The Rise of International Co-invention

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October 2013

Abstract: The rapid rise of India and China as innovating nations seems to contradict conventional views of the economic growth and development process. India and China are still at the early stages of development, yet advanced nations are granting rapidly growing numbers of patents to inventors based in these countries. Our analysis of U.S. patents shows that a majority of these patents are granted to local inventor teams working for foreign multinationals. An important fraction of these patents incorporate direct intellectual inputs from researchers outside India or China, a trend that we characterize as "international co-invention." As such, the international patenting surge of India and China 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. We explore these issues with a focus on multinational R&D in India.

Acknowledgements: We gratefully acknowledge the financial support of the U.S. National Science Foundation (SciSIP grant no. 0830233), the Portuguese National Science Foundation (PTDC/ESC/71080/2006), the Carnegie Mellon Center for the Future of Work, the Kauffman Foundation, and the World Bank. We received helpful comments from Bronwyn Hall and from seminar audiences at the NBER, Carnegie Mellon, the 2012 Asia Pacific Innovation Conference, and the Atlanta Conference On Science and Innovation Policy 2013, and we appreciate the research assistance and intellectual input of Matej Drev. The views expressed in this paper are those of the authors, and we retain sole responsibility for any errors.

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 models (Vernon 1966; Krugman 1979; Grossman and Helpman 1990; Grossman and Helpman 1991).

Despite many years of impressive growth, China, and especially India, are still in the early stages of the conventional development process -- this is evidenced by their still low levels of per capita output and income. China and India lag far behind the industrial West, of course, but they also lag behind other developing countries, such as Brazil, South Africa, and Malaysia. However, India and China are already innovating, as is evidenced by the rapidly rising number of patents granted by the U.S. and European patent offices to inventors residing in India and China. While the absolute number of patents remains low, the rates of growth have been exponential. Rapidly growing number of patent counts are not the 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 and Mani 2012; Freeman 2006). Does this trend contradict conventional wisdom? Should we abandon our conventional economic models, or at least presume that they may 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 2010)! 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. 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 India and China. We trace the dramatic growth of U.S. patents received by inventors residing in India and China across time, technological fields, organizational boundaries, and geographic space. We examine the quality of patents, as evidenced by patent citations, with a focus in this paper on activity in India. By doing so, we are able to reveal some of the facts, perceptions, and insights associated with rising innovation in these emerging economies.

We make two contributions to the literature. First, we find that the rapid growth in U.S. patents awarded to private sector inventors based in India and China are driven, to a great extent, by multinational corporations (MNCs) from advanced industrial economies and are highly dependent on collaborations between local inventors and other inventors in advanced economies.[1] Therefore, India and China's striking innovation surge may represent less of a challenge to conventional models of trade, economic growth, and development than it appears at first glance. The view that the increases in innovation in India and China 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 differently, a vertical distintegration of R&D,

[1] While Chen, Jang, and Chang (2013) and Jang, Wang, and Chen (2012) have shown the importance of international co-invention in the context of invention in certain emerging markets, we go well beyond this by examining all multinational patents and by comparing the quality of multinational and indigenous patents.

with various stages of the R&D process now being conducted in different locations around the world. The general phenonmenon of a vertical disintegration of manufacturing has been studied in the international economics literature (e.g. Yi 2003; Hummels, Ishii and Yi 2001; 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 India and China 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 India and China and briefly explains why the existing theory of vertical disintegration may explain the rise of innovation in these two economies. Section III describes our data and presents descriptive features of the rise of innovation in India and China as suggested by the data. Section IV presents empirical models and detailed regression results focusing on patent quality as well as quantity. Section IV provides insights from a field study of MNC R&D activity in these emerging markets. Section VI and discusses policy implications and presents our conclusions.

II. Background

Industrial R&D activity within the borders of mainland China has increased at a very rapid pace over the last fifteen years, and has now reached levels that are quite impressive by the standards of developing economies. It is also one of the favorite destinations for multinational R&D investment. Over the 1997–2007 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.[2] 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 16-fold in India, from 22 million to 382 million U.S. dollars over the 1997–2007 period.

Tracking patents granted by the U.S. Patent and Trademark Office (USPTO) to inventors residing in India and China provides another useful way of measuring the expansion of R&D within these countries.[3] 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 India and China as a useful indicator of innovative activity there.[4]

Figure 1 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 grew rapidly. Over the 1996–2010 period, the total number of U.S. patents granted to Indian inventors increased 25-fold. Figure 2 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

[2] The number is for majority-owned affiliates of nonbank U.S. parent companies in India or China. A "Majority-Owned Affiliate" is an Indian or Chinese 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.

[3] After we had produced the first draft of this paper, we discovered that Chen, Jang, and Chang (2013) had used USPTO data to examine R&D cooperation between Chinese and foreign inventors and Jang, Wang, and Chen (2012) used USPTO data to compare this activity in India and China. While there is some overlap between the purely descriptive parts of their papers and our work here, there are also important differences. Our paper considers both co-invention and multinational sponsorship of indigenous inventor teams, whereas they consider only the former. The econometric approach taken by these two papers differs entirely from ours. In particular, we focus on patent quality as revealed by patent citations, whereas their work does not.

