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DISCUSSION PAPER 13.08

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Abstract: This paper examines US patent citation data and analyzes how different firms in China affect knowledge spillovers. Patents granted by the US patent office to inventors located in China are collected along with their citation counts. Two kinds of patent citations, namely, citations of previous patents and those of non-patent literature, are used to measure knowledge flows. In the empirical analysis, the negative binomial and zero-inflated count models are considered. The regression results suggest the existence of heterogeneity among firms of different ownership. In terms of knowledge spillovers, US multinational corporations (MNC) perform better than those from other western countries; Taiwanese companies outperform their counterparts from Hong Kong; and Chinese private corporations contribute more than Chinese state-owned enterprises (SOEs). These results have important policy implications for the development of a knowledge-intensive economy in China.

Keywords: Knowledge spillovers; China; patent citations; MNCs; count model

1. Introduction

Are foreign multinational corporations (MNCs) indispensable to technology inflows? If MNCs play an irreplaceable role in promoting knowledge spillovers to a developing country, then they should be encouraged to do so. However, the existing literature focusing on the role of foreign MNCs in knowledge spillovers is inconsistent. Some authors show that MNCs can help with technology inflows; for example, MacGarvie (2005) finds that a 10% increase in foreign direct investments (FDI) flows between countries is associated with an increase of about 3% in cross-country patent citations. Keller and Yeaple (2009) estimate international technology spillover to US manufacturing firms via imports and FDI between the years of 1987 and 1996. Their results suggest that FDI leads to substantial productivity gains for domestic firms. The size of FDI spill-over is economically important, accounting for about 11% of productivity growth in US firms.

However, some authors argue that only some foreign MNCs are active in leading to knowledge spillovers. For example, Iwasa and Odagiri (2004) distinguish research-oriented firms whose R&D subsidiaries mainly conduct research from sale-oriented firms whose R&D subsidiaries mainly aim to support local manufacturing and sales activities. They find that a high level of local technological progress significantly contributes to the firm's innovation among research-related firms, however these results do not hold among sale-oriented firms.

These controversial findings may be due to country-specific conditions which affect knowledge spillovers through FDI. For example, Kuo and Yang (2008) argue that a region's absorptive ability is the critical capability to absorb external knowledge sources that are embodied in FDI and imports, which then contribute to the regional economic growth. Therefore, it becomes necessary to conduct country-specific research to investigate FDI's role in knowledge spillovers. In the case of China, scholars argue that foreign MNCs have made a positive contribution to technology transfer. For instance, Cheung and Lin (2004) detect positive effects of FDI on the number of domestic patent applications in China.

This paper extends the existing research by exploring a new database. Domestic corporations can learn advanced technologies from foreign MNCs through trade, personnel flows and analysis of foreign patents. The last channel, knowledge learning through patent analysis, has attracted a lot attention among scholars (Romer, 1990; Eaton and Kortum, 1999; Spolaore and Wacziarg, 2009). Most existing studies on knowledge spillovers in China merely used regional research and development (R&D) expenditure data (e.g. Cheung and Lin, 2004; Kuo and Yang, 2008), while some analyze Chinese province-level patent data (Chen et al., 2010; Du et al., 2012; Lai et al., 2006). This study differs from the existing papers by examining firm-level patent citation data. It is the first of its kind in the China-related literature.

This paper is structured as follows. The rest of the paper begins with an overview of Chinese patents granted offshore (Section 2). This is followed by a discussion of the empirical models in Section 3. Section 4 reports the results from regression analysis. Some further discussions are presented in Section 5. Finally, Section 6 concludes this paper.

2. Chinese Patents Registered in the US

Knowledge spillovers through patents appear in two forms. The first type of spillovers is associated with the patents granted to foreign firms by the Chinese patent office. In recent years, foreign owned patents grew dramatically in China. This may be caused by the increase of market competition in China (Sun, 2003; Hu, 2010). The second type of spillover effect is linked with the patents granted by foreign patent offices to firms located in China (hereafter these patents are called the "*Chinese patents*"). So far these Chinese patents have been ignored by researchers. To fill the void in the literature, this paper examines Chinese patents issued by the US Patent and Trademark Office. Patents granted by the US patent office are generally divided into utility patents and design patents. Utility patents refer to new technical solutions and are protected for up to 20 years. Design patents cover the ornamental and nonfunctional design of an item and are protected for 14 years. Generally, the technology contained in design patents is considered to be of a lower level than that in utility patents.

There are two reasons for us to focus on Chinese patents registered in the US patent office. First, detailed citation information for each patent is recorded in the US patent database. Therefore knowledge spillovers can be explored by the analysis of patent citations. Second, the patents issued by the US patent office exhibit the main trend of Chinese offshore patents. Figure 1 shows that Chinese utility patents granted in the United States overwhelm those granted by other countries. The patent number increases rapidly after 2001. This patent explosion may have been induced by the tremendous growth of FDI and patent subsidy programmes implemented by provincial governments immediately after China's accession to WTO (Hu and Jefferson, 2009; Li, 2012).

[Insert Figure 1 here]

Table 1 demonstrates that the number of utility patents granted to applicants from China is still very small relative to those granted to those from Japan and Germany. Chinese patent ownership is even behind that of South Korea and Taiwan. However, among the BRIC (Brazil, Russia, India and China) countries, China has the highest level of patent ownership. If China is about to follow the South Korean and Taiwanese patterns of growth, it is anticipated that the number of Chinese patents will increase rapidly in the near future.

