

# Gains from Collaborative R&D: A Patent Data Analysis

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## Abstract

Does cooperation between different countries accelerate the global pace of innovation? Recombinant theories of innovation suggests that diverse technological inputs are required for new invention, implying that new cross-country collaborations should increase innovative productivity in a standard gains-from-trade model. However, there is limited empirical evidence demonstrating the differential productivity of international collaboration in research and development (R&D). In this paper we conduct a comprehensive assessment of collaborative innovation between the U.S. and China, two of the largest supporters of R&D but only recent collaborators. Critically, using a comprehensive dataset of all patents filed with the U.S. Patent and Trademark Office, we examine whether collaborative inventions that engage both U.S. and Chinese inventors induce greater innovation spillovers, as measured by forward citations. We compare forward citation rates of collaborative patents to similar inventions developed only by single-country inventor teams. Our preliminary results suggest that U.S.-China collaborative patents receive more forward citations than do Chinese-only inventions

but fewer citations than do U.S.-only inventions. These results suggest that collaboration offers an opportunity for Chinese scientists to tap into new technological inputs and more effectively leverage foreign R&D inputs to invent technologies with greater spillovers, whereas U.S. inventors may choose to collaborate with Chinese inventors for reasons other than technological spillovers, such as access to robust capital markets for prototyping, technology demonstration, and manufacturing.

## 1 Introduction

Globalization brings with it the promise of increased productivity as countries engage in trade and cooperative economic production in ways that capitalize on comparative advantages. The effect of globalization on productivity may be even greater if countries also cooperate in growth-enhancing innovation, bringing together foreign and domestic technological expertise and advantages in particular innovation system functions (Hekkert et al, 2007).

Collaboration in research and development between scientists from different countries is neither new nor uncommon. Patents generated from research by multi-country inventor teams, which we will call collaborative R&D, over the years has shown that it has both advantages and challenges. Nevertheless interest and execution of such R&D has been on the rise in recent times. Multinational companies (MNCs) are increasingly applying for patents which include multi-country inventors, especially inventors from developed countries like US and developing countries like India and China (Branstetter et al., 2013). On the other hand projects like Mission Innovation show that governments are increasingly exploring new modes of collaboration in innovation.

Given this trend toward collaborative R&D the productivity of these projects is an important concern for multiple parties. Private companies need to know if there is truly any benefit from such collaboration before embarking on such ventures. On the other hand, policy makers also need to have a clear idea on the costs and benefits of collaborative R&D

before investing public funds on these projects. We hope this paper can inform decisions for both these groups by enabling them to make more informed decisions.

Importantly, our focus in this paper is not collaborative R&D in general. Instead we look at the specific case of collaborative R&D between USA and China. We have a threefold argument for choosing such an avenue.

First, information about productivity of all collaborative R&D is too general to be useful. The purpose and character of collaborative innovation from different country pairs are most likely to be entirely different from each other. Analyzing productivity of such different ventures together will provide information adulterated by multiple trends in different direction. In contrast, analyzing collaborative R&D between two specific countries give us precise, usable information.

Second, USA and China are respectively one of worlds most important innovation and production centers. Since 2007, China has produced more natural science and engineering doctoral degrees than any other country, and both the U.S. and China produce more such doctoral degrees than any other country by a significant margin (NSF, 2016). Similarly, the U.S. and China spend more money than any other single country on R&D, \$457 billion in the U.S. and \$337 billion in China in 2013. (The European Union as a whole spent \$342 billion in 2013, and the next highest single country in terms of R&D spending was Japan at \$160 billion) (NSF, 2016).

In addition to their large volume of activity, the U.S. and China may be productive collaborators in innovation due to vertical comparative advantages, such as a tradition of innovation versus cheap research labor. USA has traditionally been a center of innovation and technological leadership. China on the other hand offers skilled labors and a huge market.

They are also one of the biggest (second largest for both countries) trade partners of each other. The size of the market they share between themselves is enormous and collaborative R&D has the potential to produce goods which can gain access to both these markets, subject to IP issues (more on IP issues in section 2). Also, these two countries are worlds largest carbon emitters. We live in an age where climate change technologies are becoming more and more important every day and it is expected that these two countries will join their forces to innovate climate change technologies which will reduce carbon emission.