4 U.S. patents have been used to measure inventive output in Britain (Griffith, Harrison, and Reenen 2006), Japan (Branstetter and Sakakibara 2002), and Israel (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.

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 domestic patent data (Hu and 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. [5, 6]

Using U.S. patent data, one can further disaggregate patents generated in India and China 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 India and China 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 Japanese inventor teams.[7] However, this is not true of patents being generated in India and China. A large and growing fraction of patents with Indian or Chinese 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.[8] In addition, a growing fraction of the patents produced by purely Indian or Chinese inventor teams is created under the sponsorship of MNCs. In fact, as illustrated in Figure 1 and Figure 2, patents

[5] 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. We will discuss this issue in the latter part of this paper.

[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 August 14, 2010.

[7] Danguy (2012) provides a purely descriptive overview of the frequency of international co-invention in an expansive sample of USPTO and EPO patents, and finds it to be relatively rare.

[8] To the best of our knowledge, the first use of the term international co-invention was in Branstetter et al. (2008).

resulting from international co-invention and MNC sponsorship account for the majority of new U.S. patents granted to Indian or Chinese inventors in recent years.[9]

[Insert Figure 1 and Figure 2 here]

India and China'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 Taiwan-based inventors and South-Korea-based 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 India and China'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 India and China'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.

[Insert Figure 3 here]

Patents granted by the Indian and Chinese 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

[9] This finding was first documented in Branstetter et al. (2008).

of 49%.[10] 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.[11]

In the same way that USPTO patent data help trace the explosive growth of innovative activity in India and China, 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, or about one-tenth of India, 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. India and China'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 will start to rival the patent output of Taiwan and South Korea within a few years. It will clearly take longer for India to reach Taiwan's and South Korea's current levels.

[Insert Figure 4 here]

[10] 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.

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

By either assuming or predicting that innovation occurs exclusively in "the North," the Product Life Cycle theory (Vernon 1966) and its current variants (Krugman 1979; Grossman and Helpman 1991; Grossman and Helpman 1990) 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 India, China, and the leading nations in Eastern Europe (Zhao, 2006; Branstetter et al., 2008; Branstetter and Foley, 2010). This shift has occurred against a backdrop of rising globalization of R&D, more generally. Between 1999 and 2009, the R&D expenditure of all foreign affiliates of U.S. firms almost doubled (Barefoot and Mataloni, 2011). However, in China, these expenditures more than doubled just between 2004 and 2010, and in India they grew by a factor of ten over the same period.[12] 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 par with that undertaken in developed economies (UNCTAD 2005) .

Some work has been done to address these changes. Grossman and Rossi-Hansberg (2008) provide a theoretical model of offshoring that also includes skill-intensive tasks. Puga and 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

[12] See Yorgason (2007) and Barefoot (2012).

with less developed intellectual property rights systems, such as India and China. 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 and 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 Indian and Chinese 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" or "vertical disintegration" in the trade literature (Krugman, Cooper, and Srinivasan 1995; Hummels, Ishii, and Yi 2001; Yi 2003).

If India and China's emergence in the global innovation system follows this economic canon, co-invention created in India and China is likely to be characterized by a division of labor in the research process. As such, Indian and Chinese 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 and India 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 Indian and Chinese 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 Indian and Chinese inventors would continue to collaborate with Western inventors(Kogut and Zander 1992; Weitzman 1998; Singh 2008). We will return to this issue in the later part of this paper.

III. Data Sources and Trends

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 and 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 India and China are developing countries with still-developing patent systems, a patent grant in India or China is less likely to represent an important advance over the global state of the art. However, the USPTO will apply the same standards to patent applications originating in India or China 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 an "invention" for which we find Indian or Chinese patent grants but no U.S. patent grants. Furthermore, significant changes in the domestic patent systems in India and China make Indian and Chinese patent data inconsistent over time.

Our data come 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.[13] The second is the Disambiguation and Co-authorship Networks of

[13] 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 began work this research project, the Disambiguation and Co-authorship Networks of the U.S. Patent Inventor Database had not come out.

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.[14] The third is the COMETS database 1.0 (Zucker and 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.[15, 16, 17]

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 each patent.

For the purposes of our research, we separated Hong Kong and Taiwan from mainland China.[18] A total of 12,419 patents are identified as those with at

[14] 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.

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

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

[17] 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.

[18] One issue arises for the years after 1997, when the United Kingdom returned sovereignty over Hong Kong to China. Some inventors residing in Hong Kong continued to list Hong Kong as their inventor country; others began to list China as their inventor country. (Note: politically, Hong Kong has never been a country, but USPTO designates a separate country code to it for classification purposes.) Before and after 1997, we identify Hong Kong addresses and consider them to be geographically distinct from mainland China. Similar mistakes can be found when a Taiwanese inventor listed Republic of China, the official name of Taiwan, as her home country. A small number 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.

least one inventor residing in China at the time of invention during the period 1981–2010.[19] 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.[20]

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. After this procedure, we find 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

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

[20] 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.

other entities such as governments, hospitals, etc. For India-based patents , 74% of total 7,754 U.S. utility patents 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. It can be concluded that firms are the main contributors of the recent increase of U.S. patents in India and China.