[Insert Table 1 here]

The patent and patent citation database maintained by the National Bureau of Economic Research (NBER) is widely used in empirical research (Hall et al., 2001). The raw data was originally published by the US patent office. It should be pointed out that researchers should be cautious with the use of the NBER database when they are examining Chinese patents. This is because a large number of patents granted to applicants located in Taiwan (category TW) and Hong Kong (category HK) are erroneously recorded in the "CN" category.[1] These patents can be identified in the US patent office's database by looking at the assignees' addresses, which are not reported in the NBER database. The use of an unchecked NBER patent database could lead to biased results. For instance, Haruna et al. (2010) examined the NBER database and concluded that mainland Chinese inventors have overwhelmingly cited Taiwanese patents. This argument might be rejected if the adjusted dataset is used.

Based on this reason, the NBER database is not used in this study. Instead, the patent data has been manually downloaded from the website of the US patent office. By searching the website of the US patent office with the field "Assignee Country = CN", the information on 5,829 patents granted during January 1980-December 2009 was able to be retrieved. 5,619 of them were successfully downloaded from the website. Among them, 1,832 patents with assignees' addresses in Taiwan and Hong Kong are deleted. The final sample used in this paper contains 3,758 patents granted during 1986-2007.

The records of patent citations need to be assessed and made uniform. Patent systems throughout the world have different citation rules. For example, the patent examiners are responsible for the majority of patent citations in the European Patent Office (Criscuolo and Verspagen, 2008). However, in the US patent registration system, citations are made by both

[1] Hong Kong patent applicants might report their country as China after 1997. For Taiwanese patents, the official name of Taiwan, Republic of China, is easily misunderstood as People's Republic of China.

inventors and examiners. Patent applicants in the US have strong motives to disclose complete citations for their inventions because failure to provide all relevant references can result in patent litigation or severe penalties (OECD, 2009, p. 108). Patent citations added by patent examiners should be excluded because these citations do not reflect the inventors' knowledge and therefore may distort the knowledge spillover effect (Alcacer and Gittelman, 2006; Jaffe et al., 1993). Those citations are identified by comparing the publication dates. If a cited patent is published after the application date of the citing patent, this citation is assumed to have probably been added by the examiners. In addition, if a non-patent citation is from a Chinese journal, or if a cited patent is originally granted in China, then it is filtered out because it is not part of the foreign knowledge inflow to China.

FDI from different countries or industries may have different impacts on knowledge spillovers. For example, Todo et al. (2009) find that Japanese MNCs contribute less to knowledge spillovers than US firms. Buckley et al. (2007) break down the Chinese industrial data by the category of ownership of the foreign investor, by local firm and by host industry. They find evidence of a greater number of positive spillovers from FDI in technology-intensive industries than in labor-intensive industries. They also find that MNCs from Hong Kong, Macau and Taiwan generate spillovers to locally owned enterprises in labor-intensive industries, in contrast to western affiliates, which positively impact the performance of local enterprises in technology-intensive industries.

Therefore, it is necessary to observe the obtained patent records by their locations, industries and ownerships. The regional distribution is highly uneven. 43% of the patents are granted to inventors in Guangdong province, 16% to those in Beijing and 27% to those in the Yangtze River delta region (Shanghai, Zhejiang and Jiangsu). The other regions of China only account for 14% of the total patents. Figure 2 illustrates patent decomposition by ownership.[2] It shows that 57% of the patents are granted to Chinese-owned entities, including academic institutions, individual inventors, state-owned enterprises (SOEs) and private firms.[3] The share of patents owned by Taiwanese enterprises is far greater than that owned by MNC subsidiaries from other foreign regions.

[2] The Chinese patents only denotes the patents granted to patent owners *located* in China, not *owned* by Chinese owners. Hence, the Chinese patents need be further identified by their ownerships.

[3] In this context, "China" and "Chinese" are specifically used to refer to the mainland of China, excluding Hong Kong, Macao and Taiwan.

[Insert Figure 2 here]

Figure 3 shows the distribution of those patents according to technological classifications. Utility patents are first distinguished from design patents, and then divided into six sectors. Among them, the new material (e.g. Nano-technology) and medical sectors represent the high-tech industries. The machine (e.g. machinery, transportation), chemical and electronic sectors are considered as medium-tech industries. The rest are pooled as low-tech industries, including inventions in plastic, printing, construction, agriculture, etc. Electronic and design patents are the two largest groups.

[Insert Figure 3 here]

3. The Econometric Models

Patent citations are commonly used as a measure of knowledge spillovers (Jaffe et al., 1993; Haruna et al., 2010). Figure 4 illustrates how patent citations reflect knowledge spillovers. First, when inventors located in China want to lodge patent applications in the US patent office, they need to search thoroughly in the related patent fields and cite prior arts. This procedure may result in learning and modifying their own inventions; this is represented as knowledge flow (a). This knowledge can be easily transferred back to internal colleagues in the same company or institute, which is knowledge flow (b). In most cases, a patent application is first filed at the home country's patent office before foreign applications are made (OECD, 2009, p.43). Therefore, even though the Chinese patent office doesn't publish citations of a granted patent, rival companies can still track down the corresponding patent granted in the US patent office. This will allow them to obtain the relevant state-of-the-art technology in the US. This indirect routine of learning, shown as knowledge flow (a-b-c), can be an important complement to direct searching through knowledge flow (d).