Third, these two countries have been increasing R&D collaboration between them in all of private, public and academic spheres resulting in a surge of collaborative patent between the two countries. US companies now have a significant R&D presence in China spanning across transportation, aviation, information technology and other sectors (Foreign Company R&D, n.d.) Branstetter et al. (2013) mentions that 29% of all USPTO utility patents with at least one Chinese inventor are owned by US MNCs. On the other hand, Chinese companies like Huawei, Humanwell and others have invested heavily in US research facilities. In 2014 patented inventions by Chinese firms including at least one US researcher were 910, 500% more than it was in 2011 (Chinese firms pour money into U.S. R&D in shift to innovation, 2015). In the public sphere, the U.S. and China have increased their formal collaborative arrangements through research centers like US-China Clean Energy Research Center (CERC). The potential for further collaboration in public sphere is high given USA and China share interest in 9 out of 11 key R&D focus areas mentioned in Mission Innovation (Mission Innovation Clean Energy R&D Focus Area, n.d.). This indicates a lot of common ground for collaboration between these two countries if they are serious about reducing carbon emissions. There has been a lot of collaboration between USA and China in academic sector as well. In 2014 and 2015 Tsinghua University alone has launched joint research projects with Microsoft, Boeing, UC Berkley, Johns Hopkins and other US research bodies (Tsinghua University, n.d.)..

The aforementioned argument shows two things. First is why we chose to narrow down our focus from all collaborative R&D to collaborative R&D between only two countries and second, why we chose USA and China as the subjects for this study. We believe this argument establishes why it is important to analyze the productivity history of collaborative R&D between USA and China. Importantly, even though this section shows USA and China have incentive to collaborate due to presence of vertical comparative advantage and other issues, USA and China also have all the characteristics which make collaborative R&D difficult-unequal IP laws, concerns about quality of R&D, vastly different culture, and a complex history that makes forging deep trust challenging. As both advantages and disadvantages of collaboration are present in US-China relations it is worth studying the productivity of collaboration in R&D between these two countries.

In this paper we have used forward citations (citing of a patent by a future patent) as the measure of productivity while patent data comes from USPTO database. In section 3.4 we show that USPTO patents are representative of both US-China collaborative R&Ds, US R&D and also, to a large extent, indigenous Chinese R&D. We expect our study will provide valuable information regarding the sort of advantage either party has gained from collaborative R&D over the years. This information should be helpful for policymakers, entrepreneurs and academics when deciding on starting new collaborative R&D.

## **2 Literature Review**

### **2.1 Collaborative R&D**

International collaboration may come in several forms including agreement towards common goals, technology mandates, free trade zones, technology transfers, collaborative R&Ds, etc. Globalization and subsequent inter-dependency means international collaboration is on the rise and accordingly collaborative R&D has gained increased traction in recent years

(Kerr. and Kerr., forthcoming). Multiple authors in recent times have studied on collaborative R&D. Kerr et al. has studied the productivity of collaborative patents from US public companies and showed how ethnicity of US companies researchers impact the use of new knowledge generated from collaborative R&D. Branstetter et al. (2013) made valuable contribution in explaining the rise of developing countries like India and China in global innovation system. Lema et al. (Lema and Lema, 2012) studied how improvement in innovation system in developing countries are ushering a new era of R&D collaboration making older models like technology transfer obsolete. MacCormack et al. (2007) highlighted how collaborative R&D can be a source of advantage if firms can show strategic aptitude.

Our work builds on this and other works done by scholars in the area of collaborative R&D. However, we believe we are the first to study the productivity of collaboration between USA and China- two countries who are very important for global future in terms of both environment and economics. In the rest of the section we will review what the literature offers regarding the advantages and disadvantages of collaborative R&D.

## **2.2 Advantages of collaborative R&D**

Advantages of collaborative R&D are akin to much discussed standard gains-from-trade. Such advantages arise in the form of specialization in division of labor, economies of scale, expansion of markets, etc. and extend way beyond lower costs or wage arbitrage(MacCormack et al., 2007). The lower cost of labor approach is more applicable to production than innovation. In innovation, collaborative partners need to strategically utilize different capabilities of researchers in different locations. For example, companies like Caterpillar, GE and others use Indian research cites to continue the research cycle ongoing for 24 hours(Hufbauer et al., 2013). Also, globally dominant research centers perform at their best when they are open to knowledge flows from around the world (Gertler and Levitte, 2005) thus making collaborative R&D seemingly more attractive.