Who owns these patents? For India, 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, 18% are assigned to Indian indigenous firms, 3% are assigned to Germany (3%), and 3% are assigned to France-Italy. These patents are owned by a single firm, STMicroelectronics Pvt. Ltd., the Indian subsidiary of French-Italian multinational electronics and semiconductor manufacturer STMicroelectronics. The remaining 5% is distributed among all other countries. For China, at the assignee nationality level, 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 remainder as a whole accounts for 6%.

At the firm level, Table 1 lists the 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. Table 2 lists the 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.

[Insert Table 1 and Table 2 here]

To measure what kinds of invention have been done in India and China, 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 5 show that, with regard to India-based patents, Computers & Communications is the leading field. India has been well-known for its software industry, so one question worth asking is: to what extent have software patents contribute to India's U.S. patent surge? Among all India-based U.S. patent grants before 2007, about 10% are software patents. A large proportion of China-based patents taken out in the U.S. are in two HJT categories: Computers & Communications and Electrical & Electronic. During the same period, the share of China-based software patents is about 5%. It can also be seen in Figure 5 that co-invention plays an important role across all categories in both countries.

[Insert Figure 5 here]

By extracting the geographic information on inventors included in patent documents, we found that among the 20,088 inventor addresses that indicate the inventor was living in India, 20,045 addresses can be associated with a particular state in India. Karnataka, Maharashtra, Andhra Pradesh, Uttar Pradesh, and Delhi are the top five states/territories that host most Indian inventors. Together, they account for 76% of the frequency distribution of India inventor addresses. These areas are also where Technology Business Incubators (TBIs), Science and Technology Entrepreneurs Parks (STEPs), Software Technology Parks of India (STPIs), universities and research institutions tend to concentrate (Sharma, Nookala, and Sharma 2012).

We found 27,238 inventor addresses indicating that the inventor was located in China. 27,177 of these addresses were sufficiently complete that we could associate the address with a particular Chinese province. We find 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.[21]

All of the above features are based on the analysis of U.S. patent data, which have limitations as indicators of invention in India and China. 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 largest national economy in the world and grants a large number of patents, patents granted by its patent office may still not be able to capture the whole picture of the rise of innovation in India and China. For these reasons, we have also analyzed European Patent Office (EPO) patent data as a robustness check. 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 Indian and Chinese inventors. It is worth pointing out that even EPO

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

data indicate that U.S. MNCs play a more important role than European MNCs in India-based patenting. 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.

Before moving on to the next section, we need to answer another important question: to what extent can we base our inference about innovation in India and China on the relatively small number of U.S. patents, especially when there is a tidal wave of patents being issued in China itself (Hu and Jefferson, 2009). The numbers of Chinese domestic patents granted by China's State Intellectual Property Office (SIPO) in the most recent years are mind-boggling. In 2011 alone, SIPO issued nearly one million patents of various kinds. The majority of these grants go to indigenous/domestic applicants. Is our focus on the international patents of Chinese inventors generating a distorted picture of the true innovation going on inside China? To answer this question, we have carefully examined Chinese invention patents, using SIPO micro data on Chinese grants over the 1985-2012 period.

The first thing we want to point out is that the overwhelming majority of SIPO grants are actually utility models or design patents. These are not true patents, in the usual Western sense of the word. Neither requires a substantive examination or a significant technical advance over the existing state-of-the-art. When we focus on China's so-called invention patents, which do require a substantive examination and, in principle, an advance over the existing technical state-of-the-art, we see significantly smaller numbers and significantly less growth. With this more restrictive definition, the total grant number drops by about 80% in recent years.

Second, as of the end of 2012, about half of SIPO invention patents are granted to foreign applicants, and among these foreign-owned invention patents, 90% of them possess a foreign priority claim. That means more than 40% of Chinese invention patents are inventions initially created abroad and then patented in China. Even this may understate the role of foreign inventors. Patents granted to MNC Chinese subsidiaries and joint ventures in China are classified as domestic grants by the SIPO. However, many of these patents are generated using intellectual inputs from outside China, including resources and capabilities located in the multinationals' R&D centers far beyond China's borders. These considerations further limit the degree to which China's impressive headline patent numbers can be taken as evidence of globally significant innovative activity.

Third, we find that domestic applicants allow their patents to expire earlier than foreign applicants by failing to pay maintenance fees over the full legal life of the patent.. This result is consistent with Huang (2012), who found similar results for invention patents initially applied for during the 1987–1989 period. This suggests that there is a quality difference between Chinese patents granted to foreign inventors and Chinese patents granted to domestic inventors.