[Insert Figure 4 here]

Knowledge flows (b), (c) and (d) are hard to observe. However, knowledge flows (a) can be represented by the patent citations in the Chinese patents granted by the US patent office. As illustrated in Figure 2, those Chinese patents are owned by different owners, such as MNCs from the US, other western countries, Hong Kong and Taiwan, as well as Chinese-owned entities. The later can be further identified as academic institutions, individual inventors, state-owned enterprises (SOEs) and private firms. This study focuses on the comparison of the roles of foreign MNCs and Chinese-owned companies in knowledge spillovers.

To account for firm heterogeneity, it is important to control for other factors that may affect the citation numbers. For instance, citation numbers might vary across industrial sectors. Buckley et al. (2007) points out that, in general, patents in the traditional technology fields may cite more references than those in the emerging technology fields. Previous studies also show that knowledge spillovers occur most often between regions that are located close to each other (e.g. Fischer et al., 2009). Therefore, the location of an inventor may also affect patent citation numbers. For example, inventors in Beijing or Shanghai may find it easier to obtain international patent information than those in the hinterland. Finally, a patent's application year is included to capture the effect of the growth of Chinese patents. Therefore, the regression model can be written as

$$\lambda_i = \exp\left(\alpha + \alpha_y year + \sum_{j=1}^{7} \alpha_j O_{ij} + \sum_{k=1}^{3} \alpha_k R_{ik} + \sum_{h=1}^{6} \alpha_h I_{ih} + \varepsilon_t\right) \quad (1)$$

where λ_i is the number of citations by patent *i*. Dummy variables O_{ij}, R_{ik} and I_{ih} stand for the ownership, regional and industrial characteristics of patent *i*. $\alpha, \alpha_y, \alpha_j, \alpha_k$ and α_h are the coefficients to be estimated. ε is the error term. The time variable, application *year*, is centered to its mean so that it is meaningful to take zero value. The equation takes the exponential form because the citation numbers (λ_i) are count data and therefore only take positive values. Nevertheless, Equation (1) can be converted into a linear model, that is,

$$\ln \lambda_i = \alpha + \alpha_y year + \sum_{j=1}^{7} \alpha_j O_{ij} + \sum_{k=1}^{3} \alpha_k R_{ik} + \sum_{h=1}^{6} \alpha_h I_{ih} + \varepsilon_t \quad (2)$$

There are two kinds of patent citations, namely, the patent that cites previous patents (PP hereafter) and the patent that cites non-patent literature (NP hereafter) such as academic journal papers. Patents which cite NP literature are considered of higher quality than those which do not (Branstetter, 2005). In this study, these two indicators are used complementarily to assess knowledge spillovers. Since the patent citations are count data, the Poisson distribution and the negative binomial (NB hereafter) distribution are applicable to this data (Hausman et al., 1984). Figure 5 shows that the frequency distribution of the PP citations is skewed to the right tail, which is well captured by the Poisson and NB distributions. The Poisson distribution has an implicit restriction, that is, the variance of the sample is equal to the mean. However, a count dataset is commonly observed with different values for its variance and mean. Therefore, the negative binomial distribution should be employed in the case when there is over-dispersion (the variance being larger than the mean).

[Insert Figure 5 here]

Figure 6 highlights an extraordinary proportion of zeros in the frequency chart of the NP citations. To deal with this phenomenon, zero-inflated count data models have been proposed and are frequently used in the literature (Lambert, 1992; Greene, 1994). The zero-inflated count model assumes that the sample data is drawn from two different populations. One is called the "certain-zero" population because the outcome is always zero. The other is called the "potential-zero" population and the outcome is drawn from the count data (Poisson or NB) distribution. Thus, each explanatory variable can have an effect on either (i) the probability that an observation *always* takes the zero value or (ii) the magnitude of the count outcome, given that the observations *possibly* take the zero value. Therefore, the zero-inflated count data models consist of two regressions; a Logit regression which models the probability that an observation is drawn from the certain-zero population, and a Poisson or NB regression that determines the counts. Denote p as the probability that a sample is from the certain-zero population, and then the Logit model is defined as

$$\text{logit}(p) = \ln(\frac{p}{1-p}) = \beta_c + \beta_y year + \sum_{j=1}^{7} \beta_j O_{ij} + \sum_{k=1}^{3} \beta_k R_{ik} + \sum_{h=1}^{6} \beta_h I_{ih} + \varepsilon_t \quad (3)$$

where β represents a set of parameters to be estimated.

[Insert Figure 6 here]

4. Regression Results

The regression results are shown in Table 2. The dependent variables in Models 1 and 2 are the counts of PP citations and NP citations, respectively. Estimated coefficients in Model 1 are derived under the assumption of a NB distribution rather than the Poisson distribution. The reason for this is that the dispersion value *Alpha* is greater than zero, which confirms that the dependent variable is over-dispersed. This means that the NB distribution fits Model 1 better than the Poisson distribution.

