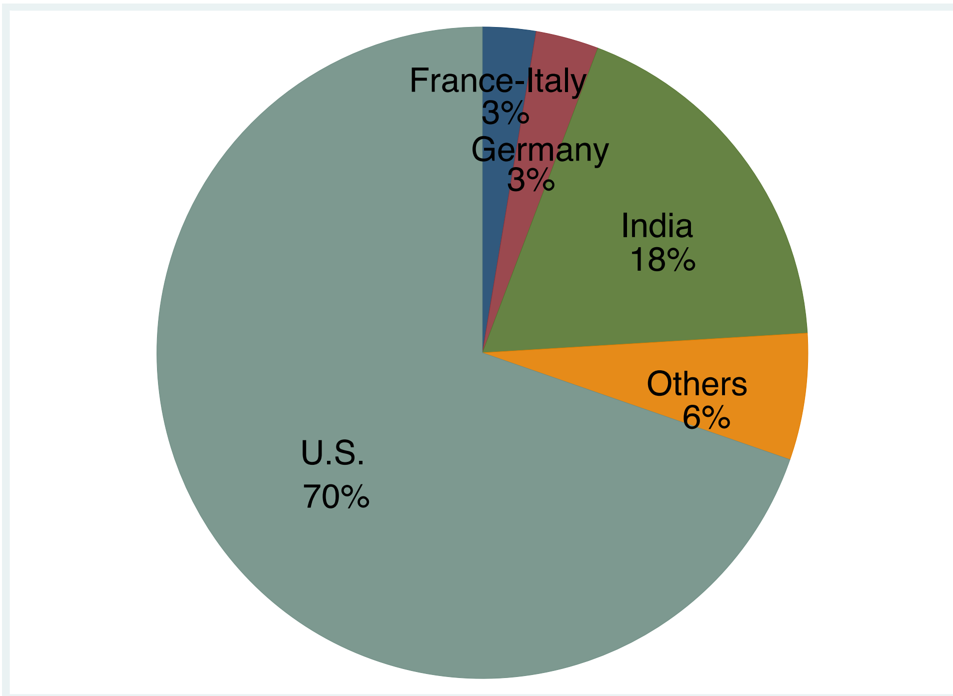

FIGURE 8: SHARE OF FIRM-OWNED INDIA-BASED USPTO PATENTS BY ASSIGNEE NATIONALITY

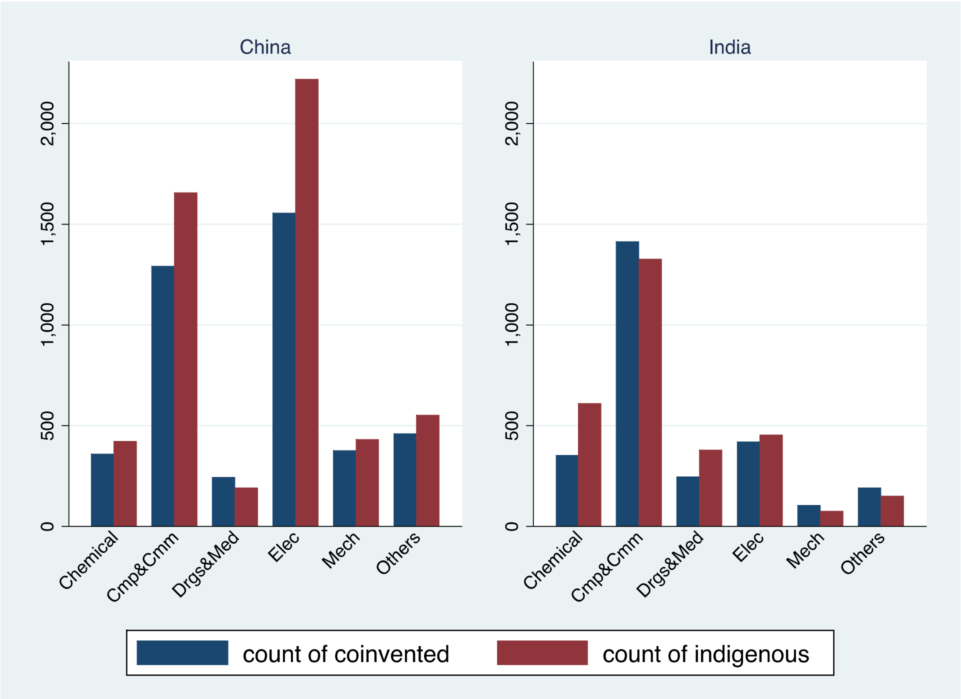

FIGURE 9: FIRM-OWNED CHINA- AND INDIA-BASED USPTO PATENTS ACROSS HJT TECHNOLOGY CATEGORIES

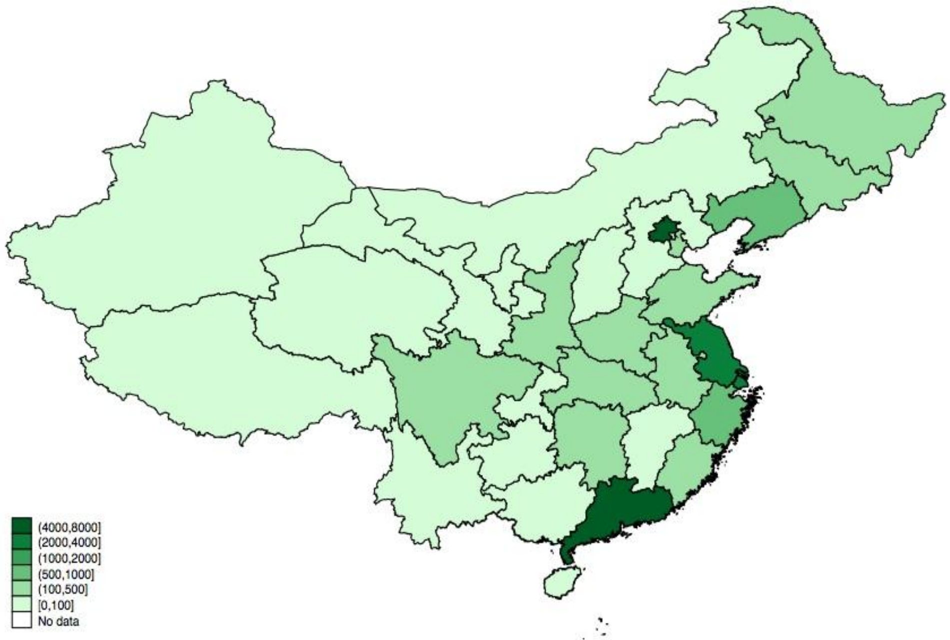

FIGURE 10: GEOGRAPHIC DISTRIBUTION OF CHINESE INVENTORS (MAINLAND ONLY) OF USPTO PATENTS

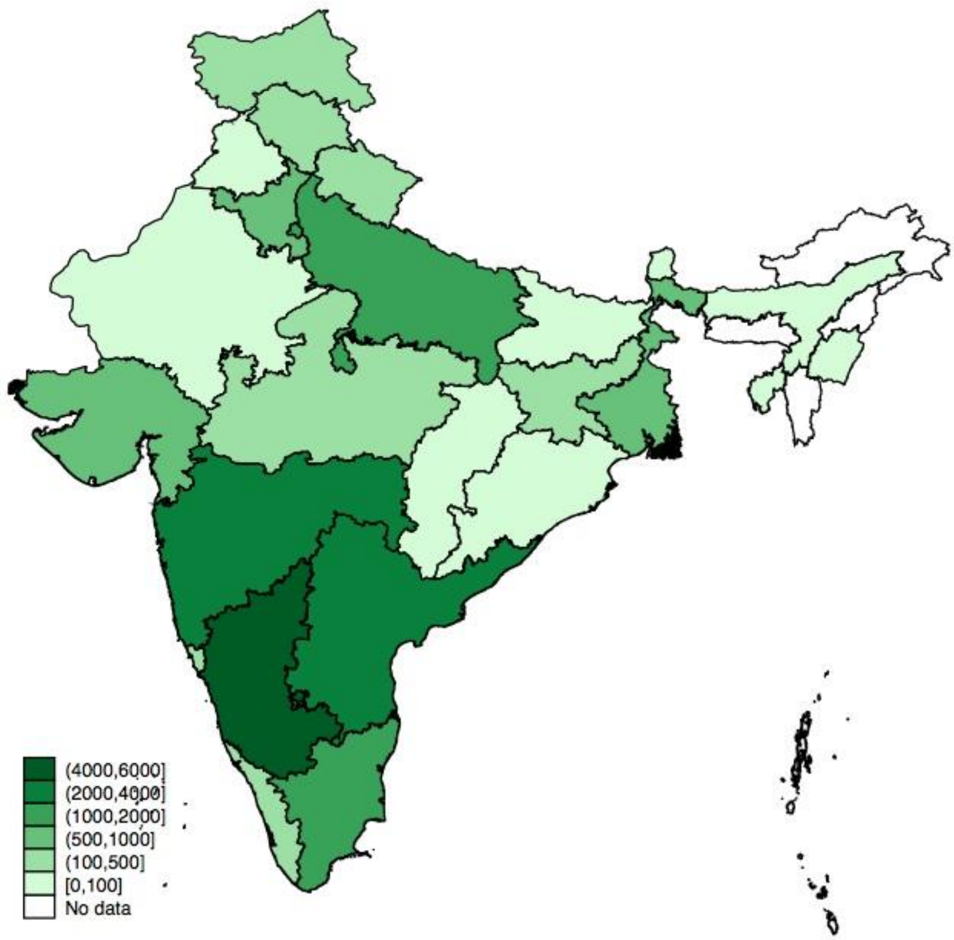

FIGURE 11: GEOGRAPHIC DISTRIBUTION OF INDIAN INVENTORS OF USPTO PATENTS

TABLE 1: TOP 10 FIRM ASSIGNEES OF CHINA-BASED USPTO PATENTS

Rank	Assignee Name	Nationality	Number	Share