These concerns are strongly reinforced by the extremely low propensity for Chinese inventors, in the aggregate, to apply for and receive patent protection for their Chinese inventions in patent jurisdictions outside China. For decades, researchers seeking to quantify innovation have used the fraction of domestic patents for which foreign patent protection is sought, and the number of foreign jurisdictions in which patent protection for a given invention is sought, as indicators of patent quality. Even in advanced countries with mature patent systems, the need to file patent applications quickly in order to avoid being foreclosed by rival innovators means that firms often begin the patent application process, at least at home, at a very early stage in the R&D process, before even the inventors themselves have a clear sense of the ultimate economic value of the patent. Under international patenting rules, firms have up to a year after the domestic filing during which they can start the process of seeking patent protection in foreign jurisdictions, with the "priority date" established by their home patent application filing date. We generally observe that firms are more selective in their foreign patenting, applying for the patent protection in major markets outside the home country only when the invention appears sufficiently important to merit the additional time and expense of multiple foreign patent filings.

In the context of these considerations, it is interesting to observe that the top 100 U.S. patent applicants seek to protect nearly 30% of their domestic patents in at least one major foreign market, such as Japan or the EPO. In striking contrast, we find that the top100 Chinese domestic applicants seek patent protection for less than 6% of their inventions in the U.S., only 4% in Europe, and only 1% in Japan. If we look at the number of domestic patent grants for which Chinese firms pursue the patent application process all the way to the successful receipt of a foreign patent grant, the numbers are vanishingly small. So far, fewer than 3% of Chinese invention patents have been successfully patented in any major market outside China, and fewer than 1% have been patented in 2 or more major markets. Even after decades of rapid growth, China is still a significantly smaller economy than the U.S. or Western Europe. If Chinese inventors possess new-to-the-world technology, it would seem to be well worth their while to take out patents in these markets that are still larger, in aggregate terms, than China itself. The fact that Chinese inventors forego the opportunity to do so for the overwhelming majority of their domestic patents appears to represent a striking vote of no confidence in the quality of their inventions.

A more detailed discussion of the SIPO data and the unique features of the Chinese domestic patent system is beyond the scope of this paper, but a number of recent studies call into question the degree to which China's flood of domestic patents really indicates a substantial degree of indigenous innovation.[22] We note here two recent studies of special interest. Lei et al. (2012) note widespread government subsidies for domestic patenting in China, but show that an increase in these subsidies appears to increase the number of patents but not the quantity of innovation. Eberhardt et al. (2011) study domestic and foreign patenting by Chinese firms, and conclude that the only Chinese firms engaging in real innovation are those also taking out significant numbers of patents outside China.

IV. 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 (Krugman, Cooper, and Srinivasan 1995; Hummels, Ishii, and Yi 2001; Yi 2003). Previous research found that invention being generated in developing countries is incremental in nature (Zhao 2006; Puga and Trefler 2010). These findings suggest that Indian and Chinese 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 Indian or Chinese 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 Indian or Chinese input might be of lower quality than the patent output of all-Western inventor teams. Interviews with

[22] Hu and Jefferson (2009), who undertook an early quantitative study of the impressive increase in China's domestic patenting, suggested that it was primarily driven by an increase in the propensity to patent rather than an increase in real innovative effort.

India-based R&D personnel and managers suggest that R&D in India largely follows this pattern.

We will seek to validate that perception by measuring the relative quality of India-based USPTO patents in multiple ways. First, we will compare co-invention generated in 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 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 (H2). *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.*

Besides overall comparisons, we also want to assess the dynamics of the patent quality across different patent categories. Conversations with multinational R&D managers suggest that it takes time for talented researchers in emerging economies to become "mature." This implies our next hypothesis.

Hypothesis 3 (H3). *The quality gap between patents (including co-invention) produced by MNCs in India and patents produced by the same MNCs in their home countries is declining as MNCs gain more experience of doing R&D in India.*

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 Indian engineers could put their skills and experience to work for indigenous firms that increasingly compete directly with the MNCs. It will therefore be important to see 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 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 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 over time.*

Throughout this section of the paper, our focus will be on MNC R&D in India. In ongoing research, however, we are conducting a similar empirical investigation of MNC R&D in China, and, in the sections below, we will offer a qualitative comparison of our results for India with those we obtain when running similar regressions on a Chinese data set.

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 (Hall, Jaffe, and Trajtenberg 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 (Trajtenberg 1990; Jaffe, Trajtenberg, and Fogarty 2000; Harhoff et al. 1999; Hall, Jaffe, and Trajtenberg 2005). 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 (Hall, Jaffe, and Trajtenberg 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" (Hall, Jaffe, and Trajtenberg 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" (Cameron and 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 (Wooldridge 1999; Wooldridge 2002; Cameron and Trivedi 2005; Gourieroux, Monfort, and Trognon 1984; Hall, Griliches, and Hausman 1986). 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 lower significance levels than the NB model. 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 estimation results are qualitatively consistent with the PQML results presented in this paper and are available upon request. PQML estimators can be obtained by estimating an unconditional Poisson model with robust standard errors (Wooldridge 1999; Cameron and Trivedi 2005).