[Insert Table 2 here]

Model 2 consists of two regressions, the count data regression under the assumption of NB distribution as well as the Logit regression. The Vuong test in Model 2 is a test of the zero-inflated count data model against the ordinary count data model. It suggests that the zero-inflated count data model is preferred to the ordinary count data model. Furthermore, the dispersion value *Alpha* in Model 2 suggests that the zero-inflated NB model is a better fit than the zero-inflated Poisson model.

The interpretation of the regression results in Table 2 is not straightforward. As the two original models are non-linear (see Equations 2 and 3), the estimated coefficients are not marginal effects. Apart from the non-linearity, Models 1 and 2 contain three sets of dummy variables. To avoid the dummy variable trap, three dummies or the reference variables (one in each set) are excluded from the regression procedure. These include Chinese privately owned corporations (CN-P hereafter), the rest of China and the electronic sector. Consequently, the estimated coefficients of the dummy variables should be explained in comparison with the reference groups which are not included in the models. For the convenience of interpretation, the concept of so-called “base conditions” is introduced which refer to firms (i) being located in the “rest of China”, (ii) owning patents in the electronic sector and (iii) being registered in 2003.[4] Given this definition, the following four useful “rules” are developed which can help the discussion of the regression results in Section 5.

[4] It is because the variable *year* is centred to its mean, 2003.

Rule 1: In the NB regression in Model 1, the coefficients have an additive effect on log(λ_i) and thus have a multiplicative effect on λ_i.

For example, in Model 1 the estimated coefficient of the intercept is 2.22. It means that under the "base conditions" the patents owned by CN-P on average have 9.21 (=$e^{2.22}$) PP citations. The estimated coefficient of the variable *US* is 0.29, which implies that the patents owned by US MNCs on average have 12.30 (=$e^{2.22}$ $e^{0.29}$) PP citations (Halvorsen and Palmquist, 1980).

Rule 2: The Logit regression results should be explained by the change of the relevant odds.

The odds are defined as the *ratio* of the probability that a patent belongs to the "certain-zero" population *to* the probability that the patent is from the "potential-zero" population. For example, the estimated intercept (-3.28) of the logit regression (model 2) is the estimated logit for CN-P owned patents under the "base conditions". Therefore, e^{logit} (= $e^{-3.28}$ = 0.038) are the estimated odds for the CN-P owned patents under the base conditions. In other words, the probability of those CN-P owned patents belonging to the "certain-zero" population is $e^{-3.28}/(1+e^{-3.28})$ =0.036.[5] Another example is the coefficient (6.89) for the variable *Taiwan*. It implies that the estimated odds for TW patents under the base conditions are $e^{-3.28+6.89}$. Thus the probability for those TW patents from the "certain-zero" population is $e^{-3.28+6.89}/(1+e^{-3.28+6.89})$= 0.974. The two examples show that the majority of the CN-P owned patents come from the "potential-zero" population, and in contrast, the majority of the TW-firm owned patents come from the "certain-zero" population. Therefore the TW and CN-P firms are so different that it becomes not meaningful to compare their patents in terms of the number of NP citations.

[5] As e^{logit} represents the odds which are defined as p/(1-p), one can derive the expression for probability p= e^{logit} /(1+ e^{logit}).

Rule 3: The results of the NB regression in Model 2 are linked with the results of the Logit regression. The NB regression only reflects the characteristics of the "potential-zero" population.

For example, the intercept (-0.56) in the NB regression in Table 2 means that under the base conditions the CN-P patents in the "potential-zero" population on average have $e^{-0.56}$=0.57 NP citations. The estimated coefficient of the variable *Taiwan* is 2.25. However, this doesn't mean that under the base conditions the TW-firm owned patents on average cite $e^{2.25}*e^{-0.56}$=5.42 NP citations. Instead, it should be interpreted as that under the base-conditions the TW-firm owned patents in the "potential-zero" population, which is only 2.6% (=1-0.974) of the total TW-firm owned patents, on average cite 5.42 NP citations.

Rule 4: In terms of the overall performance between the TW-firm owned and CN-P owned patents, the results of the NB and Logit regressions of Model 2 should be combined for comparisons.

For instance, as it has been shown, under the base conditions 96.4% (=1-3.6%) of the CN-P owned patents belongs to the "potential-zero" population while this figure is only 2.6% for the TW-firm owned patents. For those patents, the CN-P owned patents on average cite 0.57 NP citations and the TW-firm owned patents cite 5.42. Hence, under the base-conditions, the CN-P owned patents cite 0.55 (=0.57*96.4%+0*3.6%) NP citations, while the TW-firm owned patents cite 0.14 (=5.42*2.6%+0*97.4%) NP citations. Therefore, given the base-conditions, the CN-P owned patents on average cite almost four times more NP citations than the TW-firm owned patents.

5. Discussions

Following the Rules 1-4 defined above, the regression results under the base-conditions of Table 2 can be transformed into Table 3. To facilitate comparisons, the ranking of relevant citation counts are provided as well. Furthermore, Figure 7 presents the scaled counts of patents, PP citations and NP citations under the base conditions. However, even if the "base conditions" are relaxed by varying the values of the industrial and regional variables and *year*, only the magnitude of the counts will change and the ranking remains. Therefore, the ownership effect can be analyzed based on Table 3 and Figure 7. It is shown that patent numbers are not in line with the citation numbers. TW and CN-P firms have the largest shares of Chinese patents granted by the US patent office. However, it doesn't necessarily mean that these two kinds of companies play the most important role in creating knowledge spillovers. It may be simply that there are more TW and CN-P firms than the other types of patent owners. Therefore, it is necessary to compare the quality of knowledge spillovers among the different owners, which is reflected by patent citation numbers.