Another source of potential strategic benefit from international collaboration comes from the different economic, social and educational characteristic of different countries. At a certain stage of development a country may have advantages (or disadvantages) related to the socio-economic status of that country and may take part in the certain part of research which corresponds to the specific countrys comparative advantage. This is called vertical specialization in literature(Branstetter et al., 2013) For example, India and China now have troves of highly skilled engineering labor at a relatively cheaper cost. This creates a very attractive opportunity to outsource engineering jobs in China which would bring cost advantages. However, a strategic thinking would be to create projects which are entirely impossible to accomplish in United States alone. SemCo, a US semiconductor company, used engineering labor in China to carry out large experiments for product and process improvement innovations. Here SemCo thought more strategically than just substitution of labor at a cheaper cost. They saw an opportunity to innovate processes which are entirely impossible to do in USA because of unavailability labor in such large numbers. It is important to note that while developing countries (China, in this case) have more skilled labor they lack the scientific leadership and background to come up with such kinds of innovations mentioned above. In similar scenarios collaboration creates a win-win situation for both parties involved.

Examples like SemCo are more visible today as there is a growing realization that innovation capacity is now dispersed around the world as opposed to being centered in a few developed, western countries. In a recent paper Kerr et al.(Kerr. and Kerr., forthcoming) shows that this realization leads to more collaborative patents. It is also important to note that in order to realize the strategic advantages mentioned above it is necessary to collaborate with foreign researchers as opposed to completely outsource the process. Collaboration is necessary at least at the beginning of foreign R&D work because new teams require mentoring to familiarize with the R&D process of the firm. A scientist from the

home office can take the role of fostering the foreign team until it gains its own capability to implement the research all on its own. For these and related reasons it is observed that collaborative patenting is inversely related with time elapsed since a firm starts collaborating.

A related point on collaborative R&D is that countries with different levels of capacity for innovation has been increasing. Developing countries with high absorptive capacity are becoming active participant in technology innovation instead of being the passive recipient of technology transfer initiatives(Lema and Lema, 2012). Firms from China, India, South Korea or similar countries were previously used to base their business model on transferred technology, generics or piracy. That is not true any longer as firms in these countries, including and apart from multinational enterprises operating in those places, are increasingly investing in research and development capacity. These changes are the result of a multitude of factors. For a specific example we may look to India where a combination of long term investment of education sector, large market size, sustained economic growth, sustainable flow of foreign direct investment and the return of trained, highly skilled non-residents from the west is changing it from a business process outsourcing hub to a knowledge based economy(Ely and Scoones, 2009). As a result business model for firms in these countries are now more and more based on innovation supported with intellectual property rights.

Collaboration can also expand the market of an innovation by tapping into the contextual knowledge from international partners. Having inventors with the experience of different location, culture and preferences can lead to empathic designs (Dorothy Leonard and Jeffrey F. Rayport, 1997). It is important to use such inputs to come up with products suitable to markets in developing countries. The growing middle class in these countries like India and China represents a huge market expansion opportunity.

Last but not the least, collaborative R&D is super critical today because of climate

change. Climate change mitigation is a global public good (Barrett, 2007) and success in fighting this problem depends largely on how countries can design institutions and incentives to collaborate. Treaties filled with hollow promises and incentives to free ride will not succeed and given collaborative R&D's many fold advantage we believe this can be an important tool in supplying the public good of climate change mitigation technology.

So in a nutshell we see that increase in collaborative R&D between developed and developing countries is a result of changes occurring to both sides. Developing countries have become more ambitious with expansion of their research capacity. On the other hand, developed countries have become aware of the strategic and market opportunities available in developing countries. However, we are facing a global problem in climate change and that means we need to collaborate in more numbers and efficiency if we want to prevent disaster to billions of lives.