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 current 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. We do this because we are concerned that an inventor working in the 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 India-based U.S. patents in recent years. In addition,, 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 arrangements. 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 on our India-based patent sample, including all USPTO patents that are granted to 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 an Indian-based patent *i* receives by the end of 2010. The key coefficients of interest are those on *Coinv* and *MNC*, which are dummy variables indicating whether or not a patent is co-invented and whether or not it is assigned to a multinational assignee. The key task here is to compare co-invented and MNC-owned patents generated India with patents generated by Indian indigenous firms. 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. If larger teams are required for more "fundamental" (and potentially more valuable) inventions (Jones, 2006), and larger teams are more likely to be international teams, then this could introduce a mechanical positive association between co-invention and quality -- the *TeamSize* variable helps us control for this. $Gdelay$ 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" (Cameron and 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. Column 1 includes a co-invention dummy; Column 2 includes a MNC assignee dummy; Column 3 includes both dummies. Across all three specifications, the coefficients on the co-invention dummy and the MNC assignee dummy are positive and significant. The coefficient of 0.239 in Column 1 can be interpreted that co-invented patents receive 27% (exp(0.239)-1) more non-self forward citations than purely Indian generated patents. Similarly, Column 2 suggests that MNC-sponsored patents—with a multinational assignee—receive 45% more citations than ones under the sponsorship of Indian indigenous enterprises, whether they are co-invented or not. It turns out that almost all co-invention in India is found in MNC-sponsored patents, so we cannot estimate much of a separate coefficient for the MNC assignee dummy when we also control for co-invention dummy in Column 3. The two dummies are highly 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. Running similar regressions on a parallel China-based patent data set yields similar results. With China-based patent data, it is possible to separately estimate multinational sponsorship and international co-invention effects. Both are positive, statistically significant, and collectively point to a multinational patent premium that is roughly the same magnitude as what is observed in India.

[Insert Table 3 here]

D. Cross-border Comparisons within MNCs

Next, we want to know whether patents produced by MNCs in India are of lower quality than those produced by the same MNCs in their home countries (H2). To do so, we keep only those India-based 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 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 India-based patents by the end of 2010. Our specification is as follows:

(2) $$E(C_i) = \text{PatAge} \cdot \exp\,(\beta_0 + \beta_1 \text{Coinv}_i + \beta_2 \text{Domestic}_i + \beta_3 \text{PatStock}_f + \beta_4 \text{TeamSize}_i + \beta_5 \text{Gdelay}_i + F_i + H_i + T_i$$

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 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 India 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 India-based inventors when the patent application was filed. We divide our data into three periods: 1–5 years of India experience, 6–10 years of India experience, and more than 10 years of India experience.

Results are presented in Table 4 and Table 5. Table 4 shows that 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. With regard to the dynamics of the quality difference, the point estimates for interaction terms in Table 5are 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 for co-inventions in India, but the results are still quite weak. These results are consistent with a division of labor between Indian R&D personnel and Western R&D personnel within the boundaries of MNC in which much of the more fundamental, more frequently cited work is disproportionately likely to be conducted on the Western side.

Interestingly, similar regression analyses on Chinese data reveal a different pattern. There is no statistically significant difference in quality between China-generated multinational invention and invention generated in the multinational's home country. Efforts to track the evolution of quality differences over time, as in Table 5, suggest that, in the case of China, there has been rapid relative improvement in the measured quality of the MNC invention conducted in China. Understanding the differences in the Indian results reported here and the results obtained from our Chinese data is the focus of ongoing research.

[Insert Table 4 and Table 5 here]

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

Is the quality difference between MNCs and indigenous firms narrowing over time? (H4) We can examine this by dividing the 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 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) $$\mathrm{E(C_i) = PatAge \cdot exp\ (\varphi_0 + \varphi_1 Coinv_i * Gyear_{<2000} + \varphi_2 Coinv_i * Gyear_{2000-2004} + \varphi_3 Coinv_i * Gyear_{2005-2009} + \varphi_4 MNC_i * Gyear_{<2000} + \varphi_5 MNC_i * Gyear_{2000-2004} + \varphi_6 MNC_i * Gyear_{2005-2009} + \varphi_7 PatStock_f + \varphi_8 TeamSize_i + \varphi_9 Gdelay_i + H_i + T_i}$$

Results from this regression specification are given in Table 6. These results suggest that the quality premia associated with co-invention and with MNC sponsorship do not appear to be fading over time in India. Instead, both remain economically and statistically significant. When we run a parallel regression on our Chinese dataset, we find evidence suggesting that the quality premium associated with international co-invention appears to fade over time, but the quality premium associated with multinational sponsorship remains strong, both in magnitude and in statistical significance.