1	HON HAI PRECISION IND. CO., LTD.*	Taiwan	2,958	30.36%
2	MICROSOFT CORPORATION	U.S.	765	7.85%
3	HUAWEI TECHNOLOGIES CO., LTD.	China	430	4.41%
4	INTEL CORPORATION	U.S.	197	2.02%
5	INVENTEC CORPORATION***	Taiwan	177	1.82%
6	CHINA PETROCHEMICAL CORPORATION (SINOPEC)**	China	173	1.78%
7	SEMICONDUCTOR MANUFACTURING INTERNATIONAL (SHANGHAI) CORPORATION	China	139	1.43%
8	IBM	U.S.	129	1.32%
9	SAE MAGNETICS (H.K.) LTD.****	Hong Kong/Japan	128	1.31%
10	METROLOGIC INSTRUMENTS INC.	U.S.	92	0.94%

* Figure here represents the sum of patents taken out under HON HAI (FOXCONN) and its China-based subsidiaries.

** The original dataset confused CHINA PETROCHEMICAL CORPORATION (SINOPEC), a Chinese company, with CHINA PETROCHEMICAL DEVELOPMENT CORPORATION (CPDC), a Taiwanese company. The figure presented here is after correction.

*** Figure here represents the sum of patents taken out under INVENTEC CORPORATION, INVENTEC APPLIANCE and INVENTEC ELECTRONICS (NANJING) CO..

**** SAE MAGNETICS (H.K.) LTD. is a wholly owned subsidiary of TDK, a Japanese multinational electronics manufacturer. However, SAE MAGNETICS (H.K.) LTD. itself has manufacturing branches in mainland China. For our research purpose, we will treat it as a Hong Kong firm in our analysis.