### **2.3 Disadvantages of collaborative R&D**

However, collaborative R&D also has some disadvantages including but not limited to difference in intellectual property (IP) laws, transaction costs to coordinate between parties, costs incurred to combine complementary assets located in different countries, etc. (Lewis, 2014). Outcome of R&D activities are inherently uncertain and thus negotiation on sharing the fruits of R&D is challenging especially when it is between a developed and a developing countries. Developing countries, not surprisingly, suffers from inappropriate IP laws as well as weak implementation. In China, IP laws are evolving rapidly(Dechezleprtre et al., 2011) but still not enough developed to induce confidence in researchers to apply for patents jointly as there has been high-profile IP disputes between two countries in recent past. US-China Clean energy Research Center (CERC) is a case in point. CERC has a mandate to conduct joint research, development and demonstration activities. However, there were not a single joint patent four years after the initiation of CERC. Interestingly, both Chinese and US scientists in CERC applied for patents but all of them had an inventor list exclusively including

either US or Chinese scientists (Lewis, 2014). This is remarkable given 90% of the research activities in CERC are joint research involving scientists from both countries (Marlay and Jianing, 2015).

## **2.4 Concerns about quality of Chinese patents**

There are concern that quality of Chinese innovation is lagging behind than those in developed countries especially when we are talking about cutting-edge innovations (Li et al., 2010). This has an important implication for our research. If Chinese patents are actually of lesser quality and represents less important innovations then forward citation counts should be low compared to US patents. Importantly, if collaborative R&Ds result in knowledge flows then we would also expect collaboration between China and US should increase the productivity of patents. As we would see in section 4, both of these are validated by our empirical analysis.

## **2.5 Knowledge Gap on the Productivity of Collaborative R&D**

There has been a lot of work on international collaboration in innovation as mentioned in the introduction. One strand of this literature focuses on the drivers of collaborative activities (Boekholt et al., 2009), (Jeong et al., 2014). Efforts have also been made to see if collaborative research is more productive but the domain of such investigation has been limited to research papers instead of patents (Pravdi and Olui-Vukovi, 1986). A related important work by Branstetter, Li and Veloso (Branstetter et al., 2013) studies the impact of indigenous patent compared with collaborative patent. Kerr and Kerr (Kerr. and Kerr., forthcoming) analyzes United States Patent and Trademark Office (USPTO) data to analyze productivity of collaborative patents. While the definition of collaborative R&D used by Kerr et al. is similar to ours (see next section), our analysis is fundamentally different from Kerr analysis in two ways. First, Kerr analyzes the productivity of collaborative patents vis--vis US patents by US public companies only while our analysis includes all research done by US inventor

teams. Second, we narrow our focus on collaborative patents between US and Chinese inventors while Kerr analyzed all collaborative activities. So our analysis broadens the scope by including both US private, public and academic patents which gives us a more general understanding of collaboration productivity. On the other hand we specifically target US-China collaboration so this gives very specific information to policy makers on benefits and costs of collaborating with the biggest trade partner and most important strategic counterpart in global issues like climate change, regional development and international security.

## 3 Methodology

### 3.1 Definition: Collaborative R&D

We measure collaborative R&D using the home country of inventors listed on patents. This is an imperfect but useful proxy measure of actual collaboration. As noted in individual case studies (Bergek and Bruzelius, 2010), co-invention across inventors from different countries does not necessarily imply that resources from multiple countries have been brought to bear on a particular R&D project. This measure also excludes from consideration the innovative activity of multinational corporations using foreign knowledge but employing inventors of only one country. Nevertheless, we assert that international co-invention is correlated with international cooperation and therefore a useful proxy measure for international cooperative innovation. We also note that our selected measure is used widely in the literature (see for example, Gao et al, 2011) and that no alternative measure exists that could be feasibly collected in a comprehensive empirical study.

We also emphasize here that our study's aim is to quantify the relationship between patent inventorship and the subsequent rate of innovation spillovers, as measured by forward citations. This relationship provides relevant quantification of the relative importance of international collaboration in the global innovation system but does not directly inform

whether directing additional effort toward international collaboration would induce greater innovation spillovers than effort directed within national innovation systems only. To address the later relationship would require strong identifying assumptions about the exogeneity of collaboration. Such assumptions may exist for individual case studies where, for example, barriers to collaboration are unexpectedly lifted, but are unlikely to exist for a comprehensive set of technology sectors, as we are able to explore in this study.

Stated another way, this study is not an impact evaluation. An impact evaluation on the productivity of collaborative R&D would have been ideal but we cannot do that due to the classic selection bias (Heckman et al., 1996) problem. To illustrate the issue briefly, let us assume the analysis of our results suggest collaborative R&D is less productive. However, it may be due to the fact that only those inventions use collaborative method which are inherently less important. So what we are doing here is much more like an empirical review of the productivity history of collaborative R&D between USA and China.