[Insert Table 3 here]
[Insert Figure 7 here]

Three points can be drawn from the results. First, the firms in different ownership subgroups can be compared. For the western MNCs, US MNCs contribute more knowledge spillovers than other western MNCs. Even though the patent numbers are close for these two types of firms, the US MNCs' patents have twice as many PP and NP citations than the patents owned by other western MNCs. For the TW-HK FDI, TW companies outperform their HK counterparts in terms of patent counts and NP citation numbers. For the domestic firms, Chinese private corporations overwhelm Chinese SOEs in PP and NP citations as well as in patent numbers.

Second, the best performers from each subgroup can be compared, that is, the US, TW and CN-P firms. In terms of the numbers of patent and average PP citations, the TW (1100 and 7.69) and CN-P firms (932 and 9.21) are close. However, CN-P firms are more engaged in science-related innovation than the TW patents, as indicated by the NP counts for total (0.55 vs. 0.14). Nonetheless, the CN-P owned patents still fall behind the US-firm owned patents in terms of PP and NP citations.

Third, two different categories of inventors are observed by examining the NP citations. The first category includes the TW firms and Chinese individual inventors (CH-I). Table 3 shows that 97% of TW-firm owned and 86% of CH-I owned patents do not have NP citations. However, for those CH-I and TW firms that have NP citations, their average NP citations are quite high (5.42

and 1.34 counts, respectively). Aw and Lee (2008) made the same observation about Taiwanese firms in their sample. As for CH-I inventors, there is another complication. A large number of the CH-I inventors are in fact owners of private enterprises. Their patents should be categorized into the CH-P group, but the owner's chose to register their inventions under their private names rather than the names of their unsecure companies. The second category is represented by the US and Hong Kong firms. 96% of the patents owned by US MNCs are related to scientific research in their inventions and the average NP citation counts are pretty high (1.22). In contrast, only 8% of the patents owned by HK-firms are related to in-depth research and even for these patents the average NP citation count is very low (0.57). Therefore, the quality of US-firm owned patents is consistently high while the quality of HK-firm owned patents is uniquely low. Since the TW and HK firms are of different patterns, they should *not* be combined into one group as has been done in previous research (e.g. Buckley et al., 2007; Du et al., 2012)

Apart from ownership effects, the results in Table 2 also show regional, industrial and time variance effects. Patents owned by firms in Beijing and the Yangtze River delta have more PP citations than those owned by firms in other parts of China. This facilitates the future inventors to follow up. In addition, patents owned by firms in the Yangtze River delta are distinguished from those owned by firms in other regions in terms of their NP citations. The average NP citation count of the patents in the Yangtze River region is 0.63 ($=e^{-0.56+0.52}*[1-e^{-3.28+6.89}/(1+e^{-3.28+6.89})]$), which is much higher than 0.55 ($e^{-0.56}*[1-e^{-3.28}/(1+e^{-3.28})]=0.55$) in other regions of China. Therefore the strength of knowledge spillovers is much stronger in Beijing and the Yangtze River delta, especially in the latter. In contrast, even though Guangdong has the highest number of patents, the knowledge spillover from those patents as measured by their PP and NP citations is pretty weak. The industrial effect echoes Buckley et al. (2007). That is, the patents in the traditional technology fields may cite more references than in the emerging technology fields. Finally, time is not an important factor. The number of PP and NP citations increase over time (positive coefficients in Table 2), which may indicate more knowledge spillovers. However, the marginal effect of time (due to the small magnitude of its coefficient) is not as dramatic as for the other factors.

6. Conclusions and Policy Implications

Using patent citations as a proxy for knowledge spillovers, this study explores whether foreign MNCs have done better in terms of knowledge spillovers than domestic companies. The primary finding is that MNCs from the US and Taiwan as well as Chinese privately owned firms perform better than Chinese SOEs and MNCs from other regions (including Hong Kong). Among the better performers, the Chinese privately-owned firms are very similar to Taiwanese companies in terms of the number of patents and patent citations, though they are lagging behind the US corporations. Therefore, keeping the market open and absorbing knowledge spillovers from western MNCs is still essential for Chinese domestic firms to catch up in advanced innovation.

The findings also suggest some strategies that Chinese policy makers can employ to enable technological catch-up. Since heterogeneity exists among Taiwanese firms and only a small number of them conduct in-depth innovation, Chinese domestic firms should be encouraged to learn from and eventually surpass these companies. Since Chinese privately owned firms are better prepared for catch-up than the SOEs, they should receive preferential treatment to engineer the economic transformation toward the knowledge-based economy. Finally, the inventors in the Yangtze River delta region are found to provide much stronger knowledge spillovers than those in Beijing and Guangdong. Therefore, policy makers should draw lessons from the existing practices in the Yangtze River delta region.

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Table 1 US utility patents granted to inverters from selected countries.