TABLE 2: TOP 10 FIRM ASSIGNEES OF INDIA-BASED USPTO PATENTS

Rank	Assignee Name	Nationality	Number	Percentage
1	GENERAL ELECTRIC COMPANY	U.S.	464	8.12%
2	IBM	U.S.	450	7.87%
3	TEXAS INSTRUMENTS, INCORPORATED	U.S.	418	7.31%
4	CISCO TECHNOLOGY, INC.	U.S.	162	2.83%
5	INTEL CORPORATION	U.S.	151	2.64%
6	STMICROELECTRONICS PVT. LTD.*	France & Italy	151	2.64%
7	HONEYWELL INTERNATIONAL INC.	U.S.	126	2.20%
8	SYMANTEC OPERATING CORPORATION	U.S.	116	2.03%
9	RANBAXY LABORATORIES LIMITED	India	102	1.78%
10	MICROSOFT CORPORATION	U.S.	96	1.68%

* STMICROELECTRONICS PVT. LTD. is the Indian subsidiary of STMicroelectronics, a French-Italian multinational electronics and semiconductor manufacturer.

TABLE 3: CROSS-FIRM COMPARISON WITHIN CHINA (1981-2009)

DV: # of non-self citations received as of the end of 2010	(1) Control for co-invention	(2) Control for assignee type	(3) Control for Both
Chinese co-invention	0.264***		0.160*
	(0.0531)		(0.0654)
Multinational assignee		0.411***	0.310***
		(0.0741)	(0.0906)
3-year patent stock prior to application date (in thousands)	0.0356	0.0223	0.0256
	(0.0199)	(0.0221)	(0.0219)
Grant delay in years	0.131***	0.134***	0.131***
	(0.0267)	(0.0266)	(0.0266)
Team size	0.0438**	0.0581***	0.0490***
	(0.0150)	(0.0133)	(0.0148)
Constant	-6.909***	-7.042***	-7.081***
	(0.834)	(0.855)	(0.862)
Grant year dummy	Yes	Yes	Yes
HJT subcat dummy	Yes	Yes	Yes
Observations	6808	6808	6808
Offset	ln(pat_age)	ln(pat_age)	ln(pat_age)
Log pseudolikelihood	-14417.7	-14390.8	-14362.4
Chi-square	848.2	943.0	987.9
Pro>chi-square	9.06e-137	6.57e-156	1.93e-164

Robust standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 4: CROSS-FIRM COMPARISON WITHIN INDIA (1979-2009)

DV: # of non-self citations received as of the end of 2010	(1) Control for co-invention	(2) Control for assignee type	(3) Control for Both
Indian co-invention	0.239**		0.171*
	(0.0851)		(0.0806)
Multinational assignee		0.375**	0.264
		(0.144)	(0.138)
3-year patent stock prior to application date (in thousands)	0.00760	-0.000294	0.00358
	(0.0119)	(0.0121)	(0.0122)
Grant delay in years	0.123***	0.132***	0.127***
	(0.0282)	(0.0285)	(0.0281)
Team size	0.0465***	0.0526***	0.0479***
	(0.00615)	(0.00566)	(0.00603)
Constant	-8.643***	-8.817***	-8.793***
	(0.586)	(0.578)	(0.577)
Grant year dummy	Yes	Yes	Yes
HJT subcat dummy	Yes	Yes	Yes
Observations	4280	4280	4280
Offset	ln(pat_age)	ln(pat_age)	ln(pat_age)
Log pseudolikelihood	-13541.4	-13545.0	-13512.2
Chi-square	2037.3	2087.0	2051.7
Pro>chi-square	0	0	0

Robust standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 5: CROSS-BORDER COMPARISONS WITHIN MNCS (CHINA, 1996-2009)

DV: # of non-self citations received as of the end of 2010	(1) Full sample	(2) Firms with >30 CN patents
Chinese co-invention	0.0938	0.0839
	(0.0522)	(0.0618)
Purely Chinese invention	0.0182	0.0212
	(0.0785)	(0.0621)
3-year patent stock prior to application date (in thousands)	-0.0305	-0.0325
	(0.0517)	(0.0591)
Grant delay in years	0.0876***	0.0975***
	(0.0217)	(0.0293)
Team size	0.0632***	0.0654***
	(0.00802)	(0.0103)
Firm fixed effects	Yes	Yes
Grant year dummy	Yes	Yes
HJT subcat dummy	Yes	Yes
Observations	36707	23751
Offset	ln(pat_age)	ln(pat_age)
Number of firms	283	18
Log pseudolikelihood	-88154.3	-56892.9
Chi-square	365593809.9	4.06127e+10
Pro>chi-square	0	0