[Insert Table 6 here]

V. Peering inside Co-invention: Lessons from Interviews of 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. We supplemented these interviews with telephone-based interviews of multinational R&D managers in India, and one member of the research team also participated in on-site interviews in Delhi, Mumbai, Hyderabad, and Bangalore. Our interviews focused on several aspects of multinational R&D activity: How are the international research teams formed? What do the backgrounds of Indian or Chinese participants look like? Where do the main ideas in 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?

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 India-based and China-based research manpower is being used to contribute to global research projects whose ultimate application will be in global markets, not just the local market. Most interviewees emphasized their commitment to a long-run research presence that could engage the large and growing endowment of engineering human resources in the local labor market in the service of their firm's global R&D agenda.

Second, we also received confirmation of the view that while the endowment of raw talent in China and India is immense and impressive, these talent pools still contain 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.[23] That being said, talented local 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 local 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 the local market.

Nevertheless, a simple story of collaboration in which U.S.-based engineers come up with the ideas and give the orders and local 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 local side, as well as cases in which the projects were conceived, developed, and implemented entirely by the local side, with very little Western input.

Many interviewees placed far more stress on the importance of “(re)engineering products for the local 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. India now has more cellular phone subscribers than the United States has citizens.

[23] We are drawing a sharp distinction here between "indigenous" local personnel who are educated in India or China and spend their entire professional lives there, and "multinational" personnel with Western educations and long-term work experience in the West, who may nevertheless have an Indian or Chinese ethnic background. The statement about managerial capability applies to the former, most definitely not to the latter. Interestingly, these judgments were often rendered by multinational managers who had the same ethnic background as their "local" employees.

However, India and China are still both poor, developing countries, and the tradeoff between cost and functionality is quite different for a local customer—even a local corporate customer—than it is for a Western customer. Therefore, a significant fraction of local engineering personnel were employed in the ongoing process of reengineering Western products for the local market—in ways that were both subtle and profound. This activity was taking place in both China and India, but the tone of the interviews suggested a significantly greater intensity of this effort in China. In the context of this reengineering work, it is not surprising that local engineers often take a leading role. However, the division between "reengineering for the local market" and "contributing to the global R&D agenda" was a fuzzy one and, over time, the same local 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.

Finally, 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.

VI. Conclusions and Implications

In this paper, we have analyzed the patterns found in India- and China-based U.S. patents. In doing so, we found that a majority of India's U.S. patents are owned by foreign MNCs, with U.S. firms playing an especially important role. Similarly, a majority of China's U.S. patents are owned by non-Chinese MNCs, with Taiwanese and U.S. firms playing a significant role. 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 Indian and Chinese inventors and found that the majority of Indian and Chinese inventors are clustered in the most economically advanced regions in both countries, where FDI is also concentrated.

We complemented statistical analyses of the patent data with in-person interviews with researchers in multinational R&D subsidiaries. These interviews confirmed that India- and China- 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 and India. 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.

We have used forward citations from patent documents to compare the quality of India-based patents in multiple ways. Our results support our R&D

vertical disintegration argument. Our study suggests that the increase in U.S. patents in India and China 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, India and China'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 India and China 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. The increase in R&D activity in emerging economies such as India and China represents a growing international division of R&D labor. 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 investment in the traditional innovation centers of the West as the "burden of knowledge" rises, but this can be 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 India and China, advanced economies will also benefit from a faster pace of innovation and a more rapidly expanding stock of knowledge.

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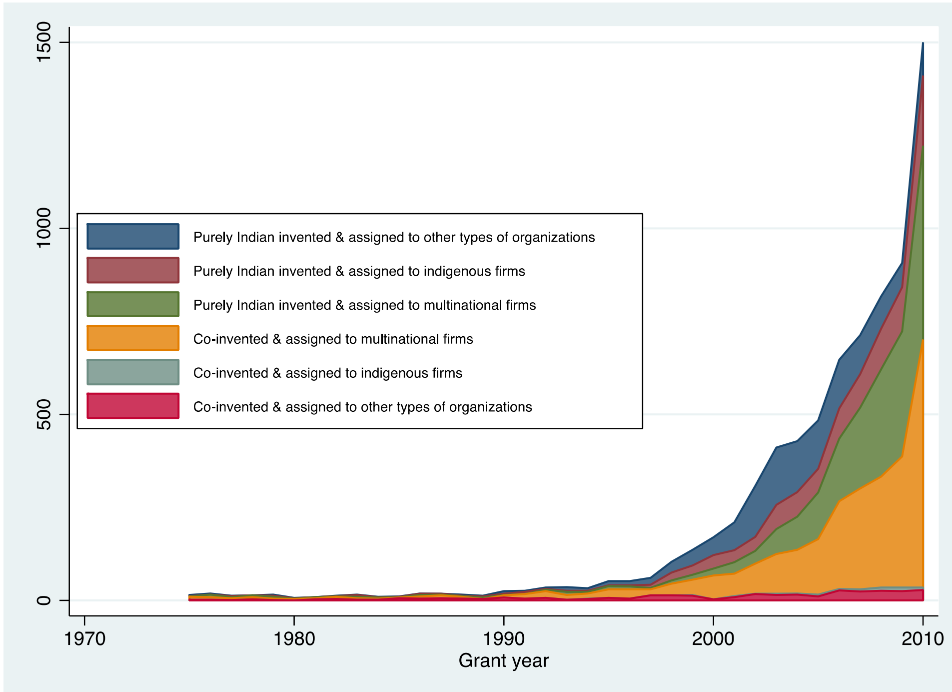