### **3.2 Measuring international collaboration using patents with multi-country inventors**

We measure international collaboration in invention using the country of inventors available in the list of inventors in a patent application. Patents with inventors from more than one country are considered collaborative R&D. According to a few researchers, this is an imperfect measure (Katz and Martin, 1995). Katz et al. argue that multiple authorship does not give any information about the magnitude of collaboration between the authors and sometimes co-authorship is because of very small contribution, Bergek et al. (Bergek and Bruzelius, 2010) has further expanded the question of using multiple-authors as collaboration in R&D. Using a case study method involving one US multinational firm they show only 83% of patents with multi country inventors can be seen as the result of true international collaboration. However, it is virtually impossible to adopt a case-study method in an empirical

study studying all invention in last 30 years. Here we would argue that we have sacrificed a bit of depth to massively gain in terms of width of understanding. A review of literature suggests our approach is widely used and accepted as a measure of R&D collaboration. In this paper we take up this widely used (Mapheus, 1958) (Kerr. and Kerr., n.d.) (Ma, Zhenzhong and Lee, Yander, 2008) (Carayol and Roux, 2008) (Archambault, 2002) approach because it gives a reasonably good measure of collaboration and provides practical feasibility.

### **3.3 Forward citation as a measure of productivity**

A forward citation is quite close to bibliographic citations found at the end of research papers. All patents are required to cite previous patents which have, in some way, contributed to the innovation of the product in question. Citations may be added by inventors, patent attorneys managing patent applications on behalf of inventors, or patent examiners. A patent gets a forward citation when a new invention is built on the knowledge contributed by the cited patent, meaning there is some knowledge flow from the cited patent to the citing patent. It is easy to see why then such a measure is a good proxy for patent productivity and induced spillovers. In fact, many studies (Jaffe, 1986) (Jaffe and Trajtenberg, 1998) (Hagedoorn and Cloudt, 2003) (Moretti, 2004) (Branstetter, 2006) have used forward citations as a proxy for the value of a patent.

Using forward citation as a measure of productivity and spillovers is not entirely free from criticism though. It has been stated that citations are sometimes added ex-post patent application by patent examiners rather than innovators meaning the cited patent actually played no role in spurring the later innovation (Megan, 2004). However, Jaffe, Trajtenberg and Fogarty (2000) shows even though noisy, forward citations do indicate communication between inventors. Megan (2004) also draws similar conclusion using a different methodology. Perhaps more importantly our study is focused towards finding the productivity of patents. When a patent is cited, regardless of being cited by an examiner or by the inventor

themselves, it shows that more work is going on the field of cited patent meaning directly or indirectly this patent has made valuable contribution to a field that is still relevant and continues to generate new innovations.

Thus in light of these evidences and keeping in line with previous literature we believe forward citation to be a significant indicator of knowledge flows and use it as a proxy for patent productivity.

### **3.4 Data**

We use patent data from United States Patent and Trademark Office (USPTO) database. We scraped the USPTO website for any patent with at least one US or one Chinese inventor from the year 2001-2012. In a preliminary sampling of the available data, we have examined 44,196 patents with at least one US or Chinese inventor granted by USPTO within the designated time period. In our sample, we have oversampled USPTO patents with Chinese inventors to improve our statistical power. In subsequent work, we will examine the entire universe of patents with at least one U.S. or Chinese inventor. In our sample, 9,248 patents involve at least one US inventor but no Chinese inventor, 33,864 involve at least one Chinese inventor but no US inventor, and 1,084 had both US and Chinese inventors. The full sample of patents filed over this period with at least one U.S. or Chinese inventor includes substantially more U.S. inventor-only patents.

The data also contains patent class (primary and secondary) information. In our initial dataset we found more than 5000 USPTO patent classes. We restructured these classes by deleting the subclasses and keeping only the main classes. For example USPTO class 335 refers to innovations in electricity: magnetically operated switches, magnets and electromagnets (Class Definition for Class 335). There are a lot of subclasses in this class. For example subclass 335/152 refers to plural vacuum or hermetically sealed switches, 335/206 refers to

plural permanent magnet actuated switches. In our current analysis, we are utilizing only the primary class (335 in this example) and dropped all subclass information.