Countries	1993	1997	2001	2006
US	59,579	68,931	97,282	96,590
Japan	21,794	22,705	32,890	37,083
Germany	5,927	5,990	9,945	9,090
South Korea	685	1,822	3,318	5,703
Taiwan	340	934	3,599	5,165
France	2,495	2,538	3,666	2,983
Canada	1,042	1,291	2,461	2,507
UK	1,709	1,890	2,475	2,062
Italy	991	943	1,270	1,069
Hong Kong	31	56	166	236
Brazil	36	28	50	65
Russia	1	30	49	24
India	11	28	114	236
China	32	29	64	304

Source: Author’s own work based on the NBER patent data.

Table 2 Regression results.

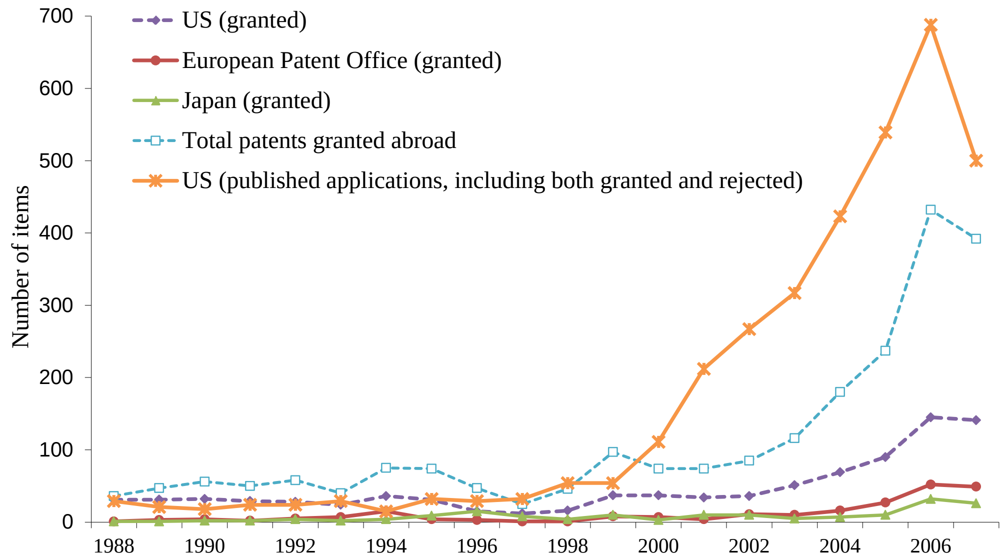
		Model 1		Model 2			
		(NB)		(NB)		(Logit)	
	Intercept	2.22	(0.06)***	-0.56	(0.24)**	-3.28	(1.25)***
	Year	0.01	(0.00)**	0.03	(0.01)*	0.79	(0.11)***
Ownership	*US*	0.29	(0.07)***	0.76	(0.36)**	1.63	(1.11)
	Other Westerns (*OW*)	-0.4	(0.08)***	0.25	(0.38)	1.47	(1.00)
	Taiwan (*TW*)	-0.18	(0.05)***	2.25	(0.36)***	6.89	(0.94)***
	Hong Kong (*HK*)	-0.13	(0.06)**	0.56	(0.46)	5.68	(1.01)***
	CN SOEs (*CN-S*)	-0.27	(0.05)***	0.19	(0.23)	1.28	(0.74)*
	CN Academics (*CN-A*)	-0.39	(0.06)***	0.39	(0.21)*	-1.23	(0.89)
	CN individuals (*CN-I*)	-0.14	(0.07)*	0.85	(0.35)***	5.07	(1.26)***
Region	*Beijing*	0.15	(0.05)**	0.05	(0.18)	1.09	(0.88)
	Yangtze	0.19	(0.05)***	0.52	(0.19)***	2.62	(0.90)***
	Guangdong	-0.1	(0.05)*	-0.28	(0.22)	-0.51	(0.92)
Industry	*New Material*	-0.01	(0.08)	0.47	(0.28)*	-1.81	(1.56)
	Medical	-0.09	(0.06)	1.36	(0.21)***	-4.79	(1.26)***
	Chemical	0.43	(0.07)***	0.39	(0.25)	-14.73	(80.5)
	Machinery	0.05	(0.05)	0.19	(0.27)	2.11	(0.72)***
	Low-tech	0.24	(0.06)***	0.99	(0.34)***	3.61	(0.87)***
	Design	0.15	(0.04)***	-1.55	(0.25)***	-3.44	(0.54)***
	Alpha	0.55	(0.02)***	4.75	(0.34)***	Vuong test	7.60***

Note: Standard error in parentheses. *p<0.1, **p<0.05, ***p<0.01. Variable *year* is centered to its mean, 2003.

Table 3 Transformed regression results of patents under the base conditions.