FIGURE 1: THE RISE OF CO-INVENTED AND MNC-SPONSORED USPTO PATENTS IN INDIA

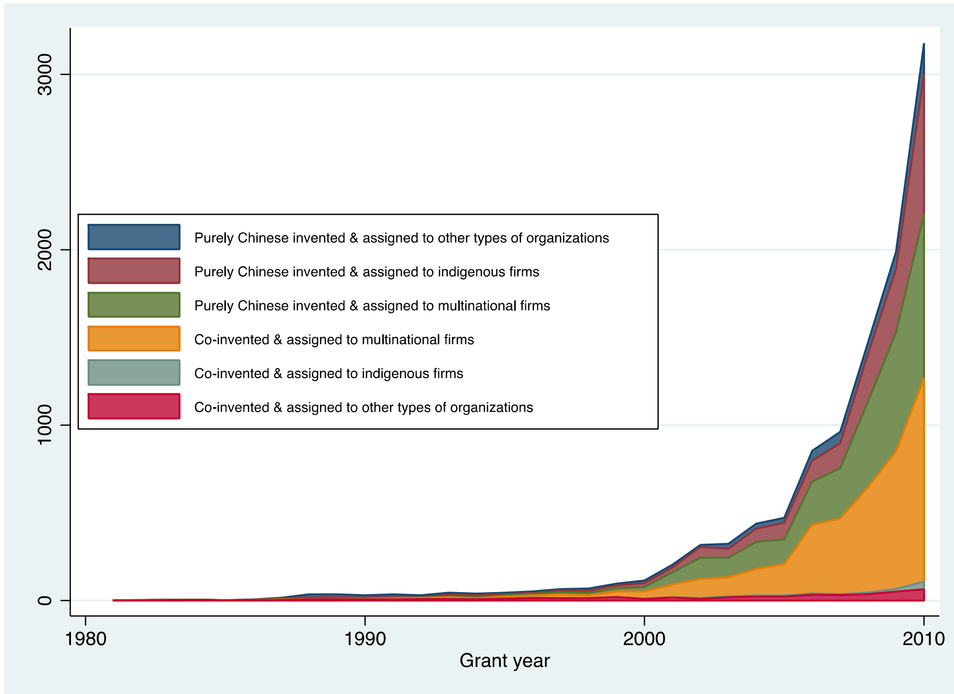

FIGURE 2: THE RISE OF CO-INVENTED AND MNC-SPONSORED USPTO PATENTS IN CHINA

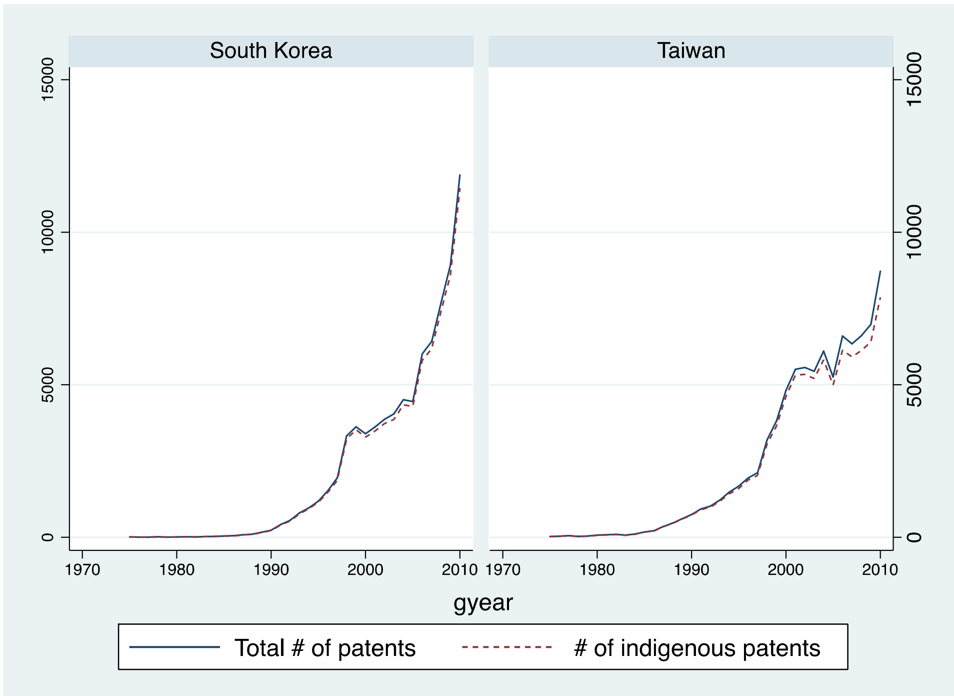

FIGURE 3: PATTERNS OF USPTO PATENTING FROM SOUTH KOREA AND TAIWAN

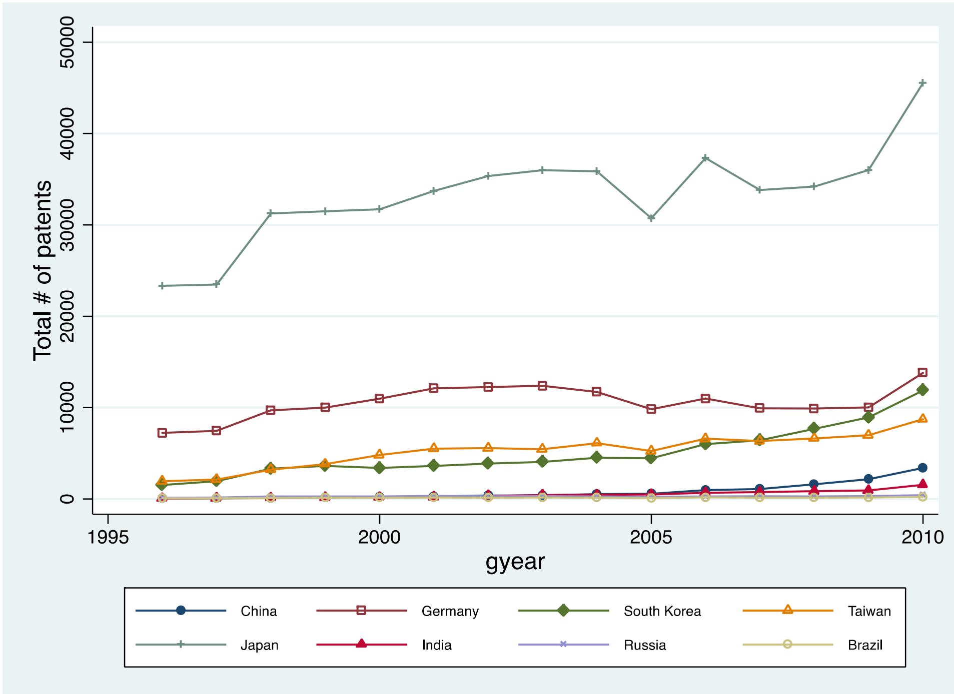

FIGURE 4: INDIA- AND CHINA-BASED USPTO PATENTING IN COMPARATIVE PERSPECTIVE