### **3.5 USPTO patents as a representative sample**

It is quite straightforward to see why USPTO patents can be seen as a representative sample of US innovations and US collaboration with China. However, using USPTO patents to represent indigenous Chinese innovation may cause concern to some. Here we explain why policy changes in China has made USPTO patent database suitable for this study.

Chinese government, both at central and regional level, actively inspires indigenous Chinese firms to file patents both locally and internationally(Li, 2012). This inspiration came in the shape of special funds designed to subsidize costs and fees of patenting with more subsidy available for international patenting. This can be seen as Chinas push to transform itself from being only a production to become an innovation center as well. Such an approach may lead to a distortion where indigenous Chinese patents are filed in USPTO even if their quality may not warrant it.

The implication of this events is very interesting for our study. The subsidy programs began around 1999-2000 while our dataset begins from 2001. And 2001-2002 is the time period since when USPTO has seen a remarkable surge in Chinese patents. So we can reasonably claim that our dataset begins from a point since when USPTO starts to represent indigenous Chinese innovation closely. As a result, we will be able to generalize our results as a comparison between indigenous Chinese research and collaborative R&D between USA and China.

An argument against using USPTO as a representative sample of Chinese innovations is that regardless of subsidies not all but only higher quality indigenous Chinese innovations

will find their way to USPTO database and thus our results will be biased. However, if USPTO database is representative of higher quality Chinese patents only then that means we will perceive Chinese patents to be more productive than they actually are. However, our results in section 4 show that we find Chinese patents to be less productive than US or collaborative patents. This means even if USPTO sample is not representative of Chinese innovation our results will suffer from only downward bias and there is no way that we are over signifying our findings.

### **3.6 Empirical Strategy**

The empirical strategy used in this paper is quite straightforward. We have used OLS regression to see the impact of having US or Chinese scientists in research teams. The dependent variable in all the regressions is the number of forward citation received per year. We have used citation per year instead of total citations because using total citation will give us results weighted more towards older patents. Older patents are around for more time and so more likely to receive more citations. So if we use total citation then our result (impact of collaboration) will be biased downward as older patents have proportionally less collaborative R&D than newer patents.

We have used four (eight) OLS regression to analyze the data. The first regression uses only a dummy variable (CN\_dummy) indicating the presence of a Chinese scientist. This model gives us the impact of having Chinese scientist vis--vis not having a Chinese scientist in the list of inventors. In the second model we include a dummy variable for interaction which equals to 1 if there is at least one Chinese and one US inventor in the list of inventors. This is the variable indicating R&D collaboration between the two countries. Even though this gives us the parameters of interest we still need to control for variables which may have an impact on the outcome variables. In model 3 we have added controls for the patents' age. Even though we have already used citation per year to nullify the impact of age on number

of citations there may be other impact of age- like the diminishing relevance of an innovation and so we include it as a control. In model 4 we have included fixed effects for patent class. Patent class are fixed for a certain cited patent and may have impact through channels like amount of innovation done in a certain technology class. After these four models we redo the analysis this time replacing the dummy variable indicating presence of Chinese inventors with a similar variable for US inventors. This lets us compare collaborative R&D with China to indigenous US innovation.

$$citns\_per\_year = \beta_0 + \beta_1 * CN\_dummy \quad (1)$$

$$citns\_per\_year = \beta_0 + \beta_1 * CN\_dummy + \beta_2 * intrctn\_dummy \quad (2)$$

$$citns\_per\_year = \beta_0 + \beta_1 * CN\_dummy + \beta_2 * intrctn\_dummy + \beta_3 * total\_inventors \quad (3)$$

$$citns\_per\_year = \beta_0 + \beta_1 * CN\_dummy + \beta_2 * intrctn\_dummy + \beta_3 * total\_inventors + ipc\_class \quad (4)$$

## 4 Results

In our analysis we include USPTO classes as it is reasonable to believe that different classes of innovation may receive greater or lesser citations purely due to fixed trends of patent filing in that specific technological area. For example, patents in boot and shoe making (USPTO class 012) may receive fewer forward citations then patents in Electricity: magnetically operated switches, magnets, and electromagnets (USPTO class 335) simply because there is less inventive activity in shoe making than magnetically operated switches. We did not want such inherent class characteristics to contaminate the results while comparing US and Chinese patents.