Robust standard errors clustered by the MNC in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 6: CROSS-BORDER COMPARISONS WITHIN MNCS OVER TIME (CHINA, 1996-2009)

DV: # of non-self citations received as of the end of 2010	(1) Full sample	(2) Firms with >30 CN patents
Co-invention*1-5 years of China experience	0.101 (0.0755)	0.0689 (0.119)
Co-invention*6-10 years of China experience	0.0180 (0.0526)	0.0239 (0.0230)
Co-invention*More than 10 years of China experience	0.539*** (0.137)	0.660*** (0.0922)
Purely Chinese Invention*1-5 years of China experience	-0.175 (0.104)	-0.282* (0.126)
Purely Chinese Invention*6-10 years of China experience	0.132* (0.0593)	0.137* (0.0566)
Purely Chinese Invention*More than 10 years of China experience	0.519*** (0.0723)	0.523*** (0.0873)
3-year patent stock prior to application date (in thousands)	-0.0276 (0.0503)	-0.0271 (0.0562)
Grant delay in years	0.0900*** (0.0210)	0.102*** (0.0273)
Team size	0.0629*** (0.00798)	0.0649*** (0.0101)
Firm fixed effects	Yes	Yes
Grant year dummy	Yes	Yes
HJT subcat dummy	Yes	Yes
Observations	36707	23751
Offset	ln(pat_age)	ln(pat_age)
Number of firms	283	18
Log pseudolikelihood	-88071.7	-56791.9
Chi-square	598349855.8	4.59456e+09
Pro>chi-square	0	0

Robust standard errors clustered by the MNC in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 7: CROSS-BORDER COMPARISONS WITHIN MNCS (INDIA, 1996-2009)

DV: # of non-self citations received as of the end of 2010	(1) Full sample	(2) Firms with >30 IN patents
Indian co-invention	-0.212***	-0.182*
	(0.0613)	(0.0895)
Purely Indian invention	-0.229*	-0.189
	(0.109)	(0.113)
3-year patent stock prior to application date (in thousands)	-0.00344	0.00461
	(0.0180)	(0.0232)
Grant delay in years	0.101***	0.115***
	(0.0130)	(0.0138)
Team size	0.0626***	0.0638***
	(0.00490)	(0.00556)
Firm fixed effects	Yes	Yes
Grant year dummy	Yes	Yes
HJT subcat dummy	Yes	Yes
Observations	40324	32633
Offset	ln(pat_age)	ln(pat_age)
Number of firms	234	21
Log pseudolikelihood	-142502.3	-116929.6
Chi-square	8.45260e+11	5.53888e+10
Pro>chi-square	0	0

Robust standard errors clustered by the MNC in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 8: CROSS-BORDER COMPARISONS WITHIN MNCS OVER TIME (INDIA, 1996-2009)

DV: # of non-self citations received as of the end of 2010	(1) Full sample	(2) Firms with >30 IN patents
Co-invention*1-5 years of India experience	-0.298***	-0.339***
	(0.0652)	(0.1000)
Co-invention*6-10 years of India experience	-0.0971	-0.0768
	(0.169)	(0.164)
Co-invention*More than 10 years of India experience	-0.120	-0.153
	(0.145)	(0.155)
Purely Indian Invention*1-5 years of India experience	-0.312*	-0.287*
	(0.123)	(0.144)
Purely Indian Invention*6-10 years of India experience	-0.1000	-0.0761
	(0.116)	(0.104)
Purely Indian Invention*More than 10 years of India experience	-0.370***	-0.321***
	(0.0699)	(0.0795)
3-year patent stock prior to application date (in thousands)	-0.00445	0.00302
	(0.0175)	(0.0226)
Grant delay in years	0.101***	0.115***
	(0.0129)	(0.0138)
Team size	0.0629***	0.0645***
	(0.00489)	(0.00531)
Firm fixed effects	Yes	Yes
Grant year dummy	Yes	Yes
HJT subcat dummy	Yes	Yes
Observations	40324	32633
Offset	ln(pat_age)	ln(pat_age)
Number of firms	234	21
Log pseudolikelihood	-142463.8	-116898.3
Chi-square	8.82700e+11	4.73898e+10
Pro>chi-square	0	0