Table 1: 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 2: 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.

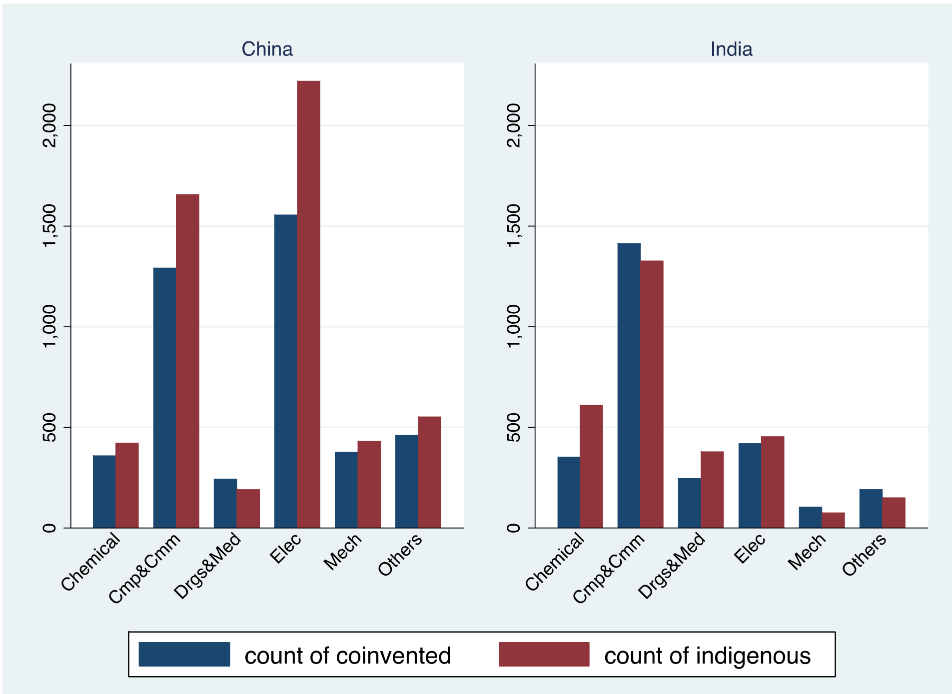

FIGURE 5: FIRM-OWNED CHINA- AND INDIA-BASED USPTO PATENTS ACROSS HJT TECHNOLOGY CATEGORIES

TABLE 3: 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 4: 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 5: 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 6: 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

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