The results here are pretty interesting. Model 4 tells us that Chinese patents without any US inventors receive 0.08 less citations per year compared to US patents without any Chinese inventors. This conforms to our discussion in section 2.4 in the literature review

Table 1: Regression results illustrating gains in productivity for Chinese patents

	(1)	(2)	(3)	(4)
	citation_per_year	citation_per_year	citation_per_year	citation_per_year
	b/se	b/se	b/se	b/se
cn_dummy	-0.073*** (0.01)	-0.074*** (0.01)	-0.044*** (0.01)	-0.079*** (0.01)
us_cn_interaction		0.029* (0.01)	0.044*** (0.01)	0.042** (0.01)
Age_years			0.036*** (0.00)	0.015*** (0.00)
total_inventors			-0.001 (0.00)	0.004*** (0.00)
constant	0.195*** (0.00)	0.195*** (0.00)	-0.038*** (0.01)	0.098*** (0.01)
Observations	44191	44191	44191	44191

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

section where we mentioned that Chinese patents may be of lower quality than US patents. Importantly, the interaction variable in this model is positive and statistically significant meaning collaborative R&D increases forward citation per year by 0.04 when compared with Chinese patents.

The results in table 2 are mathematically equivalent to the results in table 1, but offer a different perspective. US patents receive about 0.08 more forward citations per year than other patents in the dataset and collaboration with Chinese scientists actually decrease forward citations, on average, by 0.04 citations per year. So the results suggest that even though collaborative R&D in case of Chinese scientists as resulted in more forward citations, the exact opposite has happened for US scientists.

The results in table 2 are very interesting. Virtually they are the same as table 1 but with opposite signs. US patents receive about 0.08 more forward citations per year than other patents in the dataset and collaboration with Chinese scientists actually decrease forward citations, on average, by 0.04 citations per year.

Table 2: Regression results illustrating losses in productivity for US patents

	(1)	(2)	(3)	(4)
	citation_per_year	citation_per_year	citation_per_year	citation_per_year
	b/se	b/se	b/se	b/se
us_dummy	0.069*** (0.00)	0.074*** (0.01)	0.044*** (0.01)	0.079*** (0.01)
us_cn_interaction		-0.045** (0.01)	0.000 (0.01)	-0.037** (0.01)
Age_years			0.036*** (0.00)	0.015*** (0.00)
total_inventors			-0.001 (0.00)	0.004*** (0.00)
constant	0.120*** (0.00)	0.120*** (0.00)	-0.082*** (0.01)	0.019** (0.01)
r2	0.004	0.005	0.042	0.115
df_r	44189.000	44188.000	44186.000	43838.000
bic	52696.719	52697.375	51036.589	47509.549

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

So the results suggest that even though collaborative R&D in case of Chinese scientists has resulted in more forward citations, the exact opposite has happened for US scientists.

## 5 Discussion

There are three aspects to this result. First is the lesser productivity of Chinese patents relative to patents with U.S. inventors. Second is the increase in forward citation for collaborative patents compared to Chinese patents. Third, and perhaps most interesting, the decrease in forward citation for collaborative patents compared to US patents.

Lesser productivity of Chinese patents is easily explainable. As it has been mentioned in literature (Li et al., 2010) (Lema and Lema, 2012), Chinese firms and scientists are latecomers in innovation and have not yet developed the wide foundation of novel innovation as their western counterparts. Li mentions that latecomer firms upgrade their technological

capabilities through constant acquisition, assimilation, and improvement of imported or licensed foreign technologies or products. So if it is true that emerging market economies like China are mostly engaged in improvement of already existing products in order to lower the costs or adapting to own markets, then it is only reasonable that these patents will receive fewer forward citations than the ones developed in western economies like USA. While Chinese patents may be of great economic value, they may not be as novel and therefore do not appear to have the same impact on future innovation as U.S. patents.

The results also suggest that collaboration with US scientists resulted in more forward citations for Chinese patents. This should be the case as US is an innovation hub and offers a lot of knowledge flows to Chinese scientists to produce more useful innovation. Chinese scientists can also offer localized knowledge and understanding of the demand of the huge Chinese market which can make the innovation more productive. This result are suggestive of a phenomenon whereby Chinese inventors tap into expertise of U.S inventors and engage in collaborative efforts that induce more spillover innovation than Chinese inventors working alone.