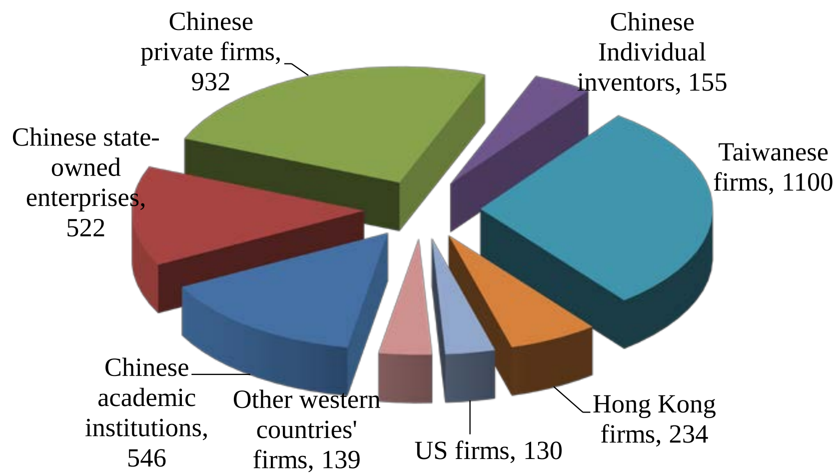
	Basic counts		Model 1		Model 2				
			Rule 1		Logit, Rule 2		NB, Rule 3	Rule 4	Total rank
	Patent number	Patent rank	PP counts	PP rank	*p*=1	*p*=0	NP counts for *p*=0	NP counts for total	
TW	**1100**	1	**7.69**	5	**0.97**	**0.03**	**5.42**	**0.14**	7
CN-P	932	2	9.21	2	**0.04**	**0.96**	**0.57**	**0.55**	3
CN-A	546	3	6.23	7	0.04	0.96	0.84	0.81	2
CN-S	522	4	7.03	6	0.12	0.88	0.57	0.5	5
HK	234	5	8.08	3	0.92	0.08	0.57	0.05	8
CN-I	155	6	8	4	0.86	0.14	1.34	0.19	6
OW	139	7	6.17	8	0.04	0.96	0.57	0.55	3
US	131	8	**12.3**	1	0.04	0.96	1.22	**1.18**	1

Note: *p*=0 denotes the probability that the sample is generated from the "certain-zero" population; *p*=1 denotes the probability of "potential-zero" population. The values underlined are mentioned in the paragraphs where the four rules are defined.



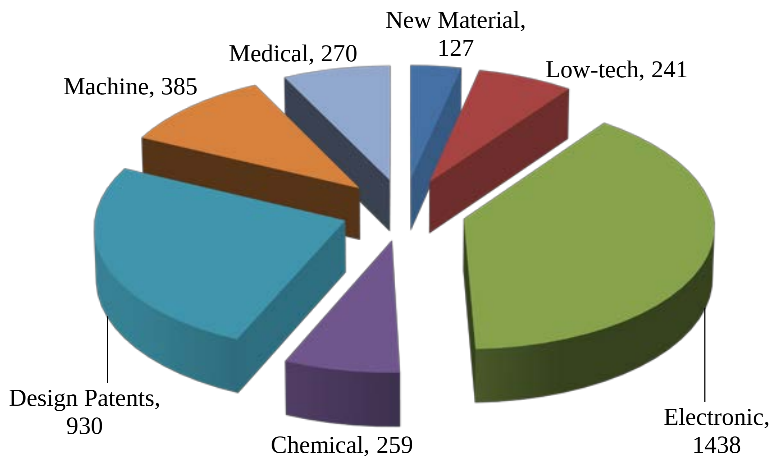
Source: Author's own work based on the patent statistics in the Chinese patent office (www.sipo.gov.cn/sipo2008).

Figure 1 Number of Chinese utility patents granted by selected countries.



Source: Author's own work based on the patent database maintained by the US patent office.

Figure 2 Distribution of Chinese patents by ownership.



Source: Author's own work based on the patent database maintained by the US patent office.

Figure 3 Distribution of Chinese patents by sector.