Robust standard errors clustered by the MNC in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 9: CROSS-FIRM COMPARISON WITHIN CHINA OVER TIME (1981-2009)

DV: # of non-self citations received as of the end of 2010	(1) Control for co-invention	(2) Control for assignee type	(3) Control for Both
Co-invention*Grant year < 2000	0.495***		0.365*
	(0.135)		(0.166)
Co-invention*Grant year 2000-2004	0.279***		0.219*
	(0.0831)		(0.101)
Co-invention*Grant year 2005-2009	0.116		-0.00914
	(0.0721)		(0.0773)
Multinational assignee*Grant year < 2000		0.516***	0.294
		(0.142)	(0.180)
Multinational assignee*Grant year 2000-2004		0.318*	0.182
		(0.124)	(0.147)
Multinational assignee*Grant year 2004-2009		0.426***	0.425***
		(0.0989)	(0.106)
3-year patent stock prior to application date (in thousands)	0.0358	0.0228	0.0244
	(0.0198)	(0.0225)	(0.0221)
Grant delay in years	0.133***	0.134***	0.134***
	(0.0268)	(0.0266)	(0.0267)
Team size	0.0460**	0.0587***	0.0505***
	(0.0152)	(0.0134)	(0.0151)
Constant	-7.053***	-7.099***	-7.199***
	(0.852)	(0.863)	(0.877)
Grant year dummy	Yes	Yes	Yes
HJT subcat dummy	Yes	Yes	Yes
Observations	6808	6808	6808
Offset	ln(pat_age)	ln(pat_age)	ln(pat_age)
Log pseudolikelihood	-14388.0	-14385.3	-14330.1
Chi-square	871.3	927.6	908.3
Pro>chi-square	2.62e-140	1.20e-151	4.64e-146

Robust standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 10: CROSS-FIRM COMPARISON WITHIN INDIA OVER TIME (1979-2009)

DV: # of non-self citations received as of the end of 2010	(1) Control for co-invention	(2) Control for assignee type	(3) Control for Both
Co-invention*Grant year < 2000	0.327		0.277
	(0.206)		(0.212)
Co-invention*Grant year 2000-2004	0.109		0.0476
	(0.106)		(0.118)
Co-invention*Grant year 2005-2009	0.332***		0.252**
	(0.0918)		(0.0939)
Multinational assignee*Grant year < 2000		0.351	0.163
		(0.250)	(0.247)
Multinational assignee*Grant year 2000-2004		0.265	0.233
		(0.136)	(0.154)
Multinational assignee*Grant year 2005-2009		0.743***	0.614***
		(0.151)	(0.155)
3-year patent stock prior to application date (in thousands)	0.00766	-0.000550	0.00283
	(0.0119)	(0.0121)	(0.0123)
Grant delay in years	0.124***	0.134***	0.129***
	(0.0287)	(0.0288)	(0.0287)
Team size	0.0463***	0.0523***	0.0475***
	(0.00605)	(0.00564)	(0.00598)
Constant	-8.672***	-8.802***	-8.773***
	(0.588)	(0.598)	(0.595)
Grant year dummy	Yes	Yes	Yes
HJT subcat dummy	Yes	Yes	Yes
Observations	4280	4280	4280
Offset	ln(pat_age)	ln(pat_age)	ln(pat_age)
Log pseudolikelihood	-13523.2	-13529.2	-13480.0
Chi-square	1973.3	2319.3	2209.9
Pro>chi-square	0	0	0

Robust standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.00$