The fact that collaborative R&D receives fewer citations compared to indigenous US patents can be explained by the fact that USA is already an innovation leader. In terms of producing cutting-edge technologies it most likely has relatively little to gain from China in terms of technological knowledge. Instead, the motivation for U.S. inventors to collaborate with Chinese inventors may be motivated by reasons that would not induce a greater number of spillover inventors. For example, U.S. inventors may collaborate with Chinese inventors to access foreign markets for new products or to secure opportunities for larger scale technology demonstration and manufacturing. These kinds of relationships are more likely to improve the commercialization of technologies rather than lead to new spillover inventions, the effect of commercialization on spillovers notwithstanding (Scotchmer, 1991). As we mentioned in

section 2, SemCo utilized the abundance of Chinese engineering labor to conduct process innovation studies in China. Even though these sorts of inventions are less productive for future innovations, they have their business value to US entities.

Our results are indicative that collaboration with US scientists leads Chinese scientists to engage in innovation which is more productive than usual Chinese inventing. However, the same is not true for US innovators. Instead, our results are consistent with an interpretation that U.S. researchers may have different reasons for collaboration, that collaboration may enable U.S. researchers to conduct research which is not implementable in the USA and that provides access to resources relevant for commercialization and not invention. So for USA the reward for collaboration with China is not in better innovative capacity but in commercial gains.

## 6 Conclusion

The results of this study shows that the collaboration between USA and China is a testament to not only Chinas rapid growth in innovative capability but also their labor availability and market size. Because countries only collaborate if there are mutual gains from trade, the differential impact of collaboration on innovation spillovers suggests that the U.S. and China have asymmetrical reasons for collaboration. Our results are consistent with an interpretation that Chinese inventors seek collaboration with U.S. inventors to tap into new technological expertise whereas U.S. inventors seek collaboration with Chinese inventors to access resources for commercialization and manufacturing.

An important aspect of the strategic dynamics of U.S.-China collaboration in innovation is that even though US firms can access the strategic advantage it gains from collaboration, the business value of such collaboration may be diminished because of unequal IP laws. If

China can provide effective IP protection for innovations then USA will have more incentive to collaborate with Chinese scientists to tap into the Chinese market. This will be beneficial for China too. As Chinas growth is slowing down, they are approaching the Lewis turning point where maintaining the growth rate requires technological innovation and development (Das and NDiaye, 2013). As this paper shows USA has a lot to contribute in that direction as involvement of US scientists is likely to increase the productivity of innovation and faster the process of gaining innovative capacity. So the onus is on China to modify their IP laws to international standard so that scientists and firms from developed countries find more incentive to collaborate with Chinese scientists. Chinese government has recently undertaken a specific focus on indigenous innovation (McGregor, 2010) but if this study is any guide, achieving innovative capacity comparable to traditional innovation leaders without collaborating with them is perhaps possible but imposes much greater barriers.

From the US perspective, it must be recognized that China is fast becoming an innovation center from being only a producer. Given the efforts of Chinese government, it is clearly visible that China is slowly becoming more and more capable in innovation. If USA now joins Chinese scientists then this process will be faster. However, this will also mean that USA will have significant presence in Chinese research facilities and also Chinese markets.

USA and China both stands to gain valuable but differentiated gains from collaborative R&D. It is easy to see the rise of China and Indias innovation capability as a threat to countries like USA, Germany and Japan. In fact the threat is most likely real- developing countries are trying to capture the role of innovation hub themselves. However, without collaborating with the more advanced nations the growth in innovation capability will be slow and may even be too late to sustain the impressive economic advancement these countries have achieved in recent times. On the other hand, traditional innovation hubs risk becoming redundant in global innovation systems if they do not collaborate with these new powers in

innovation. So collaborative R&D will be useful for both the parties as it will accelerate the rise of China and also maintain relevance of USA in global innovation system.

We acknowledge that there are a lot more to study in this topic. The success of Chinas indigenous innovation policy needs to be evaluated. It is also important to quantify the financial returns US firms gain through collaborative R&D with China. If sufficient information on these topics can be unveiled then a game theoretic analysis on the possibility of collaboration in innovative capacity can be highly useful for the purposes of policy making in both these countries.

*\*Please note that the analysis presented here are only primary and still incomplete. We intend to use panel data in our final analysis and currently awaiting for data from PATSTAT.*

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