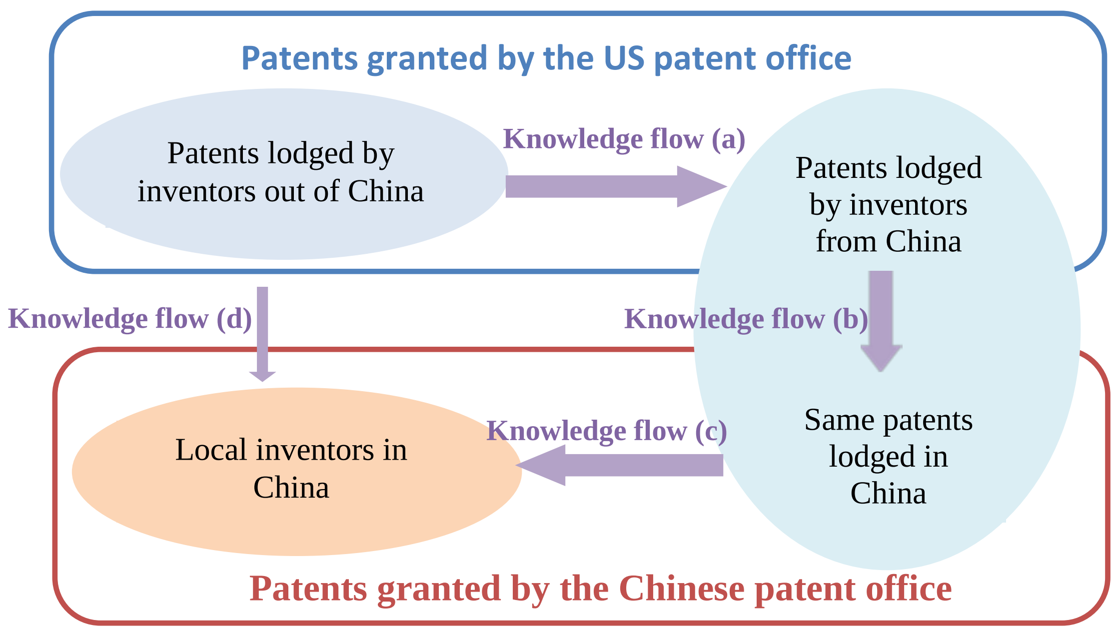
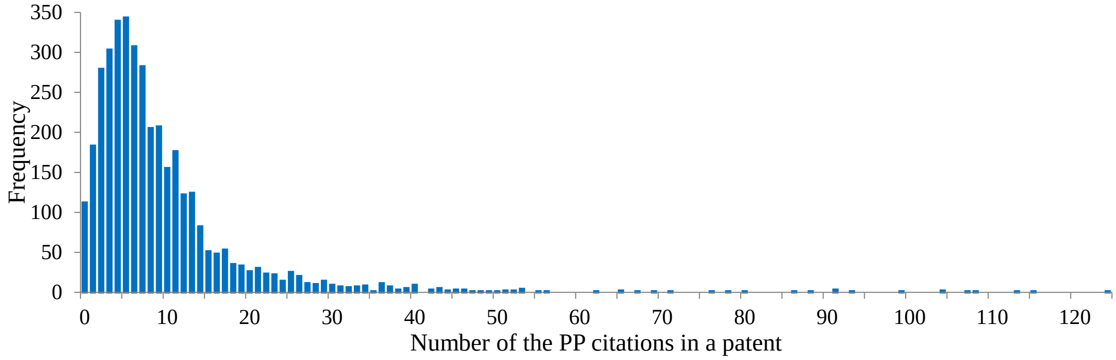
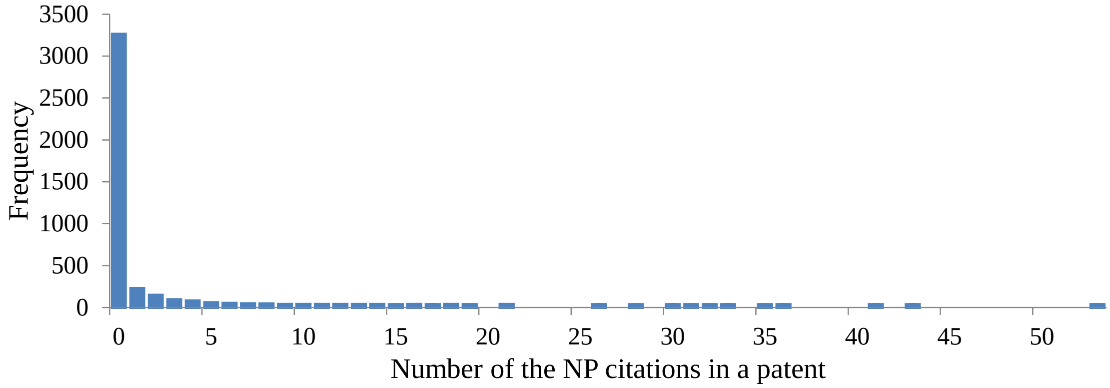


Figure 4 Knowledge flows through patent citations.



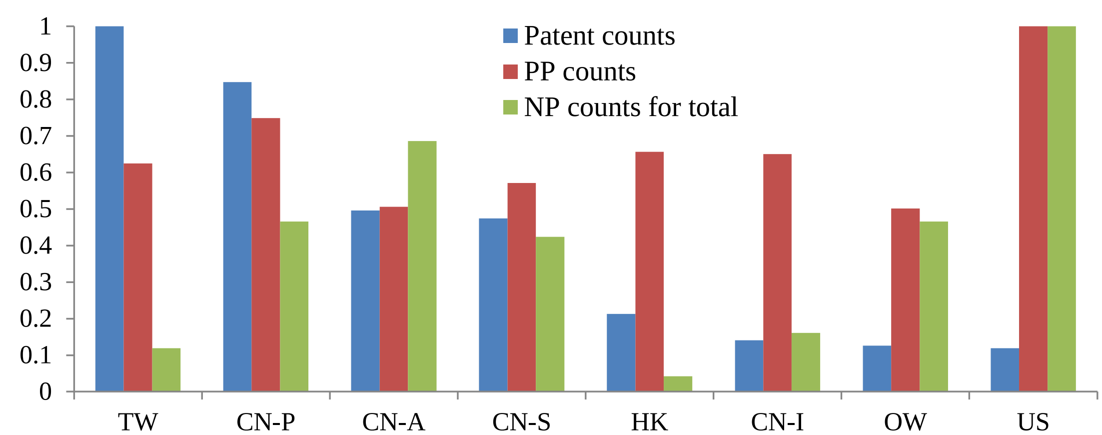
Source: Author’s own work based on the US patent office’s database.

Figure 5 Frequency chart of the PP citations.



Source: Author’s own work based on the US patent office’s database.

Figure 6 Frequency chart of the NP citations.



Note: The counts are divided by the maximum values in the groups: patent counts are divided by 1100 (thus TW is scaled to 1), PP citations by 12.30 and NP citation by 1.18.

Figure 7 The scaled counts of patents, PP and NP citation numbers by ownership.

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